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Editors

Proceedings of the 22nd International Conference on Industrial Engineering and Engineering Management 2015

Core Theory and Applications of Industrial Engineering (Volume 1)

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Preface

It is my great pleasure to welcome all the delegates come all the way for the 22nd International Conference on Industrial Engineering and Engineering Management 2015 (IEEM 2015). It is their great efforts that bring out the proceedings of IEEM 2015 which records the new research findings and development in the domain of IEEM. What is more excited, they are the experts or scholars with significant achievements in the field. I believe that the proceedings will serve as the guidebook for the potential development in IEEM and play a great role in promoting the IEEM development.

With the ongoing dramatic paradigm shifts of industrial engineering theories and applications, more and more enterprises have realized it is the key to innovate their products by utilizing the advanced technology to enhance their core competitiveness. It is quite imperative to bring professionals form both academia and business together to share their new findings and experience.

IEEM 2015 caters to the purpose by providing a platform to exchange the state-of-the-art research, achievement exhibition, case study, and development in the field of IEEM, as well as promoting its application. The papers selected all center on the main themes of the conference: Industrial Engineering Theory, Industrial Engineering Technology Practice, Information Technology Application and Development, Automation System Theory and Application, Value Engineering, as well as Engineering Management Method and Practice. All the papers included in the proceedings have undergone rigid peer review. We have also invited some prominent experts as our keynote speakers.

The conference is sponsored by Chinese Industrial Engineering Institution, CMES, and organized by Guangdong University of Technology, China. We would like to extend our sincerest thanks to Atlantis Press for their generous support in the compilation of the proceedings. We also would like to extend sincerest thanks to Guangdong University of Technology for holding such an excellent event, and to

all the delegates, keynote speakers, and the staff of the organization committee for their contribution to the success of the conference in various ways.

Thank you very much!

October 2015

Ershi Qi
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Contents

Part I
Industrial Engineering

Modeling and Optimization of Functional Response Based on Kriging Model

Qing-an Cui and Bo He

Abstract In the continuous complex production process, the value of quality characteristics is not only a single observation value, but a continuous response curve existing in a given space, which named functional response. This paper proposed a quality optimization method for functional response. Firstly, it obtained the sample combines with the uniform design method and established a functional response model with the Kriging model. Then, it measured the difference between the objective model and the established model using an integral differential method thus translated the functional response optimization to the single response optimization. And then a relation model of samples and single response was built by Kriging model. Finally, to realize quality optimization, it used the GA method to reach the global optimum. The research on the optimal design of LC filter indicated that, the proposed method overcomes the shortages of the traditional single response optimization and obtained better results.

Keywords Circuit optimization · Functional response · Kriging · Quality optimization

In modern manufacturing, we can get the desired output quality characteristics by controlling and adjusting the appropriate process parameters. Therefore, the process parameter optimization is an important way to realize the improvement of the product quality [1, 2]. In the process of modern industrial production, the value of the response is often a continuous variable, such as contour machining mechanical parts, optimal design of the filter circuit, etc. Traditional single and multiple response studies have been unable to meet the needs of the development of production. Therefore, continuous response theories are proposed. The case of a one-dimensional response variable is known as a 'profile response' [3] or a 'functional response' [4]. The functional response optimization is a method that is

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to select the appropriate level of impact factors, mainly through a series of experiments and to obtain the maximum possible objective function through finding the optimal sequences of factors. Traditional optimization methods are more concentrated in a simple static response, which can only achieve suboptimal results. The optimization results can still be improved. This research on the functional response optimization can compensate for the lack of the above-mentioned optimization and get better optimization results.

Researchers have considered the functional response in the process of quality optimization. An example of the functional response experiment was given by Nair et al. [5] who studied the design of an electric alternator. The response of interest in the experiment was the electric current generated at different rotational speeds at which the alternator operates. This design consisted of 8 controllable factors and 2 noise factors and got the closest target current function by using the Taguchi method. In the modeling, Del and Castillo [6] proposed a full Bayesian two-stage mixed effects regression model to solve the problem of robust parameter design of the functional response. Their method can estimate the probability of a particular function, but it ignores the correlation between functions and may be wrong in setting of the same factor. Alshraideh [7] proposed a spatio-temporal Gaussian random function model which can be more flexible in the modeling of expected function and the correlation between the functions.

Few researches were done on functional response problems in experimental design, modeling and optimization, besides the existing modeling methods of functional response are often a simple first-order or second-order polynomial. The low-order polynomial representation is poor in global representativeness and only effective in solving some simple relationship problems, but will often lead to the problem of inadequate fitting when the process is more complicated. The existing optimization methods are too simple to handle complex problems and get the optimal value, especially those that do not have a specific form.

This paper proposes a quality optimization method for functional response. Firstly, it obtains the samples combines with the uniform design and establishes a functional response model with the Kriging model. Then, it measures the difference between the objective model and the established model by using an integral differential method, thus transforming the functional response optimization to the single response optimization. And then a relation model between samples and single response is built by Kriging model. Finally, to realize quality optimization, it uses the GA method to reach the global optimum. In this research, the response surface method and functional response theory are briefly analyzed and then a specific method of implementation steps is given. The case study on the optimal design of LC filter indicates the effectiveness of this method.

1 Theory Introduction

1.1 Functional Response Optimization

Functional response means an experiment that can generate a continuous, curvilinear response *Y*(*s*) under the influence of the variable *s*. Before the establishment of the functional response model, we need to find the factors affecting the response curve

$$s = \{x_1, x_2, \ldots x_k\} \tag{1}$$

Traditional single response needs experimental design and statistical analysis to obtain the statistical factor model to the response of the variable *y*,

$$y = f(x_1, x_2, \ldots x_k) + \varepsilon \tag{2}$$

$f(x_1, x_2, \ldots x_k)$ is a determined function and often takes the form of a first-order or second-order polynomial. ε represents the error, which is generally believed as $\varepsilon \sim N(0, \sigma^2)$ and is independently and identically distributed. As for the functional response we need to establish the statistical factor model on the functional response variable *Y*(*s*)

$$Y(s) = G(x) + \varepsilon \tag{3}$$

The purpose of the functional response optimization experiments is to obtain an ideal curve through the finding of optimal factor sequence. The curve should be as close as possible to the ideal target profile *z*(*x*) as required. After the establishment of the functional response model, we should compare it with the desired target curve. Methods commonly used for comparison are the discrete point method and the integral difference method. We use the integration difference method in this paper,

$$d = \int_{x_1}^{x_2} [G(x) - z(x)]^2 dx \tag{4}$$

After we obtain the gap *d* between the functional response model and the target curve, the functional response optimization can be transformed into a traditional single-response, which is the establishment of the model between impact factors and the single-response *d*. After the global optimization, we can get the optimal factor sequence corresponding to the functional response and achieve the purpose of the functional response optimization.

1.2 Kriging Model

Kriging method is an approximate model based on statistical forecasting method in random process which is widely used in mathematics geology. It also has the statistical characteristics of smooth effect and the statistical characteristics of minimum estimation variance and plays an important role in the linear geostatistics [7]. Kriging has a greater advantage in the simulation experiments, including a given input conditions and determined output values, often used in computer-aided design [8]. Matheron puts Krige's achievement into theories and systems, proposed a 'regionalized variable' [8]. Wu et al. [9] applied the Kriging model to the modeling of complex product in multi-stage manufacturing process, aiming to achieve the minimum mass loss under noise distribution and optimize the design level in manufacturing process control variables offline. Tu et al. [10] proposed modeling approach to the characteristics of compressor based on Kriging algorithm. With marine diesel engine as an example, they discussed the impact of the related initial parameters and relevant models for the prediction error [11].

2 Research on Experimental Design, Modeling and Optimization of Functional Response

2.1 Basic Idea

For functional response, establishing an approximation model of effect factor and functional response is one of the key steps to its implementation. The model should be representative and able to address more complex issues. In order to reduce the cost, the samples which model required should be as few as possible. All points in the scope of feasible region may be a fitting model of optimal solutions, but the experiment is unlikely arrangement at each parameter combination, so the choice of the sample must be reasonable, and can be obtained by a certain experimental design method. After establishing the robust model, we should make a global optimization to the established models, and it is very important to choose the right algorithm for global optimization.

2.2 Key Issues

Before constructing the approximation model, we need to obtain sample sets of factors which are representative. Orthogonal design, uniform design and spatial grid are common methods to obtain samples. Uniform design is about experimental points uniformly distributed in the feasible region and factors distributed evenly. These factors are only involved in the experiment once, which abandons the repeated participation of factors of orthogonal design experiment approach. Because the factors are arranged uniformly, and all information of factors can be collected, so the information on factors obtained by uniform design is excessive. This method is particularly suitable for experimental processes whose impact factors are numerous.

The key of quality optimization is to establish the approximation model between quality characteristics and influence factors. Kriging model is an unbiased estimate model whose variance is the minimum. Compared with regression analysis, it can provide a better global forecast. Import the sample set of uniform design to MATLAB, after the determination of model parameters include $f(x)$, nuclear function $r(x)$ forms and parameters, we can establish the relational model between output response and input factors. In recent years, we began using Kriging model as approximate models of complex systems to optimize the system in the aerospace, automotive, IC and CAD development, instead of the response surface model.

After the selection of modeling and samples, we need to consider the measure of the gap between fitting model and target model. Because the research problem is the gap between the two curves, so we use the method to make integral difference in a certain interval. To replace the functional response model with integral difference, and regard it as an ultimate objective, namely, when the minimum of integral difference is achieved, the minimum gap between the fitted model and the target model of the input parameters is also achieved, so we can achieve objective and obtain optimal combinations of parameters. There are several methods to optimize a function or model; we can divide them into two major categories: analytical method and the direct method. We can obtain the exact solution by analytical methods, and we can only obtain approximate solutions by direct method.

2.3 Implementation Steps

From the above analysis, the basic steps are presented here about research on optimization of functional response based on Kriging model, the specific implementation steps as follows:

1. Clear research questions and the objective function to determine the expression $z(x)$.
2. Select the impact factors and achieve ranges of each factor based on the prior knowledge.
3. Get the observed samples using a uniform design or a uniform grid based on Joint Table and normalize the data $S = \{x_1, x_2 \ldots x_i\}, x \in \mathrm{X}$.
4. Obtain the simulation curves for each group of data samples based on field testing.
5. Use Kriging model to build the simulation curve model, use the second-order polynomial to determine $f(x)$, Gaussian kernel function andθwhose initial value is assumed to be isotropic, and size is 10.

$$\hat{f}(x) = f(x)^T \beta^* + r(x)^T \gamma^* \quad (5)$$

$$r(d_k) = \exp\left(-\theta_k d_k^2\right) \quad (6)$$

$$d_k = \left| x_i^k - x_j^k \right|, \quad (j = i, \ldots, m;\ i = 1, \ldots, n) \quad (7)$$

6. Measure the gap d between the objective model $z(x)$ and the simulation curve model $\hat{f}(x)$ using integral differential method

$$d = \int_{x1}^{x2} \left[\hat{f}(x) - z(x)\right]^2 dx \quad (8)$$

7. Transform the functional response optimization to the single response optimization. And then build the relation model of impact factors and gap d by Kriging model.
8. Use GA to optimize the relation model to get the minimum d_{min} and the relative optimal combination of parameters.

3 Case Study

To demonstrate the effectiveness of the proposed method, we take the LC filter circuit optimization as a case study. Filter circuit is a kind of electronic circuit scan which can make the useful signal go through and filter out the useless signal [12]. In the design of the filter circuit, the filtering performance of the system depends mainly on the parameters' values of circuit element. Previous studies are mainly about single response and static response of the filter circuit, such as fluctuation band, stop-band attenuation characteristics and so on. They can only obtain the suboptimal optimization results. Through the experimental design, modeling and optimization of the functional response, we can optimize the dynamic response of filter circuit to achieve the comprehensive optimization effect, improve the optimal results and get better quality characteristics.

The 2-order type K band-pass filter circuit [13] is composed of inductance L_1, L_2, capacitance C_1, C_2, resistance R and AC voltage $\tilde{V}$ in this case. The design index of circuit should satisfy these conditions (the center frequency 500 kHz, the

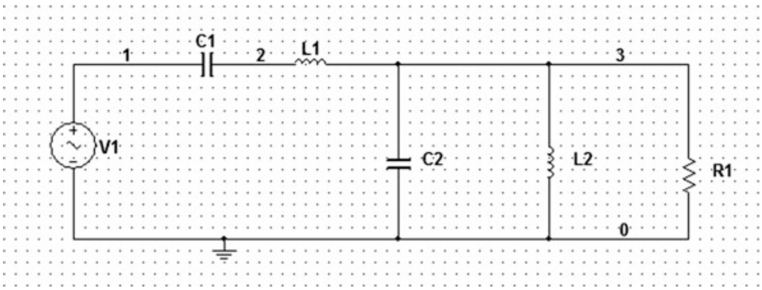
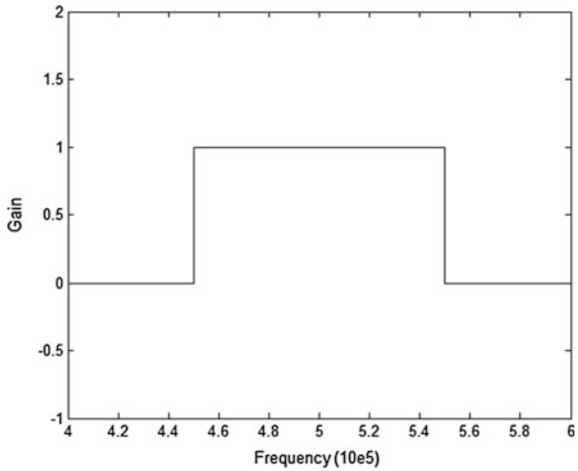


Fig. 1 Two-order type K BPF

Fig. 2 Ideal BPF



bandwidth 100 kHz, band fluctuation, less than 1 dB, the transition bandwidth 80 kHz and the stop-band attenuation greater than 16 dB) (Fig. 1).

The ideal band-pass filter model of the circuit is with the center frequency being 500 kHz, the bandwidth 100 kHz, no fluctuation in the pass band and attenuation tends to infinity (Fig. 2).

In this case, take the resistance R_1 and power supply V_1 as the set value, select C_1, C_2, L_1, L_2 as the influence factor. According to existing knowledge, each value' range of influence factor is shown in Table 1.

3.1 Experimental Design and Modeling

The purpose of parameters optimization of the filter circuit is to make the simulation circuit as close as possible to the ideal target circuit. After normalizing each factor,

Table 1 Range of infleunce factors

	1	2	3	4
Influence factors	C_1/Pf	C_2/pF	L_1/uH	L_2/uH
Range	96–116	2400–2900	860–1050	34–42

based on Join Table and Uniform Design, we can acquire the observed samples which consist of 64 groups as $S = \{x_1, x_2, x_3, x_4\}$ (Table 2).

For each group sample, Multisim is used to simulate the circuit and obtain the corresponding amplitude-frequency curve. Krining models amplitude-frequency curve and compares it with the target function $z(x)$ when the frequency range is from 400 to 600 kHz. Finally, gap d is received by integral calculus.

Table 2 64 groups of observation samples of influences factors

	x_1	x_2	x_3	x_4
1	115.375	2767.188	931.25	35.5
2	106.625	2696.875	907.5	36.875
3	115.687	2517.188	946.093	41.75
4	107.875	2853.125	1014.375	41
5	101.312	2759.375	916.406	39
6	104.75	2439.063	966.875	38.875
7	111.937	2423.438	925.312	37.25
8	96.625	2540.625	940.156	39.75
9	98.187	2868.75	1041.094	38.625
10	110.062	2564.063	913.437	40.375
11	106.937	2618.75	1050	39.5
12	106	2720.313	895.625	41.25
13	100.687	2837.5	928.281	41.875
14	103.812	2587.5	934.218	34.75
15	105.062	2665.625	922.343	39.875
16	107.562	2493.75	889.687	39.375
17	101.625	2884.375	1011.406	34.875
18	101.937	2571.875	862.968	37.5
19	105.687	2900	943.125	37.375
20	98.812	2704.688	955	40.75
21	111.625	2892.188	960.937	40.5
22	113.812	2735.938	1023.281	40.125
23	99.75	2681.25	963.906	38
24	102.562	2657.813	949.062	35.25
25	112.25	2798.438	1047.031	36.125
26	112.562	2689.063	865.937	38.75

(continued)

Table 2 (continued)

	x_1	x_2	x_3	x_4
27	108.187	2603.125	937.187	38.5
28	115.062	2579.688	1038.125	37.625
29	103.5	2728.125	999.531	37.75
30	109.75	2845.313	910.468	34.25
31	116	2829.688	978.75	38.375
32	114.125	2478.125	892.656	36.5
33	114.75	2634.375	877.812	40.875
34	105.375	2532.813	1026.25	36.75
35	97.562	2821.875	990.625	36.625
36	96.312	2642.188	1020.313	37.125
37	111.312	2610.938	969.843	35.875
38	100.062	2626.563	898.593	36.25
39	112.875	2548.438	1002.5	39.125
40	113.5	2876.563	901.562	39.625
41	109.125	2407.813	1017.344	38.125
42	96.937	2743.75	886.718	34.625
43	108.812	2814.063	952.031	37
44	106.312	2485.938	993.593	35.625
45	104.437	2860.938	874.843	35.75
46	97.875	2454.688	904.531	38.25
47	108.5	2525	871.875	35
48	110.687	2782.813	883.75	37.875
49	99.125	2806.25	868.906	40.25
50	111	2462.5	987.656	41.125
51	114.437	2673.438	1005.469	35.125
52	101	2556.25	981.718	34.125
53	97.25	2595.313	975.781	41.375
54	103.187	2415.625	880.781	41.5
55	100.375	2470.313	1008.438	40
56	104.125	2775	1032.188	41.625
57	113.187	2446.875	957.968	34.5
58	99.437	2431.25	1035.156	35.375
59	107.25	2751.563	972.812	36.375
60	102.25	2509.375	1044.063	40.625
61	102.875	2790.625	984.687	39.25
62	98.5	2501.563	919.375	36
63	109.437	2650	996.562	42
64	110.375	2712.5	1029.219	34.375

$$d = \int_{400k}^{600k} \left[\hat{f}(x) - z(x)\right]^2 dx \tag{9}$$

Transform the functional response into a single response and use software builds a Kriging model between factors C_1, C_2, L_1, L_2 and gap d. Here, the second-order polynomial, Gaussian kernel function and θ whose initial value is assumed to be isotropic, whose size is 10 are combined to determine the $f(x)$.

$$\hat{f}(x) = f(x)^T \beta^* + r(x)^T \gamma^* \tag{10}$$

3.2 Optimization of Functional Response

For optimization, it adopts genetic algorithm. The range of factors is in Table 1. After 63 iterations, the minimum objective gap d is obtained at 48062 and the combinations of optimal parameters are shown in Table 3.

Genetic optimization results of the optimal design (Fig. 3).

3.3 Discussion

The original design is based on the traditional EDA optimization algorithm whose shortcomings are that too many iterations, no convergence or local convergence. These problems, make the result not the best optimal solution within the design space. Hence, this paper proposes functional design optimization based on Kriging model that can solve these problems and achieve better performance. The result of comparing between the original design and optimum design is shown in Fig. 4.

From the above chart, the frequency in the stop-band in the original design is attenuating too slowly. While the proposed not only keeps the original design's advantage of small ripple (less than 1 dB) but also makes transitional zone more stepper (attenuation rate is 2 dB greater than the original design). Over the entire spectral range, the proposed can meet the requirement of the performance indicators. Moreover, the filtering performance is significantly better than that of the original design.

Table 3 Parameters contrast of original design and optimization design

	C_1/pF	C_2/pF	L_1/uH	L_2/uH	Y_{min}
Original design	106.103	2652.582	954.929	38.194	52,073.78
Optimizaton design	100.15	2899.816	1029.446	34.827	48,062.24

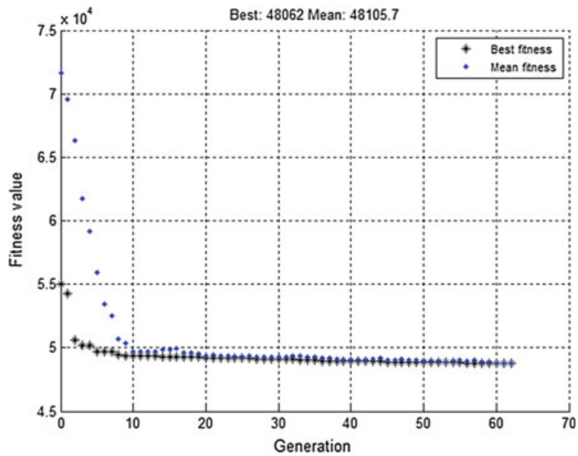


Fig. 3 Genetic optimization diagram

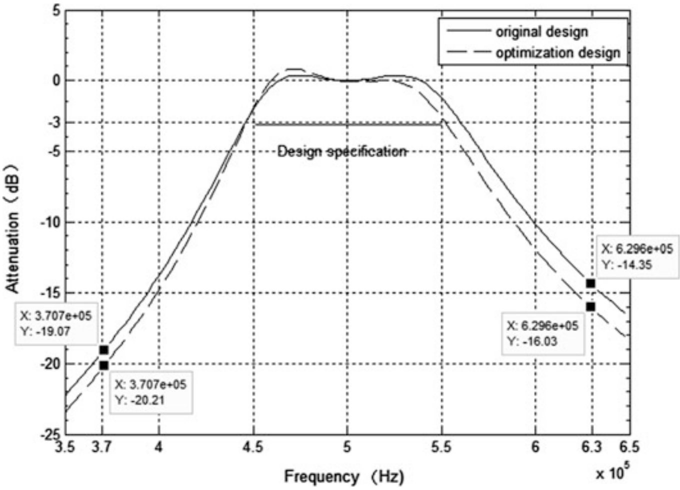


Fig. 4 Comparison between original design and optimum design

4 Conclusion

For parameter design optimization, this paper presents functional response optimization ideas based on Kriging model. It establishes the model between the impact factors and the output factors in Kriging model. Then it obtains the samples by using the uniform design and adopts the GA method to reach the global optimization and realize quality optimization. Compared with the traditional static response optimization, this method can get better optimization results and make up for the shortage of other research in this area. This paper also gives the specific implementation steps of the method. The design and optimization are reasonable and the results of the case study can also demonstrate the practicality and effectiveness of the method in circuit optimization. This paper discusses the basic theory of Kriging Model and conducts system optimization by using GA combined with Kriging model and proves it capable of running in the MATLAB environment.

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Evaluation of Auto Parts Industry Cluster in Jiangxi Province

Hui Chen and You-yuan Wang

Abstract The formation of industrial clusters to strengthen the contact each enterprise in the cluster and reduce transaction cost. Auto parts industry cluster is new power of the development of the auto industry. Industrial cluster competition will effectively promote the development of auto industry. In this paper, combining with the basic theory of industrial cluster, evaluation on the auto parts industry cluster in Jiangxi province by using the geographic concentration index of industrial cluster, then gives some countermeasures.

Keywords Auto parts · Geographic concentration · Industrial cluster

1 Introduction

The formation of industrial cluster will strengthen the relationship all related enterprise, reduce the cooperation between the various costs. Industrial cluster is drive regional growth engine [1]. Industrial cluster is beneficial to form regional innovation system, improve the regional competitive advantage and promote regional economic development [2]. Industrial cluster development pull function on the regional economic growth can be achieved by improving the enterprise's productivity and optimize the allocation of resources.

Chinese auto parts industry cluster in got great development in recent years, however, compared with foreign counterparts, there are big gap. As the demand for cars and car production is growing, also in the rapidly growing demand for auto parts, but the core components depends heavily on foreign imports. According to

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customs statistics, foreign brand market share accounted for about 70 %. Foreign brands are dominant position in the high-end market [3].

Independent components of enterprise manufacturing capacity 90 % were focused on the parts of the low-end products, only 10 % of the enterprises producing high technology content of components in the domestic auto parts market, But the most part this 10 % of high-end, is also the foreign joint venture production [4]. Low technology content and low profit of low-end products for the domestic auto parts industry is hard to get fast development. Most building or have built auto parts industry cluster are in low stage of development, product added value is not high in China [5]. Domestic scholars believe that the evolution of the industrial cluster and the cluster there are inverted u-shaped relationship between [6]. Cluster development is divided into four stages: the early stage, the rapid growth stage, the steady development stage and decline stage.

Automobile industry cluster has developed to a certain period, but, as with other domestic industry, it is difficult to achieve breakthrough in Jiangxi province. Now, analyze the present situation of auto parts industry cluster in Jiangxi province to determine the stage of development, found the problem, and prompt improvement. Making full use of the unique advantages in Jiangxi province, developing the auto parts industry, makes it the power to promote the development of economy in Jiangxi province. It is significant to the revitalization and realize the rise of central of Jiangxi province.

2 Auto Parts Industry Cluster in Jiangxi Province

2.1 The Present Situation of the Auto Parts Industry Cluster in Jiangxi Province

Jiangxi province automobile industry started earlier, it began in the 1950s. Now Jiangxi has grown into the industry cluster area. The Nanchang, Ganzhou, Fuzhou three automobile industry cluster has formed. According to the statistical yearbook analysis in Jiangxi province And after calculation, from 2010 to 2013 the industrial contribution rate are 7.8, 11.4, 12.12 and 17.70 in Jiangxi province automobile industry. Mainly auto parts industry in the rapid development of automobile industry in Jiangxi province, Production of automobile type is more widely, from light, medium to large passenger cars, cars. Automotive market segments have sprung up Quanshun, Lufeng, Changhe and a series of popular models.

In order to take the initiative to adapt to the new normal economic development, in-depth implementation of the five functional areas in Jiangxi province development strategy, based on the new urban development function, firmly seize development does not relax, vigorously promote the new industrialization and urbanization, adhere to the incremental tuning structure, promoting the upgrade with innovation, to speed up cultivating new economic growth point, and strive to create distinctive modern industrial clusters. After long time of development, the center of Nanchang city XiaoLan accessories parts radiation industry cluster has been initially formed in Jiangxi province another local auto parts industry is a pillar industry.

2.2 Jiangxi Province Auto Parts Industry Cluster Identification

In many of the literature in foreign countries, industrial cluster identification is usually based on location quotient. Wang [7] think regional commercial method can pass the location quotient coefficient to judge whether the regional industrial agglomeration. Location quotient is also called specialization rate, its economic meaning is refers to the industry occupies a share of a given area occupies the share ratio of the industry and the economy as a whole.

Location quotient in between 0.85 and 1.15, the industry location quotient of the coefficient is not significant in statistical sense, can be regarded as equal to 1.

$$LQ = (X_{jm} \div X_m) \div (X_{jk} \div X_k) \quad (1)$$

It is the calculation formula of location quotient, this paper USES the production output value to calculate the coefficient of location quotient. On this equation, *LQ* means Location quotient, *X* means output value, m said a region, *k* said a national region, *j* said the industry, X_{jm} represents the output value of a certain area industry, X_m means one regional output value, X_{jk} means the production value of *k* national *j* industry, X_k means *k* country's total output value.

Identify the auto parts industry cluster in Jiangxi province by location of commercial. To this end, we choose nine auto industry development mature provinces, location quotient coefficient calculated using the formula (1), then compared with Jiangxi province. Refer to obtain 'China statistical yearbook 2014' and the provincial statistical yearbooks data and calculation. The following Table 1

Table 1 Part domestic province automobile industry cluster corfficient of location quotient in 2014 [8]

Number	Region	LQ
1	Beijing	2.431238704
2	Liaoning	1.53467411
3	Shanghai	3.278786355
4	Jiangsu	1.413301243
5	Zhejiang	0.89686092
6	Shandong	1.470377792
7	Hubei	2.944260467
8	Guangdong	1.098215417
9	Chongqing	3.450335155
10	Jiangxi	0.849994927

According to Table 1: the location quotient coefficient of Zhejiang, Guangdong and Jiangxi are small, between 0.85 and 1.15, no significant in statistical sense. The gap is bigger in Jiangxi province and other provinces. In other parts of the industrial cluster has formed, but Industrial cluster is not obvious in Jiangxi province. It means that the automobile industry cluster development in the region has yet to mature, It needs to further promote the development of cluster.

3 Evaluation of Auto Part Industry Cluster Concentration in Jiangxi Province

3.1 Evaluation Method

Scholar Krugman On the basis of the average degree of Lorenz curve in measuring distribution, many empirical studies of industrial concentration degree and theoretical method to measure the degree of equity of distribution, He has done a lot of empirical research on industrial agglomeration [9]. But Ellision and Glaeser [10] point out the defects of Spatial Gini coefficient. He thinks that when the space Gini coefficient is lager than zero, there is not necessarily the phenomenon of industrial cluster. Because it was not considered that account the scale of the enterprise and regional differences may be said there is a deviation on the degree of industrial concentration.

To solve the defect of space Gini coefficient, Ellision and Glaeser [10] built industrial geographic concentration index to measure the degree of industrial geographic concentration, It is calculation formula.

$$\gamma = \frac{\sum_{i=1}^{M} (S_i - X_i)^2 - \left(1 - \sum_{i=1}^{M} X_i^2\right) H}{\left(1 - \sum_i X_i^2\right)(1 - H)} \tag{2}$$

$$H = \sum_{j=1}^{N} Z_j^2 = \sum_{j=1}^{N} \left(\frac{X_j}{X}\right)^2 \tag{3}$$

Formula (3) means that there were N enterprises in the industry in one economic entity, The economy is divided into M a geographical area, the N enterprise distribution in M area. S_i means that i output value of the regional industry accounted for the proportion of the full value of the industry. X_i means i the full value of the area proportion of the total output value of economy. H is Hector fender index, X_j means j enterprise scale, X represents the total market size, what Z_j had represented the first j enterprise's market share, N is the number of companies within the industry.

3.2 Auto Parts Industry Cluster Concentration Calculation

Refer to obtain 'China statistical yearbook 2014', 'China automotive industry yearbook 2014' and the provincial statistical yearbooks data and calculation. The following Table 2.

Based on Ref. [11] method to calculate H. Computation formula is as follows:

$$H = \left(\frac{b}{a} * \frac{1}{Y}\right)^2 * a \qquad (4)$$

The b on behalf of the regional industry output value. A is the number of companies in this area. Y represents the industry output value.

According to the data in Table 2, after get H value was calculated by the formula (4), Industrial geographic concentration index was calculated by the formula (2). The following Table 3:

If the industrial geographic concentration index is higher, the concentration of industrial clusters would be greater. It can be seen from Table 3 that automotive industrial geographic concentration index is higher, the industry cluster development more mature in Shanghai and Hubei. Zhejiang and Jiangxi's geographic concentration index is low, industrial cluster has not yet ripe. Compared with other provinces and cities who's auto industry development more ripe, the number of automobile enterprises, enterprise scale is a gap. But, the car industry has a greater contribution to Jiangxi economic development indeed. The development of the auto parts industry cluster will be an opportunity to accelerate economic development in Jiangxi.

Table 2 Automobile industry related date and parts in the whole country in 2014

Number	Region	Auto industry output value ($ten thousand RMB)	GDP(One hundred million RMB)	The number of the car industry enterprises
1	China	392,254,000	568,845.20	11599
2	Beijing	32,692,487	19,500.56	216
3	Liaoning	28,655,000	27,077.65	433
4	Shanghai	48,840,800	21,602.12	554
5	Jiangsu	57,656,600	59,161.75	1305
6	Zhejiang	23,233,900	37,568.49	1623
7	Shandong	55,445,347	54,684.33	1301
8	Hubei	50,083,200	24,668.49	1306
9	Guangdong	47,076,000	62,163.97	620
10	Chongqing	30,113,047	12,656.69	678
11	Jiangxi	8,404,141	14,338.50	176

Table 3 Parts industrial geographic concentration index in 2014

Number	Region	γ
1	Beijing	0.002378049
2	Liaoning	0.000636911
3	Shanghai	0.007471832
4	Jiangsu	0.001851361
5	Zhejiang	0.000044440
6	Shandong	0.002048454
7	Hubei	0.007109956
8	Guangdong	0.000093362
9	Chongqing	0.002965177
10	Jiangxi	0.000011697

4 Countemeasures

According to current situation of auto parts industry cluster development in Jiangxi province, we put forward the following suggestions:

1. Auto parts enterprises need enhance effective cooperation through clusters and other enterprises and research institutions to protect its market competitiveness of products and services. A cluster is a good platform for communication between enterprises. The cooperation and exchanges between enterprises and research institutions can promote and improve product and service quality, and further promote the automotive parts industry matures, constitute a virtuous circle.
2. Colleges and universities and research institutions can learn more about auto industry development needs in production practice. It will be more convenient to access to the application of scientific research resources, and enhance the level of industry from technical angle, so as to achieve a competitive advantage in the auto parts industry in Jiangxi.
3. Government's departments can promote the characteristics of the local economy can be formed in the region, with car brand advantage to attract more investment. From the data we can see that the number of auto parts enterprises there is a gap in Jiangxi province and the scale of the automobile industry in the more developed provinces, which requires the joint efforts of the government and the market.

5 Conclusion

Jiangxi Province should actively promote the development of industrial clusters. Cluster strategy can unite competitive enterprises, the formation of key industries, the use of the relevant departments and growth opportunities in sectors of the economy, is conducive to the region's ability stark features, core strengths and radiation strength, attracting all kinds of investment, business and professional talent to embody the province open clusters, automobile network forms of organization. Jiangxi province for various actors in the cluster network has enough power to participate in the cooperation in the cluster. We should seize the opportunity to promote Jiangxi Province Poyang Lake Ecological Economic Zone and the rapid development of the automotive industry and accelerate the cluster development of auto parts industry in Jiangxi Province, Jiangxi Province to promote the realization of economic takeoff.

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ReliefF Based Forward Selection Algorithm to Identify CTQs for Complex Products

An-da Li and Zhen He

Abstract Complex products contain a huge number of quality characteristics (QCs). To efficiently control the manufacturing processes of complex products, identifying critical to quality characteristics (CTQs) is required. This study proposes a feature selection algorithm named ReliefF based forward selection (RFS) for CTQs identification. RFS combines ReliefF with a forward selection algorithm to handle the problem of feature (QC) redundancy. Empirical study has shown that RFS can select fewer CTQs while maintaining a high accuracy rate compared with ReliefF. The proposed algorithm is efficient in identifying CTQs.

Keywords Complex products · CTQs · Feature selection · Forward selection · Relieff

1 Introduction

Defined by Hobday and Rush, a complex product is an item that has high cost and engineering-intensive components, which is complicated from both technical and managerial perspectives [1]. Chinese Academy Bo-hu LI thought that the features of complex products include customer demand complexity, product technology complexity, manufacturing process complexity, test maintenance complexity, project management complexity and work environment complexity [2]. From the perspective of quality, the quality control becomes harder when the structure of a product is more complex and the number of product components increase. There is a need to select the critical to quality characteristics (CTQs) or key characteristics

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(KCs) from a number of quality characteristics (QCs), since not all QCs are equally informative, some have strong relevance to the final quality, and others have weak relevance or no relevance to the final quality of products. Feature (or variable) selection techniques aim to discriminate between QCs that are relevant to the product quality and those are not [3]. These techniques are efficient in identifying CTQs, as some practitioners have already used these techniques to identify CTQs [3–5].

Feature selection techniques can be classified into three categories: filter, wrapper and embedded. Filter techniques are preprocessing phases before learning, which eliminate irrelevant features before applying learning algorithms [6]. Advantages of filter techniques are that they can be easily scaled to high-dimensional datasets, and they are computationally simple and fast. The disadvantages of filter algorithms are that they ignore the interactions with learning algorithms, which lead to worse classification performance [7], furthermore, many filter algorithms even can't handle the problem of feature redundancy (correlation). Information Gain (IG) and ReliefF are two common filter techniques [8, 9]. Wrapper techniques require one certain learning algorithm and use its performance to select features well suited to the learning algorithm [10]. The advantage of wrapper techniques is that they have better classification performance with certain learning algorithms; disadvantages are that they would easily cause the problem of over-fitting and they are computationally intensive. There are different search strategies for wrapper techniques, such as sequentially forward selection (SFS) and sequentially backward selection (SBS) [11]. Another category of feature selection techniques is embedded approach. In embedded models, the selection of features is integrated in the building of learning algorithms. C4.5 is a common embedded technique [12].

Reference [5] introduced the filter technique ReliefF to the identification of CTQs for complex products. As mentioned above, many filter algorithms can't handle the problem of feature redundancy, as do ReliefF. In this paper, we combine ReliefF with a forward selection method to handle the feature (QC) redundancy. The experimental result has shown that the proposed method effectively eliminated QCs while maintaining a high accuracy rate compared with standard ReliefF.

2 Methodology

2.1 ReliefF Algorithm

ReliefF algorithm is an extension of Relief algorithm [13, 14]. Relief is first proposed by Kira and Rendell at the end of last century. The method is designed to select features of the dataset with two classes, and it can't handle missing values in the dataset. The basic idea of Relief is finding the features' distinction capacity between positive class and negative class. ReliefF is developed by Kononenko [9]

Input: M learning instances with L features and C classes
Output: the vector $\mathbf{W} = (W(F_1), \ldots, W(F_L))$

set all weights $W(F_l)$=0, l=1 ...L;
for i=1 to m **do**
  randomly select an instance X_i;
  search for k nearest hits H_j of X_i;
  for each class $c \neq class(X_i)$ **do**
    search for k nearest misses $M_j(c)$ of X_i; **end for**;
  for l=1 to L **do**

$$W(F_l) = W(F_l) - \sum_{j=1}^{k} diff(F_l, X_i, H_j)/(m \cdot k)$$

$$+ \sum_{c \neq class(X_i)} [\frac{p(c)}{1 - p(class(X_i))} \sum_{j=1}^{k} diff(F_l, X_i, M_j(c))/(m \cdot k)$$

  end for;
end for

Fig. 1 Pseudo code of ReliefF

on the basis of Relief, and it can handle the multiclass problem and treat missing values. The output of ReliefF is a vector **W** which represents the weight of each feature.

Given a data with C classes and L features, each feature is denoted by $F_l\,(l \in (1, \ldots, L))$, an instance R_1 is denoted by a L-dimensional vector $(R_{1,1}, \ldots, R_{1,L})$. Then the process of ReliefF can be described as: First, randomly select an instance X_i from learning instances. Second, search for k nearest instances of X_i from the same class, named nearest hits H_j, and k nearest instances from each of different classes, named nearest misses $M_j(c)$.

Finally, the weight $W(F_l)$ for each feature F_l is updated depending on the value of X_i, H_j and $M_j(c)$. This process iterates m times, where $i \in (i, \ldots, m)$, $c \in (1, \ldots, C)$, denotes class, and $j \in (1, \ldots, k)$. The final output is $\mathbf{W} = (W(F_1), \ldots, W(F_L))$.

The pseudo code of ReliefF is shown in Fig. 1, where $class(X_i)$ denotes the class of X_i, $p(c)$ denotes the possibility of class c, which can be estimated by instances. $diff(F_l, R_1, R_2)$ is a function that calculates the difference between two random instances R_1 and R_2 for feature F_l. When F_l is nominal, $diff(F_l, R_1, R_2)$ is defined as:

$$diff(F_l, R_1, R_2) = \begin{cases} 0, & R_{1,l} = R_{2,l} \\ 1, & R_{1,l} \neq R_{2,l} \end{cases} \tag{1}$$

When F_l is numerical, $diff(F_l, R_1, R_2)$ is defined as:

$$diff(F_l, R_1, R_2) = \frac{|R_{1,l} - R_{2,l}|}{\max(F_l) - \min(F_l)} \tag{2}$$

where $\max(F_l)$ denotes the maximum value of F_l, and $\min(F_l)$ denotes the minimum value of F_l.

2.2 ReliefF Based Forward Selection Algorithm for CTQs Identification

ReliefF is efficient in finding features relevant to class [15]. However, it can't handle the problem of feature redundancy [10]. Feature redundancy is caused by feature correlation. Two features are supposed to be redundant to each other if their values are correlated. In a simple situation, assume two features F_i and F_j, which have high correlation with the class, are completely correlated. Weights $W(F_i)$ and $W(F_j)$ resulting from ReliefF would be almost identical and both have high values. The result is that both F_i and F_j will be retained because they are relevant to the class, and ReliefF doesn't remove the redundant feature. In the background of quality area, if ReliefF is used to identify CTQs, too much redundant QCs will be retained, which will increase the difficulty and cost of quality control. Therefore, a feature selection algorithm that can deal with the problem of feature redundancy is required.

A wrapper technique [10] can be introduced to eliminate feature redundancy. Assume F is a full set of features, each feature in F is denoted by F_l ($l \in (1, \ldots, L)$). Let S be a subset of F, the cross-validation (CV) accuracy of training set with the features in S is denoted by $Acc(S)$. If CV accuracy $Acc(\{F_l\} \cup S)$ ($F_l \notin S$) is higher than $Acc(S)$, then F_l is useful and it should be retained. If $Acc(\{F_l\} \cup S)$ is not higher than $Acc(S)$, then F_l is a redundant feature to S, because it doesn't help with the improvement of classification performance.

According to the analysis above, a hybrid algorithm named ReliefF based forward selection (RFS) algorithm is proposed in this paper. First, rank the features by their weights obtained by ReliefF from high to low. And the ranked feature set is denoted by FR. Then, a forward selection process is performed. Beginning from the first feature in FR, features are added one by one to the selected feature subset according to the order in FR if including corresponding feature improves the classification accuracy. A feature subset with relevant and non-redundant features is obtained by these two steps. The Pseudo code of RFS algorithm is shown in Fig. 2. In Fig. 2, FR is a set of ranked features, the elements in FR are FR_l $l \in (1, \ldots, L)$, denoting the features for learning instances; $Acc(S)$ denotes the inner 10-fold CV accuracy [10] on the training set of with feature subset S. The output of RFS algorithm is a feature subset FS, which represents a set of selected features.

Input: M learning instances with L features and C classes
Output: selected feature subset FS

use ReliefF to get each feature's weight $W(F_l)(l \in (1 \ldots L))$;
rank features according to $W(F_l)(l \in (1 \ldots L))$ in decreasing order;
add ranked features to set FR $(FR = \{FR_1, FR_2, \ldots, FR_L\})$;
$TFS = \emptyset; FS = \emptyset$;
$BestAcc = 0$;
for $i = 1$ to L **do**
    $TFS = FS \cup \{FR_i\}$;
    if $Acc(TFS) > BestAcc + \delta$ **then**
        $BestAcc = Acc(TFS)$;
        $FS = TFS$;
    end if
end for

Fig. 2 Pseudo code of RFS algorithm

Generally, verifying the performance of a feature selection algorithm requires dividing the dataset into the training set and the testing set, and RFS algorithm proposed in this paper is no exception. The training set is used to select feature subset and build the learning algorithm, while the testing set is used to evaluate the performance of such feature subset with the learning algorithm. The framework of RBF algorithm is shown in Fig. 3.

Fig. 3 The framework of RBF algorithm

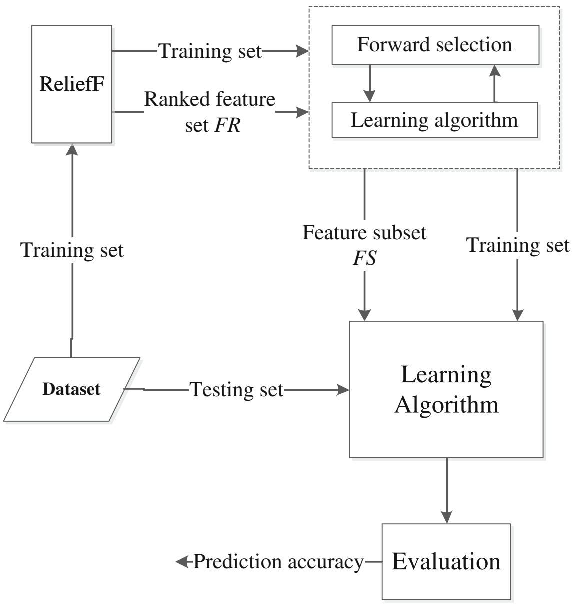

Table 1 Summary of dataset

Dataset	QCs	Instances	Classes
SECOM	590	208 (104/104)	2

Table 2 Performance comparison of ctqs identification algorithms

	RFS	ReliefF	Full set
Prediction accuracy (%)	64.48	62.02	61.36
Number of CTQs	23.7	92.6	590

3 Results and Discussion

In this section, the performance of the proposed method is evaluated by comparing RBF with ReliefF. Dataset named SECOM from UCI Machine Learning Repository [16] is used to evaluate the proposed algorithm. SECOM contains 1567 samples originally, and the samples are divided into 2 classes. In order to solve the problem of data imbalance, 104 samples with the negative class label are randomly selected to balance 104 samples with the positive class label. The summary of the processed dataset is shown in Table 1, in which QCs correspond to features.

Standard ReliefF is chosen to be compared with RFS algorithm. There are two steps for ReliefF to select CTQs. First, rank QCs by the weights obtained from ReliefF in decreasing order. Second, select first N QCs with the highest CV accuracy on the training set. Naïve Bayes classifier (NBC) [17] is chosen as the learning algorithm for its high performance and simplicity.

Table 2 shows the 10-fold CV results of CTQs identification obtained by each feature selection algorithm. The column of Full Set means the result without feature selection. The first row of Table 2 records the prediction accuracy of each algorithm. It is obvious that RFS algorithm obtained the highest prediction accuracy, and ReliefF took the second place. The prediction accuracy with Full Set was the worst, because redundant features have a bad impact on the performance of NBC [10]. The second row of Table 2 records the number of CTQs selected by each algorithm. RFS selected only 23.7 CTQs on average, which were fewer than that selected by ReliefF. Compared with the 590 QCs of original dataset, ReliefF and RFS both can reduce the number of QCs, and RFS is more efficient than ReliefF. In conclusion, the proposed algorithm RFS can select fewer CTQs than ReliefF, while maintaining a high prediction accuracy. Meaning that, the RFS is efficient in identifying CTQs for complex products.

4 Conclusion

This paper proposed a ReliefF based forward selection algorithm (RFS) to identify CTQs for complex products. A traditional feature selection algorithm named ReliefF and a forward selection algorithm are integrated as RFS, in order to efficiently solve the problem of feature redundancy. The experiment results illustrated that RFS can select fewer CTQs than ReliefF while maintaining a high prediction accuracy rate. The proposed algorithm RFS outperformed ReliefF in terms of CTQs identification.

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The Research on Cost Management of Steel-Plastic Composite Pipe Enterprise Based on Activity-Based Costing

Wen-ying Ding and Yu Yao

Abstract With the rapid development of science and technology, the enterprises need to use scientific methods to control the production cost in order to seek long-term development. It is especially important for the steel pipe enterprises which consume a lot of cost. This paper introduces the method of cost management and describes the background and the basic principle of the activity based cost. Through using activity based cost to analyze the cost in a steel enterprise in Tianjin. We analyzed the activity and activity drivers, calculated the cost of each specification and compared with the traditional method, which can obtain the large difference of product cost between the two methods.

Keywords Cost management · Activity based costing · Cost accounting

1 Introduction

In recent years, the development of the iron and steel industry is not good, so the enterprise must to carry on more sophisticated management in order to improve the income. At the same time, the enterprise needs to monitor the cost in the process of production and clear about the causes of the cost. Most iron and steel enterprises in our country use the traditional cost calculation method to manage the cost. A variety of products might cause cost information distortion, which could result in poor policymaking. In this paper, we use activity based cost to instead the traditional cost method for the steel company to account for the costs.

A steel pipe manufacturing enterprise in Tianjin, which the annual output is more than 1 million tons. It has passed ISO9000 international quality system certification in 2000 and was recognized as “Chinese well-known trademarks” by SAIC. But the factory is still using the traditional method to account costs, such as

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use paper by hand or excel to do statistics, which could result in many mistakes. For example, in a production period, a production line loss nearly 100 thousands kWh by the mistake in accounting; and in another line accounting loss a parameter to lead to the pay abnormal. These problems is big enough to hold back an enterprise's development.

2 Literature Review

2.1 Management Methods

With the development of economy and the progress of science and technology, the research on cost management has been deepened. Now we show a lot of cost management achievements in Table 1.

2.2 ABC Literature

With the enterprise pay attention to the cost management, more and more scholars turn to activity-based cost to seek a more scientific cost management mode. We summary the literature related to activity based cost (ABC) in recent 20 years.

In 1994, Petri studied the ABC in the logistics of a food company and proved the advantages of the ABC [5]. David Ben used ABC to analyze the cost for mechanical parts design and development in 2003 [6]. In 2008, Juha-Pekka studied

Table 1 Management methods

Method	Contents
Delphi	It shows the advantages and disadvantages of a design and compared with other without specific value, so it largely based on the past similar project or the experience of the evaluator [1]
Parameters cost estimation	Based on the parameters set by historical data and the total cost of the product to predict the cost [2]. But there are disadvantages that resource consumption is not adequately considered and historical data is not true [3]
Function based cost estimation	Established mathematical functions to convey production structure and features. Mason compare the regression analysis and neural networks in cost estimating by the method. It showed that the neural network model has higher accuracy, especially in the case that the function can't be resolved by a polynomial expression [4]
Activity-based cost (ABC)	Cost and value of their products are not in isolation. Activities consume resources and products consume activities. In order to reduce costs, it is necessary to eliminate unnecessary work and focus on the effective management of activity

the ABC used in different times of the company's life cycle [7]. In 2012, Manuel Schulze contacted the supply chain with ABC to optimize the production process and statistical costs [8]. In 2003, Stephan combined the ABC with the parameters obtained from the actual statistical data to calculate the unit cost of a new type of gas turbine components [9]. In 2014, Korpunenuse ABC to calculate the bioenergy cost in large-scale combined heat and power plants [10]. The advantage of ABC is that it has high accuracy while the disadvantage is the quantity of activity driver and unit activity cost are uncertain.

2.3 ABC Principle

The ABC is based on the theory of cost drivers. It track of the activity dynamic and evaluate the resource utilization to calculate cost [11]. ABC includes five major elements: resources, activity and activity centers, cost targets, cost drivers, accounting period.

Resources is the most primitive state of the enterprise production. Activities are associated with the product. The activity center is a collection of activities, which provides information about the cost, consumption, and execution of each activity. Cost targets is the product that the enterprise need to measure its cost. In manufacturing enterprise, it usually refers to a variety of products and semi-finished products [12]. The cost driver is the key theory of ABC, which includes any factor in causing the cost [13]. Accounting periods can define freely according to actual situation.

The advantage of ABC is that it can deeply reflect the business process of the enterprise. It pays attention to the cause of the cost and could clear the target of cost control, which provides more accurate information for management [14].

3 Csae Study

The steel company in Tianjin product steel-plastic composite pipe which is based on welded pipe. The internal face painting polyethylene powder, which is environmental friendliness pipes with erosion. The pipe used in a variety of fluid transfer. The enterprise uses the galvanized pipes and plastic tubes to product steel-plastic composite pipe. According to statistics, the steel-plastic composite pipe annual output of 40,000 tons and the annual profit of more than 2000 million. The following to use the plastic composite pipe of example to research the activity-based costing.

3.1 Production Processes and Activity Division

Steel-plastic composite pipes is made of galvanized pipes and plastic tubes. Before production, the galvanized pipes should be sandblasted and then pulled into the next workshop. At the same time, we product plastic tubes according to the order. Then put the tubes and galvanized pipes together. The next step named insertion, which means we put the plastic tubes into the galvanized pipes. We named the new pipes as insertion pipes. The insertion pipes need to heat in intermediate frequency to expel excess air so that the pipe internal face is compact. After cooling we packaged the pipes and pull them into finished products. Specific processes is shown in Fig. 1. Production activity is shown in Table 2.

Integration the above activity and form the activity pool as Table 3.

Form the figure we can know the production is made of sandblast activity, plastic tube activity, insertion activity, heating activity, package activity and management activity. In the specification statistics, all the pipes use the modal as "diameter * thickness * length", such as "20.5 × 2.0 × 6.0" means the pipe which diameter is 20.5 mm, thickness is 2 mm and length is 6 m. But the plastic tubes only use the diameter to statistics. So we classified the tubes according to diameter range and convey the specification to the same as other pipes according to the production number.

3.2 Determine Cost Drivers

Because of the different in pipes diameter and thickness, we can't use the weight or number as the driver cost. After analyzing the data on the steel pipe, the thesis decided to classify the specifications as capacity, putting the same capacity as a large size specifications and use the production time as the cost drivers. Internal the large specifications we use the count of pipes as the cost driver. It can reflect the differences costs between different pipes more clearly. Activity costs library and cost drivers are shown in Table 4.

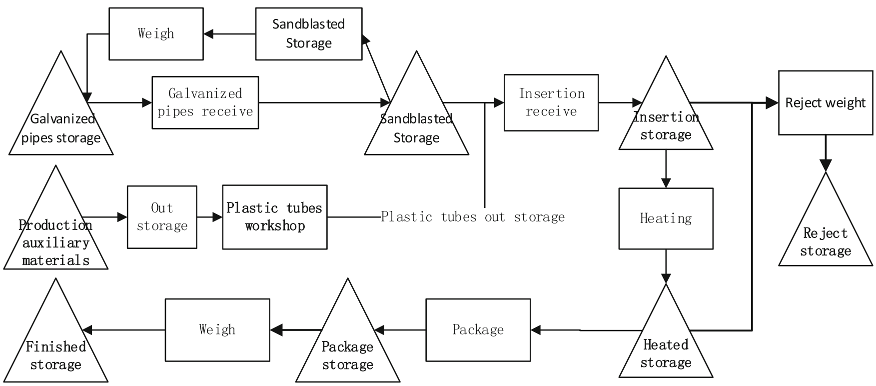

Fig. 1 Production process

Table 2 Activity listing

No.	Activity mame	Activity description
1	Galvanized pipes out storage	Pull galvanized pipes into sandblasted workshop
2	Loading	Put the galvanized pipes to conveyor
3	Drying	Put the pipes to drying plant
4	Galvanized pipes package	Pack the pipes so that easy to sandblast
5	Sandblast	Blowing the sand into pipes
6	Internal face processing	Remove the excess sand
7	Check	Check the pipes quality in sandblast workshop
8	Plastic tube loading	Put polyethylene, cross-linked polymer, hot-melt adhesives into machine
9	Smash and mixing	Use the grinder and stirrer to smash and mix the material
10	Gluing	Extrude material by extruding machine and gluing
11	Cooling	Cool the plastic tubes
12	Cutting	Set the length of cutting and cooling by water
13	Check plastic tubes	Check the tubes quality in plastic workshop
14	Insertion check	Check the pipes and tubes in insertion workshop
15	Blowing sand	Blow the sandblast pipes to keep clear
16	Dragging and inserting	Insert the plastic tubes into pipes and keep the tubes longer than pipes
17	steel-plastic composite	Blow the steel-plastic composite pipes to keep the inner surface flatten
18	Cut out	Cut out the excess plastic tubes and keep four finger width
19	Heating	Put the steel-plastic composite pipes into machine to heat in order to adhere the plastic tubes to pipes
20	Trimming	Cut out all excess plastic tubes and painting
21	Check	Check the steel-plastic composite pipes after heating
22	Package checking	Check the pipes in package workshop
23	Painting passivating agent	Painting passivating agent to the qualified
24	Drying	Put the pipes into warm-bed to dry
25	Installing plastic cap	Install the blue plastic cap into cold water pipes and install the red plastic cap into red water pipes
26	Print security label	Print security label and package
27	Production storage	Put the production into finished storage
28	Management	Management the production and repair equipment

Table 3 Integration activity

No.	Activity	Activity description
1	Sandblast activity	Including galvanized pipes out storage, loading, drying, galvanized pipes package, sandblast, internal face processing, checking
2	Plastic tube activity	Including plastic tube loading, smash and mixing, gluing, cooling, cutting, check plastic tubes
3	Insertion activity	Including insertion check, blowing sand, dragging and inserting
4	Heating activity	Including steel-plastic composite, cut out, heating, trimming, checking
5	Package activity	Including package checking, painting passivating agent, drying, installing plastic cap, print security label, production storage
6	Management activity	Management the production and repair equipment

3.3 *Steel-Plastic Composite Pipe Cost Accounting*

Now we use activity based cost to analysis the production data of the company in a half year. In the following tables the cost unit is yuan, the weigh unit is ton and the time unit is hour. Manufacturing costs are shown in Table 5, the activity drivers and activity driver rate in Table 6.

Calculation the activity driver quantity

DA: Cost driver quantity of A specification
CA: Capacity of A
PTA: Production time of A
TOA: Total output of A
TAD: Total activity driver quantity

$$DA = \frac{CA}{PTA} * TOA \tag{1}$$

$$TAD = \sum DA \tag{2}$$

Table 4 Activity costs library and cost drivers

No.	Activity costs library	Cost drivers
1	Sandblast activity library	Sandblast activity time
2	Plastic tube activity library	Plastic tube activity time
3	Insertion activity library	Insertion activity time
4	Heating activity library	Heating activity time
5	Package activity library	Package activity time
6	Management activity library	Pipes weight

Table 5 Manufacturing cost

Activity library	Sandblast	Plastic tube	Insertion	Heating	Package	Management
Manufacturing cost	1,071,267	1,486,279	1,180,417	4,323,622	427,285	870,420

Table 6 Activity drivers and activity driver rate

Activity library	Sandblast	Plastic tube	Insertion	Heating	Package	Management
Manufacturing cost	1,071,267	1,486,279	1,180,417	4,323,622	427,285	870,420
Activity drivers	Time	Time	Time	Time	Time	weight
Activity driver quantity	10,071	32,140	19,785	20,055	3343	25,464
Activity driver rate	106.371	46.244	56.662	215.588	127.815	34.182

Now we use the activity based cost to analysis the specification of pipe A and B and compare with the traditional method. The result is shown in Tables 7 and 8.

For the A specification, per cost of ABC is 799.57 while the traditional method is 360.49. The former is nearly double than latter. For the B specification, per cost of ABC is 235.95 while the traditional method is 582.07. The former is much less then latter. Form the comparing we can know the tradition method has a lot of mistakes. Sometime it may underestimated costs for some products, while over-estimate cost for the other product.

For the total cost of the enterprise, the traditional cost and activity based cost has not changed, but for the each specification the difference is significant. Now we analyze the reasons for the differences:

Table 7 Activity based cost

Activity library	Sandblast	Plastic tube	Insertion	Heating	Package	Management
Activity driver rate	106.371	46.244	56.662	215.588	127.815	34.182
Activity drivers quantity of A	237.17	1605.33	986.0	886.60	157.15	478.94
Manufacturing cost of A	25,228	74,237	55,869	191,145	20,086	16,371
Activity drivers quantity of B	1.71	2.57	2.7	2.41	0.40	5.09
Manufacturing cost of B	182	119	153	519	51	174

Table 8 The comparing of the two method

Specification	Weight	ABC	Traditional method	Different	ABC per cost	Traditional per cost	Different of per cost
A	478.94	382,936.4	172,645.87	210,290.53	799.57	360.49	439.08
B	5.09	1198.15	2955.76	−1757.61	235.95	582.07	−346.12

Traditional cost pays attend to products and allocated manufacturing costs by product yield or product hours which is lack of accuracy. Activity based cost is based on activity cost drivers, so the result is more accurate. Under the conditions of using of activity based cost, we can manage the cost in activity level. Because of the different activity, we should build different activity cost library to calculate each cost and then obtain the product cost, which will be more accurate and more clearly to reflect the consumption of production process and easy to control.

3.4 Activity-Based Costing System Development

In order to allow enterprises to monitor costs, the study uses Delphi programming language and SQL Server 2008 database to develop activity based cost analysis systems, which can account for cost and compare with traditional methods. The system can exported excel spreadsheet after analysis. Part of the cost listed in Fig. 2. Partial comparison is shown in Fig. 3. In the screenshot we blurred the pipe specifications to protect business secrets.

Size	Sandblast	Plastic tube	inserting	Heating	Package	Others	Sum
20.5X A X 6.0	10054.92	35722.76	30393.37	125976.12	9007.41	5467.92	216622.5
AX B X 6.0	8501.58	30526.94	25785.03	106740.52	7612.35	5123.78	184290.2
20.8X C X 6.0	3200.95	9551.93	8029.2	35790.59	2413.68	1774.18	60760.53
21.3X DX 6.0	11.78	43.1	36.59	164.3	10.68	9.3	275.75
25.5X A X 6.0	11767.87	34450.56	26037.64	89009.52	9271.04	6843.92	177380.55
26.0X B X 6.0	25226.2	74236.64	55863.23	191128.13	20084.12	16370.61	382908.93
26.3X C X 6.0	8662.27	23876.11	17886.86	63560.93	6322.83	5912.7	126221.7
26.5X DX 6.0	89.99	274.95	203.03	730.68	72.64	74.65	1445.94
3CX C X 6.0	26747.4	78586.81	59706.67	204276.13	21258.27	25062.34	415637.62
QX DX 6.0	14905.61	44168.95	33600.57	114903.43	11961.6	15636.32	235176.48
33.0X E X 6.0	3790.14	11109.49	8438.8	30230.46	2802.5	4253.92	60625.31
SX 3.25X 6.0	1.07	2.97	2.36	8.65	0.85	1.5	17.4
41.5X C X 6.0	25252.99	50375.4	29235.39	109256.84	10429.38	18743.8	243293.8
4AX DX 6.0	25049.44	50094.5	28999.3	116542.07	10341.37	20578.11	251604.79
4AX 3.0 X 6.0	10884.08	21355.48	12361.33	49634.69	4403.08	9500.41	108139.07
42.3XFX 6.0	561.34	1131.01	651.59	2624.41	232.87	545	5746.22
47.0X C X 6.0	20847.93	41918.81	24314.23	91154.01	8762.58	17843.31	204840.87
47.0X DX 6.0	25766.12	50984.75	29606.04	110631.74	10726.34	23688.33	251403.32

Fig. 2 Partial results of ABC

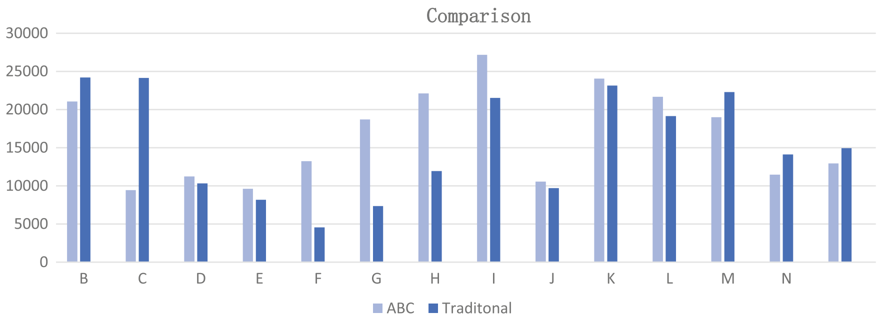

Fig. 3 comparison of the two method

4 Conclusion

In this paper we use the Tianjin pipe company as an example to establish the ABC method, determine the division of activity and cost drivers. And then we use ABC to calculate the cost in plastic composite pipe production and develop of the accounting system. After comparing the results with the traditional method we get a big difference.

Traditional cost accounting methods can't reflect the costs in various specifications clearly, which is bad for enterprises to further expand the production. Activity-Based Costing up for the lack of traditional methods by checking the consumption of every aspect and analyzing the cost drivers, whereby companies can obtain the actual consumption in various specifications, which define the specification is profit or not. It helps enterprises to re-arrange production plan and set specification price. To the loss or profit less specifications can reduce or abandon production. It is important for enterprises to further expand the scale.

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The Operations and Strategy for Container Yard Operators in Xiamen Port

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Abstract Under the "New Normal" of economy development and container shipping industry, the supply and demand of container yard service in Xiamen port mismatch increasingly, profit margins of container yard operators continue to suffer from extrusion. In facing such difficult circumference, a survey was conducted to analysis the status quo of container yard operators in Xiamen port. Characteristics of these operators were identified to analysis their operations and strategy. Then, four strategic measures, namely cost differentials, value improving, supply chain strategy and resource acquisition, are examined to help operators to struggle out of their disadvantage competitive position to achieve long term success. Our study is aiming to promote Xiamen international container yard industry to achieve a healthy and stable development, further support the position and development of China Southeast International Shipping Center.

Keywords Container yard · Operations · Strategy · Supply chain · Warehousing

1 Introduction

Nowadays container transportation plays a key role in the economy of seaport cities [1, 2]. The off-terminal container-storage yard (CY) operators as port service providers directly serve the container line operators (carriers), but also have service connection with container terminals, stevedore companies and haulers. CY operators are of particular importance for carriers and seaport container terminals, since CYs keep the empty shipping containers and their backyard storage operations have

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sizeable impact on most terminal operations [3]. Therefore, the market and service performance of off-terminal container-storage yards as a whole is to a large extent determined by the supply, demand and operations of CYs.

The main facilities of an off-terminal container yard operator are storage depot for empty containers from carriers, maintenance and repairs, cleaning and fumigation depot, chilling and cooling stations for reefer containers; some CYs may also have facilities or service for container leasing, cargo storage, loaded containers and other service optional. Besides a large piece of land near the port to hold containers, a CY operator should invest heavily in handling methods and machinery. A CY operator is indeed a warehouse enterprise to contract with carriers for empty container storage locally, to offer maintenance and other services to shipping containers related parties. As an essential part of the container transport supply chain, container yard industry plays critical role in the convergence of land and sea transport, vessel stevedoring efficiency and port logistics development [4].

The Port of Xiamen is located in southeast China's Fujian Province on the Xiamen Bay and by the mouth of Jiulong River; it is one of the country's first Special Economic Zones, acting as the main inlet of the Taiwan Strait. The Port of Xiamen is one of the trunk line ports in the Asia-Pacific region, and it ranks the seventeenth largest container port in the world and the eighth largest in China in 2014 with a throughput of 8.57 million TEUs annually [5]. However, after rapid development of container shipping in the past three decades, the emerging "New normal" is standing for the smoother growth of economy in China and its container shipping industry. To achieve the position and development of China Southeast International Shipping Center, what about the CY sector in Xiamen? Whether they have a healthy trend to support farther development of Xiamen's container shipping. Our study will reveal it.

2 Methodology

To conduct the survey and study of CY operators in Xiamen, our method follows the general procedure of enterprise survey [6], it includes questionnaire development, sampling, and interviewing. With the help of local trade association, nine main operators finished the questionnaire, and we further interviewed top management of these operators.

2.1 Questionnaire

The questions in our questionnaire are combinations of choices, scale options, blank-filling and answering, which frame into three categories: general information, operations and difficulties. There are 20 questions with over 50 sub-questions.

The resulting questionnaire was discussed with senior managers from seven different firms, who were asked to respond to the questionnaire and to note any questions which posed any sort of issues—doubtful questions, misunderstanding, vagueness, or sensitivity of the answers, etc. Many interviewed managers viewed the questionnaire as comprehensive and professional.

2.2 Sampling

The sample of firms was drawn from registered members of the Fujian CY/CFS Association. The nine CY operators interviewed by our team were 3 state-owned/controlled (SOC) enterprises, 5 Sino-foreign joint ventures (JV), and 1 privately-owned, as shown in Table 1. Note that No. 7 is indeed a small container terminal with many yard space, which doesn't fit strictly the off-terminal defined in our questionnaire. It is listed just for comparison. The location map of these operators are shown in Fig. 1. Please note these locations are their registered addresses, some CY operators have multiple depots even in Haicang port area, where operators are sparsely located on the map.

2.3 Interviewing

Personal interviews with senior executives were conducted subsequently in the office of the respondent. Prior appointments were made by telephone with the help of the association for the interviews.

3 Analysis of the Xiamen Off-Terminal Container Storage Yard Sector

After the survey by the above methods, an analysis is conducted to understand the Xiamen CY service market.

3.1 History and Development

In 1983, Xiaman initiated the first container line service in Fujian Province. Since the era of opening-up and reform police, the Port of Xiamen has been open to foreign investment, which created jobs, industries, and export opportunities for many emerging companies. In 1990s, the container shipping in Xiamen increased

Table 1 Container yard operators in Xiamen

No	Ownership	Established in	Stuffs (person)	Capital (mRMB)	Revenue (mRMB)	Depot (m^2)	Container flow/storage in 2013 (TEU)		
							Inbound	Outbound	Stored
1	SOC	2003	80	50	60	80,000	172,043	174,560	7800
2	Private	2004	55	5	20	18,000	n.a.	n.a.	n.a.
3	SOC	1997	279	US$2.5m	80	227,000	260,000	260,000	23,000
4	JV	2006	52	20	23	65,000	116,000	117,000	300,000
5	SOC	1996	73	20	16.01	53,900	76,838	75,105	151,943
6	JV	2006	589	HK$10m	163.6	200,000	237,000	237,000	17,000
7[a]	JV	2008	258	756	94.47	297,000	23,669	16,349	10,018
8	JV	1996	180	US$3m	71.33	120,000	180,000	170,000	11,000
9	JV	2005	108	25	50	140,000	217,704	225,813	14,186
		Total:	1674	/	578.41	1,200,900	1,283,254	1,275,827	534,947

Fig. 1 Locations of nine CY operators in Port of Xiamen

by leaps and bounds and ranked No. 6 in China in three consecutive years. There was still rapid growth of container shipping in the first decade of 21st century, but the growth rate trends to smooth in recent years [7]. The CY business serves the container shipping directly; their development generally follows this course.

Before, container yards were inside the container terminal and were a subdivision of the terminal, but with the change of supervision policies by the Customs House and Ministry of Communication, CYs for empty containers moved out of the terminals, these policies promoted a fast growth of CY operators, and carriers have more choice of where to put-away their empty containers. Now in Xiamen, the nine main operators serve over 40 international and domestic container carriers with annual throughput of 8.57 million TEUs and 183 container shipping lines.

3.2 Characteristics

In the thirty years of development abreast with container shipping, CY operators in Xiamen show these characteristics:

1. *Concentrated but separated location of yard operators.*
   Container terminals in Xiamen city mainly lie in Huli and Haicang, which are two of Xiamen's six districts, and so do the CY operators. By the newly

established Pilot Free Trade Zone with about 40 km^2, 7 of the nine operators lie inside. This concentrated locating makes them better serving the port and foreign trade. However, the ports in Huli and Haicang are separated by the sea, the key land traffic connection is an over-congested bridge, transportation between the two port areas is difficult, and some operators have to setup multiple yard sites for the two port ranges.

2. *Scale of capital and assets for operators are small.*
   The average depot area of the nine operators are 119,433 m^2, and only one operator has the total area less than a CY standard of Shanghai [8], where the largest port in the world lies. The registered capital of certain operators is just affordable of a tire gantry which is the necessary equipment to load/unload containers in the yard. Also, some operators are not well equipped with mostly rent gantries.
3. *Usually long operational history but monotonous in services.*
   One third of the operators were founded in the last century when container business in Xiamen was just booming. Their long experience has fostered management, operations and information system, but the service offered by these operators are still lack of diversity. Their main business is still storage, handling and maintenance service to empty container of carriers, high value-added service may be too niche for operators to cultivate. Many operators have warehousing and loading/unloading service for shippers, but there are many port logistics service providers inside and around Xiamen port, off-terminal CY operators' warehousing market share is insignificant.
4. *Lower position in the whole shipping–port supply chain.*
   The whole container shipping-port supply chain usually is "Carrier–Port–Freight forwarder–CY–Hauler", while the carrier is leading the supply chain. And in a port with typically solo port operator, which is also has strong influence in the supply chain. While the CY operators are in a weak position, they have less chance to hold the service price and profit; and in a slowly increasing container shipping market, they have to trade price for market shares in facing the ever-increasing competition.
5. *Profitability is downgrading.*
   In the 1990s while the container shipping was booming, the CY operators shared a good profit with the port terminals and carriers [9]. However, in recent years, with substantial cost increase in land, labor and machinery but significantly low increment in service volume due to the port's smoothly progress in throughput and supply chain profitability, the profit of CY operators is whittled down year by year, and their position is worse than ever.

4 Discussion

By our survey, the CY operators in Xiamen have a total yard storage area of 1.2 million square meters, however, the estimated demand is about 0.9 million square meters for the annual 9 million throughput TEUs, and supply exceeds demand, the CY business in Xiamen is a buyer's market. By the basic laws of supply and demand, some CY operators have to compete on price, sacrifice their profit to gain market share. In such a market, what are the strategies for CY operators?

Based on the market analysis of Xiamen CY businesses, there are four main strategies: cost differentials, value improving, supply chain strategy and resource based strategies.

4.1 Cost Differential Strategy

The cost differentials are not just cost reducing. In the CY business, the cost for standard services, which are storage and retrieving of empty containers, is homogenous with common equipment and workers. However, there is reducing space for the cost of other service or operations, such as information technology, container maintenance and repairing, the material ordered can be tailored to small piece just needed; good scheduling to works of retrieving, repairing, cleaning and fumigation may save ever-increasing cost of workforce. In a competitive and slowly-increased market, the cost is a key factor for operators to survive. To offer qualified service with proper cost is a challenging cost differential strategy for every operator, operations and control are always the main focus for the managerial.

4.2 Value Improving Strategy

The off-terminal CY operator is essentially a warehousing company. Like logistics enterprises, CY operators can offer value-added services for both carriers and shippers. For example, reefer container repairing, PTI inspection, tank container cleaning is highly value-added service which carrier would pay greater and have significant demand because of demanding cold-chain logistics. There are also other value-added services demanded by some shippers, such as around-the-clock service, container leasing, customs and inspection clearance, bulk cargo warehousing, loading/unloading service, these service give convenience to customers and operators can make cash flow at quite low cost.

4.3 Supply Chain Strategy

The whole container supply chain which offers container shipping and transportation services to shippers and consignees has many players in it: carriers, ports (container terminals), CY operators, land haulers, and many agents, such as vessel agents, freight forwarders, container suppliers and so on, working in between. Among them, the carrier is definitely the leader of the supply chain [10]. An off-terminal CY operator serves the carrier, and has less influence to the carrier, to the port. However, a CY operator can unite other players to play a better role in the supply chain [11]. Such as a CY operator has a world-leading container supplier as shareholder, so it is better to do leasing service and can maintain a lower repairing cost because of the offering of cost-favorable containers and components directly from the container supplier. Another CY operator cooperating with a local leading vessel agent can enforce the relationship with some carriers to keep its market share in facing fierce competition. In all, proper supply chain strategy can improve the operator both in operations, market position and profitability.

4.4 Resource Based Strategies

The resource based strategies include resource acquisition or resource shrinkage/shift. The CY operations are a less risky service but rather heavy-but-slow-return investment in near-harbor land and other resources. Because of economic scales, enough land (over 100,000 m^2) is a key resource for the CY operator, and land cost is the largest portion of CY's total cost. The separated two main container terminals locations in Xiamen port makes CY operators hard to gain enough land (whether buy or rent) and difficult in operations and management. In the long run, the Xiamen port authority is planning to move most of container terminals to Haicang area. Therefore, based on RBV [12] theory, this is both a challenge and a chance for CY operators, only those who has successful land acquisition can win the resource based competition and thereafter be gaining and sustaining long term advantage in cost saving and competitiveness. Otherwise, CY operators with its own land have a second option: to change the CY land for other business profitable if they evaluate the competitive CY business as less profitable and unfavorable. Indeed in Huli port area, where the government will turn it to mainly passenger port and business area, the land for other trades like office, exhibition will be more profitable and in trade. Therefore, some container yard owners shrink or totally change to other business will have a better prospect strategically.

In all, operators who shape their strategy arena with these four measures will get rid of the unfavorable competitive position, and may achieve long term success with a good implementation of their strategy.

5 Conclusion

In this paper we studied the market and strategic problems faced by CY operators in Xiamen port. Firstly, a survey with questionnaire, sampling, and managerial interviewing was conducted to picture the whole image of CY operators in Xiamen and to identify characteristics of the operators. Based on the survey and analysis, cost differentials, value improving, supply chain strategy and resource acquisition strategies were recommended and discussed. Our study may encourage Xiamen international container yard industry to realize a healthy and stable development in the Southeast China costal area.

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The Way of the Ease Traffic Congestion in Commercial Center of Beijing—The Analysis and Research of Level Analyses and Fuzzy Evaluation in Sanlitun Street

Cheng-hao Jiang and Guang Cheng

Abstract This article through to the impact of road traffic system congestion of fuzzy information and fuzzy factor analysis, put forward the theory of the fuzzy method to evaluate the quality of the traffic network system environment, combined with the operational research and queuing theory and relevant principle, evaluate the sanlitun area of traffic conditions, indicates that the factors affecting the traffic system, and a crossroads in sanlitun area are the secondary fuzzy comprehensive evaluation, the traffic congestion of the road network system between good and general. Results show that this method can be qualitative and quantitative comprehensive evaluation of transportation systems to the traffic, to achieve harmony in transportation system.

Keywords Traffic congestion · Analysis of evaluation · Sanlitun hub

1 Introduction

The Sanlitun Distriction is in the East Round 3. The north road in the east, the Worker Stadium is in the west, the Chaoyang Hospital is in the south, and there is a bar street in the north. There are Taikoo Li Sanlitun, Electromechanical and Sanlitun SOHO comparative luxury shopping street in the Sanlitun Distriction. So the Sanlitun Distriction is very congested, especially during the morning rush (7:00–9:00) and the evening rush (17:00–20:00), especially on Friday 17:00–22:00, it was the home game of the Beijing Guoan Football club at home in the Worker Stadium (The home stadium is the Worker Stadium), so the time was a peak. So, the situation of the road became the key rather than ordinary. So there should be trying to reduce traffic congestion, road traffic can more quickly. To achieve this purpose

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of making the traffic conditions, this is the reason of multiple aspects of decision. Let's start with unilateral mentioned.

There are many reasons that cause traffic jams phenomenon, the influencing factors of traffic congestion is very complex, so the single factor of traffic congestion evaluation cannot fully reflect the status of the traffic network. Multi-factor comprehensive evaluation method is in a visual method, recorded, and then to adopt the method of weighted average for traffic index, there are subjective and conditioned.

2 The Traffic Network System of Environmental Quality of the Secondary Fuzzy Comprehensive Evaluation [1]

There are many factors affecting the quality of the traffic environment, the main consideration is for the traffic congestion and fuzziness of the factors affecting large set as the evaluation factors.

2.1 Establish Factor Set [2]

u1 *if the red light*
u2 *traffic flow*
u3 *One-way street lane number*
u4 *Number of pedestrians*
u5 *Whether the vehicle to the left*
u6 *whether the time of the traffic jam*
u7 *Number of pedestrians running red lights*
u8 *Whether the vehicle running a red light*
u9 *If car crash*
u10 *Whether the vehicle to stop at the crossroads or driving slowly*

Factors set U = {u1, u2, u3, u4, u5, u6, u7, u8, u9, u10}, according to each factor affect the degree of environmental quality in the traffic network is divided into 5 levels (*see* Table 1). *Then, road traffic levels are divided into 5 levels* (*see* Table 2).

2.2 Membership Degree Factor Level

Sanlitun district four lanes cross south direction and direction from south to north, lane 2, from north to south direction 2 lanes; North direction is the same, a total of four lanes, each have 2 two direction.

Table 1 Degree of various factors affect the traffic environment quality (time: 1 min)

Class	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	N	0–10	5	0–5	0–2	N	0–2	0–1	0	0
2	N	11–20	4	6–10	3–5	N	3–5	2–3	1	1
3	N	21–30	3	11–15	6–8	Y	6–8	4–5	2	2
4	Y	31–40	2	16–20	9–11	Y	9–11	6–7	3	3
5	Y	>40	1	>20	>11	Y	>11	8–9	4	4

Table 2 Traffic road level

Class	Traffic index	Corresponding to the road	Travel time	Impression
1	0–0.2	Basic no road congestion	Can travel by road speed limit standard	Open all the way
2	0.2–0.4	A small road congestion	Take 0.2–0.5 times more than it was open	Smooth
3	0.4–0.6	Part of the loop, the arterial road congestion	Take 0.5–0.8 times more than it was open	Just stuck
4	0.6–0.8	A large number of loop, the arterial road congestion	Take 0.8–1.1 times more than it was open	Jam
5	0.8–1.0	Most of the traffic jams in the city	Time consuming more than 1.1 times more than it was open	Don't move

Is located in what direction the main road, east and west to the main six traffic lanes, from east to west and from west to east each have 3 lanes; Travelling from east to west direction and from west to east direction each have two lanes, a total of four lanes. The main road and so there are a row of trees in the middle (as shown in Figs. 1 and 2).

Because of the specialty of Beijing sanlitun district intersection traffic environment, and so inevitably became the location of the traffic congestion.

Aiming at the particularity of the intersection of Beijing sanlitun district, in order to more scientific and reasonable evaluation of the traffic environment quality, using field monitoring method to evaluate the results of the various factors, at 10:00 a.m. (instead of ①) respectively, and then 14:00 p.m. (instead of ②), the evening 18:00 p.m. (instead of ③) and at night 22:00 p.m. (instead of ④) to do the test, the result is:

Use the Internet, down straight the weight value of 0.8, down left the weight value of 0.2.

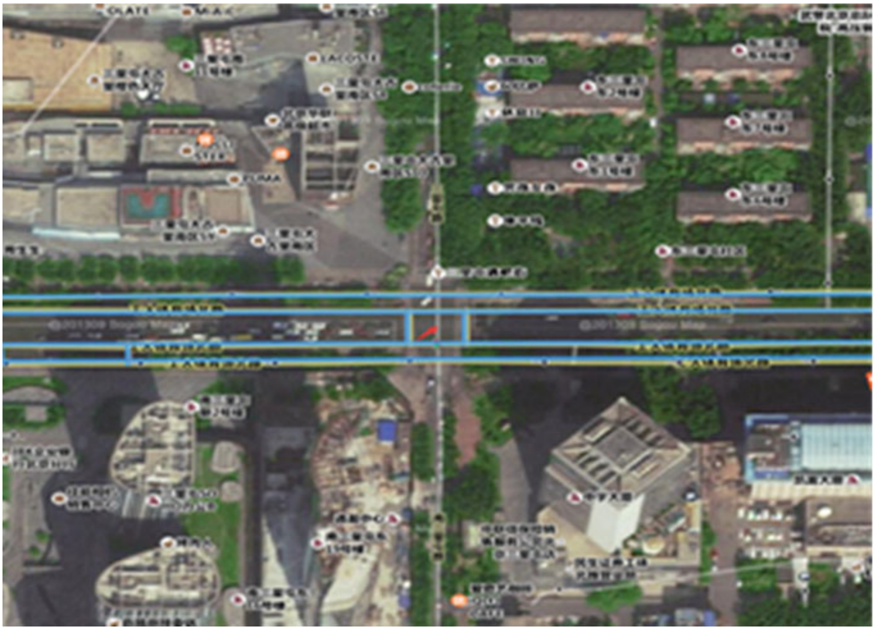

Fig. 1 The Sanlitun district intersection positioning (*red arrow* is in sanlitun area crossing)

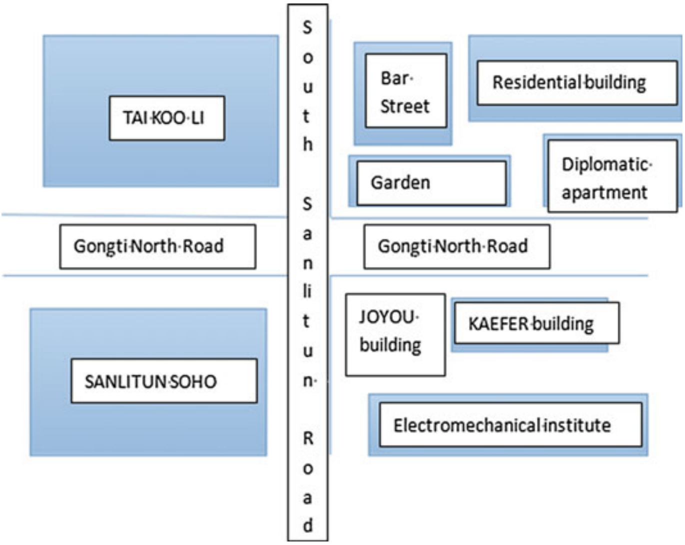

Fig. 2 The Sanlitun crossroads draw the floor plan (*red mark* is in sanlitun area crossing)

u1—as Table 3
u2—as Table 4
u3—as Table 5
u4—as Table 6
u5—as Table 7
u6—as Table 8
u7—as Table 9
u8—as Table 10
u9—as Table 11
u10—as Table 12
After the weight of each element and the normalized Table 13.

Table 3 u1

Test times	Test time (min)	Go straight		Turn left	
		A red light wait time (s)	Green passage time (s)	A red light wait time (s)	Green passage time (s)
①	12	400	320	540	180
②	8	280	200	400	80
③	5	179	121	242	58
④	15	508	392	784	116

Table 4 u2

Test times	Test time (min)	By the number of vehicles	By the number of vehicles per minute (a/min)
①	12	360	30
②	8	204	25.05
③	5	295	59
④	15	104	6.93

Table 5 u3

Test times	Test time (min)	Number of lanes	Passing rate of each lane(m/min)
①	12	6	5
②	8	6	4.2
③	5	4	14.75
④	15	6	1.16

Table 6 u4

Test times	Test time (min)	Pedestrians through the number (people)	The average pedestrian passing rate (people/min)
①	12	102	8.5
②	8	51	6.4
③	5	107	21.4
④	15	104	6.93

Table 7 u5

Test times	Test time (min)	Left the car number (a)	Every minutes left the car number (m/min)
①	12	4	0.33
②	8	4	0.50
③	5	8	1.6
④	15	0	0

Table 8 u6

Test times	Test time (min)	Whether the peak
①	12	N
②	8	N
③	5	Y
④	15	N

Table 9 u7

Test times	Test time (min)	Red light line number	Red light line number per minute on average
①	12	72	6
②	8	41	5.1
③	5	43	8.6
④	15	47	3.13

Table 10 u8

Test times	Test time (min)	Red light vehicle number (a)	Red light vehicle number per minute on average (m/min)
①	12	0	0
②	8	0	0
③	5	0	0
④	15	3	0.2

Table 11 u9

Test times	Test time (min)	Whether the accident	The number of accident (b)	The average number of accidents per minute (times/min)
①	12	N	0	0
②	8	N	0	0
③	5	Y	1	0.2
④	15	N	0	0

Table 12 u10

Test times	Test time (min)	Slow or stop the vehicle number (a)	Per minute on average number of slow moving vehicles (m/min)
①	12	0	0
②	8	0	0
③	5	6	1.2
④	15	0	0

Table 13 Factors weights set (normalized value)

Test time	Factors									
	u1	u2	u3	u4	u5	u6	u7	u8	u9	u10
①	0.241	0.248	0.199	0.197	0.040	0	0.263	0	0	0
②	0.257	0.207	0.167	0.148	0.060	0	0.223	0	0	0
③	0.248	0.488	0.587	0.495	0.900	1	0.377	0	1	1
④	0.254	0.057	0.047	0.160	0.000	0	0.137	1	0	0

2.3 Evaluation Set Is Established [4]

According to the superiority of traffic network environment quality evaluation set is established as follows (alternative set, namely traffic levels):

$V = \{1, 2, 3, 4, 5\} = \{0, 0.20, 0.50, 0.75, 1\}$ [5].

3 The Level of Fuzzy Comprehensive Evaluation [6]

With various factors at the same level of membership degree of evaluation set of the general line as a single factor evaluation matrix, it is concluded that the single factor evaluation as follows:

$$R = \begin{vmatrix} 1.0 & 0.9 & 0.5 & 0 & 0 \\ 0.7 & 1.0 & 0.5 & 0 & 0 \\ 0 & 0 & 0.5 & 1.0 & 0.7 \\ 0 & 0 & 0.5 & 0.9 & 1.0 \end{vmatrix}$$

From the evaluation set chart 1–11 matrix of the:

$$W = \begin{vmatrix} 0.241 & 0.257 & 0.248 & 0.254 \\ 0.248 & 0.207 & 0.488 & 0.057 \\ 0.199 & 0.167 & 0.587 & 0.047 \\ 0.197 & 0.148 & 0.495 & 0.160 \\ 0.040 & 0.060 & 0.900 & 0 \\ 0 & 0 & 1 & 0 \\ 0.263 & 0.223 & 0.377 & 0.137 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \end{vmatrix}$$

From various factors of the ith a hierarchical fuzzy subset for comprehensive evaluation. In order to can consider all factors, but also retain the single factor evaluation information, using model M (a, b), level of fuzzy comprehensive evaluation:

$$A = W \cdot R = \begin{vmatrix} 0.421 & 0.636 & 0.500 & 0.477 & 0.428 \\ 0.393 & 0.430 & 0.500 & 0.539 & 0.399 \\ 0.316 & 0.346 & 0.500 & 0.629 & 0.458 \\ 0.301 & 0.325 & 0.500 & 0.639 & 0.507 \\ 0.082 & 0.096 & 0.500 & 0.900 & 0.630 \\ 0 & 0 & 0.500 & 1.000 & 0.700 \\ 0.419 & 0.460 & 0.500 & 0.500 & 0.401 \\ 0 & 0 & 0.500 & 0.900 & 1.000 \\ 0 & 0 & 0.500 & 1.000 & 0.700 \\ 0 & 0 & 0.500 & 1.000 & 0.700 \end{vmatrix}$$

4 The Secondary Fuzzy Comprehensive Evaluation [7]

In general, the influence factors and the intersection of the traffic network to the importance of the environmental quality is different, in order to objectively evaluate the quality of the intersection of Beijing sanlitun district environment congestion degree, on the basis of the theory of fuzzy consistent matrix, according to the specific situation of the intersection of Beijing sanlitun district, for the following analysis.

According to the factors set the priority and fuzzy relationship matrix:

$$F = (f_{ij})_{n \times n} \text{ among } f_{ij} = \begin{cases} 1(u_i > u_j) \\ 0.5 \\ 0(u_i > u_j) \end{cases}$$

F becomes a fuzzy consistent matrix:

$$R = (r_{ij})_{n \times n},$$

It makes that

$$r_{ij} = r_{ik} - r_{jk} + 0.5$$

$$r_i = \sum_{k=1}^{n} f_{ik}$$

$$r_{ij} = \frac{r_i - r_j}{2n} + 0.5$$

Using square root method to obtain the weight set and normalized processing:

$$\overline{w} = \left(\prod_{j=1}^{n} r_{ij}\right)\overline{n} \cdot \overline{w_i} = \frac{\overline{w_i}}{\sum_{j=1}^{n} \overline{w_j}}$$

It is concluded that weight sets:

$$J = \{J_1, J_2, \ldots, J_{10}\} = \{0.1, 0.1, \ldots, 0.1\}$$

Comprehensive evaluation for each factor to the secondary fuzzy comprehensive evaluation matrix of the:

$$B = J \cdot A = (0.1932 \quad 0.2293 \quad 0.5000 \quad 0.7584 \quad 0.5923)$$

5 System Simulation Traffic Environment Quality Assessment [3]

Using the weighted average method:

$$V = \frac{\sum_{i=1}^{5} b_i v_i}{\sum_{i=1}^{5} b_i} = 0.6410$$

So the traffic level of 4, namely the impression for jam.

6 Evaluation [8]

The intersection of Beijing sanlitun area and the environmental quality in the secondary fuzzy comprehensive evaluation, the traffic network of introducing the principle of fuzzy learning trackless quality comprehensive evaluation of highway traffic environmental system; And to qualitative and quantitative evaluation of environmental system of the traffic network traffic environment quality, overcome the discriminant of field monitoring method can quantitatively traffic management system of environmental quality defects.

In the calculation of concrete, the weight of factors I adopt split method, using the evaluation model of M (a, b), which considers the influence of all factors, and keep all the information in the single factor evaluation; In practical evaluation, the choice of the factors may increase or decrease according to the specific situation, and also can reference data information. In the actual calculation, data can be calculated in the case, according to the specific circumstances, a reasonable allocation weights and evaluation model [9].

Adopt the method of fuzzy comprehensive evaluation, only according to the factors influencing the degree of environmental quality in the traffic network in various fuzzy comprehensive evaluation model is set up, you can get the result of evaluation, to avoid the subjective arbitrariness, more in line with the actual situation, not only practical, and good generality, convenience of computers such as computer programming, has broad practicability and popularization value, in areas such as machinery, construction, electronics and will have broad application prospects, is full of hope for the future [10].

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Hierarchical Planning and Control Method for Multiple Product Development Projects

Fu-peng Yin, Qi Gao and Dong Fang

Abstract Multi product development projects (MPDPs) are quite common in industries. These projects require limited resources dispersed in different departments. This paper formalizes the MPDPs planning and control problem with mathematics expression, and presents a hierarchical planning and control method. The process describes the intersection control and collaboration between different project levels and phases. This hierarchical planning and control method provides theory for MPDPs management in manufacturing enterprises.

Keywords Multiple projects · Product development · Planning and control · Two-level

1 Introduction

With the increasingly fierce competition among enterprises, it is necessary condition for the survival to adapt to the diverse needs of customers. In this environment, more and more enterprises apply project thinking and management to compress their product development lead-time. One product development can be recognized as one single project, and most companies, particularly small and medium-size enterprises, have to manage a variety of projects which share a pool of constrained resources, while taking into account divergent objectives. In this paper the Multiple Products Development Projects (MPDPs) are discussed.

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Multiple projects with limited resource which planning and scheduling has been an active area of research for more than the last four decades [1–3]. He Ting proposed a integration management mode to solve the cross-enterprise production planning problem based on the integration of project management and ERP [4]. Yang Lian-xing researched the multi-project planning under different requirements and time intervals, and proposed a new product development with multi-project collaborative planning method [5, 6]. Zhang Meihua also proposed the similar model from the perspective of resource constraint and uncertainty. Reasonable control is an important guarantee to realize the goal of project planning. Different control modes have different effects on product development [7]. Serge made a comparative analysis of outcome control, process control, and clan control, and concluded that neglecting the interdependencies between different controls may lead to an incomplete insight into how firms can most effectively manage their new product development processes [8].

In the above literature, most research on planning and control separately, and analyze the problem of resource constraints in the perspective of generalized resources or virtual enterprise. It is not only to coordinate the relationship between other enterprises, but also need to coordinate the work between various departments, in order to realize the maximization of enterprise benefit. Grazia Speranza proposed a hierarchical two-stage decomposition of the planning and scheduling process [9]. Based on the complexity and uncertainty of MPDPs, Auil pointed out that hierarchical model is suitable for planning and scheduling [10].

Yang and Sum discussed a level management structure which is frequently used for managing multiple projects. The upper-level generate the start times and due dates of projects, and the project level schedules the activities in each project independently [11]. E.W. Hansa research the hierarchical approach to multi-project planning under uncertainty [12]. In recent years, Auil also proposed a two-stage decomposition approach to formulate the non-preemptive, zero time lag multi-project scheduling problems [10]. Qiao Kun, Su Qing research the control method of the collaborative manufacturing projects based on the theory of distributed artificial intelligence [13, 14].

In this study, a collaborative and adaptive control framework is proposed. Based on the mathematics expression, the framework developed a two-level planning and control process, which describes the intersection control and collaboration between different project levels and stages. This process could lead to effective MPDPs assignments, which could in turn impact project success and eventually the performance of the organization [15].

2 MPDPs Problem Description

Three elements are defined that constitute the MPDPs problem domain: (i) a set of product development projects; (ii) a set of functional divisions; (iii) a set of development phases.

2.1 Product Development Projects

A product development project P_i is a quadruple (G_i, L_i, A_i, N_i), where G_i is a set of milestones, L_i is a set of phases of product development, A_i is a set of activities of Pi, and N_i is the set of the precedence constraints.

As shown in the definition, a product development project P_i may have multiple milestones or goals, $G_i = \{G_{i1}, G_{i2}, \ldots, G_{i|Gi}\}$, including the target project completion date $G_{i|Gi}$. For the sake of simplicity $|G_i| = 1$ for all i will be assumed in the remaining part of this paper. Phases, denoted by a set are L_i, include requirement analysis, conceptual design, detailed design, process design, manufacturing, etc. The precedence constraints can be defined by task pairs, i.e. $Ni = \{(A_{ij}, A_{ik}): j \neq k; A_{ij}, A_{ik} \in A_i\}$. Each phase of the project L_{il} contains multiple activities, denoted by a set are A_{il}. The precedence constraints between different phases depend on the precedence constraints of the activities contained in each phases.

2.2 Functional Divisions

A functional division is a related organizational unit including external unit as clients (C_c), core-companies (O_o), suppliers (S_s), etc., and internal unit as design division (ID_j), etc. A core-company is the manufacturing company cooperating with the enterprises that acquires and manages the product order. A supply is the raw materials enterprise of the enterprise. A functional division D_j inside the enterprise is a department of the enterprise that comprises a set of resources, $R_j = \{R_{j1}, R_{j2}, \ldots, R_{j|Rj|}\}$ and completes a certain phase of a mold project. Each resource R_{jk} has a capability to perform a specific activity.

An example of collaboration between different functional divisions and phases was shown in Fig. 1.

Changes of customer demand would affect due time, task allocation, etc. of product development project. Enterprise should focus on customer demand changes only real-time, and cooperate with customers to achieve demands and the project objectives. Due to the complexity of the product development, individual enterprise is difficult to complete all the development task of complex products. So enterprises need to cooperate with external functional divisions, and also need collaboration between every internal functional within the enterprise closely.

Based on the above analysis, the resource-constrained MPDPs can be defined the set $P = \{P_i\}$, and functional can be defined the set $D = \{C_c, S_s, O_o, ID_j\}$. The two set of P and D constitute the MPDPs environment, $\Omega = \langle P, D \rangle$.

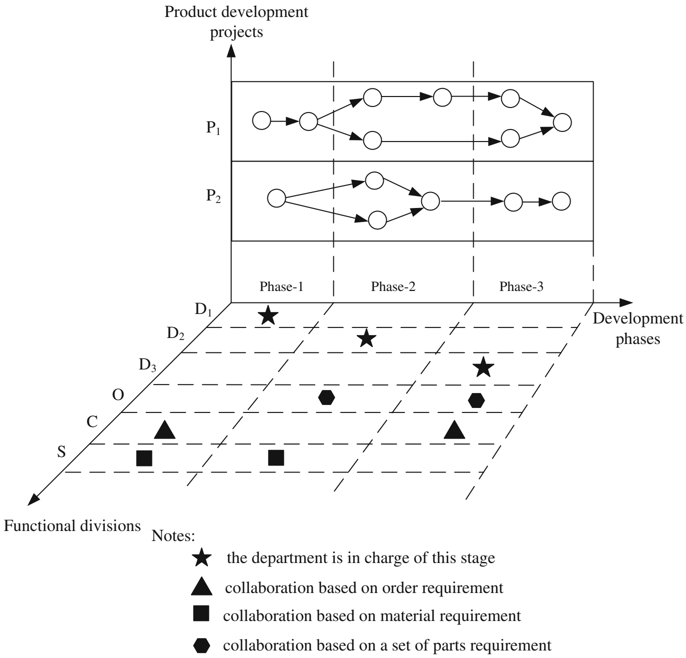
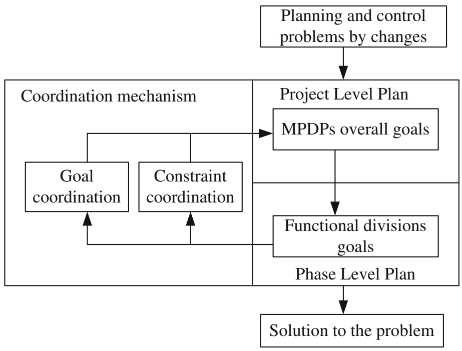


Fig. 1 An example of collaboration between different functional divisions

3 Two-Level Plan MPDEL of MPDPs

Generally, product development projects are in charge of project manager, but the resources required for the project belong to and managed by different departments. So how to coordinate the relationship between resource dispersion and resource sharing is the key to this problem. In this section the plan model of MPDPs which has project level (FA_i) plan and phase level (SA_i) plan is defined clearly. This model is more realistic. This model is more realistic. Figure 2. shows the two-level plan model.

Fig. 2 Structure of two-level plan model



3.1 Project Level Plan (FA_i)

The project level plan specifies how the project is allocated to the appropriate department or organization, which is represented by the binding relationship between the functional units and phases. The binding relationship described as an engagement $fe_{il} = (j, w)$, where $w = (w_1, w_2)$ defines the time window in which the phase is to be allocated, represents the phase L_{il} of the project P_i must be assigned to the department D_j, equate as the 0–1 variable $a_{il}^j = 1$. Else $a_{il}^j = 0$. Symbol w_1 represents the earliest start time of the phase, and w_2 represents the latest completion time. The execution time scheduled of the activities within the phase cannot exceed the time interval. The set of binding relationships $FA_i = \{fe_{i1}, fe_{i2}, \ldots, fe_{i|Li|}\}$ describe the project level plan FA_i of P_i. So MPDPs plan (FA) is a set of project plans within the MPDPs planning horizon, i.e. $FA = \{FA_i\}$.

3.2 Phase Level Plan (SA_i)

The phase level plan is detailed plan of the phase, made based on the time window and the resource situation, allocates resources within the department to the corresponding activities within the phase, represented by the binding relationship between resources and activity. For example, it can be described $se_{il} = (j, k, v)$, where $v = (v_1, v_2)$ defines the time window in which the activity is to be allocated, if the phase L_{il} of P_i has the binding relationship $fe_{il} = (j, w)$, and the activity $a_{il}(a_{il} \in A_{il})$ must be assigned to resource R_{jk}. A phase level plan of L_{il} within project P_i, denoted by SA_{il}, is a set of engagements which covers all activities in L_{il}, i.e. $SA_{il} = \{se_{i1}, se_{i2}, \ldots, se_{i|Lil|}\}$. All the phases level plan of one project can be denoted by a set $SA_i = \{SA_{i1}, SA_{i2}, \ldots, SA_{i|Li|}\}$, and the department can be denoted by a set $DA_j = \{SA_{il}\}, \forall\, a_{il}^j = 1$.

3.3 Optimized Plan

Because the binding relationship of the activities in each project is different to others, so there are different project plans. In order to compare different plans, a formal comparison function is defined, i.e. $\varnothing_i$: R $\rightarrow$ R_+, called deviation function, which represents the degree of deviation between the project actual completion time from the original completion target. Obviously a smaller value is preferable to a bigger value in this function, i.e. if the end times of two plans FA_i' and FA_i'' for a project P_i are $t(FA_i')$ and $t(FA_i'')$, respectively, $FA_i' \succ FA_i''$, if and only if $\varnothing_i(t(FA_i') - G_{i1}) \prec \varphi_i((FA_i'') - G_{i1})$, i.e. plan FA_i' is preferable to FA_i''.

If the plan can be able to meet the precedence constraints of all projects and all the resource constraints, it is called MPDPs feasible plan. An efficient MPDPs plan is a feasible MPDPs plan that no project can improve its utility without worsening the utility of any other project in the MPDP.

Each project's deviation degree can be calculated as defined in deviation function. We call the range of the all projects' deviation degree range (DR), i.e. if the range of the deviation degree of individual projects in MPDPs is less than a given tolerance τ, i.e. $\mathrm{DR}(FA) \leq \tau$, the efficient plan is called τ-balanced MPDPs plan.

4 Planning and Control Process of MPDPs

A planning is a procedure to generate a new τ-balanced MPDPs plan by adding a new product development project to the current MPDPs plan, which has been also τ-balanced throughout an ongoing MPDPs control procedure. A control is a persistent procedure to maintain a MPDPs plan to be τ-balanced all the time. This section focuses on the planning and control process of MPDPs.

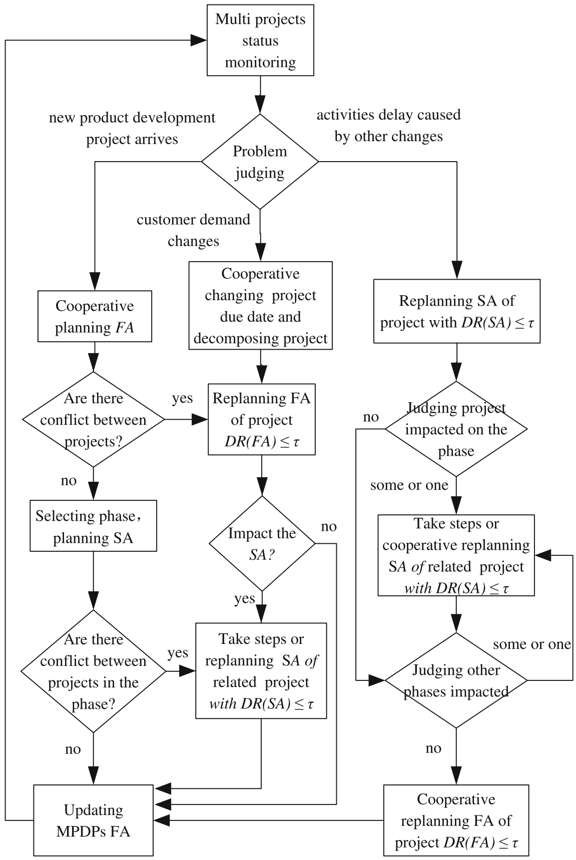
MPDPs are in dynamic environment, and the new product development project arrives at random time, therefore, the environment of each project would change with the development process. The changes would cause some projects plan change, i.e. it should rescheduling to get τ-balanced MPDPs plan. The planning and control process of MPDPs was shown in Fig. 3.

In multi projects implementation process, the status of all projects within the current project set P can be obtained through multi project monitoring, to judge the changes that influence the projects plan. The reason causing multi project environment change can be divided into three types: the new product development project, the change of customer demand, and others such as activities delay, equipment failure, personnel absent, etc. The first two are related to the customers, which need to determine or change the milestones of the projects through negotiation between the project manager and customers. The last one is generated because the internal causes of the projects, which needs to take some remedial measures (such as overtime), to avoid the whole project schedule change.

For new product, project manager and department manager cooperate to determine the milestones of the new project firstly, and then make up the initial plan of the new project. If there is no conflict between new project plan and others plan, the department manager can make the phase level plan directly, else it needs to adjust the project level plan.

This planning and control mode that considering the enterprise reality, can ensure the project duration through two level planning process. The two-level planning are complement each other, and gradual refinement. The second plan is carried out under the constraints of the first plan, and there is also the feedback process from lower to upper level. This process can realize the cooperation between different levels, and cooperation between different phases of the projects.

Fig. 3 Planning and control process of MPDPs



5 Conclusions

In this paper, we discussed the two-level planning and control method for multiple product development projects (MPDPs) with resource constraints. This method considered the dynamic and changing characteristics of the environment, is conducive to the collaboration between different projects. It implemented the multiple projects control different levels, in order to achieve the reasonable arrangement of the enterprise resource and benefit maximization. This hierarchical planning and control method provides a theoretical model for MPDPs management in manufacturing enterprises. In the future, we will research the allocation algorithm for each level, the duration of projects and the hierarchical cooperative control of the MPDPs, etc., intensively.

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A Virtual Resequencing Problem in Automobile Paint Shops

Ying Xu and Jian-gong Zhou

Abstract To enhance the efficiency of painting process and reduce painting costs, it is desirable for an automobile assembly plant to execute practices of resequencing before painting. This paper studies the virtual resequencing problem in automobile paint shops, which is aimed to minimize the number of color changes while keeping the original car body sequence unchanged. Four heuristic rules are presented for solving this problem, then a beam search (BS) algorithm based on the best heuristic rule is proposed. Computational experiments are carried out to evaluate the performance of the proposed BS algorithm. Results show that the BS algorithm can further improve the virtual resequencing outcomes.

Keywords Automobile assembly · Beam search · Heuristics · Virtual resequencing

1 Introduction

A typical automobile mixed-model assembly line consists of three main production sectors which include a body shop, a paint shop and a final assembly shop. Generally, different production sequences are preferred by various departments on an automobile assembly line. For example, in paint shops it is desirable to build blocks of cars having identical color in order to reduce the setup costs when cleaning paint nozzles [1]. However, this requirement is usually different from that of the upstream body shop, which necessitates car resequencing before paint shops. Currently, there are two resequencing modes in practice: physical resequencing with buffers, and virtual resequencing without buffers [2]. In physical resequencing, the sequence of car bodies in white from the upstream body shop is changed by means of

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physically moving car bodies using buffers. While during virtual resequencing, the car body sequence remains unchanged, however, the colors preassigned to car bodies are adjusted according to the requirement of the paint shop.

The physical resequencing via buffers such as selectivity banks has been studied by some researchers [3–9], however, there are few papers about the virtual resequencing problem in automobile paint shops in the literature. Epping et al. [10] proved that this problem is NP-complete, and presented a dynamic program which can be used to solve small size problems. Inman and Schmeling [11] conducted a simulation study on an agile assemble-to-order system applying virtual resequencing before and after painting, in which simple resequencing rules were used. Huang et al. [12] presented a genetic algorithm (GA) for solving this resequencing problem in paint shops, with the objective of minimizing the number of color changes. A small size problem instance is used to demonstrate the performance of the proposed GA. This paper attempts to develop effective approximation approaches to solving this problem, which can be employed in real production environments.

2 Problem Description

Given an initial sequence of car bodies in white with various models, each of them having a preassigned color attribute, virtual resequencing can be accomplished by reassigning these colors predetermined, while keeping the original car body sequence unchanged. It should be noted that, color reassignment can only happen among bodies with a same model, since the total demand is fixed. Any change on colors between adjacent car bodies in the sequence incurs a setup cost, therefore, the objective is to minimize the total number of color changes (#CC) in the sequence after resequencing.

Figure 1 displays a process of virtual resequencing before painting, where English letters represent car models, Arabic numerals represent colors. It can be done by sequentially reassigning a color attribute to each car body in the upstream sequence based on the car model and its available color attributes shown on the

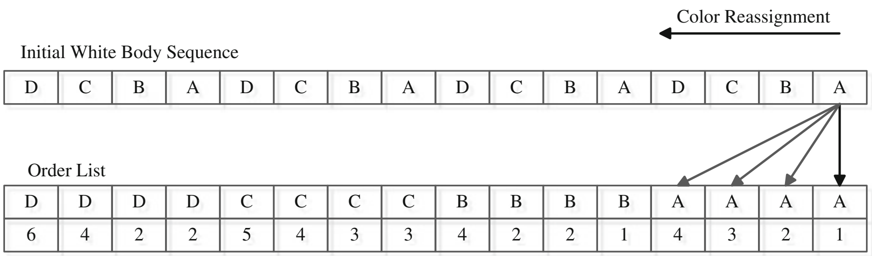

Fig. 1 An illustrative example of virtual resequencing

order list. For instance, there are 4 color options for the first car body with model A. The key of the problem is to determine which one to choose, this is also the focus of this paper.

3 Heuristic Rules

Four greedy heuristic rules are presented in this section. When reassigning colors sequentially, the four rules basically always try to choose the color same as the one assigned to the last car body, if available. When such a color is not available, a different color available to the current car model will be chosen and assigned. Different heuristics are employed by these rules while a color change is triggered. When there is a tie, choose the color on the top of the selectable order list.

3.1 Four Heuristics

For Rule 1, the color of the next available order of the same car model on a predetermined order list is selected. For instance, color 1 is selected and assigned to the first car body with model A in the initial sequence (as shown in Fig. 1) according to Rule 1.

For Rule 2, the color selection is based on the priorities of colors in the order list, which are indicated by the ratios of the number of car bodies painted in a same color to the number of total car bodies. Under Rule 2, the color option available to the current car body which has the highest priority value is chosen, which attempts to start a consecutive subsequence of car bodies with this color. As shown in Fig. 1, the first car with model A has four color options (1, 2, 3, 4), whose priority ratios are 2/16, 5/16, 3/16 and 4/16 respectively. Apparently, color 2 has the highest priority value, and therefore should be selected.

For Rule 3, the color which can start a consecutive subsequence of car bodies painted in this color with the maximum length is chosen. In Fig. 1, still considering the first car, color 4 can be successively assigned to car bodies A, B, C and D, besides, the length of this subsequence 4 is larger than that of other subsequences resulting from colors 1, 2, and 3. So color 4 is chosen under Rule 3.

For Rule 4, the color that can be assigned to the current and the next car, and meanwhile has the largest priority value is selected. When such a color is not available, the next color available for the current car model from the order list is picked. As shown in Fig. 1, the first car with model A has three common colors with the second car in model B (1, 2, 4), therefore, color 2 is chosen under Rule 4, since the priority value for color 2 (5/16) is the largest.

3.2 Computational Experiments

Computational experiments are conducted to test the performance of the heuristic rules above. Different parameter values used in the experimental design are described in detail below. The sequence length of car bodies is set to be 56 for medium resequencing range. The number of vehicle colors in the upstream sequence is 10 or 20. Three different color distributions, D_1, D_2 and D_3 are considered. D_1 representing a uniform distribution is generated assuming same color preferences among customers. D_3 reflecting noticeably different color popularities, is generated based on 2011 DuPont global automotive color popularity report. D_2 is similar to D_3, but not as extreme as D_3. In addition, the number of car models in the sequence is 5 or 10 respectively. Two model distributions, d_1 and d_2 are considered, where d_1 is a uniform distribution representing same model preferences among customers, and d_2 is similar to D_2. Probability values of these distributions are shown in Table 1, where the first column specifies parameters (model or color) and the numbers of those parameters in the sequence.

Five problem instances are generated for each of 24 combinations of model and color (number of models, number of colors, model distribution, and color distribution). All the heuristic rules and algorithms in this paper are coded in C++ language with Microsoft's Visual Studio 2010 compiler. Computational experiments are run on 2.53 GHz PCs with 2048 Mb of RAM.

3.3 Experimental Analysis

Experimental results in Table 2 show that all the 4 heuristic rules can be used to reduce #CC effectively and efficiently. In fact, their average reductions in #CC over

Table 1 The probability values of distributions

Parameter (no.)	Distribution	Probability values
Model (5)	d_1	0.2, 0.2, 0.2, 0.2, 0.2
	d_2	0.34, 0.26, 0.20, 0.14, 0.06
Model (10)	d_1	0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1
	d_2	0.18, 0.16, 0.14, 0.12, 0.10, 0.10, 0.08, 0.06, 0.04, 0.02
Color (10)	D_1	0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1
	D_2	0.18, 0.16, 0.14, 0.12, 0.10, 0.10, 0.08, 0.06, 0.04, 0.02
	D_3	0.22, 0.22, 0.20, 0.13, 0.07, 0.06, 0.05, 0.02, 0.02, 0.01
Color (20)	D_1	0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05
	D_2	0.09, 0.09, 0.08, 0.08, 0.07, 0.07, 0.06, 0.06, 0.05, 0.05, 0.05, 0.05, 0.04, 0.04, 0.03, 0.03, 0.02, 0.02, 0.01, 0.01
	D_3	0.11, 0.11, 0.11, 0.11, 0.10, 0.10, 0.07, 0.06, 0.04, 0.03, 0.03, 0.03, 0.03, 0.02, 0.01, 0.01, 0.01, 0.01, 0.005, 0.005

Table 2 Experimental results of heuristic rules 1–4 and BS algorithm

Number of models	Number of colors	Model distribution	Color distribution	Average #CC in the initial sequence	Rule 1		Rule 2		Rule 3		Rule 4		BS	
					Average #CC	Average reduction in #CC (%)	Average #CC	Average reduction in #CC (%)	Average #CC	Average reduction in #CC (%)	Average #CC	Average reduction in #CC (%)	Average #CC	Average reduction in #CC (%)
5	10	d_1	D_1	49.2	30.6	37.8	31.2	36.6	24.2	50.8	26.2	46.7	21.0	57.3
			D_2	48.2	30.4	36.9	29.2	39.4	21.8	54.8	26.0	46.1	17.8	63.1
			D_3	45.8	29.4	35.8	27.0	41.0	21.0	54.1	23.8	48.0	19.6	57.2
		d_2	D_1	50.0	30.6	38.8	27.8	44.4	21.2	57.6	24.4	51.2	19.2	61.6
			D_2	46.6	23.2	50.2	25.6	45.1	20.0	57.1	23.2	50.2	16.8	63.9
			D_3	43.8	24.4	44.3	23.8	45.7	21.4	51.1	21.6	50.7	18.4	58.0
	20	d_1	D_1	52.6	40.6	22.8	40.4	23.2	29.6	43.7	32.6	38.0	27.2	48.3
			D_2	51.4	39.2	23.7	37.2	27.6	30.6	40.5	31.8	38.1	28.0	45.5
			D_3	51.2	37.0	27.7	35.0	31.6	28.2	44.9	30.4	40.6	25.2	50.8
		d_2	D_1	51.6	37.8	26.7	38.0	26.4	29.8	42.2	32.2	37.6	27.4	46.9
			D_2	51.4	36.0	30.0	36.4	29.2	28.0	45.5	30.4	40.9	25.6	50.2
			D_3	50.4	33.2	34.1	32.8	34.9	25.8	48.8	28.6	43.3	23.6	53.2

(continued)

Table 2 (continued)

Number of models	Number of colors	Model distribution	Color distribution	Average #CC in the initial sequence	Rule 1		Rule 2		Rule 3		Rule 4		BS	
					Average #CC	Average reduction in #CC (%)	Average #CC	Average reduction in #CC (%)	Average #CC	Average reduction in #CC (%)	Average #CC	Average reduction in #CC (%)	Average #CC	Average reduction in #CC (%)
10	10	d_1	D_1	47.8	37.8	20.9	37.0	22.6	31.0	35.1	33.0	31.0	29.2	38.9
			D_2	49.0	39.4	19.6	38.4	21.6	33.0	32.7	32.6	33.5	27.4	44.1
			D_3	45.2	32.6	27.9	36.2	19.9	28.4	37.2	29.8	34.1	25.2	44.2
		d_2	D_1	48.6	36.0	25.9	38.4	21.0	29.4	39.5	32.2	33.7	28.0	42.4
			D_2	49.2	35.2	28.5	34.8	29.3	28.8	41.5	30.6	37.8	27.0	45.1
			D_3	43.4	29.2	32.7	29.4	32.3	24.8	42.9	25.4	41.5	22.4	48.4
	20	d_1	D_1	51.6	44.8	13.2	47.0	8.90	38.0	26.4	39.8	22.9	36.2	29.8
			D_2	50.6	42.4	16.2	42.0	17.0	34.4	32.0	37.0	26.9	33.4	34.0
			D_3	49.4	38.6	21.9	39.8	19.4	35.2	28.7	37.0	25.1	32.8	33.6
		d_2	D_1	52.8	44.6	15.5	45.2	14.4	35.6	32.6	38.4	27.3	34.6	34.5
			D_2	52.2	43.4	16.9	44.2	15.3	36.6	29.9	38.4	26.4	34.8	33.3
			D_3	49.6	36.4	26.6	39.2	21.0	32.0	35.5	32.8	33.9	30.2	39.1

24 combinations are 28.1, 27.8, 41.9 and 37.7 % respectively, compared to the corresponding #CC in the initial sequence. It can also be seen that the average #CC from Rule 3 is the smallest in 23 of the 24 combinations. Only under the 14th combination (10, 10, d_1, D_2), the average #CC from Rule 3 (33) is slightly larger than that from Rule 4 (32.6), however, the difference between them is less than 0.5. Therefore, among the 4 heuristic rules, Rule 3 has the overall best performance. Also, it should be noted that very short CPU running times (less than 0.05 s) are required in problem solving with these heuristic rules.

4 A Beam Search Algorithm

4.1 A Rule Based Beam Search Algorithm

A beam search (BS) algorithm based on Rule 3 is proposed. In this algorithm, level i corresponds to the color reassignment for the i-th white body in the sequence. Level 0 is a virtual starting node. Nodes at each level represent colors that can be assigned to the car body at this level, some of which are selected and retained (called beam nodes) according to some criteria during the search process. Normally, at most BW (called beam width) nodes are required, which can be determined using experimental methods.

Each beam node can sprout nodes representing selectable colors at the next level. The beam nodes are chosen based on the heuristic Rule 3. Figure 2 gives the procedures of the proposed BS algorithm.

1. At level 1, if the number of nodes, which is the number of available color options for the first car body is less than or equal to BW, all the nodes are retained as beam nodes. Otherwise, iteratively select the first BW nodes which can start longer subsequences of car bodies with same colors, as depicted in Rule 3.
2. At level i ($i > 1$), if the number of nodes is less than or equal to BW, all the nodes are retained as beam nodes. Otherwise, for each of the beam nodes at level $i - 1$, choose one child node as beam nodes at level i according to Rule 3. If the number of those beam nodes (m) is less than BW, iteratively select the first BW–m nodes which can start longer subsequences from the remaining nodes at level i using the heuristic Rule 3.

4.2 Experiments and Results

The above problem instances are solved by applying the proposed BS algorithm with a constant BW value 200, and results are recorded and displayed in Table 2.

```
Initialize white body sequence
FOR  i =1   TO   n
    /*Select beam nodes*/
    Determine the number of nodes (node[i]) at level i and the number
of nodes required to be retained (t)
    IF   i==1
        IF   node[i] ≤ BW
            THEN   t = node[i], retain all nodes as beam nodes
        ELSE   t = BW, iteratively select the first BW nodes
according to Rule 3
        End IF
    ELSE
        IF   node[i] ≤ BW
            THEN   t=node[i], retain all nodes as beam nodes
        ELSE   t=BW, for each beam node at level i–1, choose one
child node as beam nodes at level i according to Rule 3 & count the
number of those beam nodes (m)
            IF   m<BW
                THEN   Iteratively select the first BW–m nodes
from the remaining nodes at level i according to the heuristic Rule 3
            End IF
        End IF
    End IF
    Update t car sequences retained
End FOR
Output the best car sequence
```

Fig. 2 A summary representation of the BS algorithm

It can be seen that the BS algorithm, resulting in an average reduction in #CC by 46.8 %, is superior to Rule 3 (41.9 %) for all 24 combinations. This is due to the fact that the Rule 3 based BS algorithm has much more solution candidates. In addition, the CPU running times of the BS algorithm are generally less than 5 s, which is acceptable in real production environments.

Experimental results of the BS algorithm also show the impact of different parameter values as described below.

1. Number of models
   The average reduction in #CC of problem instances with 5 models is 54.67 %, which is 15.7 % larger than that of problem instances with 10 models (38.96 %). It appears that the BS algorithm has better performance for a car sequence involving less number of models. In addition, it can be seen that the number of models exercises a slightly large influence on the effect of the BS algorithm.
2. Model distribution
   The average reduction in #CC for problem instances with model distribution d_1 is 45.6 %, which is approximately equal to that (48.1 %) for problem instances with model distribution d_2. It seems that the resequencing performance is insensitive to model distribution.

3. Number of colors
   In general, the smaller the number of colors, the better the resequencing performance. The average reduction in #CC is 52.0 % for problem instances with 10 colors, while 41.6 % for problem instances with 20 colors.
4. Color distribution
   For problem instances with different color distributions D_1, D_2 and D_3, the average reductions in #CC are 45.0, 47.4, and 48.1 % respectively. It seems that this parameter does not have significant impact on the resequencing performance.

In conclusion, number of models and number of colors have greater influence on the effect of the BS algorithm, compared to model distribution and color distribution. Also, the resequencing performance of the BS algorithm is deteriorated with the increasing number of models or colors.

5 Conclusion

This paper systematically studies the virtual resequencing problem in automobile paint shops. First, four heuristic rules are proposed, among which Rule 3 has the best overall performance. A rule based BS algorithm is then presented. Experimental results show that the BS algorithm can further improve virtual resequencing outcomes. All the heuristic rules and the BS algorithm can be applied to effectively and efficiently solve the virtual resequencing problem in paint shops in real production environments.

Due to limited time and knowledge, there are still some deficiencies in this paper. This paper only explores four rules, maybe there are other better rules to be investigated. The virtual resequencing problem can also be solved by using other intelligent algorithms, such as ant colony optimization, which might obtain better solutions and will be studied in the future. Furthermore, it is also worthwhile to investigate the combined performance of jointly applying physical and virtual resequencing modes, which has not been addressed in the literature.

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Multiobjective Simulation Optimization Using Stochastic Kriging

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Abstract Multiobjective simulation optimization aims at finding Pareto optimal solutions and a common approach is to rely on metamodels to alleviate computational costs of the optimization process. We present a stochastic Kriging based multiobjective optimization algorithm to estimate the Pareto fronts of multiobjective simulation optimization problems. After the objective functions were replaced by stochastic Kriging metamodels using limit simulation costs, techniques developed for deterministic multiobjective optimization can be applied to these metamodels. Numerical experiment of a multiobjective (s, S) inventory system illustrates the potential of stochastic Kriging in stochastic simulation optimization which is especially useful in Operations Research and Management Science.

Keywords Multiobjective · Pareto front · Stochastic simulation · Stochastic kriging

1 Introduction

Discrete event simulation is a general purpose tool for analyzing dynamic stochastic systems and its' crucial role is widely recognized in many fields (e.g., logistics, supply chain management). However, due to the stochastic nature of the response(s) and the potentially extensive run costs, using simulation to support decision making directly is a hard problem. Instead, we construct approximations of the simulation models, called metamodels. A metamodel, simplifies the simulation optimization in two ways: the metamodel response is deterministic rather than stochastic, and the

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run times are generally much shorter than the original simulation [1]. Kriging is one of the most commonly used global metamodeling methodologies first developed by Krige for the interpolation of geostatistical sampling data [2] and optimization of expensive deterministic simulation models with the help of Kriging metamodels is now commonplace.

This article addresses the issue of multiobjective optimization of stochastic discrete event simulation based on stochastic Kriging technique recently developed [3]. As we known, Van Beers and Kleijnen [4] started with the application of Kriging to random simulation models. But as [5] points out, the interpolation property of Kriging is not desirable in stochastic simulation because the outputs from stochastic simulation include intrinsic output variability and this variability changes significantly across the design space. Stochastic Kriging takes account of the intrinsic uncertainty from stochastic simulation and this makes stochastic Kriging can tolerate larger output variance, which means, under a given fixed computational budget, stochastic Kriging permits a larger number of design points than Kriging. This can be advantageous because it enables better estimation and improves the accuracy of interpolation [6]. After the implicitly represented stochastic responses of the simulation were replaced by explicit deterministic stochastic Kriging metamodels, techniques developed for deterministic multiobjective optimization can be applied to these metamodels. In this article, a classical ε-constraint method [7] and the famous Nondominated Sorting Genetic Algorithm (NSGA-II) [8] are applied to get the Pareto optimal solutions of the simulation optimization problem. One simple (s, S) inventory system simulation model is used to explain the stochastic Kriging based multiobjective optimization process, and the results show that the proposed approach has the potential to simplify complicate direct optimization of the simulation models which is especially useful for time consuming simulations in Operations Research and Management Science.

The remainder of this article is organized as follows. In next section we briefly introduce the multi-objective optimization problems. Then, the proposed stochastic Kriging metamodeling methodology is explained in Sect. 3. In Sect. 4, a numerical experiment of (s, S) inventory system optimization is reported. Finally, in Sect. 5, conclusions are made and future research topics are recommended.

2 Multiobjective Optimization Problems

The ***Multiple Objective Optimization Problem*** (MOOP) can be written as follow:

$$\begin{aligned} &\min f_k(\mathbf{x}), \quad k = 1, \ldots, r, \\ &s.t.\; g_i(\mathbf{x}) \le 0, \; i = 1, \ldots, p, \\ &\quad h_j(\mathbf{x}) = 0, \; j = 1, \ldots, q, \\ &\quad \mathbf{x}^{lower} \le \mathbf{x} \le \mathbf{x}^{upper}, \end{aligned} \tag{1}$$

where $\mathbf{x} = (x_1, x_2, \ldots x_d)^T$ is the d -vector of design variables, $g_i(x)$ and $h_j(x)$ are the inequality and equality constraints, $\mathbf{x}^{lower}$ and $\mathbf{x}^{upper}$ are lower bounds and upper bounds on $\mathbf{x}$ respectively. As the objectives are usually in conflict, it is very rare to find a solution minimizing all the objectives. This leads to the definition of a compromise solution following the Pareto dominance: a vector is said to be ***dominated*** if there is another vector which is not worse in any objective and better for at least one. If a vector is not dominated by any other vector, it is optimal in the Pareto sense.

The set of all Pareto optimal (or nondominated) solutions is called ***Pareto set*** and the corresponding image by vector function f, composed of nondominated vectors, is called ***Pareto front*** or Pareto curve or surface. The shape of the Pareto front indicates the nature of the tradeoff between the different objective functions and we aim at finding the Pareto front.

Pareto fronts can't be computed efficiently in many cases and approximation methods for them are frequently used. To solve the MOOP, one classical ε-constraint method and the elitist nondominated sorting genetic algorithm (NSGA-II) are used in this paper, for easy understanding and computing efficiency.

3 Stochastic Kriging

Stochastic Kriging is a methodology developed for metamodeling stochastic simulation. Article [6] gives an excellent explanation of regression, Kriging, and stochastic Kriging metamodeling methodologies and point out that stochastic Kriging can partake of the behavior of Kriging and of generalized least squares regression because of handling intrinsic and extrinsic uncertainty in metamodeling of stochastic simulation.

In stochastic Kriging, simulation output on the jth replication at design point $\mathbf{x}$ is represented as

$$Y_j = \mathbf{f}(x)^T \boldsymbol{\beta} + M(\mathbf{x}) + \varepsilon_j(\mathbf{x}). \tag{2}$$

Formula (2) indicates that the output Y_j of the simulation response is divided into three uncorrelated parts: a trend model $\mathbf{f}(x)^T\boldsymbol{\beta}$, extrinsic (response surface) uncertainty $M(\mathbf{x})$, and intrinsic (simulation output) uncertainty $\varepsilon_j(\mathbf{x})$. The vector of functions $\mathbf{f}(x)$ is typically assumed to be known, whereas the corresponding vector of coefficients $\boldsymbol{\beta}$ needs to be estimated. The term $M(\mathbf{x})$ represents a realization of a mean zero stationary ***Gaussian random field*** (GRF) and $\varepsilon_j(\mathbf{x}), j = 1, \ldots, n$ are the independent and identically distributed mean zero simulation errors incurred on each replication at design point. In practice, the constant trend model $\mathbf{f}(x)^T\boldsymbol{\beta} = \beta_0$ has been widely adopted in the Kriging literature since it has been reported performing sufficiently well for most applications, see [9].

To generate a global predictor, we choose m design points $\mathbf{x}_1, \mathbf{x}_2, \ldots \mathbf{x}_m$, and then run n_i replications at the ith point. The sample mean of the simulation outputs at x_i is $\bar{Y}(\mathbf{x}_i) = \frac{1}{n_i}\sum_{j=1}^{n_i} Y_j(\mathbf{x}_i)$, and let $\bar{Y} = (\bar{Y}(\mathbf{x}_1), \ldots, \bar{Y}(\mathbf{x}_m))$ denotes the vector of sample means at all design points. We also represent the vector of averaged simulation errors by $\bar{\varepsilon} = (\bar{\varepsilon}(\mathbf{x}_1), \ldots, \bar{\varepsilon}(\mathbf{x}_m))$, where $\bar{\varepsilon}(\mathbf{x}_i) = \frac{1}{n_i}\sum_{j=1}^{n_i} \varepsilon_j(\mathbf{x}_i)$. The variance $\sigma^2(\mathbf{x}) = Var(\varepsilon(\mathbf{x}))$ of intrinsic noise $\varepsilon(\mathbf{x})$ is not necessarily constant and $Corr(\varepsilon_i(\mathbf{x}), \varepsilon_j(\mathbf{x})) > 0$ if common random numbers are used in driving simulation experiment. [10] shows that the use of common random numbers inflates the mean squared error of prediction for stochastic Kriging, so we use independent simulations and then the $m \times m$ intrinsic covariance matrix Σ_ε for $\bar{\varepsilon}$ can be specified as $\Sigma_\varepsilon = diag(\frac{\sigma_1^2}{n_1}, \ldots, \frac{\sigma_m^2}{n_m})$.

Let Σ_M represent the $m \times m$ covariance matrix with $\Sigma_M = Cov(M(\mathbf{x}_i), M(\mathbf{x}_j))$ across all design points, and let $\Sigma_M(\mathbf{x}_i, \cdot)$ be the $m \times 1$ covariance vector between prediction point $\mathbf{x}$ and all design points. Given that $M(\mathbf{x})$ is stationary, Σ_M and $\Sigma_M(\mathbf{x}_i, \cdot)$ are assumed to take the following forms:

$$\Sigma_M = \tau^2 \begin{pmatrix} 1 & r_{12} & \cdots & r_{1m} \\ r_{21} & 1 & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & 1 \end{pmatrix} \quad \text{and} \quad \Sigma_M(\mathbf{x}, \cdot) = \tau^2 \begin{pmatrix} r_1 \\ r_2 \\ \vdots \\ r_m \end{pmatrix},$$

where $\tau^2 > 0$ denotes the extrinsic spatial variance and the r_{ij} is the spatial correlation coefficient of the design points $\mathbf{x}_i$ and $\mathbf{x}_j$. The r_i gives respective spatial correlations between the design point $\mathbf{x}_i$ and the prediction point $\mathbf{x}$. To obtain good accuracy for Kriging, the choice of correlation function is crucial, because different correlation functions will result in different level of smoothness for the associated random processes. This paper focuses on using the product-form Matérn correlation function $r(\mathbf{x}, \mathbf{x}'; \theta)$, with $\upsilon = 5/2$ and a wide range of other choices of correlation functions are available in [11].

Suppose that $\Sigma_M, \Sigma_\varepsilon$ and β_0 are known, then the optimal mean squared error linear predictor is [3]:

$$\hat{Y}(\mathbf{x}) = \beta_0 + \Sigma_M(\mathbf{x}, \cdot)^T(\Sigma_M + \Sigma_\varepsilon)^{-1}(\bar{Y} - \beta_0 1_m), \tag{3}$$

where 1_m is the $m \times 1$ vector of ones. Because the constant β_0 and spatial correlation parameters τ^2 and θ are unknown, maximum likelihood estimates are typically used for prediction. For simplicity, sample variance $s^2(\mathbf{x}_i)$ is employed to estimate the intrinsic covariance matrix Σ_ε here. As pointed by [6], there are two steps in using stochastic Kriging to build metamodels from simulation outputs: first, use the outputs to choose parameters for the GRF; second, use this GRF to make predictions, and they make software to perform these tasks available at www.stochastickriging.net. For Kriging, a free of charge Matlab toolbox well documented in [12] called DACE is widely used. The statistical R community has also developed much software; see, e.g., [13]'s mlegp and [14]'s DiceKriging for Kriging metamodeling.

4 Stochastic Kriging in Multiobjective (*s*, *S*) Inventory System

The stochastic Kriging assisted multiobjective simulation optimization strategy proposed in this paper consists of designing an experiment to fit the metamodels, simulating at all design points to yield the multiple simulation outputs $\bar{Y}_h(\mathbf{x}_i)$ ($h = 0, \ldots, r - 1$), fitting r stochastic Kriging metamodels for the r objectives, validating and improving the accuracies of metamodels and estimating the Pareto front by classical and evolutionary multiobjective optimization algorithm.

In this section, we explore the stochastic Kriging assisted multiobjective optimization for (s, S) inventory system which is a basic building block of ***Supply Chain Management*** (SCM) [15]. In such a system, a replenishment order is placed as soon as the inventory position drops to or below the reorder point s. This replenishment order brings the inventory position back to the maximum inventory level S, where $S \geq s$ always hold. Then the objective of our simulation optimization is to determine values of s and S so as to

$$\begin{aligned} &\min \quad f_0(\mathbf{x}), \\ &\max \; f_1(\mathbf{x}), \\ &s.t. \quad x_1 > 0, x_2 > x_1, \end{aligned} \tag{4}$$

where the vector $\mathbf{x} = (x_1, x_2)$ refers to a (s, S) combination, the $f_0(\mathbf{x})$ is the total cost function and $f_1(\mathbf{x})$ stands for customer satisfaction level.

The following assumptions are used in the set of the (s, S) inventory system :

- The initial inventory is 60 items with holding cost \$1 for one item per month, and the simulated period is 120 months.
- The ordering cost is \$32 per order plus \$3 per item ordered, and the shortage cost is \$5 for one item per month.
- The order delay is uniformly distributed between 0.5 and 1, and the arrivals of demand is Poisson distributed with mean time 0.1 month.
- The size of demand per customer varies between 1 and 4with probabilities $(1/6, 1/3, 1/3, 1/6)$.
- Inventory is controlled once a month.
  The random input components (namely, the orders' lead times et al.) of the (s, S) inventory system cause the outputs to be variables, and should be treated as estimates of the true responses of the model. Commonly, there are two options

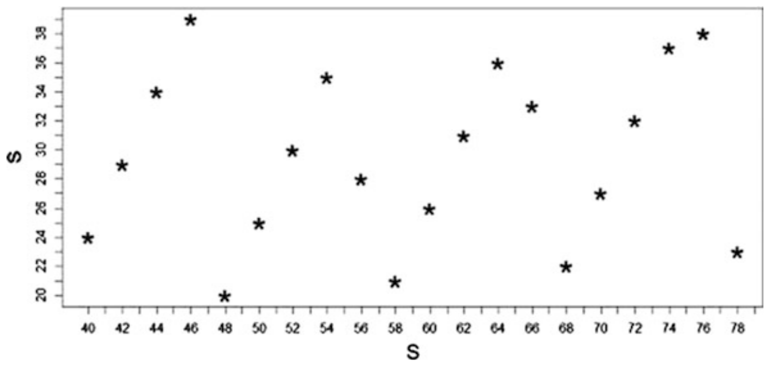

Fig. 1 A latin hypercube design for the (s, S) inventory system

to set the number of simulation replications n_i for design points $i = 1, \ldots, m$ which reflects the magnitude of the noise that we accept, also see [16]:

- simulate a fixed number of replications per design point, so $n_i = n$.
- select n_i such that the halfwidth (say) $l_h(n_i, \alpha)$ of the $(1 - \alpha)$ confidence interval for the average simulation output $\bar{Y}(\mathbf{x}_i)$ is within $\gamma\%$ of the true mean for all r responses.

For simple, we just simulate $n_i = 50$ replications at each design point in a 20 points Latin Hypercube Design (LHD) shown in Fig. 1, and the simulation results for the LHD applied to the (s, S) are displayed in Table 1, including ***mean of total cost*** (MC), ***variance of total cost*** (VC), ***mean of customer demand satisfaction rate*** (MR) and ***variance of customer demand satisfaction rate*** (VR). All simulations are executed in Arena software here.

Using the simulation results, we build two stochastic Kriging metamodels, one for MC and the other for MR. During the optimization process, the updating and

Table 1 Simulation results for the LHD of the (s, S) inventory system with $n_i = 50$

Trial	(s, S)	MC	VC	MR	VR
1	(20, 48)	121.2915	14.4360	0.7802	7.63e−04
2	(21, 58)	119.4898	17.9513	0.8655	6.28e−04
3	(22, 68)	119.4576	11.0268	0.9182	3.08e−04
4	(23, 78)	121.0587	8.7093	0.9451	1.59e−04
5	(24, 40)	124.3243	14.9496	0.7922	8.78e−04
…	…	…	…	…	…
16	(35, 54)	122.8295	7.8458	0.9653	7.67E−05
17	(36, 64)	120.9906	8.6538	0.9745	6.78E−05
18	(37, 74)	122.6542	7.2007	0.9850	3.57E−05
19	(38, 76)	122.8601	4.0723	0.9887	1.24E−05
20	(39, 46)	125.9045	6.1342	0.9461	2.39E−04

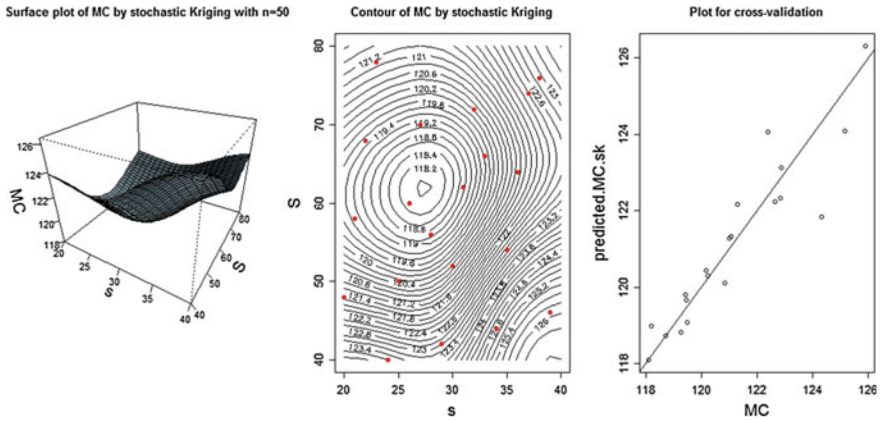

Fig. 2 Surface plot, contour plot and validation scatter plot of stochastic Kriging for MC with $n = 50$

validation of these metamodels needs to be carefully considered. For estimating the error of prediction of the stochastic Kriging metamodels, we apply the cross validation (CV) approach and other accuracy measures just as Normalized Root Mean Squared Error (NRMSE) and Normalized Maximum Absolute Error (NMAE) could also be used to evaluate overall accuracy and locally large errors of the metamodels. The NRMSE and NMAE criteria are also help to update the metamodels by adding new design points to initial design when any of metamodels is rejected by validating.

Figure 2 show the surface plot, contour plot for MC produced through a 20 × 40 grid of stochastic Kriging predictions, and the scatter plot of leave-one-out cross validation method is given also, to estimating the accuracies of the stochastic Kriging metamodels which have great influence on the final Pareto optimal solutions. In this paper, we use stochastic Kriging with $n = 50$ replications to solve the MOOP.

We also compared the Kriging metamodel showed in Fig. 3 with stochastic Kriging metamodel with $n = 50$ replications. From their surface and contour plots we know that Kriging and stochastic Kriging make similar predictions, but the smoother predictions of stochastic Kriging means stochastic Kriging can tolerate much more simulation noise than Kriging. Comparing the scatterplots of the Kriging and stochastic Kriging, shows that stochastic Kriging does perform much better than Kriging under this stochastic simulation experiment. The stochastic Kriging metamodel built for MR is not shown here, for their similar performance with the one for MC.

The results of the stochastic Kriging study of the (s, S) inventory system are depicted in the Pareto fronts shown in Figs. 4 and 5. The green ball Pareto front shown in Fig. 4 is got by directly comparing all predicted responses of the possible designs based on stochastic Kriging metamodels, the red ball Pareto fronts in Fig. 5

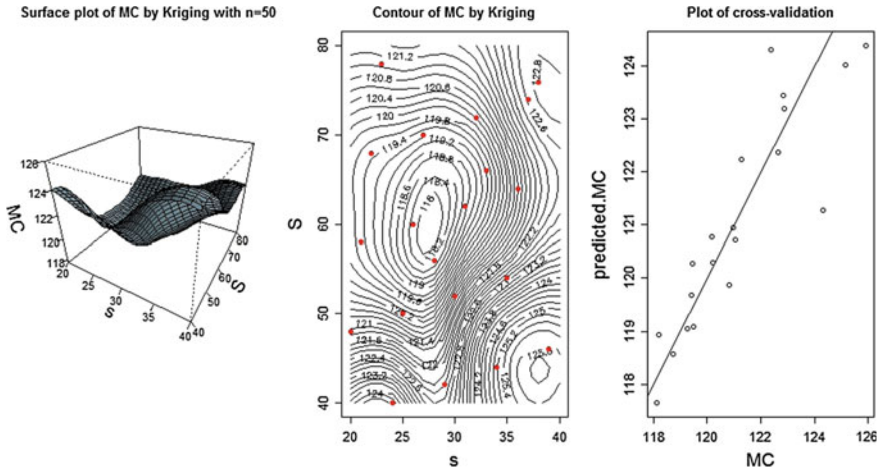

Fig. 3 Surface plot, contour plot and validation scatter plot of Kriging for MC with $n = 50$

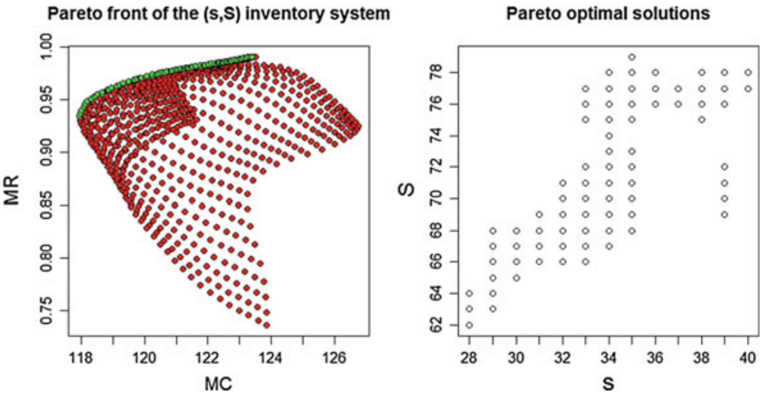

Fig. 4 Pareto front and other values of objective functions of the (s, S) inventory system predicted by stochastic Kriging metamodels are represented by *green points* and *red points* separately. The Pareto optimal solutions corresponding to the Pareto front are shown on the *right*

are estimated by ε-constraint method (left) with 101 grid points (ε) and NSGA-II (right) with population size as 100 separately, based on the metamodels. From Fig. 5, we conclude that both ε-constraint method and NSGA-II evolutionary algorithm can estimate the Pareto front exactly if only exact approximation metamodels of the true response surfaces have been built. We can also know that, NSGA-II algorithm gets better distributed set of nondominated solutions than ε-constraint method, and NSGA-II algorithm needs less computation time in our example actually. We advise using NSGA-II or other multiobjective evolutionary

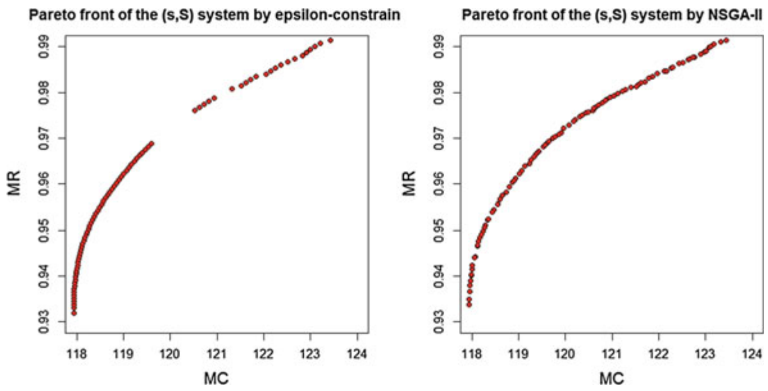

Fig. 5 Pareto front of the (*s*, *S*) inventory system multi-objective optimization by ε-constraint method (*left*) and NSGA-II (*right*)

algorithm to estimate the Pareto front of MOOP, especially when the objectives increase which makes classical ε-constraint method inefficient.

However, finding a set of tradeoff solutions is only a part of the whole story. In practice, one needs to choose only a single preferred solution. Using the useful information provided by the Pareto front of the (*s*, *S*) inventory system, a decision maker can make decisions from different points of view. If the decision maker just want to minimize total inventory cost, then (*s*, *S*) = (26, 63) corresponding to the black lozenge in the Pareto front shown in Fig. 6 can be selected, which means (MC, MR) = (118.0456, 0.9383). The green triangle and blue square in Fig. 6 are the best choices for the decision maker when MR is needed to exceed 0.9600 and when MC is required to be less than 122 in the sense of Pareto optimality. The values corresponding to green triangle and blue square are (MC, MR) = (118.9278,

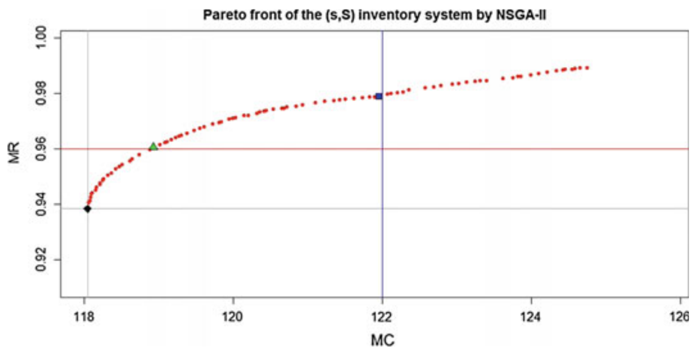

Fig. 6 Pareto front of the (*s*, *S*) multiobjective optimization and the decisions made from different points of view

0.9604) and (MC, MR) = (121.9529, 0.9790) and the Pareto optimal solutions are $(s, S)=(31, 65)$ and $(s, S)=(37, 69)$.

More discussions about how to choose the single preferred solution requires one to use a ***multiple criterion decision making*** (MCDM) technique which is beyond the scope of the current paper and [17] gives more information for interested readers.

5 Conclusions and Future Research

This paper considers the problem of multiobjective optimization in stochastic simulation based on stochastic Kriging metamodeling methodology and the optimization process is explained. The experiment has shown that stochastic Kriging modeling technology has the potential to identify Pareto fronts and finally to support decision making for the MOOP in stochastic simulation systems. One remarkable feature of this study is that, stochastic Kriging metamodels are used in the optimization process, which makes our optimization procedure could tolerate much more simulation noise and then less efforts per design point could be used in modeling to get higher accuracy metamodels which have great influence on the final Pareto optimal solutions. The following should be included in our future works. First, special sequential designs may be used to improve the precision of the stochastic Kriging models. Second, the uncertainty of Pareto front caused by the intrinsic uncertainty from stochastic simulations should be measured to support decision-making efficiently.

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Age-Related Differences in the Acceptance Process of Mobile Phones: A Closer Look at Social Influences

Shu-ping Yi, Pan Liu and Guang-ji Liao

Abstract This study examined the differences in the influence of closeness relationships between younger participants and older participants in the innovation diffusion process. Findings were as follows: (1) During the awareness stage, younger participants and older participants did not show significant differences under influences of age, while during the trial and acceptance stages, older participants showed higher intention on trial and acceptance of phones than younger participants. (2) Under the interactive influences of age and closeness relationship, the results were different. (3) For younger participants who paid close attention to the technology development of phones, if they had a high closeness relationship with the referrer, some factors influencing their purchase would become less important. (4) Older participants' reaction to the behaviors of their children, such as playing with phones and no communication with them, was related to older participants' living situations.

Keywords Age · Social influence · Mobile phone · Closeness relationship · Acceptance process

1 Introduction

Social influence played an important role on technology adoption, and it also had a significant impact on making people, voluntarily, use of IT unrelated to their career goals [1]. Whether younger adults or older adults, their behaviors will be affected by social influence directly. However, for younger adults and older adults the influence may be different.

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Generally speaking, younger adults are usually the group to follow the trends, so they are often the first group to adopt new technology products. However, younger adults are also the group, generally, keeping their products for a short period of time, they may abandon their products if the products used by people around them are the symbol of something. So how to keep younger adults using their products is a problem faced by many companies.

Compared with younger adults, older adults are not the first group to accept a new technology product generally. Usually, older adults' behaviors on accepting a technology product will be influenced by their children, as they face many problems using adopting technology products, and they need others help. Unfortunately, how older adults' behaviors are influenced by this interpersonal relationship is still studied less, especially, during the innovation diffusion process, few studies focus on the relationship between the interpersonal relationship and age on accepting a technology product.

Therefore, this study aims to understand the above-mentioned relationship during the innovation diffusion process. This study chose mobile phones as the object of this study, and it examined the effects of closeness relationships on the former three stages of the innovation diffusion process. The results of this study will aid family members, companies, and governments understand the effects of closeness relationships, and it will also help to reduce the barriers on accepting technology products.

2 Literature Review

Rogers [2] proposed a five-stage adoption process of products. In the technology diffusion process, social influence is also a vital factor, like Peres et al. [3] proposed that diffusion was driven by social influences.

According to the innovation diffusion theory, the factors influencing a person's technology choices could be divided into four categories: the adopter's personality, interpersonal communication influences, income, and the attributes of products [2]. Based on these four major categories, the questions of the interview were designed.

Social influence was defined as the degree to which a person trusted that people who were important to him thought he should finish the behavior in question [4]. What is more, social influence directly affected technology acceptance [5, 6] had been proved. However, previous studies focused only on the following four types of social influence: subjective norm [7, 8], image [9], visibility [2], and voluntariness [2, 9]. Although, social influence was associated with interpersonal closeness had been proposed [10], few studies had explored the influences of interpersonal relationships on accepting a technology product. Despite the fact that, older adults' behavior would be influenced by their children and grand-children had also been studied [11], nevertheless, the influences of closeness relationships had not been distinguished. Therefore, this study focused on the influence of closeness relationships on accepting a technology product.

3 Methodology

3.1 Questionnaire and Interview

In social psychology, the degree of intimacy contained the relative closeness and the absolute intimacy. Closeness relationships could be measured in many ways. The Inclusion of Other in the Self scale (IOS scale) could best describe interpersonal relationships using Venn-like diagrams [12], and this scale was used to measure the relative closeness generally, therefore, in this study, the IOS Scale was adopted.

According to psychology, absolutely intimacy contained real affection and assumed affection, and it can be evaluated in many ways. However, the Chinese Interpersonal Relationships Questionnaire [13] designed by Lau et al. had been used to measure Chinese interpersonal relationships. In this study, the real affection scale and the assumed affection scale of the Chinese Interpersonal Relationships Questionnaire were adopted.

The questionnaire contained three parts: (1) demographic information, (2) the real affection scale and the assumed affection scale, (3) and the adoption intention. The IOS scale was adopted for the measurement of closeness relationships. The IOS scale had been evaluated and showed highly validity and reliability. The real affection scale and the assumed affection scale showed a high reliable scoring scale (real affection: a = 0.95; assumed affection: a = 0.96). Based on the former three stages of the innovation diffusion process [2], three questions about adoption intention were designed (e.g., I want to become aware of some information regarding the phone).

In this paper, the closeness relationship was divided into two groups: the low closeness relationship and the high closeness relationship. Based on Fig. 1, all of the participants would choose two persons [according to Figure (b) and Figure (g)] from their circle of relationships to complete the questionnaire.

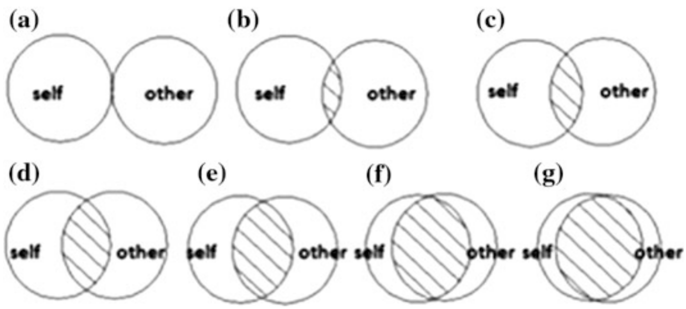

Fig. 1 The inclusion of other in the self (IOS) scale

3.2 Data Collection

A total of 36 younger participants were suitable for this study, through comparing the consistency of the close degree among the relative closeness, the real relationship (e.g., families, good friends, and colleague) participants chose, and the absolute intimacy. Ten of these younger participants were interviewed after they finished the questionnaires, and these ten younger participants came from Chongqing University.

A total of 26 older participants were suitable for this study, through comparing the consistency of the close degree among the relative closeness, the real relationship (e.g., families, good friends, and colleague) participants chose, and the absolute intimacy. The questionnaire was difficult for older participants, and they completed the questionnaires with the instructor's help.

4 Results and Discussion

The questionnaire had a reliability score of 0.951 according to Cornbrash's alpha. Cornbrash's alpha values were 0.867 (awareness, trial, and adoption), 0.917 (real affection), and 0.865 (assumed affection). To compare the data between the younger group and the older group, homogeneity and normality tests were performed. Through correlation analysis, the two independent variables, age and closeness relationship, was not show the pertinence ($r = 0.001$, $p = 0.001$). Repeated ANOVA was used to analyze the statistics, and the effect size of age, closeness relationship and their interactive effects on awareness, try and acceptance a phone was performed. In addition, the influences of some factors of demography (i.e., the using experience of mobile phone) were analyzed. Finally, based on the interview, other factors influenced the results were discussed.

4.1 Descriptive Statistics

Among the 36 younger participants (Mean age = 25.6; SD = 1.650; range = 23–30), 63.9 % were male. In contrast, among the 26 older participants (Mean age = 63.8; SD = 6.94; range = 55–79), 69.2 % were female. The educational level (ranged from 0 to 4) of the younger participants (Mean = 3.56; SD = 0.704) was significantly higher ($p = 0.001$) than that of older participants (Mean = 0.28; SD = 0.746). Relating to the phone experience, all of the participants used mobile phones. The mobile phone experience (i.e., measuring by a total of phones they used) was divided into five levels (ranged from 1 to 5), and the experience of older participants (Mean = 3.25; SD = 1.035) was significantly lower ($p = 0.007$) than younger participants (Mean = 3.77; SD = 1.227).

Table 1 The interaction effects of age and closeness relationship at the awareness stage

	Young		Old		df	F	P
	Mean	SD	Mean	SD			
Age	3.91	0.940	4.08	0.512	1	2.166	0.146
Closeness relationship	3.56	0.762	4.42	0.711	1	48.427	0.001*
Age* closeness relationship	4.19	0.583	3.50	0.939	1	10.670	0.002*

*Significant at 0.05 level

4.2 The Influence of Closeness Relationships and Age to Phone Adoption

4.2.1 Awareness Stage

During the awareness stage, the influences of age did not exhibit significant differences. As shown in Table 1, if a person recommended a phone to younger participants or older participants, all of them would be aware of the phone firstly, because they wanted to know whether the phone was right for them. However, the effect size (η = 0.035) of age was low, and it could not explain the result very well, or because the influences of age did not exhibit significant differences.

During the awareness stage, the influence of the low closeness relationship was lower than the high closeness relationship. Participants would accept a phone recommended by a person who had a high closeness relationship with them, as the high close relationship leaded the participants to trust the recommendations. In addition, the power of test (η = 0.669) of closeness relationship was big, and it could explain the result well.

The interactive effects of age and closeness relationships were significant differences. During the awareness stage, the intention (e.g., being aware of a phone) of younger participants under the high closeness relationship was higher than older participants under the low closeness relationship. The intention (e.g., being aware of a phone) of younger participants under the low closeness relationship was lower than older participants under the high closeness relationship.

4.2.2 Trial Stage

During the trial stage, the influence of age exhibited a significant difference. As shown in Table 2, if someone recommended a phone to older participants, they preferred to try a phone compared with younger participants. Effect size (η = 0.310) of age was medium, and it could explain the result to some extent.

During the trial stage, the influence of closeness relationship showed a significant difference, the influence of the low closeness relationship was lower than the influence of the high closeness relationship. Effect size (η = 0.702) of closeness relationship was big, so it could explain the result well.

Table 2 The interaction effects of age and closeness relationship at the trial stage

	Young		Old		df	F	p
	Mean	SD	Mean	SD			
Age	3.64	1.018	4.12	0.598	1	6.336	0.015*
Closeness relationship	3.40	0.858	4.27	0.994	1	58.424	0.001*
Age* closeness relationship	3.97	1.055	3.54	0.647	1	1.917	0.045*

*Significant at 0.05 level

The interactive effects of age and closeness relationships were significant differences, and maybe it was the reason caused the small effect size (η = 0.255). During the awareness stage, the intention (e.g., trying a phone) of younger participants under the high closeness relationship was higher than older participants under the low closeness relationship. The intention (e.g., trying a phone) of younger participants under the low closeness relationship was lower than older participants under the high closeness relationship. Under the low closeness relationship, younger participants preferred to try a phone. Under the high closeness relationship, older participants preferred to try a phone.

4.2.3 Acceptance Stage

During the acceptance stage, the influence of age on accepting a phone exhibited a significant difference. As shown in Table 3, the intention of younger participants on accepting a phone was significantly lower than older participants. Besides, effect size (η = 0.300) of age was medium, and it could explain the result to some extent.

In addition, the influence of closeness relationship on accepting a phone showed a significant difference. The influence of the low closeness relationship was lower than the influence of the high closeness relationship during the acceptance stage. Moreover, effect size (η = 0.820) of closeness relationship was big, so it could explain the result well.

The interactive effects of age and closeness relationships had significant differences during the acceptance stage. The intention (e.g., accepting a phone) of younger participants under the high closeness relationship was higher than older participants under the low closeness relationship. The intention (e.g., accepting a phone) of younger participants under the low closeness relationship was lower than

Table 3 The interaction effects of age and closeness relationship at the acceptance stage

	Young		Old		df	F	p
	Mean	SD	Mean	SD			
Age	3.35	0.886	3.77	0.569	1	5.969	0.018*
Closeness relationship	3.02	0.643	4.03	0.886	1	123.516	0.001*
Age* closeness relationship	3.67	0.862	3.00	0.490	1	21.083	0.001*

*Significant at 0.05 level

older participants with the high closeness relationship. Under the low closeness relationship, younger participants' and older participants' intention on accepting a phone did not show significant differences. Under the high closeness relationship, older participants preferred to accept a phone. Moreover, effect size ($\eta = 0.510$) of age and closeness relationship was big, and it could explain the result well.

As mentioned above, participants were strongly influenced by the closeness relationship during the three stages. Under the high closeness relationship, the intention of awareness, trial, and acceptance of mobile phones was high. In addition, older participants were easier influenced by the closeness relationship than younger participants.

The differences between younger participants' and older participants' intention of awareness, trial, and acceptance of a phone were not only affected by age and closeness relationships, demographic variables might also contribute to the differences. Therefore, a correlation analysis among demographic variables and the intention on awareness, trial, and acceptance of a phone was performed. The results indicated that participants with a higher level of experience ($r = 0.491$, $p = 0.009$) reported high intention of acceptance.

4.3 Factors Influencing the Acceptance of Phones by Older Participants and Younger Participants

During the three stages, all of the older participants responded that waterproof and anti-shock features would enhance their intention on awareness, trial, and acceptance of a phone. However, only two older participants mentioned that the phone should have the function of anti-shock features, whatever the relationship between them and the referrer was, maybe because their hands were not very awkward, their phone was easy to fall to the ground. For younger participants waterproof and anti-shock features were less important. Probably because when they talked a phone with their friends or others, they did not consider these.

Ten younger participants mentioned that the configuration of a phone was a major factor for them. During the awareness stage, the younger participants said that they would consider the configuration, whatever the relationship between them and the referrer was, as younger adults usually talked the configuration of a product with their friends, which might be a symbol of an image. However, older participants did not consider the configuration of a phone, as they did not understand what the configuration was. Because of their weak learning ability, they refused to learn new things.

For older participants and younger participants, during the awareness and trial stages, a referrer's used experience of a phone and the role of the referrer (i.e., whether the referrer was an expert on phones.) increased the participants intention on awareness and trial of the phone. However, regarding the decision to buy the phone, many older participants and younger participants responded that the referrer should have used the phone, whatever the relationship between them and the referrer was. If many peers around them had own the phone, it would increase their intention on purchasing, even the referrer did not use the phone.

The age level of the referrer (i.e., juvenile, youth, middle-aged, or older adults) also influenced the participants' intention. Eight older participants responded that they liked to be recommended by middle-aged people, whatever the relationship between them and the referrer was. Younger participants wanted to be recommended by youths, as they believed that other age groups knew less about phones.

The characteristics of older participants and younger participants (e.g., whether they request recommendations by others who have used the phone) highly differed in this study. During the acceptance stage, most of the older participants would ask the opinion of other persons who had used the phone, regardless of what the relationship he or she had with the referrer. Few younger participants asked the opinion of other persons if the relationship they and the referrer were good.

When asked "What's your reaction when your children continually play a phone and do not interact with you", most of the older participants responded that it was nothing, because they were able to watch TV or did other things. Two older participants responded that they became angry, because sometimes they were very busy and needed help from their children.

5 Conclusions

Based on a questionnaire and an interview, this study examined the differences in the influence of closeness relationships between younger participants and older participants in the technology diffusion process. Findings were as follows:

1. During the awareness stage, younger participants and older participants did not show significant differences under influences of age, while during the trial and acceptance stages, older participants showed higher intention on trial and acceptance of phones than younger participants. Under the influences of closeness relationship, older participants showed higher intention on awareness, trial and acceptance than younger participants.
2. Under the interactive influences of age and closeness relationship, the results were different. Younger participants under the high closeness relationship exhibited an increased intention on awareness and acceptance of a mobile phone compared with older participants under the low closeness relationship.
3. For younger participants who paid close attention to the technology development of phones, if they had a high closeness relationship with the referrer, some factors influencing their purchase would become less important. However, for older participants, the factors influencing their purchase would be still important, whatever the relationship between them and the referrer was.

4. Older participants' reaction to the behaviors of their children, such as playing with phones and no communication with them, was related to older participants' living situations.

Limitations of this study should be noted. Firstly, the education level of the old participants is lower. Secondly, the sample size of older participants is a little thin compared with the younger. Thirdly, this study needs participants to distinguish closeness relationship well.

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Performance of the Zone Control Chart for Detecting Prespecified Quadratic Changes in Linear Profiles

Yang Zhang, Xiao-wen Wang and Qing Wang

Abstract In profile monitoring, one possible and challenging purpose is detecting changes away from the 'normal' profile toward one of several prespecified 'bad' profiles. In this paper, to detect the prespecified quadratic changes in linear profiles, the zone control chart is suggested to be constructed based on the Student's *t*-statistic. The performance of the zone control charts with three different combinations of scores are investigated and compared with alternative control charts. Simulation results show that the zone charts are effective and stable, and perform much better on detecting small to moderate shifts of quadratic changes in linear profile.

Keywords Average run length · Cumulative scores · Profile monitoring · Statistical process control · Student's *t*-statistic

1 Introduction

In statistical process control, profile monitoring is using control charts to monitor the quality of a process or product which is characterized by a relationship between a response variable and one or more variables [1–3]. Most literatures developed

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control schemes to monitor the mean profile and the noise in linear or nonlinear profiles [4–9].

Almost all above approaches are proposed to detect any unanticipated changes in the process. However, in some cases, the changes may be anticipated due to the characteristics of a system or operation. That is, it may be known in advance that the process or product quality will change away from the "normal" profile toward one of several prespecified "bad" profiles. Such examples could be found in [10, 11]. To detect such prespecified changes in profiles is one challenging purpose in profile monitoring [12]. Reference [12] states that this purpose might be accomplished via a specific model in which some parameters identify departures toward the bad profiles. Based on this basic idea, two directed Shewhart-type control charts are proposed to detect the shape changes from linear profiles to quadratic profiles [13]. However, in order to be more sensitive to small shifts, a EWMA-type chart is developed based on score test [14].

Besides adapting the exponential weighted moving average or cumulative sum techniques, the zone control charts [15–17] or the run sum control chart [18–20] have been developed to enhance the sensitivity of control schemes to small or moderate shifts. In fact, the run sum control chart is a general model of the zone control chart. In this paper, the zone control chart is developed to detect the prespecified changes in linear profiles.

The remainder of the paper is organized as follows. Our proposed methodology, including the general linear profile model used to describe the process and the proposed zone control chart, is presented in Sect. 2. In Sect. 3, the performance of the zone control charts with different combinations of scores are evaluated and compared with the existing methods. Finally, conclusions and future study directions are given in Sect. 4.

2 Methodology

2.1 General Process Model with Quadratic Changes

In this paper, the linear regression model is used to describe the process where prespecified quadratic changes may happen. Assume for the jth random sample collected over time, we have the observations (x_i, y_{ij}), $i = 1, \ldots, n$, $j = 1, 2, \ldots$, and $(x_1, x_2, \ldots, x_n)$ are fixed for different j. Then the underlying process model is

$$y_{ij} = \beta_{0j} + \beta_{1j}x_i + \beta_{2j}x_i^2 + \varepsilon_{ij}, \quad i = 1, \ldots, n,\ j = 1, 2, \ldots, \tag{1}$$

where $\boldsymbol{\beta}_j = (\beta_{0j}, \beta_{1j}, \beta_{2j})$ is the coefficient vector, and ε_{ij} are independent and identically distributed normal random variables with mean 0 and variance σ_ε^2. When the process is statistically in-control (IC), the 'normal' process model should be a simple linear profile, i.e., $\beta_{2j} = 0$. However, if any form error, such as hourglass, barrel or banana, appears in the process, β_{2j} will not equal to 0. That is, in the general process model, the parameter β_{2j} could be used to identify the changes away from the 'normal' profile toward the prespecified 'bad' profiles. Hence, to quickly detect those form errors resulting in a quadratic term in the linear model, we would be more interested in the following hypotheses on the quadratic term:

$$H_0\colon \beta_{2j} = 0 \quad H_1\colon \beta_{2j} \neq 0. \tag{2}$$

2.2 Student's T-Statistic for Hypotheses in (2)

To estimate the coefficient vector $\boldsymbol{\beta}_j$ in (1), the least squares method is mostly used, and the ordinary least squares estimate is $\hat{\boldsymbol{\beta}}_j = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{y}_j$, where

$$\mathbf{X} = \begin{pmatrix} 1 & x_1 & x_1^2 \\ 1 & x_2 & x_2^2 \\ \vdots & \vdots & \vdots \\ 1 & x_n & x_n^2 \end{pmatrix}, \quad \mathbf{y}_j = \begin{pmatrix} y_{1j} \\ y_{2j} \\ \vdots \\ y_{nj} \end{pmatrix}$$

Thus, if $H_0\colon \beta_{2j} = 0$ in (2) is not rejected, then this indicates that the quadratic term can be deleted from the model, and the process is deemed as statistically in control. To test this null hypothesis in (2), the Student's t-statistic used is

$$t_j = \frac{\hat{\beta}_{2j}}{\sqrt{v_3 \hat{\sigma}^2_{\varepsilon j}}}, \tag{3}$$

where v_3 is the diagonal element of $(\mathbf{X}'\mathbf{X})^{-1}$ corresponding to $\hat{\beta}_{2j}$, and $\hat{\sigma}^2_{\varepsilon j}$ is an unbiased estimator of given by $\hat{\sigma}^2_{\varepsilon j} = (\mathbf{y}'_j\mathbf{y}_j - \hat{\beta}_j\mathbf{X}'\mathbf{y}_j)\big/(n-3)$. Under the null hypothesis in (2), t_j follows a Student's t distribution with $n - 3$ degrees of freedom, and its mean and variance are 0 and $(n-3)/(n-5)$, respectively. Therefore, a large (absolute) value of t_j will lead to rejection of this null hypothesis, and a Shewhart-type control chart can be built using the statistic t_j to detect the pre-specified quadratic changes in linear profiles. However, it is well known that the Shewhart type chart is insensitive to small shifts in process.

2.3 The Zone Control Chart

Here the zone control chart is constructed based on the statistic t_j which follows a Student's t distribution with $n - 3$ degrees of freedom. The zone control chart has eight zones, four on each side of the center line, CL. In zone control chart based on statistics following standard normal distribution, the zones include one bounded by the center line and the one-sigma limits, one bounded by the one- and two-sigma limits, one bounded by the two- and three-sigma limits, and one beyond the three-sigma limits. And then some scores are assigned to each zone.

Here, three upper control limits (UCLs) are given by $0 = \mathrm{CL} < \mathrm{UCL}_1 < \mathrm{UCL}_2 < \mathrm{UCL}_3$, and the four regions above the central line are defined as:

UZ_1 the zone between CL and UCL_1;
UZ_2 the zone between UCL_1 and UCL_2;
UZ_3 the zone between UCL_2 and UCL_3;
UZ_4 the zone beyond UCL_3.

Similarly, the four regions below the central line can be defined by setting three lower control limits (LCLs), $\mathrm{LCL}_3 < \mathrm{LCL}_2 < \mathrm{LCL}_1 < \mathrm{CL} = 0$, as follows.

LZ_1 the zone between CL and LCL_1;
LZ_2 the zone between LCL_1 and LCL_2;
LZ_3 the zone between LCL_2 and LCL_3;
LZ_4 the zone beyond LCL_3.

Then, four integer scores $S_{k,}$ $k = 1, \ldots 4$ are given and associated with the four zones above or below the central line, where $0 \le S_1 \le S_2 \le S_3 \le S_4$. When the statistic t_j is get, the zone score for jth random sample can be obtained by the following score function:

$$S(t_j) = \begin{cases} S_k, & \text{if } t_j \text{ in } \mathrm{UZ}_k \\ -S_k, & \text{if } t_j \text{ in } \mathrm{LZ}_k \end{cases}. \tag{4}$$

The zone scores are cumulative, i.e., the score for the latest result is added to the previous score. This procedure is continued until t_j falls on the other side of the central line, whereas the accumulation process ends and the chart restarts only based on the latest observed value. In general, the statistics monitored by the zone control chart is based on the cumulative sums

$$U_j = \begin{cases} 0 & \text{if } t_j < \mathrm{CL} \\ U_{j-1} + S(t_j) & \text{if } t_j \ge \mathrm{CL} \end{cases} \tag{5}$$

and

$$L_j = \begin{cases} L_{j-1} + S(t_j) & \text{if } t_j < \text{CL} \\ 0 & \text{if } t_j \geq \text{CL} \end{cases}, \quad (6)$$

where $j = 1, 2, \ldots,$ and $U_0 = L_0 = 0$. The zone control chart triggers an out-of-control (OC) signal when $U_j \geq S_4$ or $L_j \leq -S_4$. Note that if $t_j < \text{CL}$, then U_j is reset to zero, and if $t_j > \text{CL}$, L_j is reset to zero.

2.4 *Design of the Zone Control Chart*

To design the zone control chart is to determine the control limits and to select the integer scores. After determining the control limits and choosing the integer scores, a zone control chart is specified.

1. *Determination of the control limits*. In the zone control chart with normal limits, the control limits are defined using one-, two-, and three-sigma limits. Here, this idea is also applied by considering that the statistic t_j follows a Student's t distribution. Moreover, if using the one-, two-, and three-sigma limits simultaneously, the control chart will increase the false alarm rate, and reduce the IC average run length (ARL), as shown in [15, 16]. Thus, the control limits should be tuned in order to obtain a desired IC ARL (ARL_0) following the idea of using the one-, two-, and three-sigma normal limits. Define the upper control limits as

$$\text{UCL}_l = L \times F_t^{-1}(\Phi(l)), \quad \text{for } l = 1, 2, 3, \quad (7)$$

which is similar as that in [20]. Here, $F_t^{-1}(\,)$ is the inverse cumulative distribution function (cdf) of the Student's t distribution with $n - 3$ degrees of freedom, whereas $\Phi(\,)$ is the cdf of the standard normal distribution.

From the above description of the zone control chart, it is obvious that the regions above CL are symmetric to those regions below CL. Therefore, the lower control limits could be defined as

$$\text{LCL}_l = -\text{UCL}_l, \quad \text{for } l = 1, 2, 3. \quad (8)$$

Note that L in (7) and (8) is a tuning parameter, and can be chosen to give a desired ARL_0 by using the Markov chain method as shown in the Appendix.

2. *Specification of the scores*. In the literatures, these integer scores firstly are given subjectively. Four integer scores used in [15] are 1, 2, 4, 8. Reference [16] studied a general zone control chart with more different combinations of scores. On the other hand, the scores associated with the tuning parameter are chosen by

using the optimization model as in [19, 20]. It is shown in [20] that the combinations of scores (1, 2, 3, 10) and (0, 2, 3, 6) are more sensitive on small and moderate shifts, respectively. Here, in our paper, three combinations of integer scores (S_1, S_2, S_3, S_4), which are (1, 2, 4, 8), (1, 2, 3, 10), and (0, 2, 3, 6), will be discussed in simulation studies.

3 Simulation Studies

In this section, the performance of the proposed zone control chart is investigated on detecting the prespecified quadratic changes in linear profiles. The OC ARL (ARL_1) is applied to evaluate the effectiveness of the proposed method and the monitoring performance compared with alternative approaches. Here, throughout the simulations, the IC model is assumed as follows:

$$y_{ij} = \beta_0 + \beta_1 x_i + \varepsilon_{ij}, \quad i = 1, 2, \ldots, n, \tag{9}$$

where ε_{ij} is the error term which follows a normal distribution with mean 0 and variance $\sigma^2_{\varepsilon 0}$. The values of the parameters in the IC model are $\beta_0 = 13$, $\beta_1 = 2$, and $\sigma^2_{\varepsilon 0} = 1$, and the fixed value $x_i = -3 + 6(i-1)/(n-1)$ is in the interval [−3, 3], and $n = 25$, which is the same as that of the IC process model used in [13, 14].

The representative OC model, also considered in [13, 14], has the following form

$$y_{ij} = \beta_0 + \beta_1 x_i + \gamma(x_i^2 - \eta) + \varepsilon_{ij}, \quad i = 1, 2, \ldots, n, \tag{10}$$

where η describes the vertical shift of vertex and $\gamma = \delta\sigma_{\varepsilon 0}$ controls the shift magnitude. Changing the value of η can move the profile along Y-axis but wouldn't change the profile shape. More details can be found in [13, 14].

3.1 *Performance of the Zone Control Charts*

In this subsection, we present the OC performance of the proposed zone control charts on detecting prespecified quadratic changes in linear profiles. Denote the zone control chart with the scores (1, 2, 4, 8), (1, 2, 3, 10), and (0, 2, 3, 6) by Z_1, Z_2, and Z_3, respectively. The ARL_0 is set at 200, and the tuning parameter L is chosen by using Markov chain method in Appendix. The values of tuning parameter L along with the simulated values of ARL_0 for these three charts are shown in Table 1. Then the OC performance of the zone control charts can be simulated by Monte Carlo Method. Tables 2, 3 and 4 tabulate the ARL_1 values of different zone control charts for detecting the quadratic changes, respectively. Unless otherwise

Table 1 IC performance characteristics of the zone charts

	Z_1	Z_2	Z_3
L	2.1734	1.2061	1.2896
ARL_0	200.0005	199.9999	199.9995

Table 2 ARL_1 values of the Z_1 chart

δ	η				
	−1.5	1.0	3.5	6.0	8.5
0.005	73.1	73.0	72.9	74.1	73.9
0.015	25.3	25.0	25.2	25.1	25.3
0.025	12.8	12.8	13.0	12.8	12.8
0.050	8.7	8.7	8.7	8.7	8.6
0.100	5.7	5.7	5.7	5.7	5.7
0.200	4.5	4.5	4.5	4.5	4.5
0.300	3.0	3.0	3.0	3.0	3.0

Table 3 ARL_1 values of the Z_2 chart

δ	η				
	−1.5	1.0	3.5	6.0	8.5
0.005	66.7	66.8	66.9	67.5	66.9
0.015	22.0	22.2	22.0	21.9	22.1
0.025	11.1	11.0	11.1	11.1	11.0
0.050	7.3	7.3	7.3	7.3	7.3
0.100	4.6	4.5	4.6	4.6	4.6
0.200	3.3	3.3	3.2	3.2	3.3
0.300	1.6	1.6	1.6	1.6	1.6

Table 4 ARL_1 values of the Z_3 chart

δ	η				
	−1.5	1.0	3.5	6.0	8.5
0.005	68.3	68.5	69.2	70.3	70.1
0.015	20.9	21.1	20.8	21.2	20.7
0.025	9.6	9.7	9.7	9.6	9.5
0.050	5.9	5.9	5.9	5.9	5.9
0.100	3.5	3.5	3.5	3.5	3.5
0.200	2.6	2.6	2.6	2.6	2.6
0.300	1.5	1.5	1.5	1.5	1.6

stated, all of the ARL_1 values are obtained via 10,000 iterations throughout the simulations.

From Tables 2, 3 and 4, it can be seen that all these three zone charts are effective and robust with varying η, i.e., the OC profile moves along Y-axis. For example, in Table 2, as η varies from −1.5 to 8.5, the ARL_1 values of the Z_1 chart keep almost the same for specific δ.

3.2 Performance Comparisons with Alternative Methods

In this subsection, our proposed three zone control charts will be compared with alternative methods. The first is the ST chart developed in [21], which is a Shewhart-type chart based on the score test. Another Shewhart-type chart is the LR chart proposed in [13], where the likelihood ratio test is used instead. Moreover, to detect the small to moderate shifts, a STE control chart is suggested in [14] by integrating the EWMA technique with the score-test-based control chart.

Since the STE, ST, LR charts and three zone control charts are all robust with varying η, the performance of different charts are compared only under the case $\eta = 3.5$, which is shown in Table 5. Several results can be obtained from Table 5. Firstly, Table 5 indicates that the Shewhart-type charts perform uniformly worse than the STE and the three zone control charts on detecting small to moderate shifts, but are better for monitoring large shifts, as expected. Moreover, the zone control charts are much more sensitive than the EWMA-type STE chart to small or moderate shifts. What's more, among the three zone control charts, the Z_3 chart is the best in most cases except the case that the shift is very small. It is obviously that Z_2 is better than Z_3 when $\delta = 0.005$. In addition, the Z_3 chart has a worse performance than the STE chart when the shifts of quadratic changes are large.

Table 5 OC performance comparisons among different control charts ($\eta = 3.5$)

δ	Z_1	Z_2	Z_3	STE	ST	LR
0.005	72.9	66.9	69.2	178.6	191.9	194.8
0.015	25.2	22.0	20.8	93.6	165.8	171.4
0.025	13.0	11.1	9.7	46.1	125.7	134.0
0.050	8.7	7.3	5.9	14.4	53.1	61.2
0.100	5.7	4.6	3.5	4.9	11.2	14.3
0.200	4.5	3.2	2.6	2.2	1.9	2.3
0.300	3.0	1.6	1.5	1.5	1.1	1.2

4 Conclusion

In this paper, we focus on monitoring processes where prespecified quadratic changes may appear in linear profiles. The second order linear regression model is applied to describe the processes. To effectively detect small shifts in prespecified quadratic changes, the zone control chart is suggested to be constructed based on the Student's *t*-statistic. The design of the zone chart is given in detail, including the determination of control limits and the specification of scores. In simulation studies, the performance of the zone charts with three different combinations of scores are investigated and compared with alternative control charts. Simulation results show that the zone control charts are effective and stable when the OC profile moves along *Y*-axis. Furthermore, the Z_3 chart performs almost the best among the three zone charts. In addition, the zone charts perform better than alternative charts on detecting small to moderate shifts.

In this paper, the scores are given subjectively. To be more objective and effective, the scores can be searched by using optimization model in future studies. Moreover, more general prespecified changes should be considered in profile monitoring in future researches.

Appendix

In this section, the Markov chain method is given for the zone control chart for finding the tuning parameter L to achieve a desired ARL_0. For illustration, the zone chart with scores (0, 2, 3, 6) is considered here as is in [20]. In profile monitoring, the charting procedure starts with an initial score of $U_0 = +0$ and $L_0 = -0$, i.e., (U_0, L_0) = (+0, −0). Then at time j, all possible IC ordered pair cumulative scores are (U_j, L_j) = (+0, −0), (+0, −5), (+0, −4), (+0, −3), (+0, −2), (+2, −0), (+3, −0), (+4, −0) and (+5, −0). Let these ordered pairs correspond with the transient states 1, 2, 3, 4, 5, 6, 7, 8, and 9, respectively, and let state 10 be the absorbing state. Then the transition probability matrix R from the current state to the next state can be easily obtained for the zone control chart with scores (0, 2, 3, 6) and is presented in Table 6, where the probabilities in the transition probability matrix R can be calculated as follows based on the control limits and the cdf of the Student's t distribution with $n - 3$ degrees of freedom, $F_t(\,)$. Since the regions above the central line CL are symmetric to those regions below CL, we have

$$p1 = p4 = F_t(\text{UCL}_1) - F_t(\text{CL}),$$

$$p2 = p5 = F_t(\text{UCL}_2) - F_t(\text{UCL}_1),$$

$$p3 = p6 = F_t(\text{UCL}_3) - F_t(\text{UCL}_2).$$

Table 6 Transition probability matrix R

States at time j	States at time $j+1$								
	1	2	3	4	5	6	7	8	9
1	$p1+p4$	0	0	$p6$	$p5$	$p2$	$p3$	0	0
2	$p1$	$p4$	0	0	0	$p2$	$p3$	0	0
3	$p1$	0	$p4$	0	0	$p2$	$p3$	0	0
4	$p1$	$p5$	0	$p4$	0	$p2$	$p3$	0	0
5	$p1$	$p6$	$p5$	0	$p4$	$p2$	$p3$	0	0
6	$p4$	0	0	$p6$	$p5$	$p1$	0	$p2$	$p3$
7	$p4$	0	0	$p6$	$p5$	0	$p1$	0	$p2$
8	$p4$	0	0	$p6$	$p5$	0	0	$p1$	0
9	$p4$	0	0	$p6$	$p5$	0	0	0	$p1$

It should be noted that the transition probability matrix R for the zone chart depends on the choice of the scores S_k, $k = 1, \ldots, 4$. However, it still can be obtained following this procedure.

When the control limits are determined or the tuning parameter L is set, the IC ARL can be obtained using the following equation as shown in [20]:

$$\mathrm{ARL}_0 = \mathbf{s}'(I - R)^{-1}\mathbf{1}, \tag{11}$$

where $\mathbf{s}' = (1, 0, \ldots, 0)$ is the initial probability vector having a unity in the first element and zeros elsewhere, I is the identity matrix and $\mathbf{1}$ is a vector having all elements unity.

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An Economic Control Chart Optimization Method for Production Process with Time-Dependent Mean Shift

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Abstract In this paper, an extended economic optimal model integrating statistical process control and maintenance is proposed. Under the assumption that the magnitude of process mean shift is a function of out-of-control time duration, three scenarios are defined. Based on the cost structure analysis and the reliability theory, the occurrence probability, cycle time, and cycle cost are calculated, the optimization model is set up to minimize the expected cost within unit time. Tabu Search algorithm is designed to solve this model. Finally, another ordinary maintenance model is designed as a comparison. The results indicate the satisfactory performance of the proposed integrated model.

Keywords Statistical process control · Process mean shift · Quality loss · Maintenance · Optimization model

1 Introduction

In today's manufacturing production process, it is important to reduce process variation and production cost. Statistical process control and maintenance decision has been widely applied in the field of product quality engineering [1]. Statistical process control timely detects process variations, and maintenance decision could guarantee the stability of equipment operation. Generally, the close relationship between statistical process control and maintenance has been researched in various literatures, especially in the aspect of integrated models [2–4]. Ben-Daya and Duffuaa [5] was the first to consider the link between quality and maintenance; Tagaras [6] preliminarily presented an economic integrated model of statistical process control and maintenance; Linderman et al. [7] and Jin et al. [8] demonstrated the value of integrating statistical process control and maintenance by

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optimizing the total cost associated with quality, and defined three scenarios. But the models only aimed at the circumstance that the magnitudes of process mean shift is a constant value.

We extended the above research by considering that the magnitude of process mean shift is not a constant value but a function of out-of-control time duration. In reality, the gradual change of production process mean is related to tool wear or other factors, which may be influenced by the out-of-control time duration [9]. It's assumed that the length of in-control time follows the Weibull distribution, and three scenarios are defined by integrating statistical process control, corrective maintenance and plan maintenance. The Tabu Search algorithm is designed to solve this model. And another ordinary maintenance model is designed as a comparison. A set of experiments verify the advantages of the integrated model.

Table 1 Model parameters

Parameter	Description
$\boldsymbol{S}1, \boldsymbol{S}2, \boldsymbol{S}3$	Three scenarios
$\boldsymbol{k}$	Number of samplings before plan maintenance
$\boldsymbol{n}$	Sample size
$\boldsymbol{h}$	Sampling interval
$\boldsymbol{T}$	Time period of plan maintenance, $\boldsymbol{T}(\boldsymbol{k} + 1)\boldsymbol{h}$
$\boldsymbol{l}$	Control limit parameter
$\boldsymbol{UCL}$, $\boldsymbol{LCL}$	The upper and lower control limits of the chart: $\boldsymbol{UCL} = \mu_0 + \boldsymbol{l}\frac{\sigma}{\sqrt{\boldsymbol{n}}}$, $\boldsymbol{LCL} = \mu_0 + \boldsymbol{l}\frac{\sigma}{\sqrt{\boldsymbol{n}}}$
α	Type I error probability
β	Type II error probability
$\boldsymbol{T_P}$	Expected time to perform scheduled maintenance
$\boldsymbol{T_R}$	Expected time to perform corrective maintenance
$\boldsymbol{T_Y}$	Expected time to inspect the alert signal
$\boldsymbol{C_I}$	Quality loss per time unit during in-control period
$\boldsymbol{C_O}(\boldsymbol{t})$	Quality loss per time unit during out-of-control period
$\boldsymbol{C_F}$	Fixed cost per sampling
$\boldsymbol{C_V}$	Variable cost per sample
$\boldsymbol{C_Y}$	Cost of inspecting an alert signal
$\boldsymbol{C_P}$	Cost of performing scheduled maintenance
$\boldsymbol{C_R}$	Cost of performing corrective maintenance

2 Model Development

2.1 Assumptions

In this paper, Table 1 shows the model parameters, the basic assumptions are as follows:

(1) The production process may shift from the in-control condition to the out-of-control condition, it is assumed that the time of in-control state follows the Weibull distribution with probability distribution function of $f(t) = abt^{b-1}e^{-at^b}$;
(2) In the in-control state, the quality characteristic of product follows the normal distribution with mean value μ_0 and standard deviation mean σ, once the process shifts to an out-of-control state, the mean of quality characteristic changes from μ_0 to $\mu_1 = \mu_0 + \delta(t)\sigma$, and the standard deviation remains the same, where $\delta(t)$ is the function of quality shift and t is the length of out-of-control time. In reality, $\delta(t)$ could be linear function of $\delta(t) = \lambda(t)$, and could be exponential function of $\delta(t) = e^{\lambda t} - 1$, and could be constant value of $\delta(t) = \delta_0$;
(3) The quality characteristic is measured and plotted on a control chart to identify the process state. When the alert signal of out-of-control happens, stop for inspection, the expected time to inspect the alert signal is T_Y. Once the control chart signals an out-of-control condition, the corrective maintenance has to be performed at once. If no alert signal occurs after k samplings at $T = (k+1)h$, it is forced to stop for inspection, implement the plan maintenance. All equipments and processes can be restored to the as-good-as-new condition. False alarm may happen in an in-control state, type I error of control chart is derived as $\alpha = 2\Phi(-l)$, and type II error of control chart in the out-of-control is derived as $\beta(t) = \Phi(l - \delta(t)\sqrt{n}) - \Phi(-l - \delta(t)\sqrt{n})$;
(4) In the out-of-control state, it is assumed that quality loss per time unit during out-of-control period $C_O(t)$ is the function with $\delta(t)$. If $\delta(t)$ is a linear function, the $C_O(t)$ can be expressed as $C_O(t) = C_I + \gamma\delta(t)$.

2.2 The Integrated Model

In this paper, we propose an economic optimal model integrating statistical process control and maintenance to minimize the expected cycle time. Based on above assumptions, the model consists of three scenarios, as shown in Fig. 1.

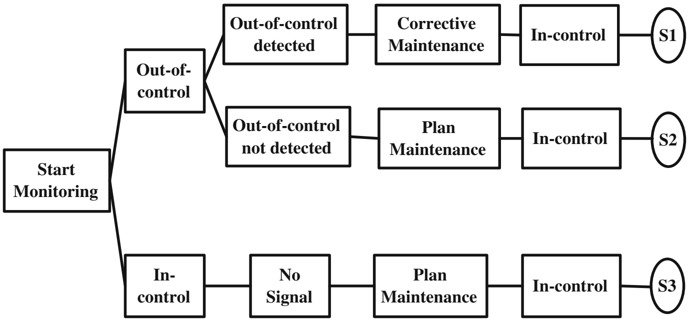

Fig. 1 Three scenarios

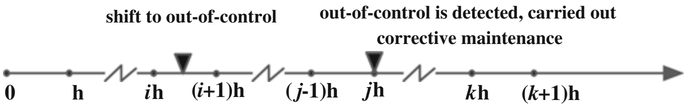

Fig. 2 Scenarios 1

2.3 Three Scenarios

In Scenario 1 in Fig. 2, the process shifts from in-control state to an out-of-control state at some time t between ih and $(i + 1)h$, the control chart detects an out-of-control condition at time jh, where $0 \le i \le k - 1, i + 1 \le j \le k$, and then results in corrective maintenance that restores the equipment to the new condition.

(1) *Occurrence probability*
In Scenario 1, the occurrence probability is:

$$P(S_{i,j}) = \int_{ih}^{(i+1)h} g_1(i,t)dt \quad (1)$$

where: $g_1(i,t) = f(t) \cdot [1 - \beta(jh - t)] \cdot \prod_{s=i+1}^{j-1} \beta(sh - t)$

(2) *Expected cycle time*
In Scenario 1, the expected cycle time consists of three parts: the total time until an out-of-control signal is detected; the total inspection time to identify the alert signal; the expected time to perform corrective maintenance. Then the expected cycle time can be expressed as:

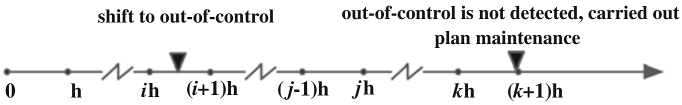

Fig. 3 Scenarios 2

$$E(Time|S_{i,j}) = jh + i\alpha T_Y + T_R \tag{2}$$

(3) *Expected cycle cost*

In Scenario 1, the expected cycle cost consists of several parts: sampling cost; quality loss; inspection cost to identify the alert signal; cost of corrective maintenance. Then the expected cycle cost can be expressed as:

$$E(Cost|S_{i,j}) = \frac{\int_{ih}^{(i+1)h} [tg_1(i,T)C_I] + (jh - t)g_1(i,t)C_O(t)dt}{P(S_{i,j})} + (C_F + C_V n)j + i\alpha C_Y + C_R \tag{3}$$

In Scenario 2 in Fig. 3, the process shifts to an out-of-control state at some time t between ih and $(i+1)h$, but the control chart does not detect an out-of-control condition, where $0 \le i \le k$, and plan maintenance is carried out at time $(k+1)h$.

(1) *Occurrence probability*

In Scenario 2, the occurrence probability is:

$$P(S_{i,k+1}) = \int_{ih}^{(i+1)h} g_2(i,t)dt \tag{4}$$

where: $g_2(i,t) = f(t) \cdot \prod_{s=i+1}^{k} \beta(sh - t)$

(2) *Expected cycle time*

In Scenario 2, the expected cycle time consists of three parts: the total time before plan maintenance is carried out; the total inspection time to identify the alert signal; the expected time to perform plan maintenance. Then the expected cycle time can be expressed as:

$$E(Time|S_{i,k+1}) = (k+1)h + i\alpha T_Y + T_P \tag{5}$$

(3) *Expected cycle cost*

In Scenario 2, the expected cycle cost consists of several parts: sampling cost; quality loss; inspection cost to identify the alert signal; cost of plan maintenance. Then the expected cycle cost can be expressed as:

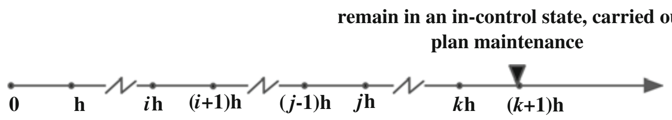

Fig. 4 Scenarios 3

$$E(Cost|S_{i,k+1}) = \frac{\int_{ih}^{(i+1)h} [tg_2(i,t)C_I + ((k+1)h - t)g_2(i,t)C_o(t)]dt}{P(S_{i,k+1})} + (C_F + C_V n)k + i\alpha C_Y + C_P \quad (6)$$

In Scenario 3 in Fig. 4, the process is still in an in-control state before plan maintenance is carried out at time $(k+1)h$.

(1) *Occurrence probability*

In Scenario 3, the occurrence probability is:

$$P(S_{k+1,k+1}) = 1 - \int_0^{(k+1)h} f(t)dt \quad (7)$$

(2) *Expected cycle time*

In Scenario 3, the expected cycle time consists of three parts: the total time before plan maintenance is carried out; the total inspection time to identify the alert signal; the expected time to perform plan maintenance. Then the expected cycle time can be expressed as:

$$E(Time|S_{k+1,k+1}) = (k+1)h + k\alpha T_Y + T_P \quad (8)$$

(3) *Expected cycle cost*

In Scenario 3, the expected cycle cost consists of several parts: sampling cost; quality loss; inspection cost to identify the alert signal; cost of plan maintenance. Then the expected cycle cost can be expressed as:

$$E(Cost|S_{k+1,k+1}) = (C_F + C_V n)k + C_I(k+1)h + k\alpha C_Y + C_P \quad (9)$$

2.4 The Optimization Model

Based on the renewal-reward process theory, the excepted cost per time unit $E(CT)$ for the integrated model can be calculated and is minimized by selecting the decision variables k, n, h, l. Therefore, the $E(CT)$ is expressed as follows [10].

$$E(CT) = \frac{E(cycle\,cost)}{E(cycle\,time)} = \frac{\sum_{i=1}^{3} P(S_i) \cdot E(Cost|S_i)}{\sum_{i=1}^{3} P(S_i) \cdot E(Time|S_i)} \quad (10)$$

Table 2 The comparison model

Scenario	$P(S'_i)$, $E(Time\mid S'_i)$, $E(Cost\mid S'_i)$
S'_1	$P(S'_1) = 1 - \int_0^T f(T)dt$ $E(Time\mid S'_1) = T + T_P$ $E(Cost\mid S'_1) = C_I \cdot T + C_P$
S'_2	$P(S'_2) = 1 - \int_0^T f(T)dt$ $E(Time\mid S'_2) = T + T_P$ $E(Cost\mid S'_2) = C_I \cdot \int_0^T tf(t)dt + C_O \cdot (T - \int_0^T tf(t)dt) + C_P$ $= C_I \cdot T + \gamma\delta(t) \cdot (T - \int_0^T tf(t)dt) + C_P \alpha T_Y + T_P$

where $\sum_{i=1}^{3} P(S_i) = 1$, $P(S_i)$, $E(Time\mid S_i)$, $E(Cost\mid S_i)$ define the occurrence probability, the excepted cycle time and the excepted cycle cost of scenario 1 through 3.

2.5 The Comparison Model

Another model is proposed as a comparison. In the comparison model, statistical process control is not used. Plan maintenance is implemented every T time. Hence, the comparison model consists of two scenarios, as shown in Table 2.

Scenario 1: Equipment remains in the in-control state until time T, and plan maintenance is carried out.
Scenario 2: Equipment shifts to an out-of-control state at some time, and plan maintenance is carried out at time T.

Similarly, the excepted cost per time unit $E(CT')$ for the comparison model is expressed as:

$$\min E(CT') = \frac{\sum_{i=1}^{2} P(S'_i) \cdot E(Cost\mid S'_i)}{\sum_{i=1}^{2} P(S'_i) \cdot E(Time\mid S'_i)} \tag{11}$$

3 The Algorithm and Example Analysis

3.1 Tabu Search

Tabu Search is a modern heuristic algorithm, and has been widely used to solve the combinatorial optimization problems. It avoids searching the repeat local optimal solutions, and guarantees the global optimal solution. In this paper, the best solution of model (10) is obtained by Tabu Search method, the implementation steps are shown as follows:

Step 1: Parameters initialization. Generate an initial solution according to the objective function;

Step 2: Evaluate whether the solution meets the terminal conditions. If it meets the constraints, stop the solving process. Otherwise, go to step 3;

Step 3: Determine the candidate solutions. Create the neighborhood solutions based on the neighborhood structure of the current solutions;

Step 4: Evaluate the candidate solutions. If the candidate solutions meet the contempt of criteria, replace the current solution with this candidate solution and go to step 2. Otherwise, go to step 5;

Step 5: Select the tabu objects of the candidate solutions. If the tabu object is better than the "best so far" state, then take it as the current choice;

Step 6: Repeat the above process until the largest iteration times is reached, for example 500 times, and finally output the optimal solution.

Table 3 Fixed parameter values

T_Y	T_R	T_P	C_F	C_V	C_I	C_Y	C_R	C_P
0.5	2	4	10	4	30	300	3000	1000

Table 4 Variable parameter values

No.	$\delta(\boldsymbol{t})$	$\boldsymbol{a}$	$\boldsymbol{b}$	γ
1	$0.05\boldsymbol{t}$	0.001	1.7	100
2	$0.05\boldsymbol{t}$	0.002	1.4	100
3	$0.05\boldsymbol{t}$	0.001	1.7	200
4	$0.05\boldsymbol{t}$	0.002	1.4	200
5	$0.03\boldsymbol{t}^2$	0.001	1.7	100
6	$0.03\boldsymbol{t}^2$	0.002	1.4	100
7	$0.03\boldsymbol{t}^2$	0.001	1.7	200
8	$0.03\boldsymbol{t}^2$	0.002	1.4	200

Table 5 Experiment results

No.	Model	Decision variables: I: l, h, n, k; II: T	$E(CT)$	Reduction (%)
1	I	2.1, 1.8, 3, 30	98.2882	7.75
	II	40	106.5436	
2	I	2.4, 1.7, 4, 32	86.9214	4.81
	II	38	91.3165	
3	I	1.8, 1.9, 3, 34	129.0198	12.77
	II	37	147.9083	
4	I	1.8, 1.7, 3, 30	99.1051	10.32
	II	32	110.5097	
5	I	1.6, 1.2, 3, 30	166.8509	8.15
	II	19	181.6496	
6	I	1.5, 1.1, 3, 32	142.8008	21.54
	II	20	181.9953	
7	I	1.5, 1.2, 4, 30	223.5601	18.59
	II	18	256.4635	
8	I	1.2, 1.1, 3, 30	170.6794	5.99
	II	16	181.5530	

3.2 Experiment Result Analysis

To verify the superiority of this integrated model, a numerical experiment is designed to compare with the plan maintenance model. It is assumed that the magnitude of process mean shift is considered to be a function of out-of-control time duration and the quality loss per time unit in the in-of-control condition is a function of the length of out-of-control time. Table 3 shows the fixed parameter values of experimental examples.

For simplicity, the magnitude of quality shift of the process mean discusses two cases of $\delta(t) = 0.05t$ and $\delta(t) = 0.03t^2$. Table 4 presents 8 experiments considering the parameters of Weibull distribution and the linear coefficient of quality loss per time unit in the out-of-control condition.

Table 5 presents the optimal results of the proposed model and the comparison model. Model I selects the optimal combination l, h, n, k and the optimal target value by the integrated model. Model II is to obtain the optimal target value of the plan maintenance model. The cost reduction shows the cost saving per unit time for model I compared to the cost for model II.

From the Table 5, we can get the following conclusions. The magnitude of process mean shift is considered to be a function of out-of-control time duration, therefore, the different function expressions will have an effect on the maintenance cost per unit time. The results of the experiments indicate the optimal model integrated the statistical process control and maintenance is superior to the ordinary maintenance model. The cost saving per unit time varies from 5.99 to 21.54 %, the proposed model has more economic performance.

4 Conclusion

In this paper, considering the process mean shift is a function of out-of-control time duration, an economic optimal model integrating statistical process control and maintenance. Three scenarios are defined to analyze the occurrence probability, cycle time and cycle cost. The integrated model is set up to minimize the excepted cost per unit time. The comparative experiments demonstrate that the integrated model has more economic benefits. In future research, we can consider different maintenance methods, control charts and other optimization algorithms.

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Real-Time Face Recognition Method Based on the Threshold Determination of the Positive Face Sequence

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Abstract Most of the current face recognition methods are not able to ensure the accuracy and real-time performance at the same time. In this paper, a real-time face recognition method based on the threshold determination of the positive face sequence is proposed. The procedure of the proposed method is as following. Firstly, the faces with different angles are detected and tracked. At the same time, the angle and position information of the faces is recorded. Secondly, the faces in different frames are matched. Then the positive faces which are matched as the same person are recognized. Finally, the final results are obtained by using the threshold determination method. The experimental results indicate that this algorithm has good recognition rates in the case of the moderate flow density and is able to satisfy the requirement of the real-time system.

Keywords Face detection · Face tracking · Real-time face recognition · The positive face sequence

1 Introduction

With the characteristics of uniqueness, non-replication and easy access, face information plays an irreplaceable role in the field of public security [1]. Existing face recognition methods are mainly divided into two directions: One is that the

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faces are recognized from the stored video images, it is easy to implement, but it often causes significant losses for the characteristic of the time lag; the other one is that the faces are recognized from the real-time monitoring images, this method ensures the timeliness of the information and has a huge advantage over the previous method. But the accurate rates of the existing real-time face recognition methods are very low. Therefore, the study of the feasible real-time face recognition method has great scientific and practical value. In this regard, this paper proposes a real-time face recognition method based on the sequence of the positive faces. Firstly, the method extracts the face sequence of the same people by the face detection, tracking and matching. Afterwards it makes the rapid face recognition for the positive face sequence. Finally, it came to the final recognition result based on the preset threshold and the recognition results. Experimental results show that this method greatly improves the accuracy and is able to satisfy the requirements of the real-time performance.

2 Algorithms Introduction

2.1 Face Detection Algorithm

Face detection is the prerequisite of face tracking and recognition in real-time system. The speed and accuracy of it are very important for the performance of the whole system. In 1995, Freund and Schapire improved Boosting algorithm and proposed AdaBoost algorithm [2]. This algorithm not only maintains the high efficiency of the traditional algorithm, but also does not rely on the prior knowledge of the classifier. So the AdaBoost algorithm solves many problems of the Boosting algorithm, and can be applied to the practical problems better [3]. AdaBoost is an iterative algorithm. Its core idea is that training different weak classifiers for the same training set and setting up these weak classifiers to construct a final stronger classifier [4].

2.2 Face Tracking Algorithm

Face tracking has a very important role in the system of the real-time face recognition. The algorithm of the face tracking is able to associate the face images of the same person in different frames together and greatly improve the accuracy of face recognition.

Popular face tracking algorithms include camshaft algorithm, particle filter algorithm [5]. Camshift algorithm is based on Meanshift algorithm [6]. It takes less time but the tracking window will be often out of shape. Particle filter is a nonlinear filtering method based on Monte Carlo method. Its core idea is to express the probability density distribution by using the particles which are sampled randomly [7]. Particle filter algorithm combines the random sampling and the importance re-sampling and is able to track the faces more stably.

2.3 Face Recognition Algorithm

Popular face recognition algorithms [8] mainly include PCA (Principal Components Analysis), LDA (Linear Discriminant Analysis), HMM (Hidden Markov Model), manifold, neural networks, etc. But the algorithms of HMM, manifold and neural networks have great time complexity and is not able to satisfy the requirement of the real-time system.

Traditional PCA algorithm is the classical subspace analysis method [9]. But it doesn't consider the category information of the samples, so it can't get the best classification effect. LDA algorithm [10] takes advantage of category information of the samples, but the calculation of it is complex and small sample size problem is often encountered. According to the characteristics of PCA and LDA algorithm, Ronald Fisher proposed the Fisherface [11] algorithm. This algorithm takes advantages of PCA and LDA and improves the accuracy of face recognition.

3 Algorithm Improvement and Overall Design

3.1 Improved Face Detection Algorithm

Firstly, a cascade classifier of the multi-angle face detection which is able to detect the faces and provide the angle information of the faces is proposed in this part. As is shown in Fig. 1, the cascade classifier of the multi-angle face detection in the paper is divided into the following four steps:

(1) A number of strong face classifiers with different complexity are trained by using the face samples and non-face samples; a strong classifier for positive and side faces is trained by using positive and side face samples; a strong classifier of right and left faces is trained by using the right and left face samples.
(2) The cascade strong face classifier is used to detect the faces.
(3) The strong classifier of positive and side faces is used to classify the faces in step 2 as positive faces and side faces.
(4) The strong classifier of right and left faces is used to classify the side faces in step 3 as right faces and left faces.

Secondly, the combined method of the AdaBoost algorithm and improved Haar classifier is used to detect the face. Then the detected faces are verified by using the

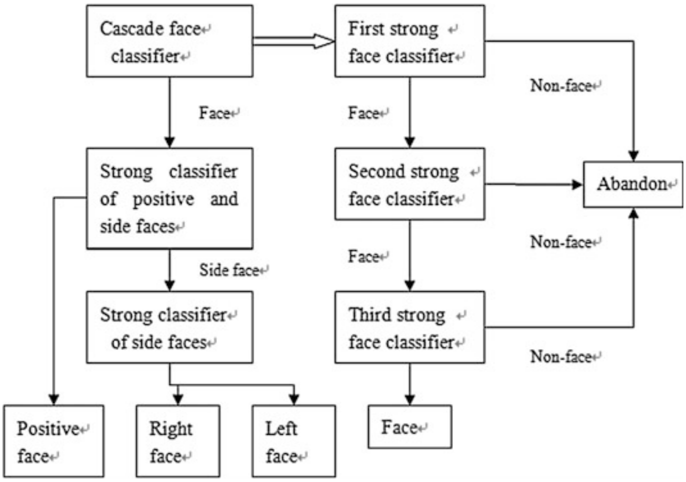


Fig. 1 The cascade classifier of the multi-angle faces

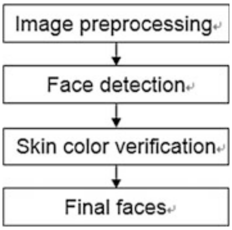


Fig. 2 The overall process of face detection

skin color verification algorithm and the non-face images will be removed. The overall process diagram of the face detection is as shown in Fig. 2.

3.2 Improved Face Tracking Algorithm

In the paper, the particle filter algorithm is used to track the detected faces. Traditional particle filter algorithm is not able to adjust the tracking window well when the tracked face gets larger. Aiming at this problem, a particle filter algorithm with adaptive window is proposed in this part. The steps of the algorithm are summarized as follows:

(1) Initialization. The window coordinates of the tracked faces are obtained. A number (M) of the particles are generated in the way of normal distribution for each detected face.

(2) The weight of each particle is normalized:

$$\overline{W}_j = W_j / \sum_{i=0}^{M} W_i \tag{1}$$

$\overline{W}_j$ is the normalized weight of particle j. If the normalized weight is less than the default threshold, this particle is discarded and re-sampling is started.

(3) The center coordinates of the tracking window are updated. $P(x, y)$ is the updated the center coordinate.

$$P(x, y) = \sum_{j=0}^{M} ((X_j + Y_j) \times \overline{W}_j) \tag{2}$$

(4) The size of the tracking window is adjusted. As shown in Fig. 3, when the size of the tracking window is changed, the weight of the particle in the same position will be changed accordingly. So the tracking window adaptive model is established according to the comparison of the weights as follows:

$$scale = W_n / W_l = \sum_{i=1}^{M} W_i / \sum_{i=1}^{M} W'_i \tag{3}$$

W_n is the sum of the non-normalized weights of the particles in this frame; W_l is the sum of the non-normalized weights of the particles in previous frame; Scale is the regulative proportion of the tracking window.

(5) The initial tracking window is replaced with the regulative tracking window and a new round of face tracking is started.

3.3 Face Recognition Algorithm

Based on the Fisherface algorithm, the method of the face recognition in the paper is divided into the following three parts:

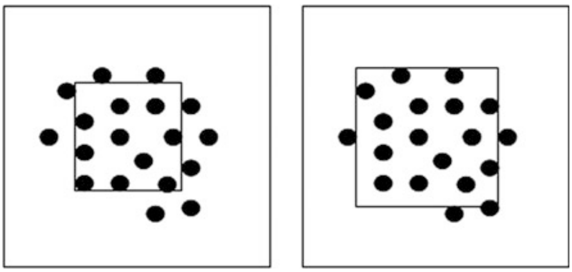


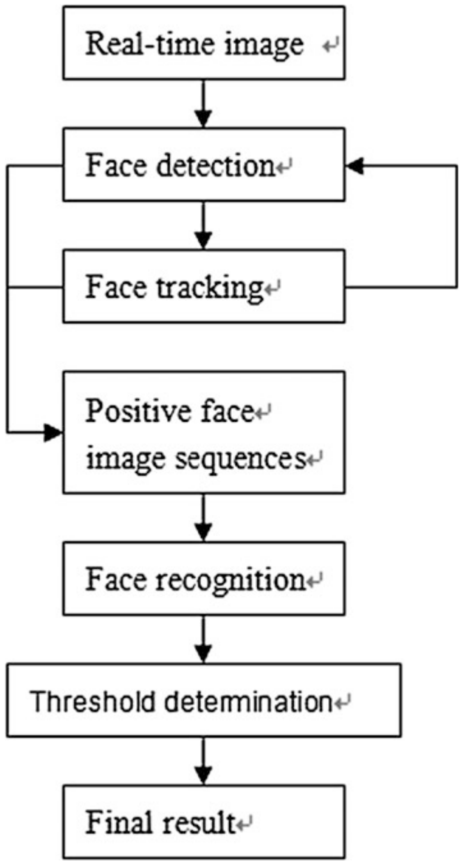
Fig. 3 The adaptive window

(1) A certain number of face samples are collected and the face sample database is created. The Fisherface algorithm is used to train the faces offline.
(2) The recognized face images are normalized.
(3) The Fisherface algorithm is used to recognize the standardized face image.

3.4 Overall Design

Based on the above selected and improved algorithm, a real-time face recognition method is proposed in this part. Firstly, the positive and the side faces are detected with the face detection algorithm which is improved in this paper in the real-time images. Secondly, the detected faces are tracked with face tracking algorithm that is improved in this paper and the sequences of the positive faces are extracted. Then the extracted positive faces are recognized with face recognition algorithm. Finally, the threshold determination for the recognition results is used to get the final result. The overall diagram is shown in Fig. 4.

Fig. 4 Overall diagram of the real-time face recognition method



The main flow of the algorithm is as follows:

(1) The faces in the first frame of the real-time images are detected and the angle information of the detected faces is recorded. The detected faces are represented as $(F'_n, n = 1, 2, \ldots, N)$. N is the number of the detected faces. If there is no face is detected, the third step is started.
(2) The detected faces in the previous step are tracked. The relevant information will be deleted when the tracked face is out of the range of the image.
(3) The faces are detected again every three frames. The detected faces are represented as $(F'_m, m = 1, 2, \ldots, M)$. M is the number of the detected faces in the new frame. If no face is detected, the faces are detected again every three frames. The detected faces are matched with the tracked faces in the previous step. The matching method is shown as follows:

$$R_{mn} = P_{mn}|C(F'_m) - C(F_n)|, \quad n = 1, 2, \ldots, N; \ \ m = 1, 2, \ldots, M \tag{4}$$

$$R'_{mn} = |C(F'_m) - C(F_n)| \in \{(0, 0), (\frac{R(F'_m) - L(F'_m)}{W}, \frac{B(F'_m) - T(F'_m)}{W})\} \tag{5}$$

R_{mn} is the matching condition 1; R'_{mn} is the matching condition 2; P_{mn} is the Bhattacharyya distance of the histogram similarity of F'_m and F_n; $C\left(F'_m\right)$ and $C(F_n)$ are the center coordinates of F'_m and F_n; L is the left border of the window; R is the right border; B is the bottom border; T is the top border; W is the default matching threshold. If the value of the matching condition 1 is least and the matching condition 2 is satisfied, it is assumed that the two matching faces are the faces of the same person. Then update the tracking window and the angle information of the face. If the match is failed, it is assumed that the face is the new face.

(4) The sequence of the positive faces are extracted when the number of the detected and tracked positive faces of the same person reaches the preset value (N) or the detected and tracked face is out of the image. Then the positive faces are recognized with the Fisherface algorithm. If the rate of the positive faces that is correctly identified as the same person in the face database reaches the preset value, it is assumed that the recognized person is the same one with the person in the database. Otherwise it is assumed that the recognized person is the stranger.

4 Experimental Results and Analysis

The image data used in the paper is the real-time images of the entrance of the school gate. The size of the image is 640 × 480. The experimental platform is the ARM Cortex A9 quad-core processor with 1.5 GHz clock speed. Experiment method is as follows: Firstly, the face images of the volunteers are collected and trained offline. Then the volunteers are mixed in the strange crowd and go through the range of the camera view to test the performance of the real-time face recognition method in this paper.

In order to show the effect of the face detection and tracking visually, the different faces are labeled with different colors in the experiment and the same faces which are matched in different frames are labeled with the same color. And that the number and the angle information are labeled in the face windows. The positive face is marked as F, the left side face is marked as L and the right side face is marked as R.

As shown in Fig. 5. Three faces are detected and tracked, among two faces are the positive faces and the other is the left face.

Next, the positive faces that are detected and tracked are extracted and recognized by using the face recognition algorithm. Figure 6a shows the extracted face sequence of one of the volunteers and Fig. 6b shows the extracted face sequence of the stranger.

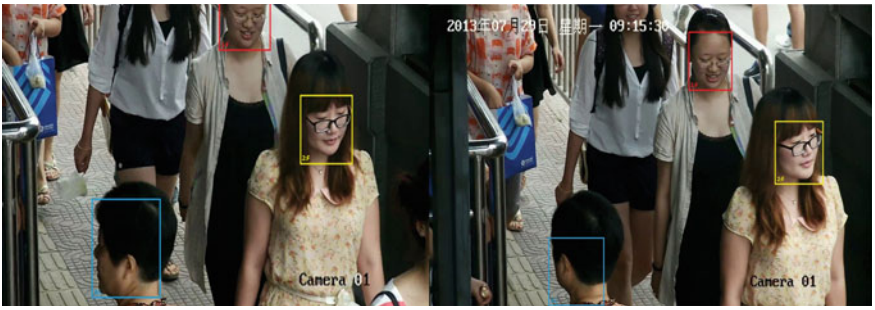


Fig. 5 Face detection and tracking

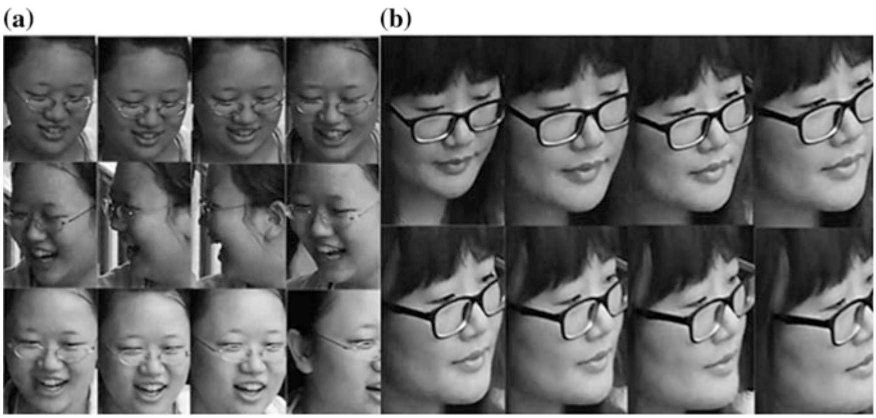


Fig. 6 Face sequences

Table 1 The experimental results

Number	Person-time	Person-time of the volunteers	False negative person-time	False negative rate (%)	False positive person-time	False positive rate (%)	The number of missing faces	Missing rate (%)
1	28	5	0	0	1	4.3	0	0
2	76	11	0	0	2	3.0	3	3.9
3	145	15	1	6.6	5	3.8	10	6.8
4	468	18	6	33.3	26	5.7	104	22.2
5	342	16	4	25	15	4.6	91	26.6
6	94	9	0	0	3	3.5	7	7.4
7	280	14	1	7.1	12	4.5	21	7.5
8	194	14	1	7.1	11	5.6	18	9.3
9	156	19	2	10.5	8	5.8	16	10.3
10	109	13	1	7.6	7	7.3	15	13.7
Total	1892	134	16	11.9	90	5.1	285	15.1

The experiment in the paper made 10 tests, and each test lasts 10 min. The experimental results are shown in Table 1.

In the Table 1, Person-time is the number of the faces that appear in the field of the camera; False negative person-time is the number of the volunteers' faces that are recognized as the strangers; False positive person-time is the number of the strangers' faces that are recognized as the volunteers; The number of the missing faces is the number of the faces that are not detected. As shown as Table 1, The flow density are small or moderate in the tests of number 1, 2, 3, 6, 7, 8, 9, 10. Experiments show that, in this case, it is easier to track the faces and extract the sequence of the positive faces. So the recognition rate is high. There are a time of peak flow in the tests of number 4, 5. The density of the faces is great and a lot of faces are obscured. So the recognition rate is reduced greatly.

The changing curves of the false negative rate, false positive rate and the missing rate with the changing of the flow density are shown in Fig. 7. With the increase of the flow density, the false negative rate and the missing rate will gradually rise. When the flow density exceeds 60 (person-time per minute), the frequency of face overlapping is increased sharply, and the error rate of the face detection and tracking is greatly increased, thus the false negative rate and the missing rate is increased exponentially. But the false positive rate is decreased with the increase of the error rate of the face detection and tracking.

At the same time, the experimental results show that the real-time face recognition method in this paper is able to satisfy the requirement of the real-time system in the case of moderate face density. Figure 8 shows the spent time of each frame with a different number of faces. In the case that the number of the faces is less than 10 and the overlap is not serious, the spent time of each frame increases linearly. In the case that the number of the faces is more than 10, the spent time and the performance of the algorithm become unstable because a lot of faces are missed or obscured.

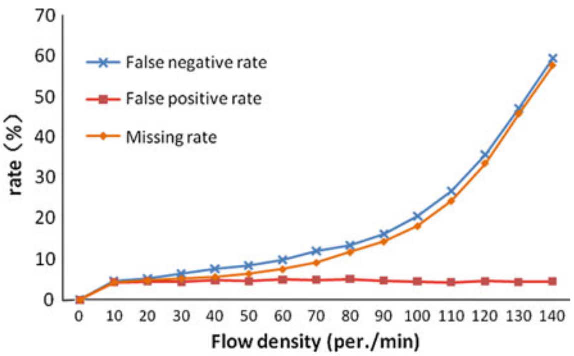


Fig. 7 The performance curves of the algorithm

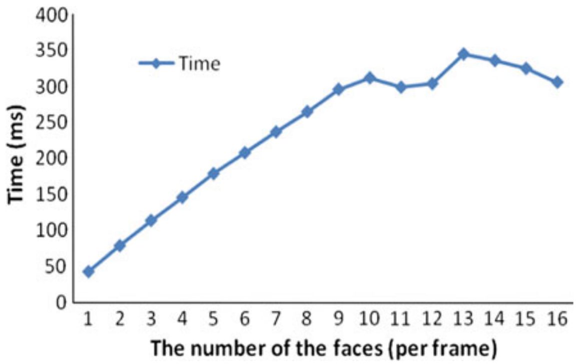


Fig. 8 The spent times of the algorithm with a different number of faces

5 Conclusion

This paper proposed a real-time face recognition algorithm with the combination of the improved AdaBoost face detection algorithm, the improved particle filter face tracking algorithm and the Fisher face recognition algorithm. The experimental results show that there are the good recognition rates with this method and it is able to satisfy the requirement of the real-time system in the case of the moderate density of the faces.

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The Application and Research of Filtering Algorithm of the Acceleration Signal of Human Movement Based on Mathematical Morphology-Median Filtering Algorithm

Xin Shi, Xiao-yong Rui, Li-hua Li, Yi-jun Guo and Zhi-qiang Zhao

Abstract In order to have better research and application of acceleration of human movement, reduce the complexity of the denoising algorithm, so as to achieve the good signal more quickly in the microprocessor chip, this paper presents a method based on mathematical morphology and median filtering algorithm according to the principle of mathematical morphology. First of all, it filters the signal baseline drift with morphological filter, then removing the impulse noise with median filter, finally smoothing the waveform by average filter. Processing the data on the MSP430 microcomputer verifies the reliability of the proposed algorithm.

Keywords Acceleration signal of human movement · Mathematical morphology · Filter · MSP430 microcomputer

1 Introduction

In today's rapid development of science and technology, the auxiliary devices of human motion have spread many aspects, such as pedometer and heartbeat detection. And the way of information interaction between the instrument and human is becoming more and more convenient. Among them, acceleration is an important essential attribute of human body, reflecting the information of human movement [1].

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The body's macro acceleration signal is the macroscopic showing of the human motion; it contains abundant human movement information; its waveform amplitude and frequency are important data reflecting the human movement. But acceleration signal has the characteristics of strong randomicity and low SNR. Because of the shaking of the movement, the signal will be affected inevitably by external distractions among which baseline drift and low frequency noise are the biggest influence on signal analysis and diagnosis [2].

As a vector signal, macro acceleration of human body has numerical value and direction. Under the condition without considering direction, the macro acceleration signal can be treated as one-dimensional signal with noise. Now the research of noise of acceleration signal involves digital low-pass filtering [3], Kalman filtering [4, 5] and wavelet threshold denoising [6–8], etc. Among the algorithms, the noise suppression ability of digital low-pass filtering for nonlinear noise is not enough; it needs to set up precise mathematical model for signal to be processed in the Kalman filtering; it has poorer noise suppression effect for pulse signal by wavelet threshold denoising. These methods have higher requirement for processing speed and large numbers of calculations. They cannot meet the need of rapid processing on the microcomputer processing chip.

On the basis of existing research, this paper denoises and smooth the acceleration signal sampled by three-axis acceleration sensor with method of mathematical morphology-median filtering algorithm. The experiments prove that the combined filter designed in the paper can greatly increase the processing speed on single chip, improve the softness and SNR of the signal and reduce the mean square error.

2 Methodology

2.1 The Basic Concept of Mathematical Morphology

Mathematical morphology is a theory that researches characteristics, shape and structure of digital image and the method of fast parallel processing; meanwhile, it is a mathematical tool of image analysis on the basis of structural elements. Its basic idea is to measure and extract corresponding shape in image by using structural elements for the purpose of the structure analysis and feature extraction.

2.2 Mathematical Morphological Operation

According to the theory of hit/strike transformation, there are two fundamental operations in mathematical morphology: erosion operation (Θ) and dilation operation ($\oplus$). And all the computations of mathematical morphology consist of the two operations. In binary morphology, for a given binary image A, it gives A structural elements B to do corrosion or dilation processing for getting the wanted signal.

Considering binary image A as a set of the point (x, f(x)), the formula that image A is eroded by structural element B is:

$$A\Theta B = \min_{B(i,j)}\{|A(m+i, n+j) - B(i,j)|\} \quad (1)$$

The formula that image A is dilated by structural element B is:

$$A \oplus B = \min_{B(i,j)}\{|A(m+i, n+j) + B(i,j)|\} \quad (2)$$

The basic operations constituted by erosion operation and dilation operation are opening operation and closing operation.

Opening operation: erosion operation then dilation operation, the formula is as follows:

$$A \circ B = (A\Theta B) \oplus B \quad (3)$$

Closing operation: dilation operation then erosion operation, the formula is as follows:

$$A \cdot B = (A \oplus B)\Theta B \quad (4)$$

2.3 Structural Elements

As an important part in the image processing, structural elements play a vital role in the processing effect. According to the result of the research by research [9], filtering effect of flat-structure element under the low frequency is better. The filtering effect changes with the increase of the length, and reaches the best effect in a certain length.

3 Regularity and Approach

3.1 The Characteristics of Human Body Acceleration and Morphological Operation

Human movement is instable and this makes the signal of acceleration collected contain many unwanted signals, such as high frequency signal and low frequency signal which are close to the wanted signal. Normally, the frequency of the signal of human movement is less than 10 Hz. This makes human body acceleration in low frequency. So low pass filter can eliminate most of the high frequency noise except the lower one.

Now, most filtering algorithm processes the signal through the transform domain and contains lots of transformation operations. The requirements for hardware are higher. For single-chip microcomputer, like micro controller, it takes up much time of the system bus and the algorithm processing will delay the operation of the whole system, which means each function module cannot work normally. If we use the microprocessor, like DSP chip, to carry out the algorithm, it will greatly increase hardware cost.

But it will reduce the complexity of the algorithm in the filtering procession from the angle of time domain. There are normal filters, such as Kalman filter, wiener filter and morphological filter, etc. The complexity of morphology is smaller in the above. Morphology contains three operations, addition, subtraction and comparison. And no arithmetic and derivative calculation are in it. Code implementation is simple on the chip. The signal can be processed quickly because the acceleration signal of human movement collected is a one-dimensional discrete digital signal and the data volume is small. And it has no effect on other performing basic code function.

The opening and closing operations of mathematical morphology has the characteristics of low pass filter. Even if the original signal contains strong noise or serious distortion, the basic shape can still be identified and refactoring. For acceleration signal of human movement, the signal distortion caused by shaking of the movement can play a good filtering effect.

3.2 The Denoising of the Combined Algorithm

In this paper, it makes an acceleration signal acquisition module by using MSP430 MCU and three-axis accelerometer, ADXL345 chip, which is put in the waist to collect the data of acceleration signal while walking. And the data will be processed and judged on the microcomputer.

Algorithm steps are as follows:

(1) *Sampling and Pretreatment*
The human movement acceleration signal collected by using three-axis accelerometer is three dimensional. We can get the basic data and waveform to analyze the signal through one axis, but in fact, the data cannot reflect the whole information of the human movement. We can get the macro acceleration of the movement through the root square operation. There is a little skill that we can use the root square algorithm programed by Carmack, the algorithm can quickly complete the operation.

(2) *Denoising*
Due to the anti-extensionality of morphological opening operation and the extensibility of morphological closing operation, the output signal amplitude would be smaller than the original signal after the denoising of the open-close filter. On the contrary, the output signal amplitude will increase after the

denoising of the close-open filter. In order to reduce the signal distortion degree, it is usually using the weighted average algorithm [10]. The combined open-close and close-open filter formula is as follows:

$$F(A,B) = (A \circ B \cdot B + A \cdot B \circ B)/2 \tag{5}$$

According to research [11], if we use the same structural elements in the process of open-close and close-open operation, it cannot completely remove the positive and negative pulse and need to use structural elements with different length, so that it can keep the details and edge of the waveform while filtering the noise. Therefore it uses two mathematical morphology filters with different length of structural elements in the processing of denoising. The formula is as follows:

$$F(A,B1) = (A \circ B1 \cdot B1 + A \cdot B1 \circ B1)/2 \tag{6}$$

$$F(A,B2) = (A \circ B2 \cdot B2 + A \cdot B2 \circ B2)/2 \tag{7}$$

(3) *Remove the pulse signal*
After the denoising, baseline drift of the waveform has been eliminated, but some pulse signal with low frequency is in it. This makes signal distortion and it is hard to identify and judge. Considering the speed of the algorithm and the effect of denoising in case of the interference, it uses the median filtering to denoise again. The formula is as follows:

$$Y = med\{X(i), \quad i \in N\} \tag{8}$$

N is the size of the moving window

(4) *Smooth*
Some low frequencies which are similar to the wanted signal are still in it. To get the waveform smooth, it needs to use the method of moving average filtering to smooth the waveform to get better result. And the formula is as follows:

$$Y = \frac{1}{N}\sum_{i=1}^{N} X(i) \tag{9}$$

4 Results

4.1 Qualitative Analysis

In this paper, we design an acceleration module with signal acquisition and signal processing. The module has two functions: data acquisition and data processing.

The module consists of MSP430F5529 and ADXL345. It is fixed on the waist of the human body and close to people's center of gravity position.

The sampling frequency of single-chip microcomputer is 20 Hz; it takes acceleration signal of actual human motion of 60 steps as the original signal; it takes 28 s. The algorithms above will be used in the chip to process the signal; the related data will be saved in the memory chip. Then we use MATLAB to show waveform after processing.

In Fig. 1, it is the digital acceleration signal of 60 steps saved in the memory chip and it is collected by accelerator. We can roughly tell each fluctuation corresponding to each single step. The signal contains high frequency signal, similar low frequency signal and baseline drift.

In the experiment, it uses the actual test data and the signal contains noise and baseline drift. In Fig. 1, it is the original signal; in Figs. 2, 3 and 4, the signals after being filtered on the MSP430 chip with different algorithms has been showed. It is obvious that median filter cannot eliminate the baseline drift; the others can have good filtering result, the signal after filtering has fluctuated near the X axis. The method in this paper has better smoothing effect than the other two; most of the noises have been filtered.

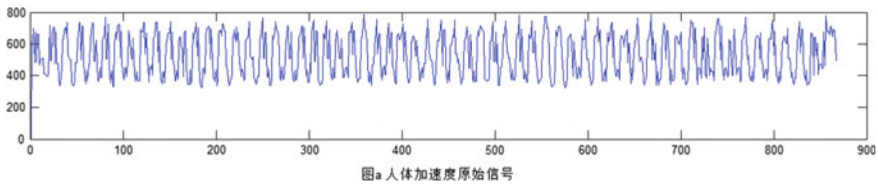

Fig. 1 Original signal of human movement

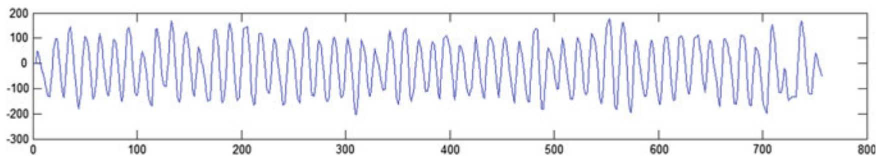

Fig. 2 Signal after being filtered by this method

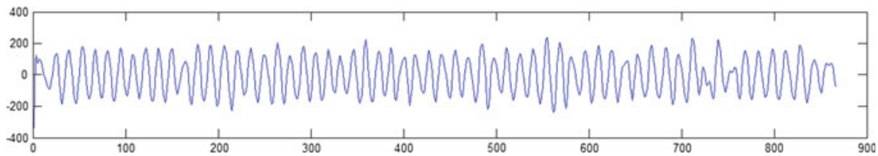

Fig. 3 Signal after being filtered by wavelet transform

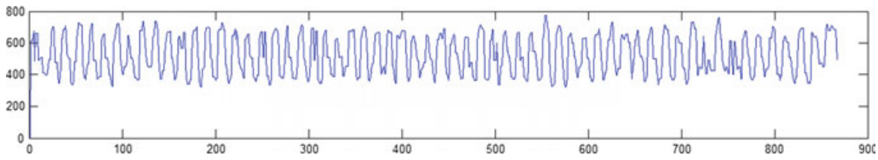

Fig. 4 Signal after being filtered by median filter

In Figs. 5 and 6, it is the signal of 60 steps and the time consumption is 42.9 s. The smoothing degree with this method in paper is superior to wavelet transform and it is convenient to data analysis.

4.2 *Quantitative Analysis*

In order to validate the code execution speed and reliability on the hardware platform, it selects code running time, identification accuracy of acceleration signal and smoothness degree as indexes to carry on the quantitative analysis.

Time is an important index of algorithm on the hardware implementation, and here, it means the time consumption when the original acceleration signal is processed on the MSP430 chip.

The recognition of acceleration signal wave refers to the signal wave statistics after being filtered. The formula is as follows:

$$f(n-2) \leq f(n-1) \leq f(n), \quad f(n) \geq f(n+1) \geq f(n+2) \tag{10}$$

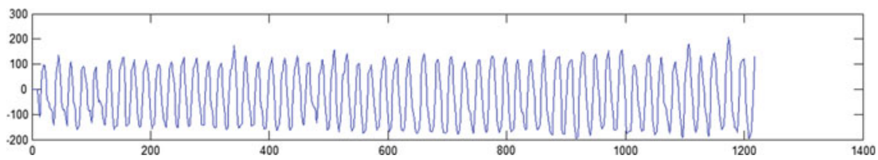

Fig. 5 Signal after being filtered by this method

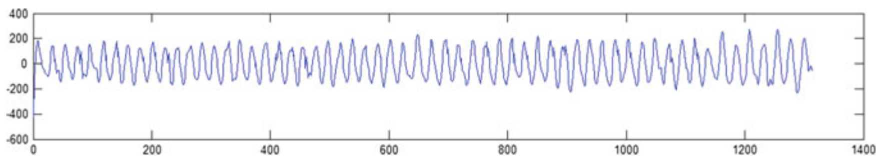

Fig. 6 Signal after being filtered by wavelet transform

f(n) refers to the acceleration signal of human motion after being filtered.

Accuracy refers that whether the signal wave can be identified correctly, its formula is $(1 - \frac{Rerror}{Rall}) \times 100\,\%$. *Rerror* is the number of wrong signal wave; *Rall* refers to the actual signal waves corresponding to the steps.

The acceleration signal of human motion is a one-dimensional signal; smoothness degree is the main principle of evaluation for the acceleration signal. The formula is as follows:

$$R = \frac{\sqrt{\sum_{n=1} [\hat{f}(n+1) - \hat{f}(n)]^2}}{\sqrt{\sum_{n=1} [f(n+1) - f(n)]^2}} \tag{11}$$

f(*n*) is the original signal, $\hat{f}(n)$ is the signal after being filtered.

In Table 1, it compares the time consumption between the method in this paper and others when codes are running on the single chip microcomputer. Three groups of experimental data are verified; the method in the paper and median filter consumes less time. In Table 2, it compares smoothness degree of signal after being filtered between different algorithms. In Table 3, it compares the accuracy of each algorithm. In general, the method in this paper can get better filtering effect.

Table 1 Comparation of time consumption

Testing data	The first group	The second group	The third group
Method	Time consumption	Time consumption	Time consumption
Method in this paper	0.8497	0.8153	1.1437
Wavelet filter	1.3267	1.2333	1.5742
Median filter	0.0472	0.0450	0.0650

Table 2 Comparison of smoothness degree

Testing data	The first group	The second group	The third group
Method	R	R	R
Method in this paper	0.3674	0.5696	0.3705
Wavelet filter	0.4477	0.6662	0.4002
Median filter	0.7451	0.9461	0.7656

Table 3 Comparation of accuracy

Testing data	The first group		The second group		The third group	
Method	Wrong number	Accuracy (%)	Wrong number	Accuracy (%)	Wrong number	Accuracy (%)
Method in this paper	0	100	2	97	5	91.7
Wavelet filter	4	93	0	100	35	41.7
Median filter	21	65	4	93	23	61.7

5 Conclusion

In order to process the collected data of acceleration signal of human movement by sensor quickly and efficiently on the MSP430 chip, a combination optimization algorithm based on morphology and median filtering is proposed. Experiments show that the proposed algorithm is superior to single median filter and morphological filter; it keeps the waveform characteristics of signal; its processing speed is faster, the quickness and reliability are proved. This algorithm is also applicable to breathing and pulse wave signals, etc. It is convenient to do the parameter statistics for wearable devices which do not pursue precision of the signal. Although the method has good effect and runs stably while processing the low frequency signal on the hardware, its amplitude distortion is serious. For the high precision requirement of object motion signal detection and the details of the physiological signal extraction, the algorithm needs to be improved and perfected to be suitable for the application.

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Research on Truck Scheduling with Preemption in Cross-Docking Systems

Jing-feng Li, Yan Ye and Hui Fu

Abstract Cross-docking is a strategy to reduce cargos' total flow time as well as total cost. This paper considers a truck scheduling problem in a cross-docking system where the unloading process can be interrupted and the number of preemption is limited. An integer programming model is developed for this problem and the objective is to minimize the makespan by determining the sequences of inbound and outbound trucks. Then, a particle swarm optimization algorithm is proposed to solve this model. Finally, computational experiments considering preemption and non-preemption are done. The results prove the proposed approach performs better than existing model does when the waiting time of cargos for unloading is very long.

Keywords Cross-docking system · Preemption · Particle swarm optimization · Truck scheduling

1 Introduction

Cross-docking is a warehouse management strategy in which the storage time of cargos is less than 24 h and sometimes less than 1 h. The structure of a cross-docking system is shown in Fig. 1. As shown in the figure, a cross-docking system generally operates as follows: (1) Inbound trucks are assigned to receiving doors to unload cargos at a specified sequence. (2) Cargos are sorted in the distribution center and transferred to shipping doors. (3) Outbound trucks are assigned to shipping doors to load cargos at a specified sequence.

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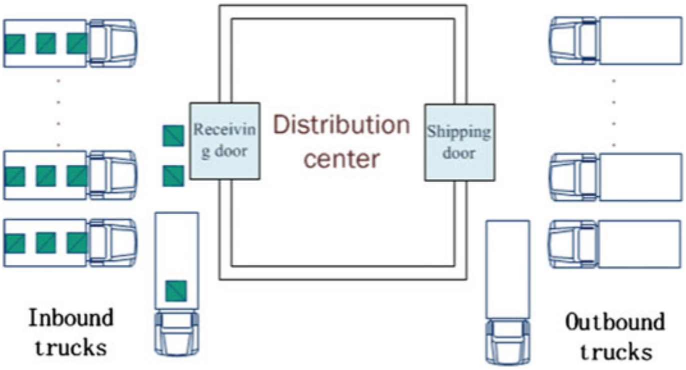


Fig. 1 The structure of cross-docking system

Most studies on truck scheduling in the cross-docking are related to a single receiving dock and a single shipping dock, such as [1–3]. Chen and Lee [4] proved the truck sequencing problem is strongly NP-hard. Yu and Egbelu [5] developed a mixed integer programming model to minimize makespan by scheduling outbound trucks. In their model, the capacity of the center is limited. At the same problem, Boloori Arabani et al. [6] applied five meta-heuristics, genetic algorithm (GA), tabu search (TS), particle swarm optimization (PSO), ant colony optimization (ACO) and differential evolution (DE) to solve it. And the experimental results show DE performed best. Li and Ye [7] studied the truck scheduling with cargos' loading/unloading sequence. They built an integer programming model and designed a GA to solve this problem. Zarandi et al. [8] aimed at minimizing the total cost of the earliness, tardiness and the number of preemption for the outbound trucks, and applied GA to solve this problem. The literature related to multiple inbound and outbound doors is few. Liao et al. [9] proposed six meta-heuristic algorithms to solve simultaneous dock assignment and sequencing of inbound trucks under a fixed outbound truck departure schedule. Kuo [10] and Lee et al. [11] respectively proposed variable neighborhood search and genetic algorithm to optimize the truck sequencing and door assigning.

Based on the study of Li and Ye [7], this paper studies the truck scheduling under the situation of inbound trucks' unloading process can be interrupted, and the interrupting times is limited. This paper aims at minimizing the makespan of the cross-docking system. A new integer programming model is proposed and a particle swarm optimization is designed to optimize the sequence of inbound and outbound trucks. At last, many experiments were done to prove the model's correctness and the algorithm's effectiveness.

2 Problem Describe and Model

2.1 Problem Describe

The cross-docking system considered in this paper is assumed to have the following characteristics: (1) There is only one shipping and one receiving door in the cross-docking center. (2) The loading time, unloading time and transferring time of each cargo are the same, and every kind cargo can't be torn apart. (3) The interrupting times of each inbound truck is limited. (4) In every truck, the cargos' loading/unloading sequences are known. (5) The receiving and shipping door only can be occupied by one truck at a time.

2.2 Mathematic Model

In order to describe the problem, the following notations are used in the model:

M total number of inbound trucks
N total number of outbound trucks
K total number of cargo types
D trucks changeover time
E maximum interrupting number of all inbound trucks
V transferring time of cargo from receiving door to shipping door
t unloading/loading time of single cargo
T total operation time
Z a big number
a_k number of cargo type *k*
au_k unloading sequence of cargo type *k*
al_k loading sequence of cargo type *k*
b_m maximum interrupting times of inbound truck *m*
x_m maximum types of cargos unloaded by inbound truck *m* at one time
c_{mi} time of inbound truck *m* docking the receiving door at the *i*th time
cc_{mi} time of inbound truck *m* whose docking sequence is *i* docking the receiving door at the sequence *i*. If the docking sequence of inbound truck *m* is not *i*, its value is 0
F_{mi} time of inbound truck *m* leaving the receiving door at the *i*th time
FF_{mi} time of inbound truck *m* whose docking sequence is *i* leaving the receiving door, If the docking sequence of inbound truck *m* is not *i*, its value is 0
d_n time of outbound truck *n* docking the shipping door
L_n time of outbound truck *n* leaving the shipping door
e_k starting time of cargo type *k* unloaded
f_k starting time of cargo type *k* loaded
r_{mk} if inbound truck *m* contains cargo type *k*, its value is 1; otherwise, its value is 0

s_{nk} if outbound truck n contains cargo type k, its value is 1; otherwise, its value is 0

m_{mkl} if cargo type k unloaded from inbound truck m later than cargo type l, its value is 1. Otherwise, its value is 0

n_{nkl} if cargo type k loaded from outbound truck n later than cargo type l, its value is 1. Otherwise, its value is 0.

Decision variables:

p_{ms} if the sequence of inbound truck m assigned to receiving door is s, its value is 1. Otherwise its value is 0

q_{nt} if the sequence of outbound truck n assigned to shipping door is t, its value is 1. Otherwise its value is 0.

An integer programming model is proposed as following:
Min T
st:

$$T \geq L_n, \quad n \in [1, N], \tag{1}$$

$$\sum_{S=1}^{E+m} p_{ms} \leq b_m + 1, \quad m \in [1, M], \tag{2}$$

$$\sum_{m=1}^{M} b_m \leq E \tag{3}$$

$$\sum_{m=1}^{M} \sum_{k=1}^{K} r_{mk} = \sum_{n=1}^{N} \sum_{k=1}^{K} s_{nk} \tag{4}$$

$$\begin{aligned} &\mathrm{cc}_{mi} \geq FF_{m'i-1} + D - Z(2 - p_{mi} - p_{m'i-1}), \\ &m, m' \in [1, M] \end{aligned} \tag{5}$$

$$d_n \geq L_{n'} + D - Z(2 - q_{nt} - q_{n't-1}), \quad n, n' \in [1, N] \tag{6}$$

$$e_k \geq r_{mk} c_{mi}, i = [\mathrm{au_K}/\mathrm{x_m}], \quad m \in [1, M], \ k \in [1, \mathrm{K}] \tag{7}$$

$$e_k \geq e_l - Z(1 - m_{mkl}), \quad k, l \in [1, K], \ m \in [1, M] \tag{8}$$

$$f_k \geq f_l - Z(1 - n_{nkl}), \quad k, l \in [1, K], \ n \in [1, N] \tag{9}$$

$$d_n \leq f_k s_{nk}, \quad k \in [1, K], \ n \in [1, N] \tag{10}$$

$$F_{mi} \geq e_k r_{mk} + a_k t, i = [\mathrm{a}u_{\mathrm{k}}/\mathrm{x_m}], \quad m \in [1, M]\ k \in [1, K] \tag{11}$$

$$L_n \geq f_k s_{nk} + a_k t, \quad k \in [1, K],\ n \in [1, N] \tag{12}$$

Constraint (1) shows the range of makespan. Constraints (2) and (3) show that inbounds' unloading process can be interrupted and the interrupting times is limited. Constraint (4) ensures that the cargos' number unloaded from inbounds is equal to the cargos' number loaded from outbound trucks. Constraints (5) and (6) indicate the receiving door and shipping door can only be occupied by one truck. Constraints (7) and (10) show that each cargo in an inbound/outbound truck can be unloaded/loaded only after the truck has docked. Constraints (8) and (9) ensure all the cargos are loaded/unloaded at a specified sequence. Constraints (11) and (12) show the inbound/outbound truck can't leave the receiving/shipping door before its unloading/loading mission done.

3 The Particle Swarm Optimization

3.1 The Particle Swarm Optimization

The particle swarm optimization is proposed by Kennedy and Eberhart [12] in 1995. It has been used to solve multifarious problems, such as, vehicle routing problem [13], distributed generation location and sizing problem [14] and anomaly detection [15]. It originated from the schooling behavior of fish, or flocking behavior of birds. In PSO, The group of particles is composed by m particles in D dimension space. For the particle *i*, its position vector is $X_i = \{x_{i1}, x_{i2}, x_{i3}, \ldots, x_{id}\}$, and its velocity vector is $V_i = \{v_{i1}, v_{i2}, v_{i3}, \ldots, v_{id}\}$. The position vector and velocity vector of each particle are changed according to the following equations:

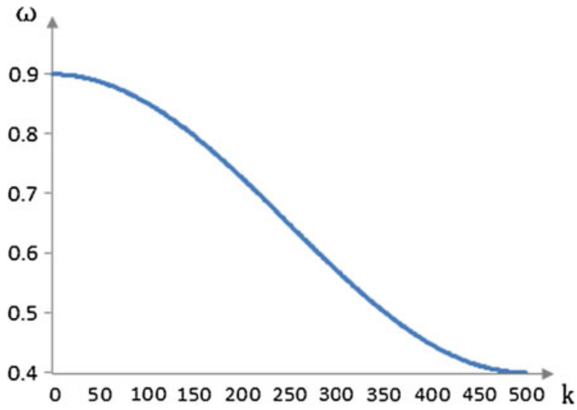
$$v_{\mathrm{id}}^{\mathrm{k}} = \omega v_{id}^{k-1} + c_1 c_1 (P_{id} - x_{id}^{k-1}) + c_2 c_2 (G_{gd} - x_{id}^{k-1}) \tag{13}$$

$$x_{\mathrm{id}}^{\mathrm{k}} = x_{id}^{k-1} + v_{id}^{k} \tag{14}$$

In these equations, i = 1, 2, 3, … , m; d = 1, 2, 3, … , D, P_{id} is the *d*th dimension of the optimal location of particle *i*; G_{gd} is the *d*th dimension of the optimal location of all particles; ω is the inertia weight coefficient; c_1 and c_2 are the learning factors; r_1 and r_2 are the random numbers in the range [0, 1].

The inertia weight ω balances the global and local exploitation abilities of the swarm. A large inertia weight is inclined to exploration, and makes the convergence of particle hard. A small inertia weight makes the convergence of particle very fast, and it sometimes leads to the local optimal. In order to get a better result, the value of ω changes as the follow:

Fig. 2 The dynamic alteration of ω



$$\omega = (\omega_{\min} - \omega_{\max})[0.5\cos(k\pi/iteration + \pi) + 0.5] + \omega_{\max} \tag{15}$$

In Eq. (15), $\omega_{\max}$ and $\omega_{\min}$ are the maximum and minimum values of ω, k is the current iteration number, and iteration is the maximum iteration number, π is the ratio of circumference.

In this paper, the value of $\omega_{\max}$ is 0.9, the value of $\omega_{\min}$ is 0.4, the value of iteration is 500. The dynamic alteration of ω is shown in Fig. 2.

3.2 Encoding

In this paper, we adopt real-number for encoding. For the problem of M inbound trucks and N outbound trucks, and the maximum interrupting times of each inbound truck is 2 (the maximum docking times of each inbound truck is 3), we build a 3M + N dimensions position vector X and a 3M + N dimensions velocity vector V. The first 3M dimensions of X stand for the sequence of inbound trucks, and the last N dimensions of X stand for the sequence of outbound trucks. Each inbound truck gets 3 dimensions position vector X and 3 dimensions velocity vector V, and each outbound gets 1 dimensions position vector X and 1 dimensions velocity vector V.

3.3 Initialization

We set the value of the first 3M dimensions of position vector X an integer in the range [1, 3M] randomly, and the value of each dimension is different. The same to the last N dimensions of position vector X, but the values are in the range [1, N].

Table 1 The position vector X

Truck no.	1	1	1	2	2	2	3	3	3	4	5	6
X	1	5	7	3	6	4	8	9	2	2	1	3

Then, we set the value of the first 3M dimensions of position vector V real-number in the range[−(M − 1), M − 1] randomly, and set the last N dimensions' values in the range [−(N − 1), N − 1].

For example, there are 3 inbound trucks and 3 outbound trucks. The position vector X is shown in Table 1. Truck2 gets two continuous numbers 3 and 4, truck3 gets two continuous numbers 8 and 9. They mean the interrupting between sequence 3 and 4, 8 and 9 haven't happen. Then, the sequence of inbound trucks is: 1-3-2-1-2-1-3. The sequence of outbound trucks is: 5-4-6.

3.4 Integer Rule

The search operation of particle swarm optimization is continuous. But the cross-docking truck scheduling problem is a discrete optimization problem. So, during the calculation, we design an integer rule to discretize particle swarm optimization.

After updating, we reset the values of the first 3M dimensions of position vector X 1, 2, … , 3M in the order of smallest to largest, and reset the values of the last N dimensions of position vector X 1, 2, … , N in the order of smallest to largest. Such as, the position vector X after updating is shown in Table 2. After discretizing, it is shown in Table 3. Truck No. 1 to No. 3 is the number of inbound trucks, and Truck No. 4 to No. 6 is the number of outbound trucks. The sequence of inbound trucks is: 3-1-2-1-3-1-3-2. The sequence of outbound trucks is: 4-6-5.

Table 2 The position vector X after updating

Truck no.	1	1	1	2	2	2	3	3	3	4	5	6
X	1.21	2.55	3.17	1.32	6.11	1.45	2.83	1.19	3.2	2.3	11.1	3.4

Table 3 The position vector X after discretizing

Truck No.	1	1	1	2	2	2	3	3	3	4	5	6
X	2	5	7	3	9	4	6	1	8	1	3	2

3.5 Calculation Procedure

The calculation procedure of particle swarm optimization is as following:

(1) Initializing the parameters of the problem, and generating the initial solution.
(2) Calculating the fitness of all the particles, then updating the local optimal particle and the global optimal particle.
(3) Updating the inertia weight ω by Eq. (14).
(4) Updating the position and the velocity of every particle by Eqs. (12) and (13).
(5) Discretizing the particle swarm optimization by the integer rule.
(6) If the particle swarm optimization meets the termination conditions, the calculating process will end. Otherwise, it will turn to procedure 2.

4 Computational Results

This paper proposed a new scheduling model, and there is no standard test data. Then, we designed the test data professionally. All the experiments were done on the computer with Intel Core i3-3240 CPU @ 3.40 GHz. The parameters of particle swarm optimization were shown as Table 4.

In order to investigate the performance of preemptive model and non-preemptive model, we defined different scales problem based on the number of inbound truck, the number of outbound truck, and the number of cargo types in every truck. And, we did 10 experiments on every different scale problem. In the experiments, we set the value of each inbound trucks' maximum interrupting times 2, that mean every inbound truck can dock receiving door 3 times. All the results were shown in Table 5. We listed the best solution, the worst solution and the average solution. In addition, M is the number of inbound trucks. N is the number of outbound trucks. P is the number of cargo types in every truck.

We can see from Table 5. When the truck number is 10, all the results of preemptive model are better than non-preemptive model. When the truck number is 16, most results of preemptive model are better than non-preemptive model. When the truck number is 20, the first result of preemptive model is worse than non-preemptive model, the middle results of them are very close, only the last result of preemptive model is much better than non-preemptive model. We can draw a conclusion from Table 5. The performance of preemptive model relies on the number of trucks, the number of cargo types in every truck and the truck

Table 4 The parameters of particle swarm optimization

ω_{max}	ω_{min}	c_1, c_2	Iteration	Particle		
				Small	Middle	Large
0.9	0.4	1.49445	500	100	300	600

Table 5 The results of no-preemptive model and preemptive model

Problem size (M × N × P)	Non-preemption			Preemption		
	Best (s)	Average (s)	Worse (s)	Best (s)	Average (s)	Worse (s)
5 × 5 × 6	1876	1876	1876	1681	1741.5	1791
5 × 5 × 12	3911	3911	3911	3476	3623	3756
5 × 5 × 24	8686	8686	8686	7666	7817	7931
8 × 8 × 6	2906	3065.5	3161	3206	3296.5	3356
8 × 8 × 12	5706	5834	5946	5681	5801.5	5911
8 × 8 × 24	12781	12781	12781	11806	12058	12431
10 × 10 × 6	3736	4064	4226	4031	4244	4396
10 × 10 × 12	7266	7383.5	7511	7261	7364.5	7441
10 × 10 × 24	15941	16013.5	16156	14666	15250	15456

changeover time. If the waiting time of cargos is less than the time of interrupting, the performance of preemptive model is better. Otherwise, the performance of non-preemptive model is better.

5 Conclusion

This paper proposes a new scheduling model in which the unloading process can be interrupted to schedule trucks. And experiments prove this scheduling model performs better than the cross-docking system with no preemption under some situation. In later work, we will study the multi-doors assignment in this model and the influence of trucks, truck pallets and cargo types to preemption.

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Inverse Optimization Model and Its Application for Safety Resource Allocation in High-Risk Industry Enterprises-Taking Mining Enterprise as an Example

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Abstract It is a realistic problem to be solved urgently for enterprises as to, under the preconditions of safety production, how to optimize system resource allocation. Firstly, the inverse optimization method is summarized, and the application of the inverse optimization method in the field of safety resource allocation is analyzed. Secondly, according to the system requirements in a dynamic situation, the inverse optimization model of safety resource allocation is constructed. Finally the model is used for mining enterprise, combined with the dynamic time-varying and nonlinear between safety resources and safety status, and the inverse optimization model of coal mine safety resource allocation is constructed, verifying the validity and applicability of the model. The results provide a theoretical support and decision-making basis for the reasonable safety resource allocation in high-risk industry enterprises.

Keywords Safety resources · Allocation · Inverse optimization · High-risk industry enterprises

1 Introduction

In recent years, the situation of safety production in China has improved year by year, but serious accidents in high-risk industry enterprises happened frequently, resulting in serious personal injury and property damage. In our country, high-risk industry enterprises usually refer to coal mine, non-coal mines, dangerous chemicals,

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fireworks, construction, transportation and communications and so on. According to the statistical data, the numbers of safety accidents and deaths are respectively 29 million times, 6.6 million people in 2014, among which the coal mine fatality rate per million tons is 0.257, but it is less than 0.03 in the United States. Safety production level of high-risk industry enterprises in our country is of huge gap compared with that in developed countries. In order to achieve safe production, high-risk industry enterprises need to carry out the reasonable safety resource allocation in order to reduce the economic losses and casualties caused by the accidents. However, under the constraint of limited safety resources, system of high-risk industry enterprises exist competition of resources, such as too much input of safety resources in a subsystem will lead to corresponding reduction of other subsystems, which will have a direct impact on the safety status of other subsystems, thereby affecting the safety level of the whole enterprise. Therefore, how to optimize system resource allocation under the preconditions of ensuring safety production, enhance the continual stability of safe production, and improve the economic benefits of the enterprises continuously, become a very important and realistic problem urgently to be solved for the safe and efficient production of high-risk industry enterprises.

In view of this, many experts and scholars at home and abroad have made large numbers of studies on the safety resource allocation, focused on safety resource allocation method, resource allocation optimization algorithm, etc. Researches on safety resource allocation method focused on emergency resource allocation with multiobjective, multistage and other aspect [1, 2], and resource allocation optimization algorithm focused on genetic algorithm, dynamic programming and heuristic algorithm, solving the problem of optimization allocation in fields such as collaborative manufacturing system, water resources, the disaster relief and so on [3–5], by optimizing the resource allocation to achieve the goal of optimization. However, the linear programming model established of above studies is more rigid processing, which is difficult to solve the problem, that is, high cost caused by the excessive of some resource allocation and the lack of other resource cannot meet the safety requirements of the whole system. Furthermore, resource allocation in the subsystem is on the basis of the principle of the maximum of the benefits or the minimum of the cost, which cannot solve how to organize the existing resources to meet the whole requirements of the system to the fullest extent. Thus, during the actual operation, the result of some feasible solutions or infeasible solutions is better than the effect of the optimal solutions. Compared with the general optimization problem, the optimization allocation of safety resources in high-risk industry enterprises should not only maximally meet the requirements of the whole system through the rational organization of safety resources, but also is the problem of inverse optimization, which adjust the resource allocation to make the feasible solutions become the optimal solution, namely inverse optimization of safety resource allocation.

Therefore, from the perspective of system requirements, safety resource allocation optimization model is constructed for high-risk industry enterprises. And then based on the actual situation, the inverse optimization model of safety resource allocation is constructed, by adjusting the resource input proportion, obtaining optimization scheme of safety resource allocation which conform to the actual situation. At last, the model is applied to mining enterprise to modify the theoretical model and method through empirical analysis, providing a scientific basis for high-risk industry enterprises to make flexible and reasonable decision-making of safety resource input.

2 Overview and Application of Inverse Optimization Method

The inverse optimization problem is proposed by Burton and Toint in 1992, which is based on the shortest path problem in the network. Specific content is: given a network of two nodes in a path, by adjusting the weight of the network arc, it becomes the shortest path between the two nodes. Recently, experts and scholars at home and abroad launched a lot of researches and achieved more substantial results, mostly concentrated in the construction of inverse optimization model and application field in inverse optimization, and mainly in the field of supply chain, artificial intelligence, transportation resource allocation and so on. Although inverse optimization allocation is rare for safety resources, but these research provide a useful reference value for the construction of inverse optimization model in high-risk industry enterprises.

The optimization allocation of safety resources of the enterprise is under the conditions of meeting the safety of the enterprise, by adjusting the allocation of various resources to make the current safety status optimal. As there are many different kinds of safety resources in the system, under the conditions of not considering the correlation between safety resources, we need to determine the appropriate objective function and constraint conditions to build the optimization model of safe resource allocation, and calculate the optimal solution which meet the safe production constraint of the system, thus reducing the redundant resources, so as to meet the safety goals and achieve sustained and stable production. Problem of safety resource allocation of the enterprise can be expressed as a linear programming model:

$$\min Z = c^T x \qquad s.t.\begin{cases} Ax \geq b \\ x \geq 0 \end{cases} \tag{1}$$

Among them, $x = (x_1, x_2, \ldots, x_n)^T$ is safety resource input of the enterprise, $c = (c_1, c_2, \ldots, c_n)^T$ is the corresponding production cost, $b = (b_1, b_2, \ldots, b_m)^T$ is possession quantity of safety resources in the subsystem. $A = \left(a_{ij}\right)_{m\times n}$, a_{ij} is unit consumption of safety resource i in subsystem j. Genetic algorithm toolbox in MATLAB is used to solve the above model.

The inverse optimization problem of safety resource allocation model of the enterprise is, for given in advance of the target x_i^*, in the meaning of some mod, how to adjust the coefficients A, b, or c in model (1) as little as possible, making the desired goal x_i^* become the optimal solution of model (1). In summary, the optimization problem of safety resource allocation is how to find optimal solutions in feasible region, and inverse optimization problem of safety resource allocation is how to make the given target point to become the optimal solution.

3 Construction of Inverse Optimization Model for Safety Resource Allocation in High-Risk Industry Enterprises

Input of safety resources in high-risk industry enterprises is decided by the requirements of the system. Under the conditions of dynamically changing of system requirements, elastic variable of the proportion of safety resource input, it is necessary to make the target point determined by the system requirements, as the infeasible solutions of optimal production plan model, become the optimal solution, by adjusting the proportion of safety resource input to make safety resource input determined by the system requirements become the optimal solution of safety resource allocation model after adjusted. Also when the infeasible solution in linear programming model (1) is much better than the optimal solution calculated from the model, it indicates that constraint value b of the linear programming model is not accurate enough or actual operation must adjust the proportion of safety resource input. At this point, we can use the proportion of safety resource input as the optimization variable of the inverse optimization model to determine the optimal safety resource allocation scheme for high-risk industry enterprises.

After actual safety resource input in high-risk industry enterprises is determined, in order to make x_i^* the optimal solution, it is feasible to use the proportion of safety resource input b as variables, minimum changing of b as the optimization objective. The corresponding inverse optimization model can be expressed as [6]:

$$\begin{aligned} &\min \|b^* - b\| \\ &s.t. \begin{cases} Ax_i^* - b_i^* \geq 0 \\ \quad x_i^* \geq 0 \end{cases} \end{aligned} \tag{2}$$

$b_i^* = b_i + \sigma_i - \beta_i$, $\sigma_i \geq 0$ and $\beta_i \geq 0$ indicate that the increment and the decrement of b_i.

Considering $\|\sigma_i - \beta_i\| \leq \|\sigma_i + \beta_i\|$, formula (2) can be converted into:

$$\min\|\sigma_k + \beta_k\|$$
$$s.t.\begin{cases} Ax_i^* \geq b_i^* + \sigma_i - \beta_i \\ x_i^* \geq 0 \\ \sigma_i, \beta_i \geq 0 \end{cases} \tag{3}$$

Converted formula (3) into the standard form, selection norm l_1, formula (3) is a linear programming problem [7]. Using the linprog function of MATLAB to solve the value of σ_k and β_k, and then determining the increment and decrement of b to determine the adjustment amount of the proportion of safety resource input, so as to adjust the original safety resource allocation scheme. Finally, determine safety resource allocation scheme in accordance with the actual situation of high-risk industry enterprises, the error of resource constraints can be found out, and then optimize the original model. Therefore, when the safety resource input changes, the solution of the optimized model is more reasonable.

4 Application Analysis of Mining Enterprise

4.1 Data Collection and Processing

Taking the mining enterprise as an example, this paper selects the coal mine X as the empirical object to test the above model. The highest production input in X enterprise are 15 million, annual output of the coal is 8 million tons. According to the characters of the coal mine safety production system and different input functions, safety resource input in coal mine is classified as four parts including the personnel input x_1, machinery input x_2, environment improvement input x_3, safety management input x_4 [8]. Collection the data of safety resource input, economic loss of the safety accident and the minimum proportion of safety resource input of X enterprise over the years.

4.2 Model Construction and Solution

(1) Objective function determination

The optimization goal of coal mine safety resource allocation is, under the premise of enterprise safety, using the minimal safety economy consumption, to maximize the benefits of the enterprise, that is, using minimal input to obtain the maximum of economic and social benefits. Coal mine safety economic consumption comprises the economic loss of the safety accident of coal mine L and the input of coal mine safety resources X, both of which show the total safety economic burden of the enterprise, that is, the safety costs [9]. With the dynamic time-varying and nonlinear between safety resources and safety status, this paper minimize the total safety economic burden Z as the objective function:

$$Z(x_1, x_2, \ldots, x_n) = L + X = L + \sum_{i=1}^{n} x_i \tag{4}$$

In this paper, the function of the economic loss of the safety accident of the enterprise is fitted by the form of Cobb-Douglas production function:

$$Z = L + X = A' x_1^{\alpha_1} x_2^{\alpha_2} \cdots x_n^{\alpha_n} + \sum_{i=1}^{n} x_i \tag{5}$$

Among them, $x_i (i = 1, 2, \ldots, n)$ is the input of safety resource i, A is a constant of technological progress level, and α_i is the relative importance of the safety resources.

Substitute the data of safety resource input and economic loss of the safety accident in X enterprise over the years into the formula $L = A' x_1^{\alpha_1} x_2^{\alpha_2} \cdots x_n^{\alpha_n}$, and then get multivariate linear regression equation by getting the logarithm on both sides. Determine the objective function after fitting the relationship between safety resource input and economic loss of the safety accident of X enterprise based on multiple linear regression.

(2) Constraint conditions analysis

Constraint of safety resource input of the enterprise is $400 \leq X = \sum_{i=1}^{4} x_i \leq 1500$.

The safety resources of personnel and machinery are interrelated and restricted. They have huge impact on the safety of coal mine, so the constraint of the proportion of personnel and machinery can be obtained as $0.6 \leq (x_1 + x_2) / \sum_{i=1}^{4} x_i < 1$.

The key resources to improve the level of coal mine safety production are the safety resource of personnel, and safety management is the daily activities of coal mine safety production. They are the relative key resources effecting on coal mine safety status, so the constraint of the proportion of personnel, safety management can be obtained respectively as $0.4 \leq x_1 / \sum_{i=1}^{4} x_i < 1$, $0.15 \leq x_4 / \sum_{i=1}^{4} x_i < 1$.

The external resources constrained on the individual characteristics of personnel mainly include three aspects: machinery, environment improvement and safety management, which are the key role of personnel, thus obtained corresponding constraint of their input proportion as $0.5 \leq (x_2 + x_3 + x_4) / \sum_{i=1}^{4} x_i < 1$. The reasonable input of personnel, machinery, and environment improvement is the key role effecting on safety management, thus obtained corresponding constraint of their input proportion as $0.7 \leq (x_1 + x_2 + x_3) / \sum_{i=1}^{4} x_i < 1$.

(3) Model construction and solution

Based on the above analysis and fitting results, the optimization allocation model of safety resources is constructed:

$$\min Z = 15708x_1^{-0.43}x_2^{-0.283}x_3^{-0.102}x_4^{-0.178} + \sum_{i=1}^{4} x_i$$

$$s.t.\begin{cases} 400 \le X = \sum_{i=1}^{4} x_i \le 1500 \\ 0.6 \le (x_1 + x_2)/\sum_{i=1}^{4} x_i < 1 \\ 0.4 \le x_1/\sum_{i=1}^{4} x_i < 1 \\ 0.5 \le (x_2 + x_3 + x_4)/\sum_{i=1}^{4} x_i < 1 \\ 0.15 \le x_4/\sum_{i=1}^{4} x_i < 1 \\ 0.7 \le (x_1 + x_2 + x_3)/\sum_{i=1}^{4} x_i < 1 \end{cases} \quad (6)$$

The nonlinear programming model (6) is transformed into the standard form and solved by genetic algorithm toolbox of MATLAB.

After 39 times of iteration, it can be obtained that the final result in this algorithm is convergent and the optimal solution is x = (174.58, 97.71, 54.67, 73.06), Z = 544.54, namely when the input of personnel, machinery, environment improvement and safety management are 1.7458, 0.9771, 0.5467, and 0.7306 million, can ensure the realization of safety objective. Under this condition, the minimal safety economic burden is 6.5875 million.

During the actual operation, the effect of some feasible solutions or infeasible solutions of the nonlinear programming model is better than the optimal solutions, indicating that constraint value b of the nonlinear programming model (6) is not accurate enough or the proportion of safety resource input can be adjusted during the actual operation. In this case, we can adopt inverse optimization model to solve how to minimally adjust constraint value b [11], serve as a basis for adjusting the proportion of safety resource input, and further optimize the resource allocation. At this condition, found the actual optimal scheme is x = (185, 160, 28, 98), based on formula (2), (3), the inverse optimization model can be constructed:

$$\min \sigma_1 + \beta_1 + \sigma_2 + \beta_2 + \cdots + \sigma_6 + \beta_6$$
$$s.t.\begin{cases} 400 + \sigma_1 - \beta_1 \leq X = \sum_{i=1}^{4} x_i \leq 2000 \\ 0.6 + \sigma_2 - \beta_2 \leq (x_1 + x_2)/\sum_{i=1}^{4} x_i < 1 \\ 0.4 + \sigma_3 - \beta_3 \leq x_1/\sum_{i=1}^{4} x_i < 1 \\ 0.5 + \sigma_4 - \beta_4 \leq (x_2 + x_3 + x_4)/\sum_{i=1}^{4} x_i < 1 \\ 0.15 + \sigma_5 - \beta_5 \leq x_4/\sum_{i=1}^{4} x_i < 1 \\ 0.7 + \sigma_6 - \beta_6 \leq (x_1 + x_2 + x_3)/\sum_{i=1}^{4} x_i < 1 \end{cases} \tag{7}$$

Taking x = (185, 160, 28, 98) into formula (7), converting into the standard form, and using linprog function of MATLAB to solve the linear programming problem. Optimal solution is $\sigma_1, \beta_1, \sigma_2, \beta_2 \cdots, \sigma_6, \beta_6$ = (0, 0, 0, 0, 0, 0.007, 0, 0, 0, 0, 0, 0), indicating that changing b_3 of model (6) from 0.4 to 0.393 can make infeasible solution become the optimal solution of the following nonlinear programming model (8).

$$\min Z = 15708 x_1^{-0.43} x_2^{-0.283} x_3^{-0.102} x_4^{-0.178} + \sum_{i=1}^{4} x_i$$
$$s.t.\begin{cases} 400 \leq X = \sum_{i=1}^{4} x_i \leq 1500 \\ 0.6 \leq (x_1 + x_2)/\sum_{i=1}^{4} x_i < 1 \\ 0.393 \leq x_1/\sum_{i=1}^{4} x_i < 1 \\ 0.5 \leq (x_2 + x_3 + x_4)/\sum_{i=1}^{4} x_i < 1 \\ 0.15 \leq x_4/\sum_{i=1}^{4} x_i < 1 \\ 0.7 \leq (x_1 + x_2 + x_3)/\sum_{i=1}^{4} x_i < 1 \end{cases} \tag{8}$$

At this point, b can be modified to (400, 0.6, 0.393, 0.5, 0.15, 0.7).

4.3 Empirical Analysis

From the model results can be seen, when the proportion of personnel reduce to 0.393, the safety resource allocation scheme determined by the actual situation will become the optimal solution of safety resource allocation model of coal mine.

(1) Personnel analysis: the personnel proportion of safety resource input in X enterprise is respectively 0.4 and 0.393 before and after optimization. Safety input of personnel is too much. Analysis shows that X enterprise extremely attach importance to their comprehensive quality improvement such as cultural, mental and physical, safety education and training times are more frequently, but the safety level is limited enhanced by safety resource redundancy of the personnel, thus leading to a waste of resources. At the same time, the degree of mechanization of X enterprise is relatively low, and working time of personnel is longer. Once the occurrence of mining accidents, they may cause more casualties, thereby increasing the burden on the enterprise.
(2) Compared with the input in personnel, the input of machinery, environment improvement and safety management were more reasonable, it is no need to adjust before and after the optimization. During the process of actual production, X enterprise should allocate the input proportion of personnel and machinery rationally, increase the input in machinery appropriately and enhance mechanization level of the personnel, then improve the mechanization level of the enterprise. Furthermore, ensure a good working environment, implement the safety management responsibility, establish and perfect the restraint mechanisms of safety management and supervision, implement the safety management to everywhere, so as to reduce the coal mine safety accident loss caused by the redundancy of personnel, and improve the efficiency of resource allocation.

From the application results of the inverse optimization, based on the adjusted and optimized of the parameters such as proportion of safety resource input in safety resource allocation model, we can clear what resources are rich and their level of rich, what resources are shortage and their level of shortage in safety resources, which is beneficial for the enterprise to develop optimization scheme of safety resource allocation in line with the actual requirements through the reasonable organization of the resources, making the current safety status of the enterprise optimal.

5 Conclusion

In this paper, we have established the inverse optimization model of the safety resource allocation for high-risk industries. The results indicate that, the inverse optimization model of safety resource allocation considers the strongly nonlinear relationship between safety resources and safety status, provides a new train of thought to solve resource allocation scheme conforming to the actual demand of the enterprises, and has important reference value for high-risk industry enterprises to develop safety resource allocation decision.

In addition, inverse optimization algorithm is available to solve the problem of how to organize the existing resources rationally to meet the whole requirements of the system. Changing the parameters in the model can make the infeasible solution of expected solution of the nonlinear programming model become the optimal solution, which has a high practical value solving the problem that high cost caused by the redundancy of some resource allocation and the lack of other resource cannot meet the safety requirements of the whole system.

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A Mixed Genetic Algorithm for Job-Shop Scheduling Problem of Robotic Manufacturing Cell with Multirobot

Yu-jun Yang, Shi-ming Shi and Chuan-ze Long

Abstract Under the consideration of the transporting time and the idle time of the robot among loading stations, machine tool and unloading station, to solve job-shop scheduling problem of robotic manufacturing cell with multirobot, this paper aims to figure out the minimum time that all work pieces are completed by the machine tool and transported to the unloading station. Firstly, this paper establishes a new scheduling method that robot transport process compose transport sequence matrix. Robot transports the work pieces to machine tool by transport sequence vector while machine tool manufacture processes it in accordance with the rules of First Come First Service (FCFS). Then, a mixed algorithm combining traditional genetic algorithm with heuristic adjustment algorithm is proposed to solve the scheduling problem. The effectiveness of algorithm will be verified by the result of experiment.

Keywords Genetic algorithm · Heuristic adjustment algorithm · Job-shop · Robotic manufacturing cell with multirobot

1 Introduction

With the development of the social modernization, the labor cost of manufacturing industry is becoming more and more expensive. However, the development of computer integrated manufacturing technology and robotic technology provides a new solution to manufacturing industry. Traditional manufacturing enterprises also have begun to apply a great number of robots and automatic technology to replace

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workers, which not only reduces labor costs, but also improves the productivity. At the same time, making reasonable production scheduling scheme can shorten the production period and bring more economic benefits to the enterprise. Therefore, researches on the scheduling problem of robotic manufacturing cell with multirobot have become a key in academic researches and most of the problem belongs to flow-shop scheduling problems [1, 2]. Actual manufacturing environment is so complex that research on the job-shop scheduling problem with transportation time is theoretical significance and application value.

Reference paper [3] use the improved tabu search algorithm to solve the problem of the job-shop scheduling problem with a single transport robot. Reference paper [4] propose a disjunctive Graph model, to solve the job-shop scheduling problem with multirobot, without considers transporting time and idle time of the robot among loading stations, machines tool and unloading station. Reference paper [5] studies the job-shop scheduling problem considering the transporting process.

2 Problem Formulation

The type of Job-shop robotic manufacturing cell with multirobot is composed of a set of m machine tool $M = \{M_1, \ldots, M_m\}$, a set of r transport robots $R = \{R_1, \ldots, R_r\}$, a loading station, unloading station and other auxiliary equipment. Each transport robot can transport only one job at one time, and each machine tool can process only one job at one time. After the job reaches the input buffer, the machine tool processes this job according to the rules of First Come First Service (FCFS). And all jobs must be moved into/out of robot manufacturing cell by robots through the loading/unloading station.

In iIn initial state, all transport robots and all jobs to be processed are ready on the loading station, and there are four assumptions listing as follow:

① All transport robots transport jobs along a fixed route; robot transport punctually and do not interfere with each other;
② The loading/unloading station and the input/output buffer of the machine tool have enough capacity to store these jobs;
③ The transport robots and the machine tool are running normally without abnormity and fault;
④ Ignore the time of loading/unloading of the robots and switching time of the jobs on machine tools.

Now a set of n jobs $J = \{J_1, \ldots, J_n\}$ need to be processed. Each job $J_j (J_j \in J)$ has ordered a set of n_j operation denoted $O_{j1}, O_{j2}, \ldots, O_{jn_j}$. The number of process in each job may be different but must meet $n_j \leq m$. The machine tool for processing each process have been specified and unique as well as considering transporting time and idle time of the robot among loading stations, machines tool and unloading station. The objective is to determine optimal feasible scheduling scheme, in order to minimize the make span $C_{max} = Min\{\max_{i=1,n}(C_i)\}$ while satisfying all the constraints and precedence. (Where C_i denotes the completion time of job J_i that reach the unloading station).

3 Multirobot Manufacturing Cell Layout

Robotic manufacturing cell is a system which is based on the idea of group technology that different types of equipments are connected by transport robots. The processing equipment of robotic manufacturing cell can reconstruct according to the specific process of the task. When the constraints or technological process changes, robotic manufacturing cell needs change from a configuration into another configuration to adapt to the change. There are mainly two problems existing in the reconfiguring the equipment layout of robot manufacturing cell: the layout and the selection of the equipment. The equipment layout mainly refers to the process of reasonable arrangement and sorting of the equipment in the robotic manufacturing cell according to requirement of the process, the production task and the equipment status; The equipment selection refers to the process of selecting the appropriate equipment from the robotic manufacturing cell according to the process planning reference [6]. When making scheduling schemes, the processing time of each process of the job is determined. In different equipment layout, routes of robot are different, and the transporting time is also different, which will directly affect completion time of the task. Therefore, formulating different scheduling schemes for different equipment layout is necessary. Reference [7] mainly researched four classic flexible manufacturing cell layouts, as shown in Fig. 1; the corresponding transport time matrix of four classic equipment layout, such as Table 1.

4 Transportation Scheduling Strategy

Each machine process o_{ji} requires a corresponding with the transport process to_{ji} before this machine process o_{ji} is processed. The first machine process o_{j1} is corresponding to the transport process to_{j1} from loading station M_0 to the machine tool μ_{j1} (μ_{j1} is the machine tool which can machine process o_{ji}). There is a transport process $to_{(jn_j+1)}$ before achieving unloading station M_{m+1}. There must be a corresponding transport process before when each machine process of each job is executed, and the machine tool processes this job according to FCFS. So just to determine each robot's transport sequence vector (i.e. the transport matrix), can obtained the only one scheduling scheme.

Example: Now there are 5 jobs being processed in a robotic manufacturing cell that have 2 transport robots and 4 machine tool which are composed according to the layout of the Fig. 1.

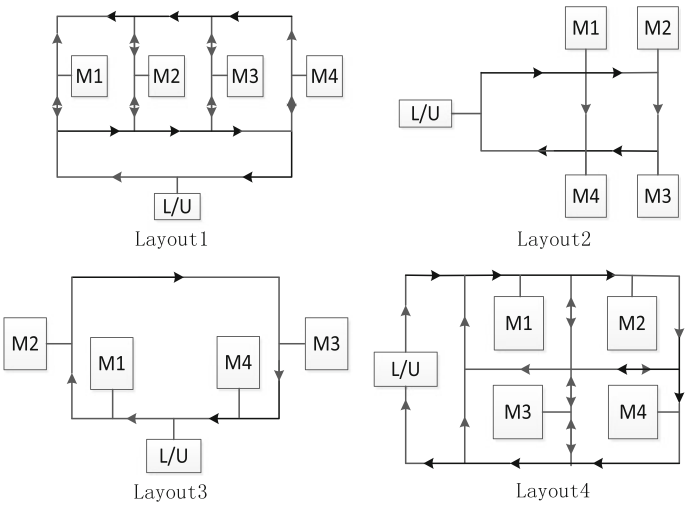

Fig. 1 Four kinds of classic miltirobot manufacturing cell layout

Table 1 Four kinds of classic layout transporting time matrix

		L/U	M1	M2	M3	M4
Layout 1	L/U	0	6	8	10	12
	M1	12	0	6	8	10
	M2	10	6	0	6	8
	M3	8	8	6	0	6
	M4	6	10	8	6	0
Layout 2	L/U	0	4	6	8	6
	M1	6	0	2	4	2
	M2	8	12	0	2	4
	M3	6	10	12	0	2
	M4	4	8	10	12	0
Layout 3	L/U	0	2	4	10	12
	M1	12	0	2	8	10
	M2	10	12	0	6	8
	M3	4	6	8	0	2
	M4	2	4	6	12	0
Layout 4	L/U	0	4	8	10	14
	M1	18	0	4	6	10
	M2	20	14	0	8	6
	M3	12	8	6	0	6
	M4	14	14	12	6	0

In Fig. 2, J_m refers to the machine tools matrix. The row and column numbers of this matrix respectively represents the job numbers and the process numbers, with 0 to representing vacancy. The numbers of the matrix T represent the process time for the corresponding position of the matrix J_m. If assume the transport sequence $Seq(R_1)$ order for robot 1: $to_{11}, to_{21}, to_{12}, to_{52}, to_{22}, to_{23}, to_{13}, to_{42}, to_{24}, to_{43}$; and the

$$J_m = \begin{bmatrix} 1 & 2 & 4 \\ 1 & 3 & 2 \\ 3 & 4 & 1 \\ 4 & 2 & 0 \\ 3 & 1 & 0 \end{bmatrix} \quad T = \begin{bmatrix} 8 & 16 & 12 \\ 20 & 10 & 18 \\ 12 & 8 & 15 \\ 14 & 18 & 0 \\ 10 & 15 & 0 \end{bmatrix}$$

Fig. 2 Machine ID and process time matrix

$$Seq(R) = \begin{bmatrix} 11 & 21 & 12 & 52 & 22 & 23 & 13 & 42 & 24 & 43 \\ 31 & 51 & 32 & 41 & 33 & 53 & 34 & 14 & 0 & 0 \end{bmatrix}$$

Fig. 3 Transporting sequence matrix

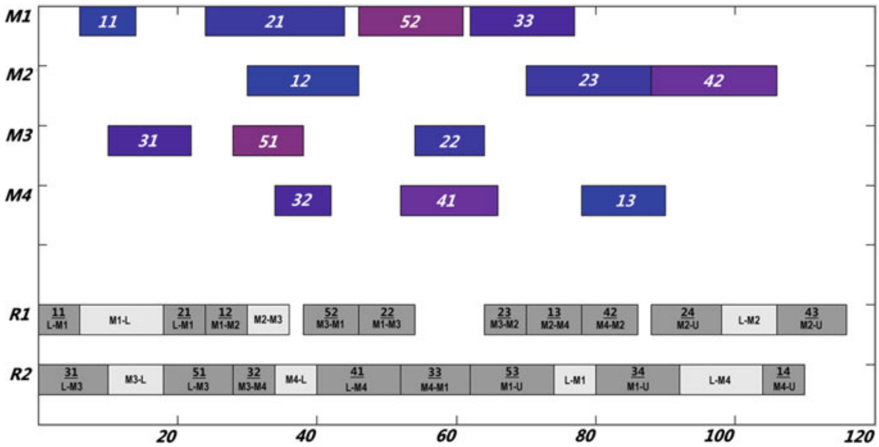

Fig. 4 Gantt

transport sequence $Seq(R_2)$ order for robot 2: $to_{31}, to_{51}, to_{32}, to_{41}, to_{33}, to_{53}, to_{34}, to_{14}$. $Seq(R_1)$ and $Seq(R_2)$ components of the transport sequence matrix $Seq(R)$ are show in Fig. 3. The robot transport sequence matrix can obtain a scheduling plant Gantt figure Fig. 4.

5 Mixed Genetic Algorithm

In the existing technical conditions and research achievement, intelligent scheduling method is one of the best and the promising method to solve the practical production scheduling problem [8]. This text proposes a mixed genetic algorithm combined the global search ability of traditional genetic algorithm and the local adjustment ability of heuristic adjustment algorithm based on the tow algorithms. Also, design a coding method for genetic algorithm based on the transporting sequence. It can effectively express a scheduling scheme. The design steps are as follows: first one is to design a kind of encoding and decoding of the transporting process problem; second one is to design the structure of fitness function based on the goal of optimization problem. And the closer to the target, the greater probability for the children generation to become population will be. Third one is the operation design that mainly includes selection, crossover and mutation operation.

The genetic algorithm has a large randomness in solving the scheduling problem, so it is necessary to use the heuristic rules to adjust the code of genetic individualism. In the production process for robotic manufacturing cell, the no-load time $tr'(M_{m1}, M_{m2})$ of robot from one machine tool to another are too large and can't be ignore. The no-load time not only affects the maximum completion time, but also increases the consumption of robot. A heuristic algorithm is used to design a reasonable method to reduce no-load and to be dedicated to the maximum completion time.

There are two processing procedures of mixed genetic algorithm.

Step 1: The transport process is encoded randomly to make an initial chromosome. The initial population consists of multiple chromosome. And the chromosome obtain the next generation through crossover and mutation.

Step 2: The chromosome is decoded into a moving sequence matrix, and then the matrix is adjusted by the heuristic rule. After that the target value is evaluated, and the fine chromosome is chosen as the next generation.

6 Computational Results

This paper adduce 40 standard examples of Job-shop robotic manufacturing cell with multirobot proposed by Bilge and Ulusoy [9]. The robotic manufacturing cell is composed of 4 machine tools, 2 or 3 robots according to those 4 kinds of layout which are already mentioned above the text. The transport time and no-load time of robot among the loading, the machine tool, unloading station of the three between is considered. Different from the reference paper [9], the time of the last process of each job transported to the unload station is taken into account during the experiment. Each example is represented by 'EX', the first number is represented by the number of Job, and after a digital represented by layout type. In the contrast group, MAS represent the result of algorithm proposed by the paper [10]. The parameter of Genetic Algorithm is as follow: the number of population is 30; the maximum genetic algebra elected is 1000; gap is 0.9; crossover rate is 0.8; mutation rate is 0.06. Use mixed genetic algorithm, which is based on transporting sequence and proposed in this paper, to run 10 times for each example and take the optimal value.

Table 2 The experimental results

Example	Paper [10]	This paper		Example	Paper [10]	This paper	
	MAS-2	GAHA-2	GAHA-3		MAS-2	GAHA-2	GAHA-3
Ex11	130	116	96	Ex61	153	139	121
Ex12	98	91	86	Ex62	123	114	108
Ex13	109	100	90	Ex63	128	107	106
Ex14	168	140	110	Ex64	189	170	139
Ex21	143	121	104	Ex71	129	146	115
Ex22	86	88	84	Ex72	92	101	88
Ex23	98	95	86	Ex73	93	93	89
Ex24	169	151	118	Ex74	156	163	138
Ex31	142	134	105	Ex81	196	171	167
Ex32	114	101	89	Ex82	172	155	155
Ex33	103	107	91	Ex83	172	155	155
Ex34	167	166	130	Ex84	251	192	177
Ex41	198	145	114	Ex91	178	136	121
Ex42	129	105	91	Ex92	123	114	106
Ex43	155	116	95	Ex93	119	114	105
Ex44	242	175	135	Ex94	181	159	131
Ex51	130	110	87	Ex101	188	166	154
Ex52	98	89	73	Ex102	154	149	140
Ex53	109	98	76	Ex103	158	161	141
Ex54	168	140	102	Ex104	246	203	172

As can be seen from the result, such as Table 2, which are 40 standard examples obtained by mixed genetic algorithm proposed by this paper, 82.5 % of the results are better than those of reference paper [10]. Different equipment layouts result in different transport time of robot between equipment in robotic manufacturing cell, so that the completion time is different. The 2 type layout is the best way in 4 kinds of design layouts. Through data analysis, we can know that adding a transport robot will speed up the completion time, and the longer the length of the transporting time, the more obvious completion time the robot will speed up.

7 Concluding Remarks

A scheduling strategy based on transporting process matrix consist of transport process sequence is proposed in this paper. Using the improved genetic algorithm and the heuristic adjustment algorithm to research the job-shop scheduling problem of robotic manufacturing cell with multirobot, the following conclusion are drawn: (1) scheduling strategy based on transport process matrix can effectively solve the scheduling problem of manufacturing cell with multirobot; (2) the mixed algorithm combining the traditional algorithm and heuristic algorithm can effectively find out the optimal solution to this scheduling problem.

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Intelligent Manufacturing Based on Cloud-Integrated Manufacturing CPS

Lei Wang, Qiang Liu and Xin Chen

Abstract In this paper, we propose a new agile automation system based on a Cloud-integrated Manufacturing Cyber-Physical System (CIMCPS). The system enables intelligent production in the manufacturing industry according to its production characteristics. Based on the CPS and the characteristics of cloud architectures, we design the framework for a manufacturing physical system based on CIMCPS. We analyze the framework and its corresponding function module, and obtain a key concept of intelligent control: the optimal state. We also present an intelligent hollow glass production line based on CIMCPS as an example of the implementation of our framework. We analyze the key technical problems and corresponding solutions of the system, and thus achieve the optimal control effect.

Keywords Cloud-integrated manufacturing cyber-physical system · Coupled optimization problem · Manufacturing resource · Optimal state

1 Introduction

Cyber-physical systems (CPS) are transformative technologies used to manage interconnected systems consisting of physical entities and computational process [1–3]. Because a physical device has more comprehensive perception and processing power, a CPS has additional functions and realizes organic coordination and interactive fusion between an information domain and a physical domain. CPSs contain a powerful infrastructure of sensors, actuators and communications

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networks, and are being increasingly recognized by enterprises. CPSs are being used in industrial automation, health care, energy area, space exploration, embedded equipment manufacture, and many other areas [4–6]. A CPS with cyber-physical fusion characteristics can significantly enhance the agility and flexibility of production control, adapt the system to complex manufacturing environment, and improve the effectiveness of production scheduling management.

Cloud manufacturing system (CMS) is a new mode of network manufacture that uses the service platform of cloud manufacturing to organize online manufacturing resources according to customers' preferences in order to provide them with different kinds of on-demand manufacturing services [7]. The cloud-integrated design and manufacturing process is a kind of service-oriented model that can gather massive amounts of manufacturing resources and expand the structure of manufacturing systems [8]. Users can use virtualization and servitization cloud manufacturing resources through the CMS. Manufacturing resource virtualization refers to the decentralized mapping of various physical resources for relevant virtual logical resources. Small manufacturing resources are deployed on the manufacturing cloud nodes of the platform to aggregate together to act as a virtual resource pool. Manufacturing resource servitization is the process of dynamic resource encapsulation and publishing, whereby resources await their activation, access, and call. CMS supports more complex resource types and resource operations. We will subsequently show use cases of resources clustered by CMS as follows.

(1) *Equipment Resource* (*ER*): It contains equipment used for the production, manufacture, diagnosis, and testing processes.
(2) *Software Resource* (*SR*): It contains application software or platforms used for design, production, manufacture, and management.
(3) *Information Resource* (*IR*): It contains data, documents, drawings, models, cases, and knowledge pertaining to the manufacturing process.
(4) *Ability Resource* (*AR*): It contains the details of the manufacturing process of high-performance computational devices, platforms, and related software facilities to support large-scale computing, design, analysis, optimization, and simulation.
(5) *Human Resource* (*HR*): It consists of experts, engineers, skillful workers or agents, etc., who participate in design, manufacture, production, testing, and management in the generalized manufacturing process.

In this paper, we introduce an integrated scheme of CPSs and CMS, and this scheme is interconnected and collaborative across system. We call this scheme Cloud-integrated Manufacturing CPS. We introduce the architecture of CIMCPS, its system characteristics and key technologies, forming an overall solution in support of industry 4.0, the manufacturing industry into the next generation [9]. The structure of CIMCPS has three characteristics suited to industry 4.0.

Based on the CMS, CIMCPS can cluster these isolated manufacturing resources and set up a self-organizing intelligent workshop to perform these manufacturing tasks.

Based on the CPS, the CIMCPS can build a feedback cycle for the manufacturing process and improve its agility as well as stability.

With support from the cloud platform with supercomputing capability and storage capacity, the CIMCPS can establish a large data center, enable scientific decision making, and execute an optimized production scheme.

The remainder of this paper is organized as follows: In Sect. 2, we introduce the framework of CIMCPS. In Sect. 3, we define the optimal state of manufacturing system and introduce some methods to achieve this optimal state. We show an application of our proposed framework in Sect. 4, and offer our conclusions in Sect. 5.

2 The Framework of CIMCPS

The framework of CPS is usually divided into three layers: the underlying perception and execution module, the middle-network communication module, and the upper calculation and decision module. In [10], the authors proposed a CPS architecture based on a credible prototype. A service-oriented architecture for a CPS was proposed in [11–12], where the framework was divided into a node layer, a network layer, a resource layer, and a service layer. Each layer of the hardware and the software resources encapsulated manufacturing services for different users. A four-layer prototype architecture of an automotive CPS was proposed in [13] with the ultimate goal of developing techniques to build safe and effective ACPSs. The authors of [14] designed and constructed the framework for a discrete manufacturing physical system based on the CPS, and analyzed the framework and its corresponding function module.

Based on past research, we develop a self-adaptive framework for CIMCPS in order to extend resources and capabilities through the cloud platform. The proposed CIMCPS framework is shown in Fig. 1, and consists of the following:

(1) *Physical layer*: It contains a variety of hardware and corresponding software facilities in the enterprise, including the real and virtual manufacturing resources. The virtual manufacturing resources would be used through resource agent selection. Physical layer allows these physical resources to access CIMPCS through smart sensor technology that uses sensor networks to obtain real-time monitoring data. Then actuator units can execute control instructions to obtain feedback from the controllers and thus improve production control performance.
(2) *Network layer*: Each physical entity, manufacturing unit, and information device in the CIMCPS can connect with another over Next Generation Internet (NGI) on Next Generation Networks (NGNs) to ensure the safety and reliability of message delivery.
(3) *Decision and planning layer*: Using the computational resources of the platform, the system makes scheduling decisions regarding the manufacturing

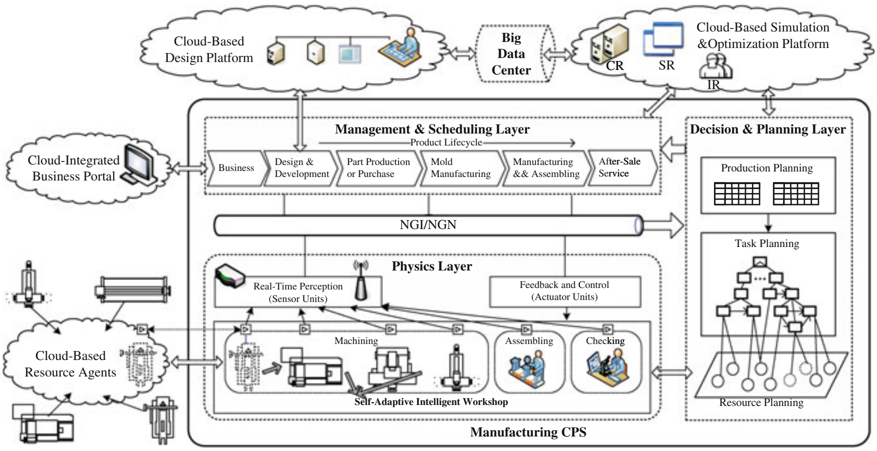

Fig. 1 The framework of CIMCPS

process primarily relating to equipment layer control and production line control. Equipment layer control optimizes the processing performance of individual components whereas production line control concerns scheduling decisions of the entire line, assigns corresponding manufacturing resources to tasks, and determines the processing sequence and start times of different machines in order to optimize production line operation and improve the control level of the product manufacturing process.

(4) *Management and scheduling layer*: It builds a bridge between the physical layer and the scheduling layer, and uses manufacturing services through the interface of services and resources. It contains a few means of accessing the platform, such as web access, numerical control equipment interface, different information services, remote desktop applications, authorized users etc., in order to effectively implement adjustments to the operation condition of the manufacturing process.

3 Optimal State

To keep up with global competition, manufacturing companies need to provide diversified manufacturing services and adapt their production planning and manufacturing plants to attain order completion in shorter time cycles. By using the self-adaptive control technology in the MCPS, the manufacturing process improves to a large extent, because it operates in an optimal or approximately optimal state, which is called the optimal state of a manufacturing system. Some key problems that need to be addressed under optimal state control are as follows:

(1) *Manufacturing process involves precise control and organization*: For example, production should not only consider the limitations of the manufacturing process, but should also take into account other constraints, such as those due to the production site. Incorporation of emergency orders inserting in the system should also be considered in the production process to change the production plan accordingly.
(2) *The decision layer responds rapidly to production scheduling instruction*: Since the manufacturing process uses the specifications of the work piece, stock, and machine, production control constraints continue to increase. This causes the scale and complexity of production scheduling to rise sharply. The decision layer must response rapidly and effectively to these changes.
(3) *Making a breakthrough in the key production process to improve production capacity*: The entire automatic production line capacity is limited by the single equipment production capacity. The optimization of the key problem facilitates the removal of capacity bottleneck and results in the improvement of automatic control level.
(4) *Solving complex structure of coupled optimization problem excited in manufacturing process*: Some optimization problems are related to each other in different stages of production manufacturing, and thus form a complex coupling structure.

All kinds of equipment and materials are used in the basic production activities of a manufacturing system, and the complexity and uncertainty of the manufacturing process limits the direction of information fusion and intelligent control. Using MCPS involving real-time perception helps monitor the manufacturing process, adaptively adjust the configuration parameters according to changes in the situation, and automatically maintain the stability of production. In other words, CIMCPS functions self-perceptively with regard to resources, self-configuration of manufacturing ability, and self-adaption of the manufacturing process. This can help attain and maintain a steady state of the manufacturing system.

4 Application Case

We use automated hollow glass processing to show how our proposed framework can realize intelligent manufacturing based on CIMCPS. Following cutting and separating, glass pieces were divided into rectangles of a predetermined size and conveyed sequentially. These rectangles, called items, were edged, washed, marked, toughened, hot-pressed, and sealed. Based on the production model and because of the complexity of the problem, glass processing involves both flow-shop and assembly-job scheduling problem. Based on this observation, we designed the intelligent hollow glass production line based on CIMCPS, as shown in Fig. 2.

Our intelligent workshop can convey real-time product information to the scheduling layer, and can simultaneously execute production orders through

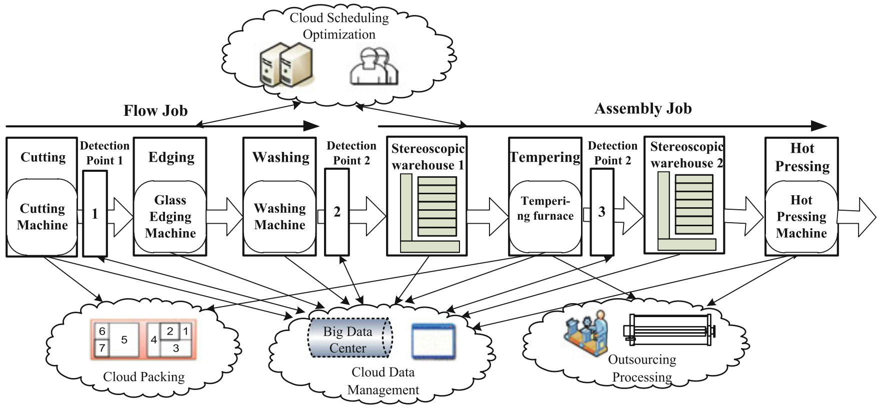

Fig. 2 Hollow glass production line based on CIMCPS

feedback to attain precise control in manufacturing. Based on actual production, our system can coordinate the production capacity of different manufacturing processes in order to realize transparent production-line load balancing. For further research on intelligent manufacturing of hollow glass, we propose the following problems and solutions.

4.1 Information Detection Point

Three auto-detection locations were set up for the production line, according to the production processing and action-execution sequences. This realized several functions, such as displaying the work process and important parameters, including real time data acquisition and recording, as well as alarms when something went wrong. The following production control actions were realized:

(1) *Detection Point 1*: Once the glass pieces were cut, Detection Point 1 was set up, as shown in Fig. 3. The geometric sizes of items were first measured according to item information, sounding an alarm when the sequence of items was incorrect. A lost sheet was detected and an alarm raised when an item was broken, and the system called the patch handler for patch processing. If the relevant item was not damaged, it was delivered to the edging machine.

(2) *Detection Point 2*: Once the items were washed and dried, Detection Point 2 was set up, as shown in Fig. 3. Following the invocation of the patch handler in case of a suspected broken item, the items were inspected to determine whether they were in place, and were then delivered to stereoscopic warehouse No. 1 on a loading car.

(3) *Detection Point 3*: Once the items were tempered, Detection Point 3 was set up, as shown in Fig. 3. Following the invocation of the patch handler in case

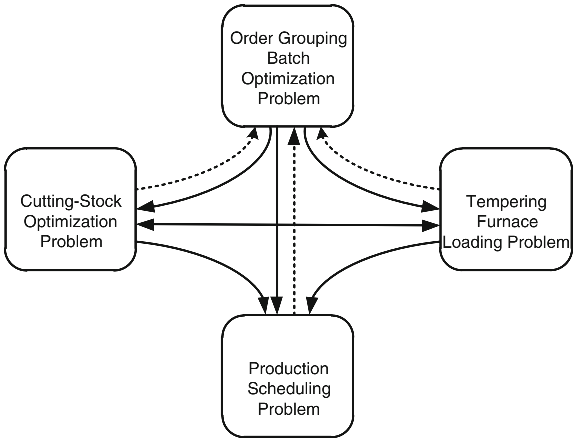

Fig. 3 The coupling relationship of production process

of a suspected broken item, the items were examined using their IDs to determine whether they were in place, and delivered to stereoscopic warehouse No. 2 on a loading car.

4.2 Production Process Based on Cloud Support

We needed to combine the hollow glass production line with the cloud computing platform featuring intelligent control in terms of the following aspects:

(1) *Cloud-integrated Packing*: A packing algorithm was deployed on the cloud platform through parallel search processing and multithread processing. Using a cloud platform with large-scale computing resources is vital to enhancing the efficiency of the algorithm.
(2) *Cloud-integrated Data Management*: Cloud storage technology is useful to store and analyze product information concerning processing. It can provide the user with ways to achieve efficient product data management and decision with regard to data fusion and data mining for large amounts of data.
(3) *Cloud-integrated Collaboration*: The use of a cloud super business portal can help collect a variety of information and realize resource sharing to take online collaboration of manufacturing services one step further, whereby it can provide outsourced processing services, such as glass tempering and hot pressing.
(4) *Cloud-integrated production scheduling*: Production scheduling is vital for the CIMCPS to process orders quickly and accurately. For real-time scheduling optimization, a large number of computing resources are required by the cloud scheduling platform to handle production exceptions, manage application and workload service levels and resources, and schedule activities.

4.3 The Coupled Optimization Problem in Manufacturing

Some related optimization problems exist in automatic hollow glass production line, so they have a complex coupling structure, as shown in Fig. 3.

(1) *Order grouping batch optimization problem*: We can group and split customer orders according to the material specifications. Order delivery dates and materials are delivered in batches in the production process in order to load balance the process. The coupling relationship reflected in the optimal objective function space depends on the cutting stock optimization rate and the tempering furnace loading rate. The solution to the job shop scheduling problem is checked to make sure that the batches fulfill the constraints.

(2) *Cutting stock optimization problem*: In the cutting stock of glass, reasonably selecting the specifications and the quantities of glass pieces helps obtain the optimal cutting stock scheme, given that the size and quantity of the items satisfy the guillotine constraint. The coupling relationship reflected in the solutions for the product batch as the input of the cutting stock optimization problem depends on the solution of the order group batching optimization problem, and needs to consider the batch-out sequential rule following cutting in order to improve the tempering furnace loading rate and reduce energy consumption.

(3) *Tempering furnace loading optimization problem*: It optimizes the loading plan to improve the tempering furnace loading rate according to the capacity of the glass tempering furnace and the arrival of the shelf. The coupling relationship reflected in the glass tempering process is a batch job source, and the loading sequence as well as the layout of items in the tempering furnace depends on the batch-out sequential rule.

(4) *Production Scheduling Problem*: It requires that production planning minimize the maximum completion period of the order according to the production process of the predecessor and successor relationships. The coupling relationship reflected in the product schedule is restrained by the production capacity of the cutting machine and the tempering furnace, and the result of ordered group batching is checked by the scheduling problem solving.

The key problem is that the decoupling method and the harmonious control should be studied in the intelligent manufacturing system control. Based on the structural characteristics of the coupling problem, we should establish an integrated coupling model based on general optimal rules, and implement cellular optimization for relevant sub-problems.

5 Conclusion

In this paper, we presented the framework of intelligent manufacturing system, and proposed a crucial conception: the optimal state of the manufacturing system. We took the hollow glass automation production line based on CIMCPS for example, analyzed key problems and corresponding solutions in intelligent manufacturing, and showed how to realize intelligent control and load balancing in intelligent workshop. In future work, we intend to study how to establish a centralized optimization model and seek decoupling method in the system.

Acknowledgments This work is supported by the project the Natural Science Foundation of China (No. 61104156), the National Key Technologies R&D Program of China (No. 2012BAF12B10), the Education and Research of Guangdong Province of China (No. 2012B091100025).

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Research on Emergency Management of Construction Project

Sheng-deng Xu

Abstract Construction industry plays an important role in our national economy, but the construction process of the construction project always have a variety of accidents, harming the business, social and public safety and interests. As to the various disasters in construction project caused by natural and unnatural factors, with the help of the emergency management theories and methods, this paper proposed five-level building construction project emergency management system, as well as management model based on the theory of emergency management stages and evaluation model based on grey-level analysis method, this study not only gives a theoretical basis to enterprises to cope with construction emergency management program, but also can improve enterprise management level, providing a new reference for emergency management.

Keywords Construction projects · Warning mechanism · Emergency management

1 Introduction

Construction project belongs to important area to the Chinese national economy, which can not only solve a lot of employment problems but also can help to achieve the gross national product. The construction units and individuals are too many, which can bring too much income and realize profits, accounted for a large part of GNP, but we cannot ignore the security problems and risk along with. Especially since the world economic recession in 2008, Chinese government has invested 4 trillion to stimulate domestic demand, and the construction industry is to become an important source of stimulating GDP. Huge investment not only brings a great opportunity to development of the construction industry, as well as a variety of technologies, processes and standards, making the occurrence risk and accidents of

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the construction industry are frequent, so emergency management issues within this industry is also worth to study.

Professor Mitroff [1] from Australia, studied emergency management in the field of construction projects in last eighties and published “Crisis Management in Construction Projects”. Professor Nickson and Siddons [2] proposed the concept of disaster, and demonstrated the construction project is not enough to rely solely on risk management. British scholar Bosher and Dainty [3] and others investigated and analyzed on the project management in UK construction industry and proposed the establishment of a unified strategic framework to deal with a variety of adverse effects on various factors in the UK construction industry environment, such as climate change, floods, agencies collapse, terrorist attacks. There are many significant achievements in the emergency management capacity assessment, such as “Richmond Assessment Law”, proposed by the British Imperial Chemical Company [4, 5]. In short, the construction project of emergency management, security management, many experts and scholars at home and abroad have done a more extensive and sophisticated research, theoretical research and applications have a very good inquiry, Based on construction projects involving various emergency management a variety of factors, proposed emergency management system and evaluation model of innovative building construction projects, provide valuable reference for building construction projects of Emergency Management.

2 Construction Project Emergency Management Model Building

2.1 Concept of Emergency Management Model of Construction Project

Construction project Emergency management model refers to arrangements in order to avoid harsh disastrous impact on the project under the relevant laws, regulations and policy guidelines for project management activities staff, resources and organization the process of the construction project [6].

Definition of emergency management construction project has the following two levels:

First, the broad definition of construction project emergency management refers to limited resources and time to complete a project in accordance under the requirements, standards with required quality; the narrow definition of construction project Emergency management only limited to the construction field with a clear quality standards, size and use of cycle, including the following important features: many constraints, large investment, high integrity, high risk, long construction period and fixity disposable [7].

Secondly, the construction project emergency management model is implemented macro-control and layout in the process of construction projects, providing methods and procedures to construction project emergency management framework with general applicability, so that this sustainable development model cannot meet the requirements of different emergency management construction projects [8–10].

2.2 Level Module Division of Construction Project Emergency Management

In the field of Construction projects emergency management is a system engineering, covering areas numerous and complex relatively fields, and therefore the study of construction projects needs to follow certain paths and scientific method, in accordance with the system of scientific theory on construction project emergency management is divided into of five modules, system mechanism level (SM-L), principle level (P-L), concept level (C-L), executive level (EX-L) and improved level (I-L) (Fig. 1).

System mechanism layer of construction project emergency management deal with features issues; principle layer refers to the objective law and the principles that construction project emergency management must follow; concept layer refers to the specific definition or the concept of disaster, theoretical implications and objects explanations of construction project Emergency Management, execution layer is the core content of construction project emergency management, solving construction project emergency management, and other content and methodological issues; improvement layer is based on a dynamic cycle of continuous improvement theory of construction projects emergency management and reasonable evaluation, adjustment, thus achieving sustainable development [11–15].

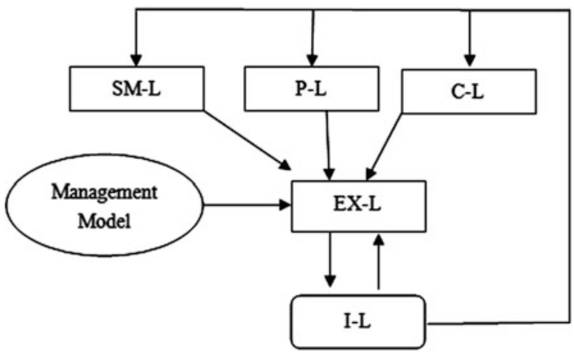

Fig. 1 Construction engineering project emergency management content system schematic

2.3 Three Phases of Construction Project Emergency Management Model

The existing construction project Emergency Management established on the basis of phases, in accordance with the a three-stage model proposed here is divided into three important stages, which are before-crisis, post-crisis and in-crisis, combined with the "system theory" to establish the whole process of dynamic construction project emergency management, taking into account the construction project itself, project management complexity, as well as ease of implementation, operational importance, therefore, "three-stage" model can avoid the cumbersome and complex division.

The "three phases of Construction project emergency management model" presented here accurately is divided into "routine emergency management system, emergency response management system and restore emergency management system." On the whole emergency management system operational mechanism, the consistent of three systems are independent of each other and interrelated effects of continuous improvement, forming a continuous improvement of a dynamic cycle of emergency management process; three modules have a conversion of mechanism, constituting a overall closed loop system, when the whole construction project meets a disaster, the system could be able to carry out effective emergency management. And this system could also have a reasonable response in peacetime, emergency time and rehabilitation construction of different processes, not just to follow the advance warning, during emergency and after the emergency rebuilding, but also be able to form a benign mode with effective evaluation and experience accumulation, increasing management improvements.

3 Construction Project Emergency Management Operation

3.1 Construction Project Daily Emergency Management

Construction project daily emergency management is monitoring, prevention, risk management and the functions of emergency management combined emphasis on the role of risk management. Combined with the characteristics of the risk management initiative in daily emergency control factors for construction projects, to establish emergency management early warning mechanism, reducing the risk of construction projects of disaster, caused by the impact of a disaster can be minimized. The main work of construction project daily emergency management is to project a variety of incentives reasonable disaster prevention and monitoring, including the identification of hazards and disaster factors testing and evaluation, education and training and the preparation of plans and so on. Disaster control methods is to strengthen the implementation of the control and analysis of the effect of the deviation of the two measures on excursion to accident identification and control, “immediate control” and “process control” in two ways.

3.2 Construction Project Restore Assessment

Construction project restore assessment is also referred to as “discontinued assessment” by the relevant project management and decision-makers in the face of disaster after the project is to determine whether the decision-making process of project emergency management, project management objectives without giving up the premise emergency management work carried out under a certain range; disaster emergencies affect more than once can bear project management within the capacity of the emergency management approach may fail, and then the entire region and society need to work together undertake emergency duties.

After a disaster has occurred in a construction project, human life and property safety is ranked on the first place, and project managers and related departments do not have enough time to consider additional measures, and then the restore assessment at this time appear to be relatively quick and easy. Here I propose a “disaster characteristic red line” and combine brainstorming and expert opinion method for disaster to get quickly and accurately determine, once characteristic of the disaster is more than the “threshold” then we can take a veto to give up construction project a expectation to set up goals and all-out rescue and emergency management with related work.

3.3 Construction Project Emergency Response Management

Emergency response management systems of construction projects mainly in the following several important steps: Alarm, loss evaluation, plan activation, emergency decision-making, emergency operations implementation, testing and evaluation. Construction project emergency management system is mainly for the project disaster positive response and the necessary emergency treatment to reduce and eliminate the impact of disasters on the construction project to bring harm, so as to effectively control and restore construction projects.

When construction projects enter into the emergency response phase, it will need to carry out immediate disaster evaluation and decision-making, adjustment, activate the relevant plans and available resources, environment and conditions, with the coordination of different departments to respond to disasters and to develop appropriate emergency response Program. Appropriate implementation procedures are as follows:

First, the relevant departments and owners involved in construction project emergency management activities at the first time and to and rescue with medical, engineering assistance, and they also have to carry out related work; secondly, with the formation of construction project contingency action plan, people can set up an emergency management team for construction projects to carry out disaster damage assessment and classification, combined with the reality of the disaster to develop emergency action plan; the third step is to carry out a comprehensive emergency response and control activities, once the emergency management plan was finalized, and on the need for timely call for clothing, food, and other equipment, energy and information resources for construction projects appropriately deal with catastrophic events, adhering to the "safety of life, protection of property" principle, to reduce losses, casualties at a maximum extent, and to eliminate hazards; and finally, on the construction project emergency management objectively evaluate implementation effect, determine whether the project disaster has been effectively controlled, and further guidance on post-project restoration and reconstruction work.

3.4 Construction Project Recovery Emergency Management

Construction Project Recovery Emergency Management's major work it to control the disaster event and the impact of control processing, elimination, once the evaluation system determines the crisis situation will be restored after the construction project management from the state of emergency "wartime" tension into the norm, but also needs to retain certain detection functions, then the construction projects enter into the recovery phase of emergency management. The main duties of this stage is to heal disaster in the construction project, to recover the project, reconstruction, and to investigate and analyze the causes of accidents, emergency management assessment process, while adjusting the construction project emergency management plans adjusted if necessary, to improve emergency management, including staffing, compensation, rehabilitation and reconstruction projects, the reasons for the disaster, project evaluation and improvement.

4 Construction Project Emergency Management Capability Assessment

Build a reasonable and complete construction project emergency management indicators need to objectively reflect the impact of various factors of emergency management process, and follow the principles and methods of constructing including scientific principles, systematic principles, operational principles and the principle of independence, qualitative and quantitative methods, such as Delphi method, Minimax deviation and minimum mean square error method (Fig. 2).

Here a three-level construction project emergency management index system has been built, which reads as follows:

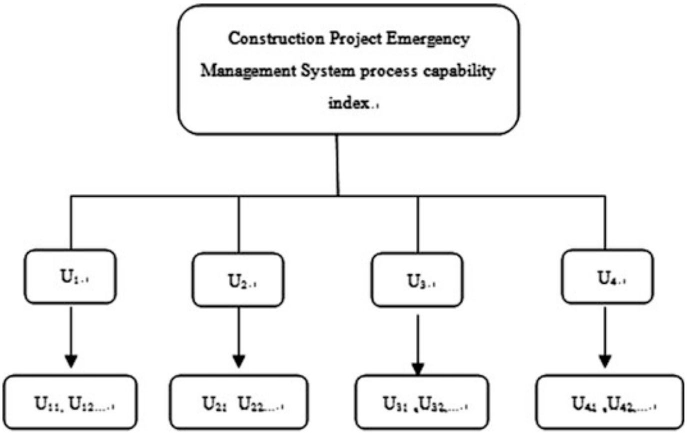

Fig. 2 Construction project emergency management process capability evaluation system

(1) Daily Emergency Management Capability Index:

$$U_1 = \{U_{11}, U_{12}, U_{13}, U_{14}, U_{15}, U_{16}\}$$

(2) Emergency response management capability evaluation:

$$U_2 = \{U_{21}, U_{22}, U_{23}, U_{24}, U_{25}\}$$

(3) Restore emergency management evaluation:

$$U_3 = \{U_{31}, U_{32}, U_{33}, U_{34}\}$$

(4) Emergency response management capability evaluation:

$$U_4 = \{U_{41}, U_{42}, U_{43}\}$$

In this paper, the gray AHP Evaluation method is applied to evaluate Construction Project emergency management. Firstly, to identify the evaluation indicators corresponding weight after stratified evaluation by means of simple and practical method of AHP hierarchical index empowerment and then comprehensive evaluation with gray theory. Next, calculate the coefficient matrix of gray evaluation, achieving a comprehensive index in accordance with the upper-level evaluation method, the final comprehensive evaluation, based on gray value judgment, and give a final conclusion.

5 Conclusion

The main reason why construction project accidents happen so frequently is because the relevant departments managers, who are responsible for emergency management and safety awareness of risk control is not strong, their emergency response capacity is limited once a catastrophic accident, and the slow control to the disaster would affect the quality. This paper studies the characteristics of building construction projects in the field of emergency management, pattern and content management, mainly achieved the following conclusions:

First, this paper proposed the idea of emergency management and disaster of construction project, and gives the relevant concepts, mechanisms and principles, defined the related concepts on construction project-level emergency.

Second, this paper proposed "three-stage" Construction Project emergency management Model, analyzes the relevant emergency management architecture, combined with the emergency response and "stage" theory to emergency management model, to determine three construction project emergency management systems, named as "daily emergency management", "Extreme emergency Management" and "Recovery Emergency Management" and their processes.

Third, this paper presents an evaluation model of construction project emergency management implementation phase, which can contribute to the relevant department and head of the construction project for the construction emergency management model, reasonable evaluation to the effect of the implementation and further improvement, optimization, adjust the emergency management activities.

Construction project Emergency Management is complex system engineering, research needs further refinement, and efficiency of emergency management activities, the accuracy will require further evaluation and optimization, AHP-GREY evaluation system also needs further study its applicability, practicality.

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The Performance of Synergetic Governance on Beijing-Tianjin-Hebei: A Case Study of Rail Transit Industry

Su-ying Gao, Ye Zhang, Long Xu, Hui Xing, Lu Zhang and Hong-feng Zhang

Abstract Based on the perspective of industrial chain, we chose the rail-transit industry chain, which takes the prior position in development as an example to do a precise research that contains dissecting the construction mode and observing the main enterprises in chain. Moreover, in order to coordinate industries, we use Shapley Mode to examine its degree and establish a reasonable mechanism of interests' distribution to explore a governance path to coordinate industries. Results show that industries tend to coordinate step-by-step and it will lead to rational distribution of interests in such region. Collaborative governance in region is an important way to accelerate interactive development of Beijing, Tianjin and Hebei to realize synergetic development. Among all approaches, industrial collaboration is priority. Consequently, the higher cooperation among industries, the better integration the region will be.

Keywords Modularization · Rail transit · Regional integration · Shapley mode · Synergetic governance

1 Introduction

On the co-development symposium of Beijing-Tianjin-Hebei, Xi Jin-ping, the general secretary of the Party, proposed that regional management should break the mindset and coordinate capital economic circle effectively. In response to the proposition, governors made regional integration speed up and enter into a substantive stage. Integration of a region's lagging with its leading regions has long been viewed by policymakers both as central to the ability to compete in the whole markets and as a mean to reduce spatial inequalities which might compromise social cohesion [1]. These regions are characterized by many similarities, such as

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geography and common customs. These characteristics enable cities to fulfill regional agglomeration. However, due to lack of an effective government, the region has not achieved desirable synergetic development. These cities could have collaborated on industrial grounds according to complementary advantage to make the dream comes true [2]. More importantly, building infrastructure construction, such as traffic network, is the basis of high efficiency operation and will guarantee the sustainable development of the region. Traffic network, including roads, railways, shipping and aviation provide material carrier to further the industrial distribution and city layout in the region. In the meantime, the opening of the Metro reduced air pollution from one key tailpipe pollutant to relief the current pollution haze in region [3].

Region consists of the center urban and other cities adjoin to the center. The center part has the ability to influence the adjacent cities and attracts much attention to and form a good spatial carrier for regional economy. As a new mode of industrial organization, the extension of industrial chain rationally manages the resources and rapidly fuels the economy in the region.

In this study, we analyze regional integration based on the perspective of industry chain government. By doing this, we understand how to allocate the resources in micro-level and how to build reasonable industrial structure [4]. Mi [5] takes a research on the value chain's spatial reorganization and upgrading path on late-coming transformation country. Meanwhile, more contributions share a common concern for the relationship on the industry chain between states intervention and societal autonomy [6]. On this basis, we build the mechanism to distribute regional interests in order to integrate regional members and agents. Once all cities maximize their own interests, regional governments would be more efficient and the policy of governments for regional integration is realized through the industrial chain in micro-level shown in Fig. 1 [7–9].

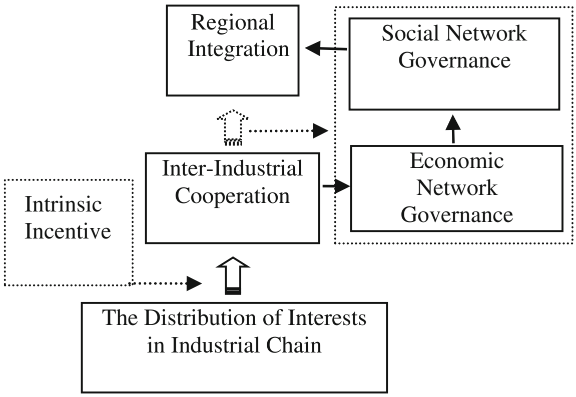


Fig. 1 Policy of governments for regional integration

2 Definition of Research Subjects

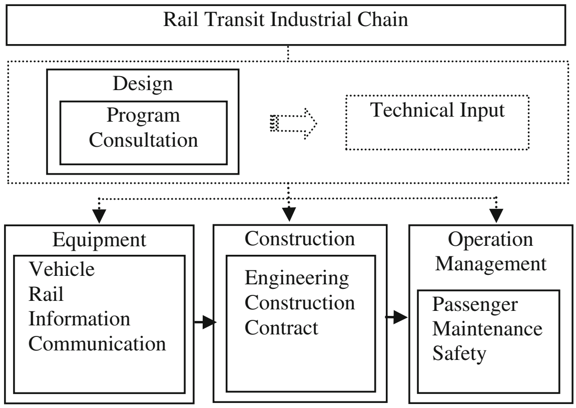
Because of its impact on sustainable development of the region, rail construction in China is currently at the peak and will be a top-priority in coming years [10]. Studies in Beijing-Tianjin-Hebei have shown that an-hour traffic circle strengthens the link between the central urban and other cities. More specifically, building efficient transport system is the essential way to promote cooperation between Beijing, with high density and level of high-tech information, Tianjin with advanced manufacturing technique and the base of manufacture Hebei. We are taking a look at how to integrate and distribute rail-transit industry. Industrial chain is broadly defined as a whole system in which component enterprises cooperate in the productive process under certain technical level. Final goods, intermediate goods as well as the techniques in chain shape the different forms of industry chain [11, 12]. These enterprises in chain utilize their comparative advantages, e.g. technology, information, and brand to form and perfect the industrial chain [13], and optimize allocation of regional resources to meet the demands of multidimensional areas through continuous competition and cooperation [14]. Allan Collard-Wexler conducted a study on the U.S. steel industry to verified vertically integrated production and reallocation of output was responsible for an increase of the industry's productivity [15].

With economic development, enterprises in industrial chain are more likely to be modularized [16]. Modular industrial chain is a semi self-regulated system in which enterprises are separated and integrated into various complex subsystems under certain rules [17]. In such industrial chain, the upstream enterprises do not entirely depend on their downstream ones to make profits. Those attributions apply to production level and value creation as well. The fundamental reason for formation of modular industry chain is the technology attached to the enterprises.

Due to high complexity of technology as well as high density of innovation and high level of profitability, rail-transit industry chain is modularized [18]. Rail transit is a public facility composed of fixed tract, rail, vehicle and service. The vehicle types and technical characteristics can be divided into tram, subway, light rail transit, suburban railway, single rail transit pass, traffic system, and maglev traffic. It is often highly controlled by the government, because of its effect on public welfare and needs for large investment and long payback period [19].

In this article, we have selected the industry chain in which rail project is designed and built. The equipment and raw material firms make the upstream of chain, the constructions are in the middle of chain, and supervision, inspection and operation firms constitute the downstream. By focusing on rail transportation construction projects, we have divided the rail-transit industry into design, equipment, construction and operation shown in Fig. 2.

Fig. 2 Composition of rail transit industrial chain



3 Materials: A Reality Analysis of Components in Rail-Transit Industrial Chain

3.1 Upstream Firms

Beijing is the nucleus of hi-tech industry and undertakes the upstream position in rail-transit industrial chain, because of its unique advantages in market, technology, talent, policy and resources [20]. In 2014 volume of business technology contracts in Zhongguancun Software Park, modern traffic network reached to 28.5 %, ranking the first place. Since 2011, Beijing national rail transit base has been located in Fengtai Science Park that possesses advanced R&D technology and excellent production conditions in the mainland [21]. There are many leading state-owned enterprises in the Park, e.g. China Railway Group Limited, Beijing National Railway R&D Institute of Signal and Communication Co. as well as private enterprises, e.g. Beijing Dinghan Technology Co., Traffic Control Technology, and Beijing Railway Institute of Mechanical and Electrical Engineering Co. The technology innovation alliance of rail-transit industry is composed of all these enterprises in Beijing [22].

The development of high-tech accelerates the rapid growth of rail-transit industry. The industrial park has currently three national enterprise technical centers, nineteen Beijing urban hierarchy enterprise technical centers, one national engineering technology center, and three Beijing urban hierarchy technology development mechanisms, each of them has a technology enterprise hatching center. These institutions provide technology guarantee for rail-transit and related industries. Beijing takes the major role in research and design, but, because of the high cost of land and human wage, the equipment manufacturing in Beijing is not well organized, and thus it cannot take the leading role in manufacturing industry.

3.2 Midstream Enterprises

Since the planned economy period, Tianjin is known as the industrial city and has been undertaking the important position of rail-transit manufacturing industry. According to the smile curve, while the equipment manufacturing industry, in the middle of the chain, has low added value and profits, its output value makes 30–35 % of the whole industry chain [23]. As the core of manufacture, the equipment manufacturing industry plays the connecting role to the industrial chain. As duopoly in rail-transit industry, both China CNR and CSR Corporations have established strong ties with Tianjin. The industrial base of the former was settled in 2010 in Tianjin Dongli Distinct to meet the needs of railway and urban rail transit, and the latter invested three billion RMB to settle its industrial base for the development of rail-transit vehicles and key components.

In Hebei province, many equipment-manufacturing enterprises with low output value and low level of technology are located in the middle of industrial chain. These firms mainly provide human resources and low-grade equipment manufacturing services for the industrial chain.

3.3 Downstream Firms

The downstream firms in rail-transit industrial chain such as Beijing Subway Operation Co., Tianjin Subway Operation Co. and Tianjin Metro Group Co. regulate the routes in Beijing-Tianjin-Hebei region and provide services for engineering supervision, testing, operation and consultation. Beijing Subway Operation Company was opened in 1969 and currently is a state-owned oversize professional operator in urban rail-transit network. This company has constructed the first subway line in Beijing and has been in charge of operation of urban and inter-city railway train, including subway lines 1, 2, 5, 8, 10, 13, Ba-tong, Olympic Branch and airport. Tianjin Metro Group Co. was founded in 2000 and is currently a large state-owned enterprise that supervises the rail transit planning, investment and financing, construction and operation management, and business development. All the enterprises are shown in Table 1.

4 Shapley Method

A review of past research is an important part of this stage of the assessment. D'Aspremont and Jacquemin [24] created a model about noncooperative R&D in duopoly with spillovers, they broaden the application scope of Game Theory. Liu and Li [25] carried out the research about the vertical cooperative innovation alliance game mode in firms of industry chain. We analyzed the interests'

Table 1 Rail-transit industrial module representative firms (filtered as enterprise business income)

Design consultation	Beijing Dinghan Technology Co. Beijing Zongheng Electro Mechanical Technology Development Co.
Equipment manufacturing	Beijing Feb. 7th Railway Transportation Equipment Co. (CNR) Shijiazhuang Vehicle Co. (CSR) Hebei Stone Copper Casting Co. (CSR) Tianjin JL Railway Transport Equipment Co. (CNR) Tangshan Railway Transportation Equipment Co. (CNR) Vichen Group Lohr Transportation Industry Tangshan Nevada Corporation Tianjin Railway Signal Factory
Construction	China Railway Group China Railway Construction Corporation China Railway Signal & Communication Corporation Tianjin Metro Group Co.
Operation service	Beijing Subway Operation Co. Tianjin Metro Group Co. Tangshan Wantong Motor Repair Co. Tangshan Automobile Sales and Service Branch Railway Transportation Equipment Co.

distribution of industrial chain in Beijing-Tianjin area by using the Shapley Method. In the theory of cooperative game, to make the society more stable, profit allocation should be fair and rational. The enterprises at the middle of chain that deviate from the major alliance will lose some earning, and thus will prefer to stay with the alliance, leading to its further stability [26].

Different from traditional industry chain, modular industrial chain has a unique value generating mechanism. From the perspective of self-interest maximization, enterprises in the chain tend to pursue the surplus profit. According to the study of Anderson [27], the net benefits of transit systems appear to be much larger than previously believed. In the process of industrial production operation, it matters how to balance the efficiency of the chain and the interests of individual enterprises. The optimal strategy means that all in the chain share the surplus profits through value creating on production activities.

Enterprises pursue profit maximization includes producing activities and non-producing activities in this process, the former which can enhance social welfare but the latter will consume the welfare [28]. In order to avoid this phenomenon, the foundation of smoothing the industrial chain is the establishment of a reasonable mechanism for interests' distribution that will encourage enterprises to cooperate by sharing profits in the chain is necessary [29]. From the perspective of Multiparty Cooperative Game, all parts of the chain will likely adapt to the cooperation mode. As a result, we use the Shapley Mode to analyze the mechanism of interests' distribution in the chain.

There are various definitions for Shapley Mode:

Definition 1 Suppose the partners have the assemble $\mathrm{N} = \{1, 2, 3, \ldots, \mathrm{n}\}$; each subset S $(S \subseteq N)$ is the alliance of set N and $P(N)$ is the entire alliance.

Definition 2 A real function v is the characteristic function of $P(N)$, and function $v(S)$ is the formula to calculate the maximum profit in alliance S. Function $\mathrm{v}(N)$ is the profit produced when the partners joint together, and with no one in the alliance, the profit is zero.

Definition 3 To each alliance, v is a convex game, if $\mathrm{v(U) + v(T) \leq v(U \cup T) + v(U \cap T)}$.

Definition 4 The payment vector x that meets the following conditions is the distribution of profit about v. $\mathrm{x_i \geq v(\{i\})},\ \mathrm{i} = 1, 2, 3, \ldots, \mathrm{n},\ \sum_{\mathrm{i} \in N} \mathrm{x_i} = \mathrm{v}(N)$.

Definition 5 In alliance S, x is a feasible plan to distribute if the distribution vector x meets the conditions $\sum\limits_{\mathrm{i} \in N} \mathrm{x_i} \leq \mathrm{v}(S),\ S \subset N$.

Regarding the Cooperative Game Theory, Shapley Method is used in multi-cooperation countermeasure and similarly in analysis of interests' distribution in modular industry chain.

In the network of industrial chain, v(*N*) is the set of the member enterprises and v is profit function. Under the cooperation of N, the total profit of the assemble is v (N) and the profit distribution of each partner is so-called Shapley:

$$\phi_{\mathrm{i}}(\mathrm{v}) = \sum_{S \in S_{\mathrm{i}}} \mathrm{w}(|S|)[\mathrm{v}(S) - \mathrm{v}(S - \mathrm{i})] \quad \mathrm{i} = 1, 2, \ldots, \mathrm{n}.$$

$$\mathrm{w(|S|)} = \frac{(\mathrm{n} - |S|)!(|S| - 1)!}{\mathrm{n}!}$$

The weight coefficient $\mathrm{w(|S|)}$, $\phi_{\mathrm{i}}(\mathrm{v})$ is the probability to appear of the Union members, is the potential contributions of the enterprise i to the alliance, also it can definition the assigned profit of member i in cooperation N [30].

We used Shapley Method to calculate the optimal condition in theoretical condition, compare the result with the reality to figure out whether the mechanism of interests' distribution appropriate and the regional development coordinated.

We have chosen the following enterprises: Beijing Dinghan technology co., China CNR co., and China CSR co., as the sample. Gross profit margin is chosen to measure the enterprise revenue. Take one-year gross profit margin (GPM) as the indicator to considerate the profit distribution to apply for Shapley Method shown as Table 2.

Table 2 2009–2013 rail transit industrial representative firms gross profit margin

Sales gross profit rate (%)						
Enterprises	2009	2010	2011	2012	2013	2014
Dinghan	47.60	42.91	46.84	35.84	39.28	40.81
CSR	16.43	17.61	19.09	18.25	17.79	20.96
CNR	12.52	13.25	13.43	14.65	17.62	18.90

5 Results and Discussion

We put the data of 2009 in the function: $\phi_{\mathrm{i}}(\mathrm{v}) = \sum_{S \in S_{\mathrm{i}}} \mathrm{w}(|S|)[\mathrm{v}(S) - \mathrm{v}(S - \mathrm{i})]$

Then we calculated the theoretical value of gross profit margin in 2010:

$$\phi_{\mathrm{i}}^{2010}(\mathrm{v}) = \{46.03667, 16.82333, 12.76333\}.$$

we took the discrete degree of $\phi_{\mathrm{i}}^{2010}(\mathrm{v})$ as the level to signify the equilibrium of income distribution: $C_{\Phi_{\mathrm{i}}(\mathrm{v})}^{L2011} = 16.63573$, and showed that the discrete degree of the actual data of enterprise profit distribution in 2010 was better than that of the theory. The benefit distribution mechanism of the industrial enterprises in the production and operation improved:

$$C_{\Phi_{\mathrm{i}}(\mathrm{v})}^{S2010} = 16.01466. \quad C_{\Phi_{\mathrm{i}}(\mathrm{v})}^{S2010} \prec C_{\Phi_{\mathrm{i}}(\mathrm{v})}^{L2010}.$$

We used 2010 actual profit distribution data to calculate the 2011 gross profit margin Shapley discrete degree: $\mathrm{C}_{\Phi_{\mathrm{i}}(\mathrm{v})}^{\mathrm{L2011}} = 16.63573$. The actual discrete degree in 2011, similar to 2010, showed that the real profit distribution did not reach the optimal level:

$$\mathrm{C}_{\Phi_{\mathrm{i}}(\mathrm{v})}^{\mathrm{S1}} = 17.88074. \quad \mathrm{C}_{\Phi_{\mathrm{i}}(\mathrm{v})}^{\mathrm{S2011}} \succ \mathrm{C}_{\Phi_{\mathrm{i}}(\mathrm{v})}^{\mathrm{L2011}}.$$

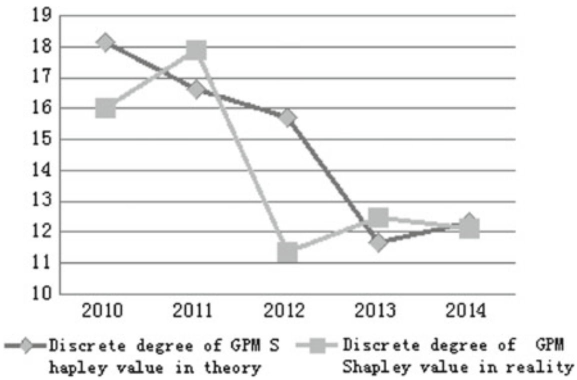
Similarly, 2010–2014 gross profit margin Shapley discrete degree $C_{\Phi_{\mathrm{i}}(\mathrm{v})}^{L}$ vector in theory is:

$L = \{18.15221, 16.63573, 15.70003, 11.68009, 12.32907\}$ and 2010–2014 real gross profit margin Shapley discrete degree $\mathrm{C}_{\Phi_{\mathrm{i}}(\mathrm{v})}^{\mathrm{S}}$ vector is:

$$S = \{16.01466, 17.88074, 11.33861, 12.45662, 12.09900\}$$

Figure 3 shows the comparison between vectors L and S. Observe the period of these five years, the actual sales gross profit margin of discrete degree in 2010 and 2012 are lower than the absolute value of sales gross profit margin. It turns out that in these two years the profit allocation mechanism of industrial chain is quite reasonable in this area. In 2011 and 2013, the discrete degree of sales gross profit

Fig. 3 Comparison of gross profit margin Shapley discrete degree between real and theory. *Note* The data comes from the company's annual reports



Note: the Data comes from the company's annual reports.

margin in real is higher than the theory of discrete degree of profit allocation mechanism of industry chain in the area. In these two years, the real profit allocation may be inferior to Shapley, but the gap is smaller. What is more, the gap in 2013 between theory and reality is much smaller than in 2011. In 2014, the theory and reality is nearly turned to be minimal. Overall, the reasonable degree of interest distribution within the region is slight fluctuations, but its gradually getting perfect.

In summary, the enterprises in rail-transit industry chain have distributed reasonably in the region. According to the results from analyzing the connection and operation between industrial chains, the industrial chain has taken into shape. Beijing is in charge of developing high-tech, Tianjin is responsible for produce intermediate goods because of its strong industrial basis and powerful backbone manufacturing enterprises. Although Hebei has been involved into the industrial chain, it only plays a limited role in this process due to insignificant scale and low added value. Overall, the structure of rail-transit industry chain has been elaborate built in the region, the collaboration among enterprises has been improved, and the efficient coordinated in the modular industrial chain has been formed. Based on the Shapley Method, we analysis the interest distribution of representative enterprises in Beijing and Tianjin. The results show that the degree of benefit distribution mechanism among enterprises has slight fluctuations, but in overall it tends to be more fairly and the mechanism of interest distribution has improved gradually.

Covering all kinds of production and services, industrial chains has formed a network to integrate regional economy. As a new type of industry cooperation organization pattern, standardizing industry chain is conducive to rationalizing its structure. And perfecting mechanism of interests' distribution formed continuous intensive to enterprises. As a result, enterprises have the willing to take part in cooperation, and the region could achieve sustainable development of industry. The industry synergy will lead to formation of regional economic network, which could help enterprises to achieve economic cooperation. The economic network will coordinate society and steady economy to achieve regional integration. The coordination of different enterprises in the region will be improved continually by strengthen their connection vertically and horizontally. Eventually, all aspects in the region become indivisible.

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An Evaluation of Impulsive Choice and Trait Impulsivity in Drug Abusers

Yan Kong and Jian-xin Zhang

Abstract The drug abusers tend to make impulsive choice, impatiently choosing a smaller-immediate reward rather than a larger-late reward. The present study compared the impulsive choice and trait impulsivity of three groups of individuals and investigated their relationship. The groups were heroin abusers, methamphetamine abusers and non-drug-using controls. Analysis demonstrated that drug abusing individuals made more impulsive choices or discounted delayed rewards more steeply than individuals with no history of drug use. And these differences did not depend on drug type. Furthermore, no significant correlation found between impulsive choice and trait impulsivity, as well as impulsive choice and drug use variables in drug groups. Overall, this study extended the understanding of behavior process in drug abusers; however, the results need to be verified in future researches.

Keywords Drug abuse · Impulsive choice · Trait impulsivity

1 Introduction

Impulsive choice refers to preference for a smaller-immediate reward over a larger-delayed reward, which is evident in many problematic behaviors including substance use. Substance dependent individuals often select the immediate and temporary benefits of drug use over, and at the expense of delayed but more sustainable rewards such as social relationships, employment, and health. Delay discounting tasks [1] have been successfully utilized to assess this type of decision-making. Delay discounting characterizes how a reward loses value as the

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delay to its receipt increases [2, 3]. It provides an explanation as to why some individuals may choose a smaller, more immediate reward (e.g., smoking a cigarette and consuming a drug) over a relatively larger, delayed one (e.g., improved health, financial stability, and social standing). As the function by which a reward is subjectively devalued by a delay to its delivery, delay discounting can be portrayed by a hyperbolic equation [4]:

$$V = A/(1 + kD) \tag{1}$$

where V represents the current value of a delayed reward, A is the amount of the reward, D is the delay to the reward, and k is a free parameter that reflects the rate at which the reward loses value with increases in delay, and it is an index of impulsive choice. Higher k value represents stronger tendency to make impulsive decision.

In delay discounting tasks, participants are asked to choose between a series of immediate and delayed rewards. Delay discounting rates have shown discriminative validity across a wide range of substance use disorders, with individuals who use drugs being more likely to make choices that favor immediate rewards than non-users [5–7]. Specifically, research has demonstrated that heavy drinkers discount delayed rewards more than light drinkers [8–10]. Similarly, individuals dependent on opiates [7, 11], cocaine [6, 12] methamphetamine (METH) [13–15], and heterogeneous groups of substance abusers discount delayed rewards more than nondependent controls [16–18].

However, it is notable that several recent studies have shown delay discounting rates may not be equal across all substances of abuse [19, 20]. For example, Kirby and Petry found that heroin and cocaine abusers, but not alcohol abusers, had greater discounting rates than controls [20]. It should be noted, however, that several studies have shown that alcohol abusers do discount delayed rewards more than controls [8–10]. Further research will be needed to determine whether delay discounting rates are relatively similar across substance use disorders or whether certain substance use have a greater impact than others on discounting rates.

Higher rates of delay discounting are often operationalized as an index of impulsivity, and as such impulsive discounting may be related to trait impulsivity. It can be supposed that impulsive individual may likely discount delay rewards steeply and make more impulsive choices.

The current study had two main goals. One was to compare the discounting rates and trait impulsivity scores among three groups of individuals, i.e. the heroin abusers, methamphetamine abusers and an additional group as non-drug controls. The other is to determine whether impulsive choice would differentially correlated with aspects of trait impulsivity among the drug abusing groups. Given evidence that substance users have a greater tendency to discount delayed monetary rewards than healthy controls, it hypothesized that drug abusers would discount delayed rewards more than the control group, and heroin and methamphetamine abusers would have differential level of delay discounting, given that the two common drugs of abuse influence neurophysiologic functions through different neural mechanisms [21, 22]. Furthermore, in light of evidence that higher trait impulsivity is associated with more impulsive choices [7, 8], we expected no differential relationships between trait impulsivity and impulsive choice among heroin and methamphetamine abusers. In addition, magnitude effects of delay discounting, as well as individual differences on trait impulsivity, would be examined among these groups.

2 Methodology

2.1 Participants

Participants were 220 individuals of whom 47 were heroin abusers, 71 were METH abusers and 102 participated as non-drug-using controls.

The participants in the two drug using groups were enrolled from compulsory treatment centers in Beijing. Eligibility criteria included: (1) age between 18 and 45 years old; (2) minimum of 9 years of education; (3) meeting the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; American Psychiatric Association, 1994) criteria for past dependence on heroin or meth-amphetamine at the time they entered the institutes; (4) abstinent for more than 14 days. The participants were excluded if they (1) had serious medical illnesses that required pharmacological treatment; (2) had a history of head injury or neurologic illness; (3) had a past or current DSM-IV diagnosis of psychotic disorders.

The participants in the control group were recruited from security workers and medical workers who reported no previous or current history of alcohol or illicit substance abuse. And they also fulfilled the criteria of age and education period as the drug groups.

2.2 Measures

Monetary-Choice Questionnaire (MCQ) [7] was administered to assess impulsive choice. This instrument comprises 27 items presenting choices between smaller, immediate rewards ($11–$80) and larger, delayed rewards ($25–$85). For example, on the first trial participants were asked ‘Would you prefer $54 today, or $55 in 117 days?’. The participant indicated which option he or she would prefer to receive by ticking the option on the questionnaire. In present study, amount of U.S. dollars in all options were replaced by that of Renminbi through an exchange rate at 1:6. Each item in the questionnaire is characterized by a value, k (i.e., discounting rate), representing the amount of discounting of the later reward that renders it equal to the smaller reward. A single k estimate (discounting-rate parameter) [7], the geometric mean of all item-level k values, represents the overall rate of discounting (k in Eq. 1). Discounting-rate parameters can range from 0.0016 (selection of the delayed reward option for all items, or no discounting) to 0.25 (selection of the immediate reward option for all items, or always discounting). The questionnaire can also identify discounting rates respectively for small ($25–$35), medium ($50–$60) and large ($75–$85) delayed-reward. The k values were used as the dependent variables. As k increases, the person discounts future rewards more steeply. Accordingly, higher k values correspond to higher levels of impulsive choice. Because k values had a positively skewed distribution, statistical analyses were performed on the natural logarithmic trans-formation of these values: $\ln(k + 0.001)$.

Barratt Impulsiveness Scale (BIS-11) is a widely used instrument evaluating the trait impulsivity [23]. The Chinese version of BIS-11 [24] was used in this study. It consists of 30 items with a 5-point response scale. This questionnaire contains three subscales: (1) motor impulsivity, e.g. "I do things without thinking", which indicates propensity for action without thought, (2) nonplanning impulsivity, e.g. "I plan tasks carefully", which assesses the ability for purposive future action and (3) attention impulsivity, e.g. "I don't pay attention", which illustrates the capacity for sustained attention. The higher BIS-11 scores are the higher impulsivity. The total scores and three subscale scores were analyzed.

2.3 Procedure

The drug abusing participants received a structured interview administrated by a researcher and an assistant in which participants' information on demographics and history of drug use were collected. Then they completed the self-report questionnaires of BIS-11 and MCQ. Information on drug use included age of onset, frequency of use (episodes per month: (1) one to three times upon a month, (2) one to three times upon a week, (3) daily), dose of use (average amount in each episodes), duration of use (the number of years since the onset of the use), route of drug administration and days of abstinence. The participants in non-drug control group only filled out a set of questionnaires comprising demographics, BIS-11 and MCQ.

2.4 Data Analysis

All statistical analyses were made by using SPSS for Windows 17.0 package program. Chi square (χ^2) test was used for categorical variables when comparing groups. Data for continuous variables was analyzed using independent sample *t* test, One-way ANOVA or repeated-measure ANOVA followed by LSD post hoc testing or contrast when the variance analysis revealed a significant main effect. Pearson correlation analysis was used to evaluate the relation between drug use variables, discount rates and trait impulsivity. It was accepted as statistically significant level for the results that the observed *p*-value was less than 0.05.

Table 1 Demographic and substance use characteristics of participants

Variables	Heroin	METH	Control	Test statistics	p
n	47	71	102		
Gender (% male)	81	72	75	χ^2 = 1.242	0.537
Age (years)	40.3 (7.4)	33.7 (8.3)	24.9 (4.1)	F = 102.406	<0.001
Duration of education (years)	10.3 (1.7)	10.5 (1.9)	14.4 (1.4)	F = 158.894	<0.001
Age of onset (years)	25.1 (5.6)	27.0 (7.3)	–	t = −1.553	0.123
Duration of drug use (years)	15.0 (6.1)	3.6 (2.7)	–	t = 12.155	<0.001
Frequency of drug use (%1:2:3)	19/17/64	51/26/24	–	χ^2 = 19.570	<0.001
Average dose of drug use (grams)	0.40 (0.42)	0.28 (0.25)	–	t = 1.839	0.077
Abstinence (days)	85.0 (19.4)	99.4 (44.6)	–	t = −2.398	0.018

Note Unless otherwise noted, entries represent means and standard deviations

3 Results

3.1 Group Characteristics

We conducted an initial series of comparisons among three groups on demographic variables and between two drug abusing groups on substance use variables. As shown in Table 1, there were no group differences in gender; however, the three groups were significantly different on age and education years. Using LSD post hoc test, we found heroin and METH abusers were significantly older than controls while METH abusers were younger than heroin group. Variance analysis was used for group comparisons of dose of drug use, duration of drug use, and abstinence days since last use. The results indicated heroin abusing group showed longer duration of drug use (methamphetamine for METH group; heroin for heroin group) and less days of abstinence compared with METH group. Chi square test revealed that heroin abusers took drug more often than METH abusers. There were no group differences in age of onset and average dose of drug use between heroin and METH groups.

3.2 Impulsive Choice and Magnitude Effect

After natural logarithmic transformation, discount rates of three groups derived from MCQ were listed in Table 2. The one-way ANOVA of transformed k_{est} values revealed that the group effect existed ($F_{(2,217)}$ = 3.305, p = 0.039). Applying LSD

Table 2 Log transformed delay discounting rates of participants

Variables	Heroin	METH	Control
$LN\ (k_{est})$	−3.52 (1.82)	−3.60 (1.67)	−4.12 (1.43)
$LN\ (k_S)$	−3.35 (1.85)	−3.46 (1.67)	−3.81 (1.54)
$LN\ (k_M)$	−3.48 (1.91)	−3.49 (1.79)	−4.01 (1.54)
$LN\ (k_L)$	−3.65 (1.83)	−3.78 (1.73)	−4.48 (1.46)

Note Data are given as mean (standard deviation); k_{est} is the estimate of delay discount rate from the whole-scale choice pattern; k_S, k_M and k_L represent discount rates respectively for the small, medium and large magnitude of delay rewards

post hoc test to these data, both drug groups showed greater delay discounting than the control group ($p < 0.05$) whereas there was no difference found between the heroin and METH groups. The drug abusers had only reliably higher values of k than controls at large reward with reference to ANOVA and post hoc test results (group effect: $F_{(2,434)} = 5.095$, $p = 0.003$; k_S-k_L and k_M-k_L comparisons: ps < 0.01). A repeated-measure ANOVA with magnitude of delay reward (i.e. small, medium and large) as the within-subject variable and group as the between-subject variable revealed a significant main effect of magnitude ($F_{(2,434)} = 21.384$, $p < 0.001$), while pairwise within-subject contrast analysis indicated k_S and k_M were both higher than k_L (ps < 0.001) without significant difference found between the two former discount rates ($p > 0.05$). Figure 1 shows the mean estimates of ks for the three groups as a function of the magnitude of the delayed reward. The differences were not similar across the three reward magnitudes, therefore yielding nonparallel lines in Fig. 1. Moreover, the variance analysis did not find a significant effect of magnitude × group interaction ($F_{(4,434)} = 2.095$, $p = 0.081$). The decrease in discount rate as amount of reward increased was not reliable overall, as well as for each group separately.

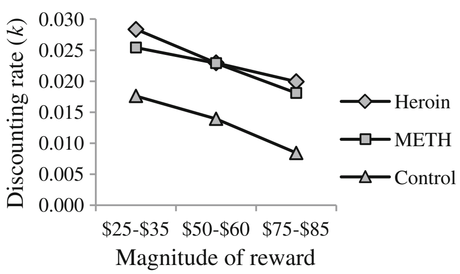

Fig. 1 Mean discounting rates as a function of delayed reward magnitude for controls and the two drug groups

Table 3 Total and subscale scores of participants on BIS-11

Variables	Heroin	METH	Control
Total score	42.20 (13.86)	36.55 (16.13)	19.93 (9.81)
Nonplanning	43.83 (17.54)	36.34 (21.00)	17.18 (13.84)
Motor	39.84 (19.26)	39.65 (19.88)	15.49 (12.96)
Attention	42.93 (13.35)	33.66 (15.48)	27.11 (10.83)

Note Data are given as mean (standard deviation)

3.3 Trait Impulsivity

Table 3 displays trait impulsivity scores on BIS-11 among different groups. ANOVA results showed significant group difference on total scores and all subscale scores ($ps < 0.001$). Based on findings from LSD post hoc tests, compared with controls, drug abusers had significantly higher scores on the BIS-11 and three subscales ($ps < 0.01$), and heroin abusers scored higher than METH abusers on the nonplanning and attention impulsivity subscale ($ps < 0.05$).

3.4 Correlations Between Impulsive Choice, Trait Impulsivity and Drug Use

Pearson correlation analysis was conducted between impulsive choice and trait impulsivity in three groups separately. The results showed that delay discounting rates was uncorrelated with BIS scores ($ps > 0.05$) in all groups. For the drug abusers, the correlations between k_S and substance use variables including frequency, average dose, and duration of drug use were not significant ($ps > 0.05$).

4 Discussion

The purpose of this study was to examine impulsive choice and trait impulsivity in heroin and metham-phetamine abusers. In consistence with previous studies [7, 11, 13–15], we found that drug abusers had more impulsive choices or steeper delay discounting for hypothetical money reward than non-drug-using controls. However, this discrepancy did not depend on drug type as heroin and METH abusers both discounted delay rewards more steeply than controls without finding difference in discount rates between the two drug groups. It suggested that some common mechanism underlying the behavioral process of impulsive choice in drug abusers. In addition, this study did not demonstrate reliable overall magnitude effect of delay discounting or for different groups which was incongruent with previous findings

[7], though we found that discount rate for large reward was significantly lower than those for small and medium rewards. This could be explained that magnitude effect was influenced by relative amount of reward.

As the relations among impulsive choice, trait impulsivity and drug use variables were concerned, this study had two main findings. On one hand, impulsive choice was unrelated to trait impulsivity in either drug or non-drug groups though drug abusers scored higher than controls on BIS-11 and its subscales, suggesting that measures of delay discounting may characterize more specific behavioral processes than those characterized by self-report questionnaires [25]. On the other hand, impulsive decision making was not correlated with substance abuse variables including frequency, duration and dose of drug use. It might be crucial to add appropriate variables or measures representing the severity of drug dependence besides the features of drug use behavior.

The group differences that we observed demonstrate that the discount rate is a relevant construct in substance abuse research, and it can provide a starting point for the development of drug abusing interventions. Accordingly, novel interventions might focus specifically on altering the time perspectives of drug abusers, with a goal of lowering their discount rates. Such interventions may have beneficial effects in reducing drug use and improving clinical outcomes of drug dependents.

The current findings are subject to several limitations. The groups differed in age, duration of education. They might account for the observed group differences in discount rates and trait impulsivity. Another limitation is that because the present study recruited drug abusers in compulsory treatment, we have no way of evaluating the generalization of these results to the substance-abusing population in other situations. Finally, using a cross-sectional design, we cannot infer that drug use caused drug abusers to have higher discount rates. Only longitudinal study designs can address the question as to whether substance use itself results in increases in discount rates and whether individuals with high discount rates are more likely to develop drug abuse problems.

5 Conclusion

The current study mainly suggests four general conclusions. First, as in previous studies with hypothetical rewards, drug abusers generally discounted delayed rewards more steeply than did controls. Second, these differences didn't depend on the type of substance abused. Both heroin abusers and METH abusers made more impulsive choices than did controls, but heroin and METH abusers did not differ in discount rates from each other. Third, magnitude effect was not reliable across all three sizes of reward since the small and medium rewards generated similar discount rates overall, as well as for the three groups respectively. Finally, drug abusers was associated with higher trait impulsivity measured by BIS-11, furthermore heroin abusers had higher impulsivity scores than METH abusers on non-planning and attention impulsivity subscales. In addition, discount rates were not correlated with self-reported impulsivity in either heroin or METH group. This study extended the understanding of impulsive decision making in substance using population, but the results still need be verified in future researches due to the limitations of the present study.

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Comparing Two Shift Patterns of Nurse Scheduling in Chinese ICUs

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Abstract This paper compares two shift patterns of nurse scheduling, APN and ABC, which are widely used in Chinese intensive care units (ICUs). Two binary integer programming (IP) models for the nurse scheduling problems with APN and ABC patterns are presented, respectively. A general heuristic solution procedure, which considers the equity of nurse schedules and reduction in shift changes, is proposed to solve these problems. A case study of nurse scheduling based on given nurse demands is performed. Two schedules with APN and ABC patterns are constructed. It shows that ABC pattern generally needs fewer nurses and meanwhile is more apt to achieve equity in nurse scheduling, while APN pattern is more likely to reduce shift changes.

Keywords Heuristics · ICUs · Integer programming · Nurse scheduling

1 Introduction

The shortage of trained nurses is a worldwide problem, which is particularly severe in China. The bed-nurse ratio in Chinese ICUs is only 1:1.45 [1], which is much lower than the general international standard. Nurses are indispensable in a hospital's daily operations, and meanwhile, nursing service is one of the largest cost components in a hospital's budget. Therefore, it is very important for hospitals to make good scheduling decisions which can make the most use of available nurses [2–5].

Low salary and social status, heavy work pressure and duty, irregular working and rest time, all further exacerbate the lack of nurse and highly affect the quality of care. Good shift pattern and nurse schedules can improve not only nursing care quality, but also mental and physical health of nurses [6]. Due to various differences

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and requirements among hospitals and wards, there is no such a general scheduling method or shift pattern that can be applied everywhere. In fact, different methods/patterns have different characteristics suitable for different scheduling considerations [7]. Several nurse shift patterns commonly used in Chinese ICUs including APN pattern, ABC pattern, and 12-h pattern were reported by Wang et al. [8]. Yang and Wen (2011) investigated the effects of implementing APN pattern in a hospital. Surveys based on satisfactions of patients and nurses indicate the superiority of APN pattern [9]. Xu et al. [10] compared the effects of implementing APN with traditional shift patter (3 shifts with 5 handovers). Most of the existing literature study the implementation effects of shift patterns by means of questionnaire survey and simple data analysis, also, detailed descriptions of scheduling methods cannot be found.

In this paper, two shift patterns widely used in Chinese ICUs, named APN and ABC respectively, are studied. A general binary integer programming model for nurse scheduling problem, which can be adjusted according to the two patterns, is presented. Then, a heuristic solution procedure that can be adapted to different shift patterns is proposed for constructing nurse schedules. Finally, a case study is conducted to compare the effects of the two patterns.

There are four types of shifts per day involved in APN pattern. Two of them, known as A shift (8:00–15:00) and assistant shift (7:30–12:00, 14:00–17:30) are day shifts; the other two types include one evening shift (P shift, 15:00–22:00), and one night shift (N shift, 22:00–8:30). Nurses are categorized into two classes, senior and junior. Nurses in the senior class generally have more experiences and professional trainings than nurses in the junior class. According to APN, only senior nurses are qualified for A shift, while assistant shift and N shift require only junior nurses. Besides, senior nurses are further classified into two groups, which work on daily A shifts alternately (A1 and A2) [7].

The ABC pattern is modified based on the traditional multi-shift pattern. According to ABC, a working day is divided into three shifts: one day shift (A shift, 8:00–15:00), one evening shift (B shift, 15:00–22:00), and one night shift (C shift, 22:00–8:00). During each shift, at least two nurses are required to be on duty, which is intended to ensure the nursing care quality [7].

While constructing a nurse schedule, there are some restrictions that should be considered. Some of them are hard constraints, for instance, the demands for nurses in different categories during each shift must be satisfied, which can be estimated based on historical data. Furthermore, a nurse can work only one shift per day, which means the shift he/she works tomorrow can't be continuous with the one he/she has worked today. Those hard constraints cannot be violated, while there are also some soft constraints that do not have to be satisfied. Note that the constraints should be considered on the border of two scheduling periods.

2 Model and Methodology

In this section, a general 0-1 integer programming formulation which can be adapted to different shift patterns are presented, then a heuristic solution procedure is proposed to construct good nurse schedules according to requirement of different shift patterns.

2.1 A Binary Integer Programming Model

It is assumed that a scheduling period is one week. Table 1 displays the notations used in the proposed integer programming model.

The objective of nursing scheduling problem can be expressed as minimizing the personnel cost associated with a nurse schedule, as described in Eq. (1). Meanwhile, some hard constraints concerning nurse demand and nurses' workloads are given as follows:

Table 1 Notations

Indices and sets	
i	Index for nurses, $i = 1, 2, 3, \ldots$
j	Index for shifts, $j = 1, 2, 3, \ldots$
l	Index for days of a week, $l = 1, 2, \ldots, 7$
g	Index for nurse classes, $g = 1, 2$ with 1 for class senior and 2 for class junior
N	Set of i
S	Set of j
T	Set of l
U	Set of g
Decision variables	
x_{ijl}	(Binary) 1 if nurse i is assigned to shift j on day l, and 0 otherwise
Parameters	
c_{ij}	The cost of nurse i working on shift j
D_{jlg}	The number of nurses of class g required on shift j of day l
e_{ig}	(Binary) 1 if nurse i belongs to class g, and 0 otherwise
$lastn_i$	(Binary) 1 if nurse i worked on the last night shift during last week, and 0 otherwise
Ubt_g/ Lbt_g	The upper or lower bound on the number of shifts during a week arranged to nurses of class g

$$\min C = \sum_{l \in T} \sum_{i \in N} \sum_{j \in S} c_{ij} \cdot x_{ijl} \tag{1}$$

subject to

$$\sum_{i \in N} e_{ig} x_{ijl} \geq D_{j\mathrm{lg}}, \quad \forall g, j, l \tag{2}$$

$$\sum_{j \in S} x_{ijl} = 1, \quad \forall i, l \tag{3}$$

$$\sum_{j \in S} \sum_{l \in T} x_{ijl} \leq \sum_{g \in U} e_{ig} Ubt_g, \quad \forall i \tag{4}$$

$$\sum_{j \in S} \sum_{l \in T} x_{ijl} \geq \sum_{g \in U} e_{ig} Lbt_g, \quad \forall i \tag{5}$$

Constraints (2) guarantee that the demands for nurses of different classes on any shift of a week are satisfied. Constraints (3) ensure that a nurse can work only one shift per day. It is noted that a rest (or day off) shift is included in addition to regular shifts, indicating a nurse does not receive any regular shift arrangement on a day. Constraints (4) along with (5) guarantee that the number of shifts worked by a nurse during a week is no less than the lower limit and no more than the upper bound.

The above objective function and constraints for nurse scheduling can be adapted to APN and ABC patterns. However, the formulations of restrictions on working day shifts after a night shift can vary with shift patterns. For instance, assuming that six indices for shifts in APN, from 1 to 6, are used to represent A1 shift, A2 shift, P shift, N shift, assistant shift, and rest shift, respectively. Thus, constraints (6) and (7) indicate that a nurse cannot work on P shift and assistant shift after working a night shift, respectively. Constraints (8) and (9) represent that a nurse cannot work on P shift or assistant shift after working on the last night shift during the previous week, considering the successively of nurse scheduling.

$$x_{i4l} + x_{i3(l+1)} \leq 1, \quad \forall i, l = 1, 2, \ldots, 6 \tag{6}$$

$$x_{i4l} + x_{i5(l+1)} \leq 1, \quad \forall i, l = 1, 2, \ldots, 6 \tag{7}$$

$$lastn_i x_{i31} = 0, \quad \forall i \tag{8}$$

$$lastn_i x_{i51} = 0, \quad \forall i \tag{9}$$

On the other hand, there are only four indices, 1 for A shift, 2 for B shift, 3 for C shift, and 4 for rest shift, are needed in ABC pattern. Correspondingly, the restrictions on working day shifts after a night shift are expressed in constraints (10)–(13), among which inequalities (10) and (11) ensure that a nurse cannot work on A or B shift after working a night shift, respectively, constraints (12) and (13) impose restrictions on A and B shifts after working on the last night shift during the previous week.

$$x_{i3l} + x_{i1(l+1)} \leq 1, \quad \forall i, l = 1, 2, \ldots, 6 \tag{10}$$

$$x_{i3l} + x_{i2(l+1)} \leq 1, \quad \forall i, l = 1, 2, \ldots, 6 \tag{11}$$

$$lastn_i x_{i11} = 0, \quad \forall i \tag{12}$$

$$lastn_i x_{i21} = 0, \quad \forall i \tag{13}$$

Note that there might be some constraints specifically for a certain shift pattern, which should be considered. For example, since senior nurses do not work night shift with APN pattern, and junior nurses do not work A shift, the following constraints should be required in model formulation.

$$x_{i4l} = 0, \quad \forall i \text{ with } e_{i1} = 1, l \tag{14}$$

$$x_{i1l} = 0, \quad \forall i \text{ with } e_{i2} = 1, l \tag{15}$$

$$x_{i2l} = 0, \quad \forall i \text{ with } e_{i2} = 1, l \tag{16}$$

2.2 A Heuristic Procedures for Nurse Scheduling

A general heuristic solution procedure for solving the nursing scheduling problem is presented. The basic idea of this heuristic is to iteratively build a schedule for each of the days in a scheduling period. While constructing a day schedule, the nurses in different classes available for each of the shifts are identified as candidates for shift arrangement. As for each shift, the candidate nurses are selected based on some criteria. In this way, the minimum demands for nurses of different classes can be satisfied and meanwhile, some other considerations such as equity in nurse schedules and nurse preferences can be included. In this study, equity in nurse schedules and shift change reduction are considered as criteria of candidate selection.

Currently, equity in nurse schedules has received more attentions from both nurses and administrators. It can be measured by various values such as the number of night shifts and the number of day-offs during a scheduling period. Furthermore, research shows that changing shifts frequently will exacerbate nurses' feeling of fatigue. To alleviate the problem and decrease the number of shifts change, the heuristic procedure is designed with an intention to avoid frequent shift changes on each individual nurse's schedule.

The greedy heuristic procedure is depicted in pseudo code as follow:

```
1.  Initialization
2.  LOOP FOR l in T, g in U
3.     FOR j = 4
4.        Determine nurse demand
5.        Record candidate nurses
6.        Sort candidate nurses in ascending order of
          cumulative number of night shifts arranged
          (num_ns)
7.        Give priorities to nurses scheduled on last
          night shift
8.        Break ties with cumulative number of shifts
          arranged (num_s)
9.        Arrange shifts in step 4 sequentially to the
          ranked nurse candidates
10.    LOOP FOR j in S (except night and rest shifts)
11.       Determine nurse demand
12.       Record nurse candidates
13.       Sort the available nurses in ascending order
          of cumulative shifts arranged (except for rest)
14.       Break ties with cumulative number of night
          shifts
15.       Arrange shifts in step 11 sequentially to the
          ranked nurses
16.    END LOOP
17.    Arrange rest shifts to the remaining nurses
18. END LOOP
19. Parameters update
20. Output final schedule
21. END
```

The above heuristic procedure can be used to create nurse schedules in conjunction with different shift patterns including ABC and APN. Note that the heuristic uses different criteria in night shift arrangement due to more considerations, such as reduction in shift changes and equity in arranging night shifts, related to night shift are involved.

3 Case Study

A case study is conducted to compare the effects of nurse schedules constructed by using the heuristic solution procedure described in Sect. 2, along with the requirements of APN and ABC patterns, respectively. The heuristic algorithm is implemented in C++ and performed on a 2.53 GHz PC.

Table 2 Daily demands for nurses in a Chinese ICU

Time period	Total	ABC		APN	
		Senior	Junior	Senior	Junior
0:00–3:00	1	0	1	0	1
3:00–5:00	2	1	1	0	2
5:00–6:00	1	0	1	0	1
6:00–8:00	2	1	1	0	2
8:00–10:00	3	1	2	2	1
10:00–14:00	2	0	2	1	1
14:00–16:00	3	1	2	1	2
16:00–22:00	2	1	1	1	1
22:00–24:00	2	1	1	0	2

It is assumed that the total number of nurses needed per time period in a Chinese ICU is known (as shown is Table 2). Due to different requirements of ABC and APN patterns, the demands for senior and junior nurses in a period could be different.

Moreover, according to the nurse management guide of this ICU, at least one senior nurse is required on any P shift for APN pattern; while for ABC pattern, at least one senior nurse is needed on all shifts. Then, the nurse demands per shift during a day of a scheduling period (one week) associated with APN and ABC are derived respectively and displayed in Table 3.

First, the nurse schedules relating with APN and ABC patterns over a consecutive five-week horizon are constructed, respectively. It should be noted that this construction process attempts to look for only the minimum numbers of nurses in each class required to meet the nurse demands without knowing the nurses available in advance. The averages and variances of numbers of night shifts, working days, day-offs, and day-offs during weekends for nurses in same classes are displayed in Table 4.

With ABC pattern, 12 nurses, among which 5 in senior class and 7 in junior class, are needed; while with APN pattern, 14 nurses, among which 6 senior and 8 junior nurses, are required. It also appears that in general, ABC requires less nurse

Table 3 Nurse demands per shift in a Chinese ICU

Shift pattern	Shifts	Nurse demand	
		Senior	Junior
APN	A1/A2	2	0
	P	1	2
	N	0	2
	Assistant	0	1
Total		3	5
ABC	A	1	2
	B	1	2
	C	1	1
Total		3	5

Table 4 A summary of results from experiment 1

ABC_12 nurses			Results			
APN_14 nurses			No. of night shifts	No. of working days	No. of day-offs	No. of day-offs on weekends
Average	ABC	Senior	7	21	14	4
		Junior	5	25	10	2.86
		Total	5.83	23.33	11.67	3.33
	APN	Senior	0	17.5	17.5	5
		Junior	8.75	21.88	13.13	3.75
		Total	5	20	15	4.29
Variance	ABC	Senior	0.5	0.5	0.5	1.5
		Junior	0.33	0	0	5.14
		Total	1.42	4.42	4.42	3.7
	APN	Senior	0	0.3	0.3	0
		Junior	4.79	1.27	1.27	4.79
		Total	22.76	5.85	5.85	2.99

manpower than APN to meet the nurse demands, although it might result in more intensive workloads with less variation.

Furthermore, assuming the nurse component of the ICU is given, which includes 6 senior and 8 junior nurses, working shifts over a 5-week horizon are again arranged with ABC and APN, respectively. It can be seen from the summary of scheduling results displayed in Table 5 that the averages of numbers of night shifts, working days, day-offs, and day-offs on weekends relating with ABC and APN patterns are equal; however, the variances of those measurements resulting from

Table 5 Summary of results from experiment 2

ABC_14 nurses			Results			
APN_14 nurses			No. of night shifts	No. of working days	No. of day-offs	No. of day-offs during weekend
Average	ABC	Senior	5.83	17.5	17.5	5
		Junior	4.37	21.88	13.13	3.75
		Total	5	20	15	4.29
	APN	Senior	0	17.5	17.5	5
		Junior	8.75	21.88	13.13	3.75
		Total	5	20	15	4.29
Variance	ABC	Senior	0.17	0.3	0.3	0.4
		Junior	0.27	0.13	0.13	1.07
		Total	0.77	5.23	5.23	1.14
	APN	Senior	0	0.3	0.3	0
		Junior	4.79	1.27	1.27	4.79
		Total	22.76	5.85	5.85	2.99

Table 6 Total number of shift changes

Week	No. of shift changes with ABC (c_1)	No. of shift changes with APN (c_2)	$(c_1 - c_2)/c_1$ (%)
Week 1	5	3	40.0
Week 2	7	3	57.1
Week 3	4	2	50.0
Week 4	5	2	60.0
Week 5	5	2	60.0
Total	26	12	53.9

ABC are smaller than from APN, which implies ABC pattern is more apt to achieve equity in nurse scheduling than APN pattern. In fact, the equity among junior nurses is more significant than that among senior nurses.

When a nurse works a day shift after a night shift during two successive days, a shift change is said to occur. The total numbers of shift changes during each week of the scheduling horizon relating with APN and ABC are displayed in Table 6. Obviously, APN pattern is far superior to ABC, with a reduction in the number of shift changes by approximately 54 %.

4 Discussion

In general, both APN and ABC have advantages and disadvantages, several insights can be obtained and depicted as follows:

(1) When there is a shortage of nurses, ABC could be the better choice, as it can meet nursing demand with fewer nurses. For instance, in the case study, ABC can save the number of junior nurses by 12.5 % and that of senior nurses by 16.67 % compared to APN.
(2) When the equity in scheduling is considered as an important measurement, ABC should be chosen, since it can result in smaller variations in workloads among nurses of same classes than APN.
(3) When the reduction in the number of shift changes is emphasized, APN pattern should be applied as it can result in much fewer shift changes than ABC pattern.

5 Conclusion

This paper compares the ABC and APN shift patterns in nurse scheduling, which are widely used in Chinese ICUs. A general binary integer programming model for describing the nurse scheduling problem is presented. Constraints corresponding to the requirements of APN and ABC patterns are discussed. A heuristic procedure for solving the nursing scheduling problem is proposed. A case study is conducted for the purpose of comparing ABC and APN patterns.

The heuristic procedure presented in this study is basically a greedy algorithm which normally cannot ensure obtaining high quality solutions, therefore, further research can be conducted to look for better scheduling methods. On the other hand, measurements associated with nurse preferences in evaluating nurse schedules can be introduced to comprehensively compare the effects of implementing the two shift patterns.

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Tourism Supply Chain Coordination with Price Discount and Quantity Flexibility Contracts

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Abstract This paper discussed the coordination problem of a typical two-echelon tourism supply chain (TSC) which involved one hotel and one tour operator. Specifically, we solve this TSC coordination problem with practically employed price discount and quantity flexibility contracts. Optimal ordering policies are obtained respectively for the integrated and Stackelberg game model with risk neutral and loss-averse tour operator. We analyzed the effects of risk preference, price discount and quantity flexibilities on the optimum ordering decisions. Finally, a numerical example is given to illustrate the effectiveness of quantity flexibility contract in enhancing the profit of the whole TSC and the members involved.

Keywords Price discount · Quantity flexibility contract · Supply chain coordination · Tourism supply chain

1 Introduction

During the past few years, the tourism industry has evolved considerably and played an important role in the national economy [1]. Tourism supply chain management arises at the historic moment, which provides a new perspective for the tourism firms to improve their competitiveness. Tourism supply chain management has been recently studied by researchers and practitioners [2–7]. The tourism supply chain is defined as a network of tourism organizations engaged in different activities ranging from the supply of different components of tourism products or services such as flights and accommodation to the distribution and marketing of the final tourism product at a specific tourism destination, and involves a wide range of participants in both the private and public sectors [8].

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It usually involves the service providers (such as excursions, accommodation, transportation, etc.), tour operator and consumers.

More and more practice has shown that each member's actions in the tourism supply chain have an impact on other players. In the competitive environment, the members in the tourism supply chain pay attention to their own profit while ignore the overall interests. It is indubitable that the optimization of the whole tourism supply chain can bring huge economic and social effect [9]. Therefore, how to coordinate the tourism supply chain should be an important issue and is worthy of consideration [10]. Coordination is a pattern of decision making and communication among a set of interrelated players who perform tasks to achieve goals such as lowering cost and maximizing their overall profit of the supply chain [11, 12]. In the tourism supply chain, the coordination between the hotel and the tour operator is worth considering because accommodation service is an important component of tourism products, as well as an important profit source of tour operator [13]. Supply chain coordination has generated a large number of published studies. In reality, coordination strategies have already been used by many tourism firms [14, 15]. Therefore, it has practical significance to study the coordination in the tourism supply chain and thus we develop a model involving one hotel and one tour operator to study the coordination problem.

Supply chain contract, as an effective mechanism of coordination, is usually used among the firms in the manufacturing industry. Similarly, supply chain contracts can be adopted by firms in the tourism industry. In China, most of the tour operators have less bargaining power because of their small scale. The unstable market environment forces the small and medium-sized tour operators to look for ways to reduce their risk. Some of the tour operators are even loss-averse. The research on supply chain coordination considering risk preference is attracted much attention in recent years [16, 17]. It entails a new perspective to the study of tourism supply chain. However, there is a lack of attention to study the impact of tour operators' risk preference. This paper, therefore, is distinct from the previous literature by considering a loss-averse tour operator in the tourism supply chain.

A reasonable contract and contract parameters setting are extremely important for supply chain coordination. The optimization of decisions plays an important role in the performance of supply chain members. Therefore, we develop a two-echelon supply chain model involving one hotel and one tour operator to study the coordination problem. We coordinated the tourism supply chain through adjusting price discount and quantity flexibilities. Additionally, we discuss the situation with a loss-averse tour operator, expecting certain implications can be enlightened to the hotel managers.

2 Methodology

We consider a supply chain with one hotel and one tour operator, where the hotel (supplier) provides rooms (service product) and sells it through the tour operator (retailer). In this paper, hotel sells room means that hotel sells the right for guest to use the room, namely, the hotel rent the room to guest for a period of time. The hotel sells rooms to the tour operator with the wholesale prices w and the tour operator sells rooms to consumers with the prices of p. The tour operator has to decide the total reservation quantity Q according to the market demand in the selling season, denoted by x. Stochastic demand is considered, it follows a distribution with probability density function $f(\cdot)$ and cumulative distribution function $F(\cdot)$ via marketing analysis. $F(x)$ is differentiable and $F(0) = 0$. When $x < Q$, the tour operator will sell the rest of the rooms on the spot market, we assume that the probability of selling is h. When $x > Q$, the rooms booking from the hotel are not enough. The shortage of rooms will lead to a high cost because that the tour operator provides bundled services to consumers. Therefore, the tour operator will try his best to buy the rooms on the spot market, though he may pay a relatively higher price. Usually, the consumers can accept the replacement of room, if the rooms have the same level of service. Assume that the capacity of the spot market is large enough to provide adequate services. Considering the market friction, transaction cost, etc., assumes that the tour operator has to pay the extra cost if he buys rooms on the spot market. In order to ensure the validity of our models, we assume that $0 < hp_s < c < w < p$, $p_s - p + c_u > 0$.

2.1 Notations

For convenience, we summarize the notations as below, where i $(i = t, h, c)$ in subscripts are for tour operator, hotel and supply chain respectively.

p the retail price of rooms
w the wholesale price of rooms, $w = \lambda p, \lambda \in (0, 1)$
Q the reservation quantity of the tour operator
h the probability of selling the remainder rooms
p_s the price of rooms on the spot market
c the unit service cost of the hotel
c_u the unit transaction cost in the spot market
μ expected demand for the final rooms,

$$\mu = \mathrm{E}(x) = \int_0^\infty x f(x) dx$$

π_i profit for the tour operator, hotel and supply chain

2.2 Model Identification

We develop our model according to Yang et al. [18]. The profit functions of the tour operator and the hotel are as follows:

$$\pi_t = pS(Q) + hp_sI(Q) - (p_s - p + c_u)L(Q) - wQ. \quad (1)$$

$$\pi_h = (w - c)Q. \quad (2)$$

where $S(Q)$ denotes the tour operator's expected sales when the he decides the reservation quantity of Q (not including the rooms buying from the spot market); $I(Q)$ denotes expected remainder of rooms; and $L(Q)$ denotes the expected shortage of rooms. They are expressed as follows:

$$S(Q) = \int_0^Q xf(x)dx + \int_Q^\infty Qf(x)dx = Q - \int_0^Q F(x)dx$$

$$I(Q) = \mathrm{E}(Q - x)^+ = Q - S(Q) = \int_0^Q F(x)dx$$

$$L(Q) = \mathrm{E}(x - Q)^+ = \int_Q^\infty (x - Q)f(x)dx = \mu - Q + \int_0^Q F(x)dx$$

The profit of the tourism supply chain is as follows:

$$\pi_c = \pi_t + \pi_h = (hp_s - p_s - c_u)\int_0^Q F(x)dx + (p_s + c_u - c)Q - (p_s + c_u - p)\mu.$$

As a benchmark, we first consider an integrated system where the common goal of the hotel and the tour operator is to maximize the overall profit of the supply chain. This is an ideal model that the actors within the supply chain operate as an entirety. In such an integrated model, the hotel and the tour operator cooperate to determine the pricing strategies. We use the price discount contract because of its simplicity to implement in practice.

Lemma 1 *In the integrated system, the optimal reservation quantity is* $Q^* = F^{-1}\left(\frac{p_s + c_u - c}{p_s + c_u - hp_s}\right)$.

In a Stackelberg game, the procedure is as follows: in order to maximize its profit, the hotel (as leader) announces wholesale prices w. In response to the wholesale prices, tour operator (as the follower) determines the retail price p to maximize his profit.

Lemma 2 *In the Stackelberg game, the optimal reservation quantity is* $Q_S^* = F^{-1}\left(\frac{p_s + c_u - w}{p_s + c_u - hp_s}\right)$.

In reality, the relationship between the hotel and the tour operator is more competitive than cooperative. Their purposes are to maximize their own profits. It is indubitable that the performance of a decentralized supply chain is inferior to that of the integrated system according to Lemma 1 and Lemma 2. In other words, the tourism supply chain cannot be coordinated by a single wholesale price contract. Therefore, the following section analyzes the coordination mechanism with price discount and quantity flexibility contracts.

3 Results and Discussion

3.1 Supply Chain Coordination with a Risk-Neutral Tour Operator

In this section, we consider the issue of supply chain coordination where both the hotel and the tour operator are risk neutral and full rationality. The relationship between the hotel and the tour operator is modeled as a Stackelberg game, where the hotel is the leader and the retailer is the follower. With the quantity flexibility contract, the tour operator has two order opportunities. Firstly, the tour operator decides the reservation quantity Q according to the predicted market demand. The hotel has an obligation to reserve the quantity $(1 + k)Q$ of rooms to the tour operator, where $k \geq 0$. At the same time, the tour operator promises that his minimum order threshold is $(1 - r)Q$, where $0 < r < 1$. In the selling season, after the tour operator updates the market demand information, he will conduct the second ordering behavior. At this time, the tour operator can decide the final reservation quantity according to the range provided by the hotel. We assume that the cost of the hotel is related to the actual order quantity. The expected reservation quantity of the tour operator is denoted by $N_a(Q)$ and η is the elasticity of the quantity flexibility contract, where $\eta = (1 + k)/(1 - r)$ and $\eta \geq 1$. We use the superscript a to represent the model with risk-neutral tour operator. The profit of the tour operator and the hotel are expressed as follows:

$$\pi_t^a = pS_c(Q) + hp_sI_c(Q) - (p_s - p + c_u)L_c(Q) - wN_c(Q). \quad (3)$$

$$\pi_h^a = (w - c)N_c(Q). \quad (4)$$

where

$$N_c(Q) = Q(1+k) - \int_{Q(1-r)}^{Q(1+k)} F(x)dx.$$

$$S_c(Q) = Q(1+k) - \int_{0}^{Q(1+k)} F(x)dx.$$

$$I_c(Q) = \mathrm{E}(Q(1-r) - x)^+ = \int_{0}^{Q(1-r)} F(x)dx.$$

$$L_c(Q) = \mathrm{E}(x - Q(1+k))^+ = \mu - S_c(Q).$$

Theorem 1 *The tourism supply chain can be coordinated under the price discount and quantity flexibility contracts, where* $\eta \in (1, \infty)$, *and* $\lambda = \frac{1}{p}\left[\frac{c-hp_s}{\frac{1}{\eta}F\left[\frac{1}{\eta}F^{-1}\left(\frac{p_s+c_u-c}{p_s+c_u-hp_s}\right)\right]+\frac{c-hp_s}{p_s+c_u-hp_s}} + hp_s\right]$.

Proof Considering two extreme cases:

(1) The elasticity of the quantity flexibility contract is infinite $(\eta = \infty, k = \infty, r = 1)$
Under such circumstances, the optimal decision is $\lambda = 1$, namely $\mathrm{w} = p$. At this time, the tour operator gains no profit, the tourism supply chain cannot be coordinated.

(2) The elasticity of the quantity flexibility contract is zero $(\eta = 1, k = 0, r = 0)$
According to Lemma 1 and Lemma 2, the condition of achieving coordination is $w = c$. At this time, the hotel gains no profit, the supply chain cannot be coordinated.

When $\eta \in (1, \infty)$, then $\partial^2 \pi_t^a / \partial Q^2 < 0$. Let $\partial \pi_t^a / \partial Q = 0$, we can get $F(Q_h^*/\eta) = \eta(p_s + c_u - \lambda p)\left[1 - F(Q_h^*)\right]/(\lambda p - hp_s)$, where $Q_h^* = (1+k)Q_t^*$. With Lemma 1, let $Q_h^* = Q^*$, we can get λ given in Theorem 1. Under such circumstance, the hotel can set proper wholesale price to induce the system-wide optimal order quantity so that the supply chain can be coordinated.

The members in the tourism supply chain often have conflicting objectives. The tour operator hopes to strive for a larger elasticity to reduce his risk. But a larger elasticity will increase the risk of the hotel. Thus the hotel would like to increase the wholesale price. On one hand, when the elasticity of the quantity flexibility contract is infinite, the hotel treats the tour operator as individual consumer. Thus the wholesale price is equal to the retail price, the tour operator gain no profit. On the other hand, when the elasticity of the quantity flexibility contract is zero, the hotel will transfer all the risk to the tour operator. Only when the wholesale price equals to the cost can the tourism supply chain be coordinated. This is clearly irrational. Full vertical integration is the most apparent and efficient way to achieve coordination [9]. Only under the conditions given in Theorem 1 can the tourism supply chain be coordinated. In this case, the coordination can result in improved performance and greater profitability for the hotel, tour operator and the entire supply chain.

Theorem 2 *Under given wholesale price, π_t^a increases with η.*

With the increase of η, the hotel's risk increases while the wholesale price decreases. If the tour operator is risk preference, he will choose the low elasticity and high price discount strategy. If the tour operator is risk averse, he will choose the high elasticity strategy. In this case, the risk is transferred from the tour operator to the hotel, thus the hotel raises the wholesale price to ensure his own profit. In order to evade risk, the tour operator would be willing to accept a higher wholesale price.

3.2 Supply Chain with a Loss-Averse Tour Operator

This section we consider the issue of a tourism supply chain involved one risk-neutral hotel and one loss-averse tour operator. In order to simplify the model, this section does not consider the shortage of rooms. According to the process of utility function that exhibits loss aversion in Schweitzer and Cachon [19], our utility function is:

$$U(\omega) = \begin{cases} \omega, \omega \geq 0; \\ \theta\omega, \omega < 0. \end{cases} \tag{5}$$

where ω is the tour operator's initial wealth, $U(\omega)$ is the tour operator's utility over final wealth, θ $(\theta \geq 1)$ is risk-aversion coefficient. The higher the θ is, the higher risk-averse degree of the tour operator will be. When $\theta = 1$, the tour operator is risk-neutral. The superscript b represents the model with loss-averse tour operator.

Under price discount and quantity flexibility contracts, without considering the shortage of rooms, the profit of the tour operator is $\pi_t^b = pS_c(Q) + hp_sI_c(Q) - \lambda pN_c(Q)$. When $x < Q(1-r)$, the profit function of the tour operator will be $\Pi_t^b = px - \lambda pQ(1-r) + hp_s[Q(1-r) - x]$. Let $\Pi_t^b = 0$, we can get $q = Q(1-r)(\lambda p - hp_s)/(p - hp_s)$, where q is the break-even demand. When $x < q$, the tour operator will suffer losses. Denote that $Q_h^b = (1+k)Q$, we can get $(1-r)Q = Q_h^b/\eta$. At this time, the utility of the tour operator is as follows:

$$U(\pi_t^b) = \pi_t^b + W. \tag{6}$$

where

$$W = (\theta - 1)\int_{0}^{B(Q_h^b)} [(p - hp_s)x - Q_h^b(\lambda p - hp_s)/\eta]f(x)dx$$

$$\pi_t^b = Q_h^b(1-\lambda)p - p\int_{0}^{Q_h^b} F(x)dx + hp_s\int_{0}^{Q_h^b/\eta} F(x)dx$$
$$+ \lambda p\int_{Q_h^b/\eta}^{Q_h^b} F(x)dx$$
$$B(Q_h^b) = Q_h^b(\lambda p - hp_s)/\eta(p - hp_s)$$

Theorem 3 *There is an optimal reservation quantity* Q_t^{b*} *that maximize the expected utility of the tour operator.*

Denote that $Z(Q_h^{b*}) = \partial U(\pi_t^b)/\partial Q_h^b = 0$, we can get the following theorem.

Theorem 4 *The optimal reservation quantity* Q_t^{b*} *decreases with* θ.

Proof With $\partial Z(Q_h^{b*})/\partial\theta < 0$, $\partial Z(Q_h^{b*})/\partial Q_h^{b*} < 0$, we can get $\frac{\partial Q_h^{b*}}{\partial\theta} = -\frac{\partial Z(Q_h^{b*})}{\partial\theta} / \frac{\partial Z(Q_h^{b*})}{\partial Q_h^{b*}} < 0$.

Theorem 4 shows that the loss-averse tour operator is more conservative than the risk-neutral one. The optimal reservation quantity of the loss-averse tour operator is lower than that of the risk-neutral tour operator. In order to reduce the risk of idle rooms, the tour operator would like to decrease the reservation quantity. The higher the degree of risk-aversion is, the lower the reservation quantity will be.

Theorem 5 *The optimal reservation quantity* Q_t^{b*} *decreases with* λ, *but increase with* η.

With Theorem 4 and Theorem 5 we can know that the order behavior of the tour operator is related to his risk preference, the price discount coefficient and the elasticity of the quantity flexibility contract. Given certain contract elasticity, if the hotel increases the wholesale price, the unit profit of the tour operator will decrease. Then the tour operator would like to reduce the reservation quantity, aiming to reduce the risk. In addition, under certain wholesale price, the increase of contract elasticity will reduce the risk of the tour operator. Such behavior will motivate the actual order behavior of the tour operator and increase the sales of rooms. In order to coordinate the supply chain, the hotel should provide greater contract elasticity when he cooperates with a loss-averse tour operator.

In reality, in the tourism supply chain, the common phenomenon is that a large tour operator gathers the orders of several small tour operators. The small tour operator is usually loss-averse due to its small market share, whereas the big tour operator is always risk-neutral because he has more bargaining power and can get a more favorable wholesale price from the hotel. The profit sharing contract is usually used between the large tour operator and the small tour operators. From the analysis above, we can conclude that in order to increase the sales and expand the market share, the large tour operator can provide a higher profit sharing proportion to the small tour operator.

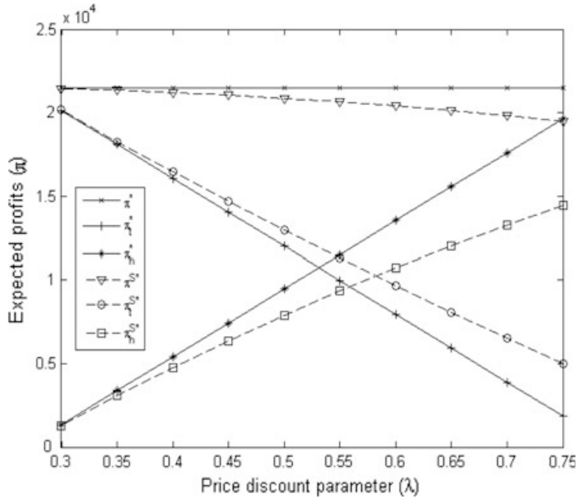
4 Numerical Analysis

Numerical experiments are conducted in this section to gain some managerial insights. According to the report of I Research [20], we take four-star hotels for example. Let $X \sim N(150, 20^2)$, $p_s = 339$, $p = 0.48p_s = 162.72$, $c = c_u = 45$, $h = 0.12$.

With Lemma 1, we can get the optimal reservation quantity in the integrated system is $Q^* = 194.78$, and the profit of the supply chain is $\pi_c^* = 17434.56$. We derive the reasonable range of λ, that is (0.28–0.83), under which the hotel and the tour operator can cooperate with each other.

Figure 1 depicts the curves of optimal profits as functions of λ. The performance of the decentralized supply chain is inferior to that of the centralized supply chain due to the phenomenon of double marginalization (Fig. 1). With the increase of λ, the profit of the supply chain in the Stackelberg game will decrease. If the hotel is the leader in the Stackelberg game, the wholesale price will be higher. Obviously, such phenomenon is not conducive to improve the overall efficiency of the supply chain. The gap between the profit of the hotel/tour operator/supply chain in the integrated system and that in the Stackelberg game is widening according to the increase of λ. Under a certain wholesale price, the tour operator can gain higher profit in the Stackelberg game than that in the integrated system.

Fig. 1 Expected profits as a function of price discount parameter



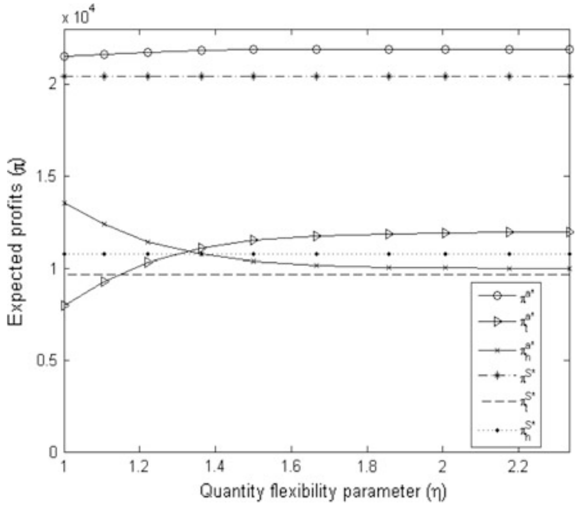


Fig. 2 Expected profits as a function of quantity flexibility parameter

Next, we consider the impact of quantity flexibility parameter (η) on the expected profits. Let $w = 97.63$, namely, $\lambda = 0.6$, $k = r$. In Fig. 2, π_i^{S*} is the profits in the Stackelberg game without quantity flexibility contract.

The profit of the whole supply chain without quantity flexibility is lower than that with quantity flexibility (Fig. 2). It means that the quantity flexibility contract is an effective mechanism in the sense the profit of the supply chain can effectively increase. Given certain wholesale price, the profit of the supply chain and tour operator increase with η, but the profit of the hotel decreases with η. The premise of the cooperation between the hotel and tour operator is that both of them can get higher profit after the cooperation. Therefore, we get the reasonable range of quantity flexibilities (1.09–1.16), under which the individual rationality and incentive compatibility can be satisfied. Both the hotel and the tour operator can earn at least their reservation profit, thus they will participate in the game. And supply chain coordination can be achieved.

5 Conclusion

This paper explores a two-echelon tourism supply chain consisting of one hotel and one tour operator. Price discount and quantity flexibility contracts are used to coordinate the tourism supply chain. Firstly, the integrated system and the Stackelberg game with price discount contract are considered. We conclude that the tourism supply chain cannot be coordinated by a single wholesale price contract. Secondly, we coordinated the tourism supply chain through adjusting price discount and quantity flexibilities. The findings show that supply chain coordination can be achieved if the model parameters satisfy certain conditions. Besides, in order to coordinate the tourism supply chain, the hotel should provide greater elasticity under the quantity flexibility contract when he cooperates with a loss-averse tour operator. Finally, a numerical example is given to illustrate the effectiveness of quantity flexibility contract in enhancing the profit of the whole tourism supply chain. We also show the conditions under which the tourism supply chain can be coordinated. These findings have significant implications for firms who are involved in the tourism supply chain.

This research can be extended in several directions in future work. For example, this paper only studies the risk preference of the tour operator. Further research can consider the coordination between the loss-averse hotel and the loss-averse tour operator. On the other hand, we just consider a two-echelon tourism supply chain consisting of one hotel and one tour operator in this paper and a multi echelon tourism supply chain can be discussed in the future study.

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Optimal Promised Delivery Lead Time for E-Tailers with Delay Dependent Customer Returns

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Abstract This paper studies how an e-tailer determines the optimal promised delivery lead time (PDL) in online retailing where not only the market demand but also the customer returns are PDL-sensitive. We first analyze the general model where the actual realized lead time *t* is a random variable. Further, we consider a special case where *t* follows uniform distribution for more specific analyses. Finally, by conducting sensitivity analyses we show the effects of different parameters, including the return sensitivities to demand and the delay, on the decision of PDL and the total profit and give some managerial insights for the e-tailers.

Keywords Electronic commerce · Promised delivery lead time · Customer returns

1 Introduction

The advent of e-business has changed the behaviors of people selling and buying products a lot in recent years. Customers enjoy lower prices and more choices from purchasing online [1]. However, competing only on price is no longer enough in today's fierce economy, which means the e-tailers should provide not only low prices but also faster deliveries to quickly respond to customers. Many firms are offering time guarantees as a marketing weapon to attract customers in a time-sensitive market [2–4]. One big difference between e-business and traditional "bricks and mortar" business is customers will wait between sale and delivery when purchasing online. This has made the back-end fulfillment process extremely important [5]. In this case, the e-tailers would consider both the price and promised delivery lead time (PDL) decisions to capture more demands. Therefore, the e-tailers should carefully decide whether to promise a delivery lead time to

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customers or not and how long it is once promising. In practice, it is quite common for the e-tailers with self-built logistics to provide a PDL, such as Amazon and JD. By building their own e-fulfilment centers, they can offer better services with a vast capital investment, either. However, some small e-tailers with capital-constrained would like to use third-party logistics (3PL) which is a lower-risk approach with less money [6]. The e-tailers using 3PL usually couldn't determine the delivery lead time exactly because of different parties, and the PDL may not be fulfilled because of uncertainties in delivery processes or to other uncontrollable factors unrelated to the e-tailers.

Another problem facing by the e-tailers is the increasing quantities of customer returns [7]. To eliminate customers' uncertainties and offer a better service to increase the sales, most of the e-tailers have offered liberal return policies. If an unconditional 100 % money-back guarantee is offered, a retailer should expect frequent product returns [7, 8]. Note that most of the returns are returned just because the customers don't like them. We call the returns that have no quality issues the False Failure Returns (FFR). Actually, only about 5 % of consumer returns were truly defective [9], and the e-tailers even their supply chains have suffered a lot due to the increasing quantities of FFR. Moreover, a latest empirical study finds that the likelihood of orders being returned depends on the consistency between retailer promises of timeliness in the delivery of orders and the actual delivery performance of the orders [10].

Thus, in this paper we investigate the tradeoff facing by the e-tailers between the shorter PDL to capture more demand and the longer PDL to decrease the probability of delay dependent returns. We firstly construct the delay dependent returns into the mathematical model and analyze the returns once delayed when the e-tailers offer PDL service. To create an appropriate model for this issue, a single e-tailer's firm is developed to study the optimal PDL decided by the e-tailer to maximize the profit. Note that we restrict the price to be exogenous by the market to make the model tractable and get better insights into the time dimension. This is also used by [11], which investigate the firms' competitive behaviors in industries where customers are sensitive to both PDL and quality of service (QoS) measured by the on-time delivery rate.

There are two streams of research that are relevant to this article. The first is research on promised lead time. Most of the earliest studies about promised lead time are considered within the production or assembly systems [12, 13]. Reference [3] develops a stylized model to analyze the impact of using time guarantees on competition among multiple firms. Similarly, [11] investigate firms' competitive behaviors in industries where customers are sensitive to both promised delivery time (PDT) and quality of service (QoS) measured by the on-time delivery rate. The latest related work is done by Li et al. [2]. They investigate how a risk-averse firm determines promised delivery lead time and price where the demand is also price- and time-sensitive. The second is research on customer returns. Different from most of the earlier research that assumed consumer returns stochastically follow a distribution [14, 15], a great deal of recent literature began to study consumer returns that depend on the decision variables of the retailer, such as pricing, refunds, and product quality [8]. However, both of the two streams of the research have not consider the interaction effect of consumer returns and PDL based on the empirical findings of [10]. Indeed, the profit of the e-tailer will go to zero when the return rate is relatively high if he do not realize the interaction aforementioned.

2 General Model Analysis

2.1 Notations

The notations used in this paper are shown as follows.

T promised delivery lead time (PDL)
D market demand
s_1 the PDL sensitive of demand when demand is PDL sensitive
R returned product quantity
t actual realized lead time with p.d.f. $f(\cdot)$ and c.d.f.$F(\cdot)$, and we have $\overline{F}(\cdot) = 1 - F(\cdot)$
α the return sensitivity to demand
β the return sensitivity to delay between actual realized lead time and PDL
p the exogenous selling price per unit
c the e-tailer's selling cost
s the residual value of the returned product.

2.2 Problem Description

This paper considers a deterministic problem. The e-tailer faces a demand D that is a decreasing function of PDL T. More specifically, we assume that the demand depends linearly on T, which is expressed by $D(T) = d_0 - s_1 T$, where d_0 represents the maximum demand as T equals to zero, and s_1 represents the demand sensitivity to PDL. $d_0 > 0, s_1 > 0$. Note that the demand is always non-negative, hence $T \leq \frac{d_0}{s_1}$. Customers are assumed to return R products for full credit and the returns have a residual value s. Now we have two assumptions in considering with the form of the returns function $R(T)$: first that the returns increase with the demand (sales), second that the more delayed in the delivery of orders with respect to T the higher will be the expected return rate. There have been a lot of empirical and modelling works done related to the first assumption and the second assumption follows the latest empirical findings aforementioned. They found that the likelihood of orders being returned depends on the consistency between retailer promises of timeliness in the delivery of orders and the actual delivery performance of the orders. Note that the actual realized time t is usually random by using 3PL. In addition, let t to be random over the interval $[\underline{t}, \overline{t}]$ with a probability density function $f(\cdot)$ and a cumulative distribution function $F(\cdot)$. Without loss of generality, we assume $\bar{t} < \frac{d_0}{s_1}$ to ensure there is always non-negative demand whenever $\mathrm{T} \in [\underline{t}, \bar{t}]$ the e-tailer promised. Then, we assume the general form of the returns function is

$$R(T) = \alpha D(T) + \beta(t - T)^{+} \tag{1}$$

where α, β denote the quantity and delay sensitive to returns, respectively. $0 < \alpha < \widehat{\alpha} < 1, \beta > 0$. $(t - T)^{+} = \max\{(t - T, 0)\}$ denotes the period between the actual realized time and the promised delivery lead time when the order is delayed. That is $(t - T)^{+} = \begin{cases} 0, & if\ t \leq T \\ t - T, & if\ t > T \end{cases}$. As the actual realized time t is a random variable, we take expectation of the returns function (1).

$$\begin{aligned} E[R(T)] &= \alpha D(T) + \beta \int_{T}^{\bar{t}} (t - T) f(t) dt \\ &= \alpha(d_0 - s_1 T) + \beta \int_{T}^{\bar{t}} \bar{F}(t) dt \end{aligned} \tag{2}$$

In the following, we first analyze the e-tailer's decision of optimal PDL in a general model, which the actual realized lead time is a random variable with a probability density function $f(\cdot)$ and a cumulative distribution function $F(\cdot)$. Then in the next session, we will consider a special case where t follows uniform distribution for more specific analyses.

2.3 Model Analysis

Both the demand and returns are sensitive to PDL. The e-tailer, assumed to risk neutral, should determine the optimal PDL by balancing the benefit yielded from demand against a probability of returning cost once the order is delayed. Then, we can obtain the objective function of the e-tailer who offers a full credit of returns as:

$$\max_{\mathrm{T}} E[\Pi_R(\mathrm{T})] = (p - c)D(T) - (p - s)E[R(T)] \tag{3}$$

Theorem 1 *The e-tailer's optimal promised delivery lead time is as follows:*

$$T^* = \begin{cases} \underline{t}, & 0 < \beta \leq \widehat{\beta} \\ F^{-1}[1 - \frac{s_1 A}{\beta(p-s)}], & \beta > \widehat{\beta} \end{cases} \tag{4}$$

where $\widehat{\beta} = \frac{s_1 A}{p-s}, A = (p - c) - \alpha(p - s)$.

Proof The first order condition of (3) is

$$E\left[\Pi_R'(\mathrm{T})\right] = -s_1 A + \beta(p-s)\bar{F}(T) \tag{5}$$

In this paper, we only discuss the case when $A > 0$, otherwise the e-tailer's profit will always be negative. (If $A < 0$, $\Pi_R(\mathrm{T}) < \alpha(p-s)D(T) - (p-s)R(T) = (p-s)(\alpha D - R) < 0$).

From (5) we can find that if $0 < \beta \leq \widehat{\beta}$, $E[\Pi_R'(\mathrm{T})]$ will always be negative which means PDL monotonically decreases with the profit. Thus, the optimal promised delivery lead time would be the lower bound of t. The e-tailer will always promise the earliest time the order can be delivered because the returns cost due to delay is relatively low. Otherwise, take (5) equals to 0, we can get the unique optimal T: $\mathrm{F}(T^*) = 1 - \frac{s_1 A}{\beta(p-s)}$, since $\mathrm{E}\left[\Pi_R''(\mathrm{T})\right] = -\beta(p-s)f(T) < 0$.

From Theorem 1, we can obtain the following properties to better understand the optimal PDL by the e-tailer. We only discuss the case when $\beta > \widehat{\beta}$, because if $0 < \beta \leq \widehat{\beta}$ the optimal PDL $T^* = \underline{t}$ and have no relationships with any parameters.

Corollary 1 *In the case of* $\beta > \widehat{\beta}$, *the optimal PDL* T^* *has the following relationships with parameters.*

(1) With the PDL sensitive of demand index: T^* is not affected by d_0, decrease in s_1.
(2) With the return sensitivities: T^* monotonically increases in both α and β.
(3) With price and costs parameters: T^* monotonically increases in c, decreases in p, s.

Proof

(1) When $\beta > \widehat{\beta}$, $T^* = F^{-1}[1 - \frac{s_1 A}{\beta(p-s)}]$, which is not affected by d_0. Note that $F(\cdot)$ is the cumulative distribution function of actual realized lead time t. Thus it's a monotonically increasing function of t. Taking the first order partial derivatives of T^* with respect to s_1, we have $\frac{\partial T^*}{\partial s_1} < 0$.
(2) Similarly, taking the first order partial derivatives of T^* with respect to α, β, we obtain $\frac{\partial T^*}{\partial \alpha} > 0, \frac{\partial T^*}{\partial \beta} > 0$.
(3) According to (4), we can also have $\frac{\partial T^*}{\partial \mathrm{c}} < 0, \frac{\partial T^*}{\partial \mathrm{s}} < 0$. As $\partial(1 - \frac{s_1 A}{\beta(p-s)})/\partial p = s_1\beta(s + c - 2p)/(\beta(p-s))^2 < 0$, the reverse function has the same monotonicity. Thus $\frac{\partial T^*}{\partial \mathrm{p}} < 0$.

Corollary 1 shows that the optimal PDL decision has no relationship with the market size d_0. If customers are more sensitive to PDL or the products are at high price and salvage (non-perishable goods), the e-tailer would like to provide a shorter PDL to capture more demand. However, if the return sensitivity to demand

and delay from the period of actual realized lead time to PDL are relatively high, which means increase the "penalty cost", then the e-tailer will choose a longer PDL to decrease the cost from reducing the risk of tardiness.

3 A Special Case for Uniform Distributed Actual Realized Lead Time

In this session, we consider a special case where the actual realized lead time t follows a uniform distribution with $t \in [0, 1]$ without loss of generally. Then we can get the c.d.f. $F(t) = t$. Thus, the equation can be rewritten as

$$T^* = \begin{cases} 0, & 0 < \beta \le \widehat{\beta} \\ 1 - \frac{s_1 A}{\beta(p-s)}, & \beta > \widehat{\beta} \end{cases} \tag{6}$$

Substituting (6) into the demand function and (3), we can get the optimal demand and profit of the e-tailer's in the uniform distributed actual realized lead time case.

$$D^* = \begin{cases} d_0, & 0 < \beta \le \widehat{\beta} \\ d_0 - s_1 + \frac{s_1^2 A}{\beta(p-s)}, & \beta > \widehat{\beta} \end{cases} \tag{7}$$

$$E[\Pi]^* = \begin{cases} d_0 A - \frac{\beta}{2}(p-s), & 0 < \beta \le \widehat{\beta} \\ \beta(p-s) + (d_0 - 3s_1)A + \frac{3s_1^2 A^2}{2\beta(p-s)}, & \beta > \widehat{\beta} \end{cases} \tag{8}$$

Corollary 2 In the special case that t follows uniform distribution, the optimal profit Π^* owns the following relationships with parameters.

(1) With the PDL sensitive of demand index: when $0 < \beta \le \widehat{\beta}$, Π^* is not affected by s_1; when $\beta > \widehat{\beta}$, Π^* decrease in s_1.
(2) With the return sensitivities: Π^* monotonically decreases in α; as β is large to a certain value $\widetilde{\beta}$, Π^* increases in β; otherwise, Π^* decreases in β.

Proof

(1) From (8-a), Π^* is not affected by s_1 when β is relatively small. From (8-b), taking the first order partial derivatives of Π^* with respect to s_1, we have

$$\frac{\partial \pi^*}{\partial s_1} = -3A + \frac{3s_1^2 A}{\beta(p-s)} = 3A\left(\frac{s_1 A}{\beta(p-s)} - 1\right)$$

Since in this case $\beta > \widehat{\beta} = \frac{s_1 A}{p-s}$, thus $\frac{s_1 A}{\beta(p-s)} < s_1$, $\frac{\partial \pi^*}{\partial s_1} < 0$.

(2) When $0 < \beta \le \widehat{\beta}$, taking the first order partial derivatives of Π^* with respect to α, β, respectively, we have $\frac{\partial \pi^*}{\partial \alpha} < 0, \frac{\partial \pi^*}{\partial \beta} < 0$. When $\beta > \widehat{\beta}$, repeating the same step, we have $\frac{\partial \pi^*}{\partial \alpha} = -(p-s)(d_0 - 3s_1) - \frac{3s_1^2 A}{\beta}$. Remind that we have assumed $\bar{t} < \frac{d_0}{s_1}$, and further we assume $\frac{d_0}{s_1}$ is relatively larger than 3. Thus $\frac{\partial \pi^*}{\partial \alpha} < 0$. $\frac{\partial \pi^*}{\partial \beta} = \frac{2(p-s)^2\beta^2 - 3s_1^2A^2}{2(p-s)\beta^2}$. If $\frac{s_1 A}{p-s} < \beta < \frac{\sqrt{6}}{2}\frac{s_1 A}{p-s}$, that is $2(p-s)^2\beta^2 - 3s_1^2A^2 < 0$, thus $\frac{\partial \pi^*}{\partial \beta} < 0$; otherwise $\frac{\partial \pi^*}{\partial \beta} > 0$. Hence, we have if $0 < \beta \le \widetilde{\beta}$ the profit decreases in β, if $\beta > \widetilde{\beta}$ the profit increases in β, where $\widetilde{\beta} = \frac{\sqrt{6}}{2}\frac{s_1 A}{p-s}$.

4 Numerical Examples

In this section, a numerical study was carried out to better understand the outcome of the problem and gain some insights for the practice. The analyses are done with $t \sim U[0, 1]$. We assume $d_0 = 20$, $s_1 = 6$, $p = 20$, $c = 8$, $s = 5$. Furthermore, we range α from 0 to 0.8 and let $\beta = 0.5, 1.5, 3, 4.5$ to explain the impact of the return sensitive index on optimal PDL decision. Note that from the assumption of $A > 0$, we have $\alpha > \frac{p-c}{p-s} = 0.8$. Thus we only discuss when $\alpha \le 0.8$ in this case. We use *Matlab 2012a* to get the results which are summarized in Figs. 1, 2 and 3.

Figures 1 and 2 show that when returns increase with sales, the e-tailer should promise a longer delivery lead time to customers and thus faces a decreasing demand. When β is relatively small, the e-tailer will promise the delivery lead time as short as they can to capture the highest demand which is 20 from Fig. 2. But if β is beyond the threshold, the optimal PDL should be raised to reduce the returns due to delay. Note that the threshold $\widehat{\beta}$ is a decreasing function of α, which means that the e-tailer will choose a longer PDL for higher β when α is relatively small.

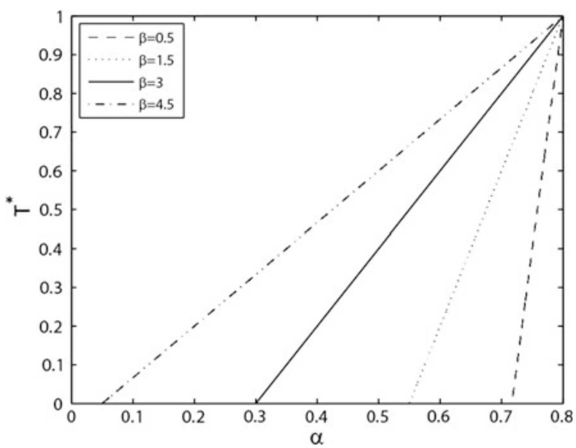

Fig. 1 The impact of α and β on PDL T^*

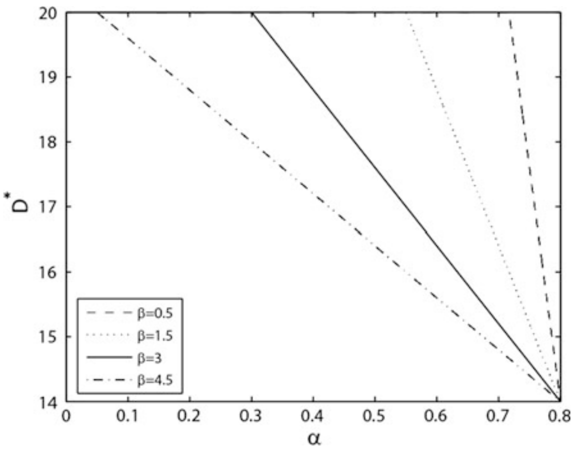

Fig. 2 The impact of α and β on demand

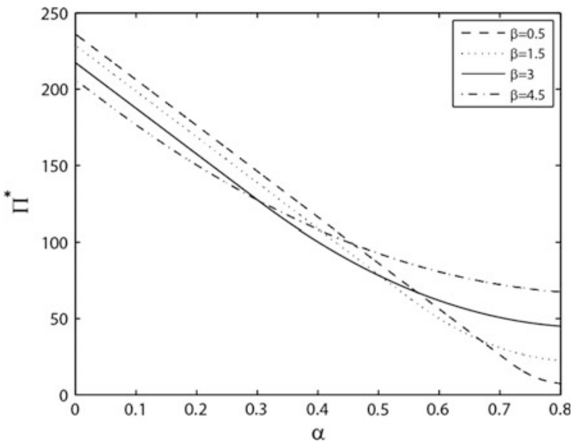

Fig. 3 The impact of α and β on profit

Figure 3 indicates the associate interaction effect of the return sensitivities to demand and delay on the e-tailer's profit. It shows that the optimal profit linearly decreases at first and then decreases with an increasing rate in α. The larger β is, the earlier the profit function becomes quadratic. Thus, when β is large to a certain value $\widetilde{\beta}$, Π^* increases in β; otherwise, Π^* decreases in β.

This also indicates that if the e-tailer does not realize the effect of returns once promise the delivery lead time $(\beta \rightarrow 0)$, they will choose the earliest time that 3PL can reach to grab all the demand $(T^* = 0)$. From previous analyses we note that the optimal PDL is also equals to 0 when $0 < \beta \leq \widehat{\beta}$ which means that there is no effect on profit even if the e-tailer overrates the benefit from PDL. However, when $\beta > \widehat{\beta}$, $T = 0$ is no longer the optimal PDL. What's more, from Fig. 3 we can induce when $\beta > \widetilde{\beta}$ the profit increases in β, which means the damage of profit from ignoring the delay dependent returns becomes bigger and bigger and the profit goes to zero when $\alpha = 0.8$.

5 Conclusion

In this paper, we study how an e-tailer determines PDL, where price is exogenous, knowing that the decision will affect both the demand and return rate. We first analyze a general model, which the actual realized lead time t is a random variable with a probability density function $f(\cdot)$ and a cumulative distribution function $F(\cdot)$. Then, we consider a special case where t follows uniform distribution for more specific analyses. We conduct sensitivity analyses for the returns sensitivities on optimal decision and the profit.

Our findings suggest that: (1) if the return sensitivity to delay of delivery is relatively low, the e-tailer will determine PDL as short as possible to capture the demand, despite the effect on customer returns; otherwise the e-tailer will choose to a not-so-fast PDL. In this case, if customers are more sensitive to PDL or the products are at high price and salvage (non-perishable goods), the e-tailer would like to provide a shorter PDL to capture more demand. However, if the return sensitivity to demand and delay are relatively high, then the e-tailer will choose a longer PDL to decrease the cost from reducing the risk of tardiness; (2) in the special case that t follows uniform distribution, the optimal profit linearly decreases at first and then decreases with an increasing rate in α. The e-tailer will choose a longer PDL with high return sensitivity to delay, and this leads to profit decreases and then increases in β.

The possible extensions could extend this work in a supply chain context, as the optimal solution of e-tailer may be influenced by the decisions of the supply chain partners. Furthermore, the risk attitude of the e-tailer and the uncertainty of demand might be explored in the future.

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Inter-Enterprise Service Interaction Modeling Method for Outsourcing Production Environment

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Abstract This paper proposes a graphical modeling method for inter-enterprise service interactions during outsourcing production processes. The relevant concepts of service interaction are firstly defined. The proposed method borrows from the principle of graphical schema modeling to depict the service interaction processes and the overall flow during inter-enterprise outsourcing production. Graphical units are illustrated, and the connections of these units are formalized. Based on that, the overall interaction event flow is formed. An exemplary case is studied to verify the proposed method and some improvements are discussed further. It is expected that our methods will provide instructions for inter-enterprise service interaction analysis and value co-creation when dealing with outsourcing production orders.

Keywords Inter-enterprise · Modeling · Outsourcing production · Service interaction

1 Introduction

As the manufacturing industry steps towards socialization and servitization, outsourcing production mode becomes trendy, especially for big manufacturers. They outsource much of their production activities to socialized service providers (SPs) to win value-added services and reduce investment [1, 2]. Under the service-dominant logic, SPs provide different kinds of competitive production services to the core enterprises, build outsourcing production orders with them, and further form an ecological production cluster within which the intertwined collaborations and interactions are operated. As SPs are in large amount, service interactions between core enterprise and SPs become vital and need to be well managed, because they affect customer experiences and expectations much. Service

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interaction derives from the concept of service encounter proposed by Shostack [3] in 1980s. It is defined as "the direct interactions between service providers and customers to provide customers with timely and relevant information to enable them to make informed decisions, complete their work easily, and co-create added value" [4, 5]. Many work have been done on the service selection, service scheduling, service interaction design, service interaction quality evaluation, etc. [6–9]. For example, Hsieh et al. [8] discussed a service interaction design mechanism to help SPs systematically manage customers' expectations in dynamic interactions. Core enterprises are provided with timely and relevant information to enable them to make informed decisions or complete their work easily. Guercini and Ranfagni [9] discussed buyer-seller interactions in facility services from some empirical case studies. The empirical results prove that interactions between buyer and seller are vital when outsourcing business services. However, these literature did not provided service interaction modeling methods to instruct SPs and customers, besides, they mostly focused on the downstream business services of the supply chain, e.g., maintenance, repair, operation service, etc., while seldom referred to the upstream outsourcing production business services processes, which are also important for product manufacturers and SPs to co-create values and win extra profits. Besides, the modeling and design method for service interaction is always empirical and lack a unified graphical way to solve it.

With the aid of new information and communication technology (ICT), inter-enterprise interactions become all-around, efficient and online-offline integrated. Except for the inter-enterprise offline interactions as usual (e.g., material/finished parts transition), through online public platforms and interfaces of enterprise information systems (EIS), core enterprise and SPs could achieve real-time interaction and communication information such as collaborative design, progress monitoring, quality feedback and so on. Thus, online-offline integrated service interactions among core enterprise and SPs should be comprehensively considered.

This paper focuses on the inter-enterprise service interaction during the upstream outsourcing production business service processes, and provides a modeling and analyzing method for the service interactions between core enterprise and SPs. Service interaction modeling and design aims to optimize customer interactions with services to match customer expectations and yield satisfactory service experiences. The service interaction contents during outsourcing production processes contains the order progress, machining methods, design for manufacturing (DFM) improvement, machining quality, logistics state, etc.

The rest of the paper are organized as follows: Sect. 2 defines the relevant concepts of service interaction, and discusses the modeling methodology during the entire outsourcing production processes. Section 3 gives a simple case study to verify the proposed methods. Finally, the conclusions and discussions about our future work are given in Sect. 4.

2 Methodology

2.1 Relevant Definitions

To build the service interaction models, some definitions should be given first, e.g., production service, service interaction, interaction content, etc.

Definition 1 Production services are defined as the business activities or processes provided by the socialized production service providers, which are product-related and service-dominant.

Definition 2 Inter-enterprise service interactions are defined as the collaboration or communication during a period of time where core enterprise directly interacts with its SPs. They can be divided into two kinds, i.e., online service interactions and offline service interactions.

Definition 3 Service interaction contents are defined as the information and data that core enterprise and SPs exchange, e.g., outsourcing order progress, service plans, production quality, etc.

Definition 4 Interaction events are defined as the activities triggered by core enterprise or SPs at certain time points to deal with the service interaction contents. We formalize the interaction events as follows:

$$E_i ::= \{Type, Tr, t, L, Dt, Info\} \tag{1}$$

where E_i is the *i*th event occurred between core enterprise and SP; *Type* stands for the online or offline interactions; *Tr* represents who triggers the event (core enterprise, SP or both); *L* is the event occurrence location; *Dt* is the state duration time after the event occurred; *Info* gives the other information of the event.

Definition 5 Interaction event connectors are defined as the connection relationships between two events, including three kinds: ordinal connector ("+"), parallel connector ("||"), alternative connector ("⊕").

E1 + E2 indicates event E1, E2 occur in a time sequence; E1||E2 indicates event E1, E2 occur consequently; E1 ⊕ E2 indicates there could be only one event occurs among event E1, E2. The priority of the three connectors is defined as:

$$"+" > "||" > "\oplus"$$

Definition 6 Interaction event flow is generated by connecting events with different connectors. It provides inspections to the overall outsourcing service interaction processes. It can be formalized as:

$$EF = \{E_1, E_2, \ldots, E_n\} \bowtie \mathbf{M}_{n\times n} \tag{2}$$

where $\mathbf{M}_{n\times n}$ is the event connection matrix, made up of the three kinds of connectors, $\bowtie$ is the natural connector in relational algebra.

2.2 Order Decomposition and SPs Selection

As the market becomes more and more competitive and dynamic, core enterprise desires more production flexibility to win profits as much as possible with limited resources and investment [10]. Thus, it becomes focusing on the core competitive business and outsources the low value-added businesses to SPs. To efficiently execute the outsourcing plans, the production orders around a certain product need to be decomposed and composed firstly. The decomposition method is based on the product Bill of Material (BOM) and its parts grouping methods (which solves the customization/personalization problems of different customer orders).

Based on the order decomposition result, outsourced production tasks have been formed. Next step is to release the tasks and select optimal SPs to undertake them. Generally, as the market evolves, core enterprise always has developed some stable SPs and some temporary SPs to form a production community/cluster where evolutionary stable relationships between them are maintained. Here, we just simply describe the SP selection processes, the detailed method and tools can be referred in our previous work [11]. First, core enterprise releases its order requirements at the online platform, SPs will apply for it based on its current manufacturing capability and production capacity. Second, core enterprise evaluates the SPs with two aspects:

(1) Estimate their capabilities and capacities using online evaluation APP tools;
(2) Investigate the SPs offline.

Note that for the stable SPs, they always have been investigated before, thus only the temporary SPs need to be investigated in this step. Third, optimal SPs are selected, core enterprise collaborates and interacts with them to efficiently accomplish the outsourced production tasks. Multiple outsourced orders corresponds to multiple service interaction flows, these inter-enterprise service interactions are complex and intertwined, thus unified graphical modeling and analyzing method should be developed for it.

2.3 Graphical Modeling and Analyzing Method

Based on the above definitions and preparation work, we further propose a graphical modeling method for inter-enterprise service interactions. In our previous research, we established a graphical schema modeling methodology to solve the material flow tracking problems in job shop level and cross-enterprise level [12, 13]. Here, we borrow its principle, extend it into inter-enterprise service interaction situation and build a new graphical modeling method.

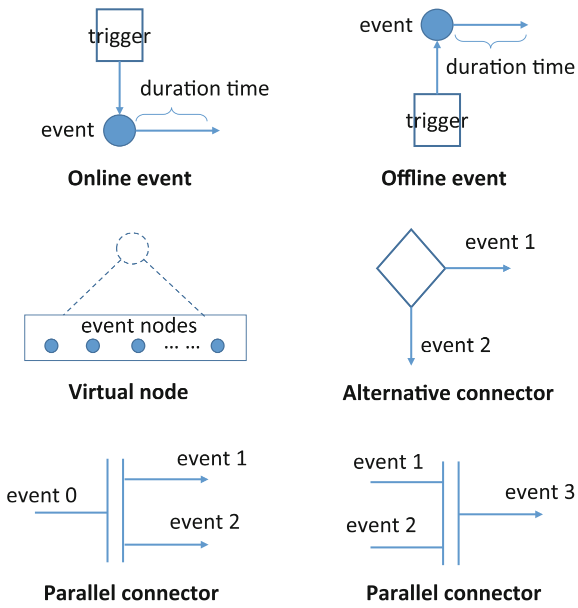
(1) *Graphical units*: to build a service interaction flow, graphical units are firstly formalized as shown in Fig. 1. The units are classified into 6 kinds: 2 event units (online event and offline event), 3 connector units and 1 virtual node units.
For online/offline event unit, it describes who triggers the event and after the event occurs, the state sustains a duration time. To reduce the complexity, some inter-connected event units and connector units can be abstracted as a virtual node unit, which is helpful to analyze the interaction granularity and simplify the interaction processes. The virtual node unit can be formalized as:

$$VN_i = \{E_1, E_2, \ldots, E_m\} \bowtie \mathbf{M}_{m\times m}, \quad m < n \tag{3}$$

(2) *Interaction event flow modeling*: by connecting the above graphical units, the real service interaction process flow can be modeled as an interaction event flow. It provides better instructions for core enterprise and SPs. Take a part manufacturing order as an example. The core enterprise outsources the task to an SP and reach a production order with it. During the production services, core enterprise interacts with SP and 13 main interaction events occurred which are listed as follows:

(a) Core enterprise releases a part manufacturing task online E_1;
(b) SP searches the requirements online and applies for it E_2;
(c) Core enterprise negotiates and investigates with the SPs offline, then select optimal SP as the supplier E_3;
(d) Core enterprise uploads the quality and due date requirements online E_4;

Fig. 1 Graphical units for the service interaction



(e) Core enterprise confirms whether the order is processing with supplied drawing (PSD) or processing with supplied material (PSM). If PSD, there is no material transportation, core enterprise uploads the drawing online E_5; if PSM, there is material transportation from core enterprise to SP E'_5;
(f) SP releases production plans online E_6 and starts machining offline E_7;
(g) SP uploads the production progress online E_8, core enterprise queries it online E_9;
(h) SP inspects the quality and upload the data online E_{10}, core enterprise queries it online E_{11};
(i) SP transports the finished parts to core enterprise offline E_{12};
(j) Core enterprise receives the finished parts, checks the quality and makes the order evaluation E_{13};

Thus, the total service interaction event flow can be depicted as Fig. 2a. From the mathematical view, the interaction event flow of the above example is formulated as follows:

$$\begin{aligned} EF &= \{E_1, E_2, \ldots, E_{13}\} \bowtie \mathbf{M}_{13\times 13} \\ &= E_1 + (E_2 || E_3) + E_4 + \left(E_5 \oplus E'_5\right) + E_6 + E_7 \\ &\quad + E_8 + E_9 + E_{10} + E_{11} + E_{12} + E_{13} \end{aligned} \quad (4)$$

where E_1–E_{13} represents the service interaction events above; $\mathbf{M}_{13\times 13}$ is the event connection matrix.

Note that there are 4 service interaction event pairs which are operated by core enterprise and SP in a time sequence, such as $E_2 \bowtie E_3$, $E_8 \bowtie E_9$, $E_{10} \bowtie E_{11}$, and $E_{12} \bowtie E_{13}$ they can be abstracted as a virtual node to simplify the interaction event flow, as depicted in Fig. 2b.

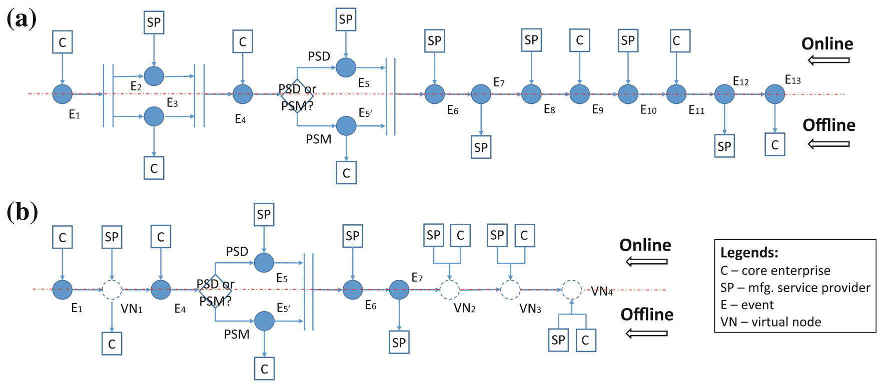


Fig. 2 Service interaction event flow. **a** the total service interaction event flow, **b** the simplified interaction event flow

3 Case Study

3.1 Case Description

We take a printing machinery company in Weinan National High-Tech Zone of China as the core enterprise (marked with A), and 6 small- and medium-sized enterprises in this industrial park are listed, acting as its SPs (marked with B–G). Around the final customer's orders of FR300 intaglio printing machine, A decomposes the production tasks into 32 kinds based on the product BOM, and outsources the tasks to B–G according to their separate capabilities and capacities. In which, 5 kinds of parts are packed as an order and outsourced to B. Through online-offline service interactions, the efficient collaborations and value co-creation could be achieved between A and B. We have developed a public platform for them to interact and communicate online (as shown in Fig. 3), this platform bridges the gap between EIS of different enterprises.

3.2 Service Interaction Modeling and Analyzing

In this section, service interactions between A and B is modeled. Firstly, actual interaction processes including the online interactions and the offline interactions between them are analyzed. Then, based on our graphical modeling method, the actual service interaction flow is built for service analyzing.

After A reaches an outsourcing agreement with B, the raw materials are firstly transported from A to B. Once B receives the materials, it will check the material quality and gives an online feedback to A. After reaching A's confirmation,

Fig. 3 Public online platform for inter-enterprise service interactions

B makes the production plans and allocates resources to undertake the order. These information are achieved via B's EIS and uploaded to the public online platform for A's querying.

During the outsourcing production processes, there are 17 main interaction events and the connection relationships among them can be analyzed according to the actual processes. We model the service interaction event flow between A and B in Fig. 4. It must be pointed out that each two interaction events (event pair) encircled by the red dashed ellipses can be abstracted as a virtual node, because A and B interact around the same service activities, for example, the part machining methods are discussed as E_9 (B proposes the alternative machining methods online) and E_{10} (A discusses with B and confirms an optimal method).

The mathematical description of the interaction event flow can be described as follows:

$$EF = E_1 + E_2 + \cdots + E_{17} \tag{5}$$

E_1 A and B reach an outsourcing agreement;
E_2–E_3 A transports raw materials to B, B checks the quality (VN_1);
E_4–E_5 B uploads the quality data, A checks and confirms the data (VN_2);
E_6–E_7 B makes production plans and uploads to platform, A checks and confirms the plans (VN_3);
E_8 B start machining;
E_9–E_{10} A, B interact and confirm the machining methods, processes, etc. (VN_4);
E_{11}–E_{12} A, B interact and confirm the machining quality data (VN_5);
E_{13}–E_{14} A, B interact and confirm the order progress of each batch (VN_6);
E_{15} B transports the finished parts to A;
E_{16}–E_{17} A, B interact and confirm the logistics state data (VN_7)

After that, A checks and accepts the finished parts, then gives the final order evaluation, which is helpful for the next order allocation and supplier selection.

Based on the model, we find the real-time service interaction information generated during the outsourcing production processes are connected to the service event flow, which are shared for analyzing, predicting and decision making.

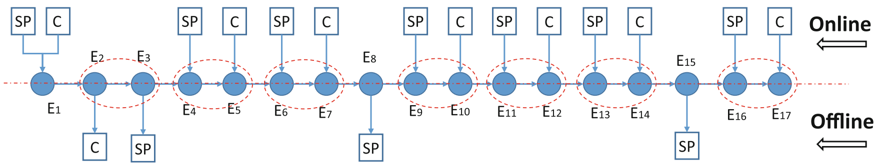


Fig. 4 Service interaction event flow

4 Discussions

This paper proposes an inter-enterprise service interaction modeling method for outsourcing production processes. It helps to unify the service interaction processes. By connecting real-time information of each interaction event into the processes both online and offline, core enterprise and SPs could make rapid decisions and co-create added value. However, there are still some aspects of the proposed method needed to be improved:

(1) The real service interaction processes are complex and intertwined, there may be loops, which we have not considered. Future we will consider more connectors to improve the methods, and more relevant information during the service interaction would be defined and gathered to analyze the interaction performance;
(2) We just consider the service interaction between one core enterprise and one SP, future work will extend it to the 1:N situations where the model will become complex;
(3) Online and offline information integration is a hard problem to be solved, and more industrial application scenarios should be further discussed to verify the method.

5 Conclusions

As the socialization and servitization boost in manufacturing industry, the service-oriented outsourcing production becomes more and more epidemic. To efficiently deal with the service interactions between core enterprise and its service providers, a unified graphical modeling method is proposed in this paper. Firstly, the relevant definitions about service interaction are given. Then, the graphical units and connectors are defined, and the service interaction event flow is generated. A simple case is given to verify the proposed modeling method. Our method provides better inspections to the service interactions during outsourcing production processes. Except for the method improvements, our future work would also include developing a software tool based on the method to visualize and model the service interaction flow.

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Sustainability Evaluation of Process Logistics Schemes in Workshop Based on Carbon Footprint and Adaptability

Chao-yang Zhang, Ping-yu Jiang and Wei-dong Li

Abstract In today's manufacturing environment, a process planning needs to be adaptable to changeable requirements due to the changes of seasons, economic situations, etc. In order to improve the adaptability and reduce the environmental impact of the process planning, a sustainability evaluation method of process logistics in workshop is proposed based on the carbon footprint and adaptability. For different process logistics schemes, the production cost, carbon emission and robustness are established. Then, a relative sustainability index is put forward via grey relational analysis to carry out a comprehensive assessment of a process logistics scheme. Finally, a case of a manufacturing workshop which processes aircraft landing gears is investigated to verify the effectiveness of the proposed evaluation method.

Keywords Adaptability · Carbon footprint · Grey relational analysis · Process logistics · Sustainability evaluation

1 Introduction

The growing energy and resource consumption have led to concerns about the economic development in countries. Manufacturing, as the backbone of industrialized society, is one of the main energy consumers and greenhouse gas contributors. Manufacturing enterprises are responsible for approximately 33 % of global total energy consumption and 38 % of greenhouse gas emissions [1]. Moreover, the need for sustainable development to attain economic, ecological and social goals is presenting new challenges to manufacturing companies. Therefore, it is important

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that the manufacturing community has access to systems that can improve energy efficiency in manufacturing processes by reducing carbon emission using new technologies and techniques.

Process planning is one of the most significant elements of manufacturing processes. It is used to plan manufacturing resources (e.g. machines and tools) and operations of jobs based on cost-effective criteria, such as manufacturing cost. Due to the increasing importance of energy savings, environmental factors like energy consumption are increasingly taken into account along with traditional performance criteria (time, quality and cost) in the process planning. Recently, many interesting studies have explored energy-efficient manufacturing with respect to environment-friendly process planning strategies and energy-aware scheduling approaches [2]. Unfortunately, they just consider the energy consumption which ignores the carbon emission.

On the other hand, the production demands are always fluctuating due to many reasons, such as the season, economic situation and so on. In order to copy with the fierce market competition, manufacturing plants must be able to respond quickly to changeable demands, production volume and product mix. It was reported that, on average, 40 % of a company's sales come from new products [3]. The change of product requirements leads to the modification of the production flow which causes the phenomenon that sometimes machines are fully utilized while sometimes they are partly utilized. However, the process planning may be fixed over a period of time because of manufacturing resources constraint.

Considering these problems, a sustainability assessment of process logistics in workshop is proposed. Firstly, the production cost, carbon emission and robustness are modeled based on carbon footprint and adaptability. Then, a relative sustainability index is put forward through grey correlation analysis.

2 Related Works

Process planning describes the transformation of raw materials into products through planning the operations of a product based on machining features, the identification of manufacturing resources that are available to the operations and the determination of the machining sequence in terms of cost-effective indicators. It has a direct influence on the design and manufacturing of products, which are closely related to environmental impacts such as energy consumption. Many studies of energy-efficient process planning have been performed. Newman et al. [4] presented a framework to validate the introduction of energy consumption in the objectives of process planning for CNC machining. Dai et al. [2] proposed an energy-aware mathematical model for job shops that integrates process planning and scheduling, and a modified genetic algorithm was adopted to explore the optimal solution (Pareto solution) between energy consumption and makespan. Zhang and Ge [5] proposed a new process planning strategy with energy efficiency consideration from the point of view of reducing energy consumption, and machining features are used and attempted to automatically or semi-automatically generate feasible process plans of a part under specific circumstance. Overall, most researchers mainly studied energy savings of process planning, but few of them considered the carbon emission, especially the process logistics in workshop.

On the other hand, the production demands are always fluctuating due to many reasons, such as the season, economic situation and so on. In order to copy with the fierce market competition, manufacturing plants must be able to respond quickly to changeable demands. The facility layout has been studied many times from robust and dynamic perspectives. An approach to design a robust layout was proposed in a context where the certainty of the information available decreases over time, and a resolution approach based on a fuzzy evolutionary algorithm is presented which includes uncertain customer demands for each product [6]. Bozorgi et al. [7] proposed a solution for dynamic facility layout problem with equal departments by applying data envelopment analysis with consideration of some specific criteria which are cost, adjacency, and distance requested. Nematian [8] presented an exact method to the single row facility layout problem based on a new class of variables and an extended branch and bound method. However, there are few research about the robustness evaluation of process logistics.

In order to improve the robustness of process planning to copy with changes of production demand, the concept of adaptable design is introduced. Adaptable design can be defined as a design paradigm that extends the intended utility of products and design through design and product adaptation [9], and it is aimed at creating designs and products that can be easily adapted for different requirements. Presently, adaptable design focuses on the design of adaptable products, primarily in mechanical engineering. Gu et al. [10] provided a comprehensive review on adaptable design that aims at developing adaptable products to satisfy the various requirements of customers. Xue et al. [11] introduced a method to identify the optimal adaptable product based on changeable requirements which were described as functions of the life-cycle time parameter. Cheng et al. [12] developed a model for product adaptability evaluation through measuring two types of product adaptability, i.e., essential adaptability and behavioral adaptability. However, this design approach has not been applied in other engineering disciplines to improve their adaptability, for example, process planning, production scheduling.

3 Problem Modeling

3.1 Problem Description of Process Logistics in Workshop

Process logistics designing is to select the proper process sequences and machines. Before modeling the problem, some assumptions for the process logistics need to be described as follows:

(1) The machining time and machining cost of each process are determinate;
(2) The length and width of a machine are fixed at different periods;

(3) Facilities have fixed orientations, so the shape of a facility is fixed at different periods;
(4) For a machine, its centroid is regarded as the pickup/drop-off point;
(5) Material handling devices move parallel to the x-axis or y-axis;
(6) Information of material handling devices is deterministic, including handling speed and cost per meter;
(7) The initial productivity requirement of the workshop is deterministic and capacities of initial facilities are adequate.
(8) The production demands are fluctuating in the future, but will not exceed the workshop productivity.

Before carrying out the cost, carbon emission, and robustness evaluation, some notations for the process logistics are explained in Table 1 firstly. It is important to note that most of the indexes and parameters defined in this section will be used for the following models.

Table 1 Notations for the process logistics

Notations	Description
$M = \{M_1, M_2, \ldots, M_m\}$	There are m machines in the workshop
(x_g, y_g)	The centroid (or location) of machine g
$V = \{V_1, V_2, \ldots, V_v\}$	There are v kinds of material handling devices.
$N = \{N_1^t, N_2^t, \ldots, N_n^t\}$	There are n kinds of manufacturing tasks, $t = 0, \ldots, T$
$P = \{p_1^t, p_2^t, \ldots, p_n^t\}$	Numbers of parts for each manufacturing task in Period t
$L = \{l_1, l_2, \ldots, l_n\}$	Numbers of process logistics for each manufacturing task
r_{ij}	Numbers of processes of process logistics j of manufacturing task i
α_{ij}	A binary quantity that is equal to 1 if the jth process logistics is selected
β_{ijk}^g	A binary quantity that is equal to 1 if process k of jth process route of manufacturing task N_i is machined by M_g
T_{ijk}^g	Machining time of the process k of process logistics j on machine g
MC_{ijk}^g	Machining cost of the process k of process logistics j on machine g
γ_{ijk}^h	A binary quantity that is equal to 1 if process k of jth process route of manufacturing task N_i is transported by V_h
VC_i^h	Transportation cost of the manufacturing task N_i
T_i^g	The total machining time of the manufacturing task N_i on machine M_g
$L_{k,k+1}^{qij}$	The transportation distance of process k of jth process route of manufacturing task N_i
S_h	Speed of device V_h
P_{ijk}^g	The average power of machine M_g when machining process k of jth process route of manufacturing task N_i
EF^{el}	Carbon emission factor of energy consumption
VE_i^h	Transportation energy consumption of device V_h when transporting part N_i

(continued)

Table 1 (continued)

Notations	Description
IC_g^{cool}	The initial coolant quantity of the machine M_g
T_g^{cool}	The mean interval of coolant update of the machine M_g
EF_g^{cool}	Carbon emission factor of coolant of the machine M_g
CE_{ijk}^{tool}	The cutter production carbon emission of process k of jth process route of manufacturing task N_i
T_{ijk}^{tool}	The lifetime of cutters

3.2 Sustainability Evaluation of Process Logistics in Workshop

Here, the sustainability evaluation is carried out from three respects, i.e., production cost, carbon emission and robustness.

1. *Production cost evaluation of process logistics*

The production cost mainly comes from manufacturing processes and transportation processes, thus it can be obtained through (1).

$$PC(N_i^0) = \sum_{j=1}^{l_i} \alpha_{ij} \cdot \sum_{k=1}^{r_{ij}} MC_{ijk}^{g} \cdot p_i^0 + \sum_{j=1}^{l_i} \alpha_{ij} \cdot \sum_{k=1}^{r_{ij}-1} VC_i^h \cdot L_{k,k+1}^{qij} \cdot p_i^0 \tag{1}$$

2. *Carbon emission evaluation*

In a workshop, the inputs are raw materials or semi-finished products, while the outputs include end products and effluent. In between, many activities will generate carbon emission, such as machining processes, assembling, spraying, transporting, storage, etc. Based on the analysis of carbon footprint, carbon emission of a single part processing mainly comes from four parts, i.e., energy consumption of machining processes, auxiliary material consumption, tool wear and transportation process [13].

The carbon emission of energy consumption of machining processes is mainly from machine tools:

$$CE\left(N_i^0\right).maching = \sum_{j=1}^{l_i} \alpha_{ij} CE(N_i^0)_j \,.\, maching \tag{2}$$

$$CE\left(N_i^0\right)_j.maching = \sum_{k=1}^{r_{ij}} \sum_{g=1}^{m} \beta_{ijk}^{g} P_{ijk}^{g} T_{ijk}^{g} \cdot EF^{el} \tag{3}$$

During the processing, machine tools consume some auxiliary materials, especially coolant. Coolant is generally circulated by a coolant pump and will decrease bit by bit until it is updated because some of the coolant is adhered to metal chips. Hence, coolant is supplied for compensation after a period of time. Hence, the following (4) and (5) are adopted to calculate carbon emission due to coolant consumption.

$$CE\left(N_i^0\right).cool = \sum_{g=1}^{m} \frac{IC_g^{cool}}{T_g^{cool}} \cdot EF_g^{cool} \cdot T_i^g \tag{4}$$

$$T_i^g = \sum_{j=1}^{l_i} \left(\alpha_{ij} \cdot \sum_{k=1}^{r_{ij}} \beta_{ijk}^g T_{ijk}^g \right) \tag{5}$$

Carbon emission of cutting tools is estimated from the viewpoint of tool life, as shown in (6) and (7). And some cutting tools, particularly those for a solid end mill, are recovered by regrinding after reaching their life limit. In this study, carbon emission of a cutting tool is estimated by comparing machining time of a process with tool life and considering the regrinding process.

$$CE\left(N_i^0\right).tool = \sum_{j=1}^{l_i} \alpha_{ij} CE\left(N_i^0\right)_j .tool \tag{6}$$

$$CE\left(N_i^0\right)_j .tool = \sum_{k=1}^{r_{ij}} \frac{CE_{ijk}^{tool}}{T_{ijk}^{tool}} \sum_{g=1}^{m} \beta_{ijk}^g T_{ijk}^g \tag{7}$$

Carbon emission of transportation processes in the workshop is connected with modes of transport and the distance of transportation, which can be obtained through (8) and (9). Different transportation machines will consume different resources, for example, conveyer belts or cranes need electric energy and forklifts may use diesel which will generate carbon emission directly.

$$CE\left(N_i^0\right).tran = \sum_{j=1}^{l_i} \alpha_{ij} \cdot CE\left(N_i^0\right)_j .tran \tag{8}$$

$$CE\left(N_i^0\right)_j .tran = \sum_{k=1}^{r_{ij}} \sum_{h=1}^{v} \gamma_{ijk}^h \cdot VE_i^h \cdot p_i^0 \cdot L_{k,k+1}^{qij} \cdot EF^{el} \tag{9}$$

Referring to the (2)–(9), carbon emission of multi-part processing is the sum of the aforementioned carbon emission, as shown in (10) and (11).

$$CE\left(N_i^0\right) = CE(N_i)\,.\,maching + CE(N_i)\,.\,cool + CE(N_i)\,.\,tool + CE(N_i)\,.\,tran \tag{10}$$

$$CE_{total} = \sum_{i=1}^{n} CE\left(N_i^0\right) \tag{11}$$

3. *Robustness evaluation of process logistics in workshop*

Since the demands are fluctuating, the process logistics need to adapt to that situation. Here, the adaptable design method [9] is used to evaluate the robustness. Three aspects of robustness are considered, i.e., logistics time (LT), production cost (PC) and machine load (ML).

For the logistics time, the robustness can be obtained through the comparison between the process logistics scheme PLS_q and original one PLS_0 :

$$R\left(PLS_q, LT\right) = \sum_{t=1}^{T}\sum_{i=1}^{n} p_i^t * AF(N_i^t, LT) \tag{12}$$

$$AF(N_i^t, LT) = \begin{cases} \frac{LT\left(N_i^t, PLS_0\right) - LT(N_i^t, PLS_q)}{LT(N_i^t, PLS_0)}, & LT\left(N_i^t, PLS_0\right) \geq LT(N_i^t, PLS_q) \\ 0, & otherwise \end{cases} \tag{13}$$

$$LT(N_i^t, PLS_q) = \sum_{j=1}^{l_i} \alpha_{ij} \cdot \sum_{k=1}^{r_{ij}-1} \frac{L_{k,k+1}^{qij}}{S_h} \tag{14}$$

$$LT(N_i^t, PLS_0) = \sum_{j=1}^{l_i} \alpha_{ij} \cdot \sum_{k=1}^{r_{ij}-1} \frac{L_{k,k+1}^{0\mathrm{ij}}}{S_h} \tag{15}$$

Similarly, the robustness of production cost can be acquired through (16)–(19):

$$R\left(PLS_q, PC\right) = \sum_{t=1}^{T}\sum_{i=1}^{n} p_i^t * AF(N_i^t, PC) \tag{16}$$

$$AF(N_i^t, PC) = \begin{cases} \frac{PC\left(N_i^t, PLS_0\right) - PC(N_i^t, PLS_q)}{PC(N_i^t, PLS_0)}, & LC\left(N_i^t, PLS_0\right) \geq LC(N_i^t, PLS_q) \\ 0, & otherwise \end{cases} \tag{17}$$

$$PC(N_i^t, PLS_q) = \sum_{j=1}^{l_i} \alpha_{ij}^t \cdot \sum_{k=1}^{r_{ij}} MC_{ijk}^g \cdot p_i^t + \sum_{j=1}^{l_i} \alpha_{ij}^t \cdot \sum_{k=1}^{r_{ij}-1} VC_i^h \cdot L_{k,k+1}^{qij} \cdot p_i^t \tag{18}$$

$$PC\left(N_i^t, PLS_0\right) = \sum_{j=1}^{l_i} \alpha_{ij}^t \cdot \sum_{k=1}^{r_{ij}} MC_{ijk}^g \cdot p_i^t + \sum_{j=1}^{l_i} \alpha_{ij}^t \cdot \sum_{k=1}^{r_{ij}-1} VC_i^h \cdot L_{k,k+1}^{qij} \cdot p_i^t \tag{19}$$

The robustness of machine load is shown in (20):

$$R\left(PLS_q, ML\right) = \sum_{t=1}^{T} AF\left(PLS_q, ML^t\right) \tag{20}$$

$$AF\left(PLS_q, ML^t\right) = \begin{cases} \frac{ML\left(N_i^t, PLS_0\right) - ML\left(N_i^t, PLS_q\right)}{ML\left(N_i^t, PLS_0\right)}, & ML\left(N_i^t, PLS_0\right) \geq ML\left(N_i^t, PLS_q\right) \\ 0, & otherwise \end{cases} \tag{21}$$

$$ML\left(N_i^t, PLS_{\mathrm{q}}\right) = \frac{\max\limits_g T^g - \min\limits_g T^g}{\max\limits_g T^g} = 1 - \frac{\min\limits_g \sum_{i=1}^n T_i^g}{\max\limits_g \sum_{i=1}^n T_i^g} \tag{22}$$

3.3 *Sustainability Index Based on Grey Relational Analysis*

Grey relational analysis based on grey system theory, initialized by Deng [14], is used to solve the complicated interrelationships among the multiple responses effectively. Since grey system theory was found, it has been widespread applied in the academic circles, which can quantify the degree of grey incidence to that degree of difference between the reference sequence and comparative sequence. The larger the gray correlation degree, the greater the correlation between the reference sequence and the sequence of the comparison. Here, the relative sustainability index is proposed based on grey correlation analysis, and the following steps are to be followed while applying grey relational analysis [15]:

(1) *Normalizing*: normalizing the initial results of production cost, carbon emission and robustness to avoid the effect of adopting different units to reduce the variability. If the target value of the original sequence is “the-larger-the-better”, then the original sequence is normalized using (23), e.g. production cost and carbon emission; if the purpose is “the-smaller-the-better”, then the original sequence is normalized using (24), e.g. robustness.

$$x_i^*(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \tag{23}$$

$$x_i^*(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \tag{24}$$

(2) *Grey relational coefficients*: Following the data preprocessing, a grey relational coefficient can be calculated using the preprocessed sequences. The grey relational coefficient is defined as follows.

$$\gamma\left(x_0(k), x_i^*(k)\right) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \Delta_{max}} \tag{25}$$

$$0 < \gamma\left(x_0(k), x_i^*(k)\right) \le 1 \tag{26}$$

where $\Delta_{0i}(k)$ is the deviation sequence of reference sequence $x_0(k)$ and comparability sequence $x_i^*(k)$, namely, $\Delta_{0i}(k) = \left|x_0(k) - x_i^*(k)\right|$, $\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k}\left|x_0(k) - x_j^*(k)\right|$, $\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k}\left|x_0(k) - x_j^*(k)\right|$, and ζ is the distinguishing coefficient, $\zeta \in [0, 1]$

(3) *Relative sustainability index*: The relative sustainability index can be obtained through calculating the grey relational grade, which is a weighted sum of the grey relational coefficients and is defined as follows:

$$RSI_i = \gamma\left(x_0, x_i^*\right) = \sum_{k=1}^{n} \beta_k \gamma\left(x_0(k), x_i^*(k)\right) \tag{27}$$

$$\sum_{k=1}^{n} \beta_k = 1 \tag{28}$$

Here, the grey relational grade $\gamma\left(x_0, x_i^*\right)$ represents the level of correlation between the reference and comparability sequences. If the two sequences are identical, then the value of the grey relational grade equals to one. The grey relational grade also indicates the degree of influence exerted by the comparability sequence on the reference sequence. Consequently, if a particular comparability sequence is more important to the reference sequence than other comparability sequences, the grey relational grade for that comparability sequence and the reference sequence will exceed that for other grey relational grades.

4 A Case Study

In order to verify the rationality of the proposed model, a case of a manufacturing workshop which processes aircraft landing gears is investigated. Since the aircraft landing gear contains many parts, we take outer cylinders (Part 1) and twisting force arms (Part 2) as an example for the process logistics evaluation problem. The outer cylinder mainly has 2 process logistics schemes, which the twisting force has 3 ones.

The process information of the parts are shown in Table 2. In the workshop, there are 6 machines, i.e., ordinary lathe (M1), CNC lathe (M2), lathe-mill cutting center (M3), Horizontal milling machine (M4), CNC drilling machine (M5), grinding machine (M6), and the information is listed in Table 3.

For this workshop, the current requirements (Period 0) and potential requirements of the parts are shown in Table 4. The potential requirements, i.e., Period 1–4, are obtained according to the historical data. The requirements of these two kinds of parts are fluctuating.

Through executing the sustainability evaluation method, the results of six process combinations are obtained, which are shown in Table 5. The optimal results of the six process logistics schemes are marked with underlines.

Table 2 The process information of the two parts

Task	Process logistics	Process	Machine	Machining time	Machining cost
1	1-1	1	M1	9	10
		2	M2	6	15
		3	M6	5	9
	1-2	1	M3	11	12
		2	M6	7	14
2	2-1	1	M1	9	7
		2	M4	2	12
		3	M3	3	15
	2-2	1	M3	8	6
		2	M5	4	14
	2-3	1	M1	5	12
		2	M2	4	14
		3	M4	2	8
		4	M5	4	16

Table 3 Information of machine tools

Machine	M1	M2	M3	M4	M5	M6
Name	Ordinary lathe	CNC lathe	Lathe-mill cutting center	Horizontal milling machine	CNC drilling machine	Grinding machine
Coordinate	0.0	10.0	0.5	12.5	0.10	10.10
Power	1.2	2.4	3.1	1.9	2.3	2.7

Table 4 Current and potential requirements of the parts

Parts	Period 0	Period 1	Period 2	Period 3	Period 4
Part 1	25	16	31	27	23
Part 2	30	27	24	33	26

Table 5 Results for multi-row FLP of the aircraft manufacturing workshop

No.	1	2	3	4	5	6
Process combination	1-1	1-1	1-1	1-2	1-2	1-2
	2-1	2-2	2-3	2-1	2-2	2-3
Production cost	3103	2035	3718	2790.5	**1722.5**	3405.5
Carbon emission	**68.18**	80.10	73.90	82.49	94.40	88.20
Robustness of LT	38.26	113.69	22.54	57.66	**133.09**	41.94
Robustness of PC	37.51	83.59	10.99	59.56	**105.63**	33.03
Robustness of ML	0.48	**1.71**	0.63	0.65	0.92	0.88
RSI	1.61	**2.11**	1.43	1.55	2.05	1.41

From Table 5, it can be clearly seen that the production cost of No. 5 scheme is the best, which is 1722.5 yuan. While the production cost of No. 3 is the highest, and it exceeds two more times than that of No. 5. For carbon emission, the No. 1 is the best scheme, whose carbon emission is only 68.18 $kgCO_2 - e$. The carbon emission of No. 5 is 94.40 $kgCO_2 - e$, which has the biggest impact on the environment. However, the robustness of LT and PC of No. 5 scheme are the best, which reach 133.09 and 105.63, respectively. For the robustness of ML, the No. 2 scheme is the best.

On the other hand, through executing the grey relational analysis, the relative sustainability index can be obtained which comprehensively considers the production cost, carbon emission and the robustness of LT, PC and ML. From Table 5, it is obvious that the RSI of No. 2 reaches 2.11, which is the best scheme. And the No. 5 scheme is the second best one. The No. 6 scheme is the worst one compared with the other ones.

5 Conclusion

In order to reduce the environmental impact of the process planning, a sustainability evaluation method of process logistics in workshop is proposed based on the carbon footprint and adaptability. For different process logistics schemes, the production cost, carbon emission and robustness evaluation are established. Then, a relative sustainability index is put forward via the grey relational analysis method to carry out a comprehensive assessment of process logistics schemes. Finally, a case of a manufacturing workshop which processes aircraft landing gears is investigated to verify the effectiveness of the proposed evaluation method.

The method can provide fundamental research for process logistics optimization for carbon emission reduction and sustainable improvement, which will be studied in the future work.

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Optimal Configuration of Cluster Supply Chains Considering Workload and Safe Stock Balancing with Analytic Target Cascading

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Abstract In-depth analysis of cluster supply chain operation mode which takes workload and safety stock balancing into account and especially focused on configuration policy, established of a vertical multi-source procurement in cluster supply chain configuration (CSCC). On the basis of analyzing the independent decision-making cluster enterprises, we also introduce analytic target cascading (ATC) to solve a hierarchical structure optimization problem and the results have proved the effectiveness of ATC for CSCC problem. This article solves practical engineering and management provides a systematic analysis, modeling and solving ideas.

Keywords Workload balancing · Safe stock · Industrial cluster · Supply chain configuration · Supplier selection · Analytic target cascading

1 Introduction

Recently, as the uncertainty of the demand about 3C product market, production enterprises usually according to the requirements of the orders to arrange their time schedule. There are problems with this kind of strategy, uncertainty demand means a production enterprise can't deliver the goods on time, they have to take the risk of

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bad customer responses. Above all the conditions along with this uncertainty, production enterprises are going to resolve the problems with the thought of workload balancing [1]. Existing ways to maintain the Production workload balancing are stock holding and fluctuating price of production with sales promotion. The first method means production workload or capacity utilization constant and using stock recycling to content the peak value of demand. The second method means keeping the requirements of orders consistent with the productions capacity. But they will ignore some problems when using these methods. For example, if a production enterprise are not take the spare capacity and safety stock into account, it will have some trouble like lower load, lower stock. With the lower stock, the cost of operation will be down [2]. All these relations are the starting point of my research.

Industrial clusters refers to enterprise group which is focus on specific industries with in a certain area and has division cooperation in different scale enterprises [3]. Production enterprises gain the advantage of cost and time by using efficient resource sharing or coordination and distribution. It helps enterprise group forming regional competitiveness to obtain better brand of production and market opportunity [4]. Cluster production launched by the leader enterprise which owns industrial brand and organized manufacturing company with supplier of the part in the form of supply chain. In order to guarantee the time and quality of orders' delivery, production enterprises make use of the advantage of cluster and deliver their orders to the downstream firm in the supply chain. This multiply chain collaborative production called cluster supply chains. Industry clusters are gradually becoming development model that are used in developing the resource sharing of the economy in many nations. The research of the operation cluster supply chain becoming a hot trend recently.

When we considered the conditions of production load and safety stock constant, speedy supply chain configuration faced order become a key stage of cluster supply chain. Supply chain Configuration is an integer decision process which faced integer operation of supply chain. We have to choose the most appropriate supplier to form supply net, setting constrain relation of network node, inter-decision, control and parameters of operation to make the character expression of supply chain attain the best situation. Cluster supply chain generally with short life cycle. CSSS are mostly using to solve which kind of single-supply-chain should make up of a CSC to accomplish specific order in cooperation. The division ways in multiply-chain and inside-chain choose make orders' completed index like cost and time attain the best expectation [5].

Analytic Target Cascading is a thought of system design optimization, which based on model and multilevel. Large-sized design program can be transformed into pintsized program through dividing original system into multilevel system. Each level can analyze the mode independently. From the top level, problem can be solved and at the same time, sub-problem design target can be cascaded. If cascaded target subclasses are not feasible, which can't meet the convergence standards, target cooperation from high level will lead to a process of target cascading. If the result of the optimizing can meet the demand of target, target cascading will go on until the bottom level. When all the subclasses attain a consistency condition, all kinds of secondary outcomes will make up of the finial design of the system [6]. This excellent flexibility will provide feasible solving ways for complex system cooperation problem which has many decision individual, multi-connected structure and multi-coupling relationship in their cluster supply chain.

For the universality of the research result and refraining from the complex of simulation and calculation, this thesis pay attention to a specific assembling process of product, main research problems including 1> the creation mechanism of cluster supply chain and multiply-chain cooperation order division with capacity restriction 2> the step of ATC simulation and solution method in Industry cluster 3> contrasted research between ATC and the effect and efficiency of traditional calculation 4> in industry cluster, the relation of product load and safety stock in the configuration of supply chain with different kinds of cluster supply chain forming.

2 ATC Optimization Configuration Model of Cluster Assembly Supply Chains

2.1 Problem Description

Clusters are generally three types of enterprise types exist, namely with the brand's production chief organizer (L) and a single manufacturer in the supply chain (M) and suppliers (S). The light box shown in Fig. 1. This paper studies the operation of these enterprises and various forms of cooperation in the cluster, including the chief and single-chain/manufacturer and single-chain between manufacturers and suppliers of vertical type procurement. In the real world, said the operation model is not uncommon, for example, the presence of highly integrated industry cluster brand in a class of specialized operating companies, market-oriented unified orders in the use of original equipment manufacturers (OEM) is assigned to the cluster the manufacturing enterprises. Procurement refers to the vertical chief orders later, based on cost optimization, security of supply, price control, load control and other targets, to one or more long-term and stable cooperative relations between the manufacturer/single-stranded purchase.

2.2 Problem Assumptions and Symbols Explanation

The concept of the above-mentioned operation of the relationship shown in Fig. 1. Before application specific optimization configuration, you need to configure a more appropriate supply chain strategy, the model can be configured to convert the supply chain. Aiming chief, manufacturers and suppliers of the three levels of the

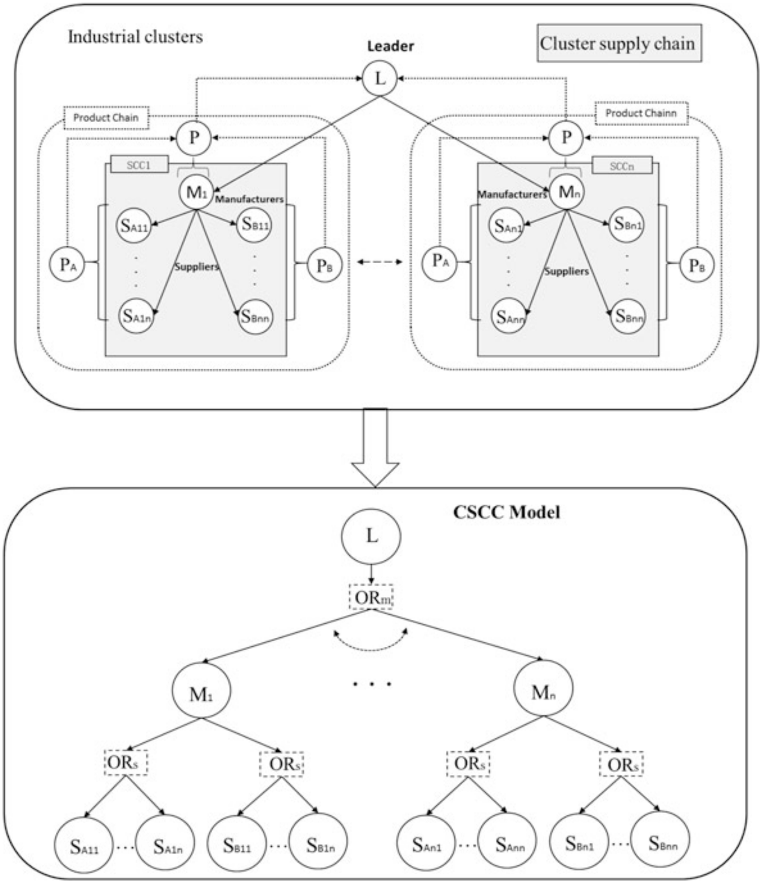

Fig. 1 The cluster supply chain operation model and configuration model

supply chain to make assumptions in Table 1, respectively, and then configure the policy and notation and definition in Table 2.

2.3 ATC Optimization Configuration Model of Cluster Assembly Supply Chain System

Firstly, the issue of cluster system analysis and assumptions, the total cost of the establishment of the cluster system to minimize the model as shown in Table 3.

Where: The objective function (1) for the entire cluster supply chain total cost (Total Cost, TC), consists of four parts: 1> main business cost (Cost Of Goods Sold, GOGS), refers to the company's production and sales with the main Direct costs of

Table 1 Problem assumptions and generality explanation

No.	Problem assumptions	Generality explanation
1	The holder enterprises as Leader, and will issue an order manufacturers	Brand owners for market orders
2	Market demand obey orders is too distribution, demand information transfer without a time delay	In line with market rules, rapid transmission of information
3	Distribution chief according to the manufacturer (supply chain) the total cost of the order quantity (proportional)	Short cyclical dynamic alliance, decided to pursue corporate profits
4	Number of manufacturers involved in the production are no more than three	Reduce the difficulty of cost and coordination
5	Supply chain only consider purchasing a product	Typical assembled supply chain
6	Does not consider upstream node	Simplified the range of model configurations
7	Single chain node using regular inspections basic stock strategy and provide a guaranteed service time for the downstream order	Operation of the market behavior of the general law
8	The key product BOM factor set as 1:1	Parts assembly ratio of 1:1
9	Various manufacturers and suppliers have the largest production capacity limit	The capability and capacity to respond to market dynamics complementarity between cluster enterprises, companies need to maintain a certain scale to professional development

business-related products or services must be invested, including raw materials, labor costs (wages) and fixed asset depreciation, GOGS of this paper to consider the purchase cost of nodes, assembly costs, distribution costs; 2> safety stock costs (Safety Stock, SSC) see (3); 3> Turnover stock costs (Cycle Stock Cost, CSC) see (4); 4> in-process stock costs (Work In Process, WIPC) see (5). (6) for the safety stock (Safety Stock, SS), the node prevent uncertainty factors (such as fluctuating demand, limited production capacity.) and in the average mean extra demand for foreign stocks held in order to ensure a certain node service levels to meet customer order requirements, the standard deviation of demand, net replenishment time, the level of service, but also, and spare capacity (Excess Capacity), namely: related. (7), (8) Working Capital stock (Cycle Stock, CS) for the sale of equipment shipments within the normal period. (9), (10) WIP (Work in Process, WIP) refers to the number of all processing or distribution stock status. (11) For the calculation of the single chain shall node needs and market demand is assumed to obey the normal distribution, information transfer chain between nodes without a time delay, lower demand for real-time access to all the nodes adjacent to each order cycle. For the calculation of the single chain node shall mean the demand equation (12)–(15).

As shown in Table 4, Where: (16) as the chief objective functions, including the lowest total cost of the entire cluster, and the proportion of single-chain distribution

Table 2 Notation and definition

Notation	Definition	Notation	Definition
i	The number of single chain	$y_{ijO_{ij}}$	Select O_{ij} situation $y_{ijO_{ij}}$ alternative options, use 0 or 1
m	Total number of single-chain industry cluster platform	t_{ij}	Order processing cycle within a single chain i node j
j	Single chain node number $j \in \{1, \ldots, n\}$	$T_{ijO_{ij}}$	Alternative options O_{ij} of production lead
n	The total number of nodes within a single chain	S_{ij}^{out}	Output service time within a chain i node j
M	All single-chain set of options	S_{ij}^{in}	Single chain I within a node j Enter the service time
d_i	Order allocation ratio of single-stranded i	τ_{ij}	Net replenishment time single chain i node j
N_{ij}	Alternative set of options within a chain i node j	c_{ij}	chain i node j unit production costs
O_{ij}	Alternative options Number of single chain i node j	α_{ij}	Given the level of service corresponding to the Z value
$V(ij)$	Adjacent upstream node set of nodes within a single chain	H	Estimates of operating hours supply chain
$E(ij)$	Adjacent downstream nodes within the node set of single-stranded	n_{ij}	BOM table coefficient, considering is 1
$cap_{ijO_{ij}}$	Maximum capacity constraint alternative energy options O_{ij}	Z_{ij}	Demand in the chain i node j
cap_{ij}	chain i node j maximum capacity constraints	μ_{ij}	Demand within a chain i node j
$c_{ijO_{ij}}$	Alternative options O_{ij} unit production costs	σ_{ij}	The standard deviation of demand within a chain i node j
μ_j	Multi-demand chain node j m	σ_j	Multi-node j demand chain standard deviation
μ_L	Mean chief demand of the connected orders	σ_L	Chief of the orders demand standard deviation

supply chain and service time goals; (17), (18) is a single chain distribution ratio and loose coupling hours; formula (19) chief hours and hours of single-chain coupling relationship; constraints (20)–(22) single-chain distribution ratio does not exceed the sum of 1, the total number of single-stranded choose three. (23), there is a coupling between the (24) the total cost of the cluster and the proportion of single-chain distribution supply chain and service time.

As shown in Table 5, where: (25) for the supply chain node (manufacturer) objective functions, including single-chain distribution rate and service time goals; (26) the total cost of a single-stranded target; (27) the manufacturer's service time single-stranded foreign service time; constraints (28) of each node within a single chain of production and production options in advance of alternative options in

Table 3 ATC System Model

$TC = Min\sum_{i=1}^{m} GOGS_i + SSC_i + CSC_i + WIPC_i$	(1)
$COGS_i = \sum_{i,j\in N_{ij}} H_{ij}c_{ij}\mu_{ij}$	(2)
$SSC_i = \sum_{i,j\in N_{ij}} h_{ij}C_{ij}SS_{ij}$	(3)
$CSC_i = \sum_{i,j\in N_{ij}} h_{ij}C_{ij}CS_{ij}$	(4)
$WIPC_i = \sum_{i,j\in N_{ij}} h_{ij}W_{ij}WIP_{ij}$	(5)
$SS_{ij}=\begin{cases} 0 \\ (for\, NRT_{ij} < NLB_{ij}) \\ (cap_{ij} - \mu_{ij})NRT_{ij} + \frac{\sigma_{ij}^2}{cap_{ij}-\mu_{ij}} \\ (for\, NLB_{ij} \le NRT_{ij} < NUB_{ij}) \\ \alpha_{ij}\sigma_{ij}\sqrt{NRT_{ij}} \\ (for\, NRT_{ij} \ge NUB_{ij}) \end{cases}$	(6)
$CS_{ij}=\frac{1}{2}t_{ij}\mu_{ij}$	(7)
$C_{ij} = c_{ij} + \sum_{i,j\in v(ij)} C_{ij}$	(8)
$W_{ij} = C_{ij} - c_{ij}/2$	(9)
$WIP_i = \mu_{ij}T_{ij}$	(10)
$Z_{ij} = \sum_{ie\in E(ij)} n_{ije}Z_{ie}$	(11)
$\mu_{ij} = d_i\mu_j$	(12)
$\sigma_{ij} = d_i\sigma_j$	(13)
$\mu_{ij} = \sum_{ie\in E(ij)} n_{iej}\mu_{ie}$	(14)
$\sigma_{ij} = \sqrt{\sum_{ie\in E(ij)} n_{iej}^2\sigma_{ie}^2}$	(15)

advance of correspondence; constraints (29) for each node in a single chain of unit production costs and choice unit production cost alternative options correspond; constraint (30) is the maximum capacity for each node can be bound with a single chain maximum capacity select alternative options could restrain correspondence; constraint (31), (32) Choose state alternative options, and a single strand of a node can only select from one of the alternative options; constraint (33) is a single-stranded equality constraints safety stock calculations; constraint (34) is a single-stranded equality constraints stock turnover calculated; constraints (35) net replenishment time calculation equation of equality constraints; constraint (36) represents the immediately preceding time constraints, the input to calculate the service time equal to the adjacent upstream largest service time; within the constraints (37), represented by a single chain each Maximum capacity constraint alternative energy options; constraint (38), represented by the response time of the distribution node constraint; constraint (39) represents the values of the relevant variables constraints.

Table 4 Leader node

$(P_L) Minimize \sum_{i=1}^{m} \left(\mathrm{TC}_i + \left\| w_{Li}^{d} \circ (d_{Li}^{L} - d_{Li}^{l}) \right\|_2^2 + \left\| w_{Li}^{ST} \circ (ST_{Li}^{L} - ST_{Li}^{l}) \right\|_2^2 \right) + \varepsilon_{d_i} + \varepsilon_{ST_i}$	(16)
$\sum_{i=1}^{m} \left\| w_{Mi}^{d} \circ (d_{Mi}^{L} - d_{Mi}^{M}) \right\|_2^2 \leq \varepsilon_{d_i}$	(17)
$\sum_{i=1}^{m} \left\| w_{Mi}^{i} \circ (ST_{Mi}^{L} - ST_{Mi}^{M}) \right\|_2^2 \leq \varepsilon_{ST_i}$	(18)
$ST_i^L = Max(ST_1^M, ST_2^M, \ldots, ST_m^M)$	(19)
$\sum_{i=1}^{M} d_i^L = 1$	(20)
$0 \leq d_i^L < 1$	(21)
$\sum_{i=1, d_i \neq 0}^{M} 1 \leq 3(sum(d_i) \leq 3)$	(22)
$where\, TC_i = GOGS_i(di) + SSC_i(di) + CSC_i(di) + WIPC_i(di)$	(23)
$d_i = f(ST_i^L, TC_1^L, \ldots TC_1^L \ldots, TC_N^L)$	(24)

3 ATC Method

Step method for solving complex application ATC system is as follows: first, to establish the correct target and the ATC system model having a layered structure; the second step, indicating the amount of critical connections between layers of the system, including the response capacity and link variables, response the amount is the amount of shared system elements between father and son, the subsystem element is connected to the shared variable volume, connected by the amount of consistency to coordinate parent element; the third step, the establishment of a local objective function layers of the system model; the fourth step, according to the literature to select the ATC solution strategy; fifth step, select solving coordination methods (such as weight update method, penalty function method, etc.), solving local target system optimization layers. For a detailed description of ATC coordination solving process, choose low-level convergence as the first solution strategy, the ATC model simplified three-layer structure as shown in the figure, and in the middle sub-layer as an example demonstrating its operating logic. B, C, respectively, feedback and cascading flow of information,m,n represents the number of times the flow of information.

4 Experiment Simulation

We set the number of single supply chains of common components in the cluster as m = 5. The production alliance leader takes the order as $u = 300, \sigma = 180$. And

Table 5 Suppy chain node

$(P_i) Minimize \left\| w_{Mi}^{d} \circ (d_{Mi}^{M} - d_{Mi}^{L}) \right\|_2^2 + \left\| w_{Mi}^{ST} \circ (ST_{Mi}^{M} - ST_{Mi}^{L}) \right\|_2^2$	(25)
$TC_i = Min \sum_{i,j \in N} h_{ij} \left[C_{ij} \left(SS_{ij} + CS_{ij} \right) \right]$ $\sum_{i,j \in N} h_{ij} \left(d_i^M W_{ij} \mu_j T_{ij} \right) + \sum_{j \in N} Hc_{ij} d_i^M \mu_j$	(26)
$ST_i^M = ST_{in}^{out}$	(27)
$\sum_{O_{ij} \in M_{ij}} T_{ijO_{ij}} y_{ijO_{ij}} - T_{ij} = 0$	(28)
$\sum_{O_{ij} \in M_{ij}} c_{ijO_{ij}} y_{ijO_{ij}} - c_{ij} = 0$	(29)
$\sum_{O_{ij} \in M_{ij}} cap_{ijO_{ij}} y_{ijO_{ij}} - cap_{ij} = 0$	(30)
$y_{ijO_{ij}} = \begin{cases} 1 \\ 0 \end{cases} O_i \text{ is chosen to be } 1, \text{else to be } 0$	(31)
$\sum_{O_{ij} \in M_{ij}} y_{ijO_{ij}} = 1$	(32)
$SS_{ij} = \begin{cases} 0 \\ (for\, NRT_{ij} < NLB_{ij}) \\ (cap_{ij} - d_i^M \mu_j) NRT_{ij} + \frac{(d_i^M \sigma_j)^2}{cap_{ij} - d_i^M \mu_j} \\ (for\, NLB_{ij} \leq NRT_{ij} < NUB_{ij}) \\ d_i^M \alpha_{ij} \sigma_{ij} \sqrt{NRT_{ij}} \\ (for\, NRT_{ij} \geq NUB_{ij}) \end{cases}$	(33)
$CS_{ij} = \frac{1}{2} d_i^M t_{ij} \mu_j$	(34)
$NRT_{ij} = S_{ij}^{in} + T_{ij} + t_{ij} - S_{ij}^{out}$	(35)
$S_{ij}^{in} = \underset{(i,j) \in A}{Max} (S_{ij}^{out})$	(36)
$cap_{ijo_{ij}} \geq d_i^M \mu_j$	(37)
$S_{ij \in D} \leq MST$	(38)
$y_{ijO_{ij}}, S_{ij}^{out}$ are non-negative integers $i \in N$	(39)

other relative parameters are initialized. The simulation is conducted by Matlab 7.11 in a PC with 2.4 GHz CPU and 8 GB RAM. The optimal value of whole system is 252,108,945, $d_1 = 0.360, d_2 = 0, d_3 = 0.370, d_4 = 0, d_5 = 0.270$.

5 Conclusion

On the basis of considering the production load and cluster supply chain with safety stock, this paper totally analyzed the strategy of configuration and made the mode of cluster supply chain configuration which is vertical, multisource and universality. The distributed decision model of CSCC is building by analyzing the independent decision demand. It also bring in ATC which has hierarchical optimizing structure to solve the problems. In this paper, we will take ATC from the theoretical level to expand application level, it will provide a systematic thought about solving practical engineering and management issues.

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Minimizing Makespan in a Flow Shop with Two Batch Machines

Jin-dian Huang, Jian-jun Liu, Qing-xin Chen and Ning Mao

Abstract On the background of the heat-treatment operation in the mould manufacturers, a flow shop scheduling problem is described to minimize makespan with two batch machines. The jobs differ from each other in weights and due-dates. An improved mixed integer linear programming (MILP) model is developed. A heuristic is proposed to improve the computing efficiency of the improved MILP model. A small-size instance is conducted to validate the optimal solution can be obtained by the improved MILP model. Large-size instances are designed to demonstrate the computing efficiency of the improved MILP model and the heuristic.

Keywords Batch processing · Flow shop · Heat-treatment · Mathematical formulation

1 Introduction

Heat-treatment is an important process in mould manufacturing. Quenching and tempering are two main stages in heat-treatment shop floor. After cutting processing, most mould jobs need to quenching and tempering, which are important to ensure the precision, intension and life-span of the mould production [1]. Heat-treatment is a bottleneck process in the mould manufacturing facility, since the mould heat-treatment furnaces is a kind of exiguous resource and the processing time of heat-treatment is long (reaching dozens of hours). The quenching furnace

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and tempering furnace are batch machines which can simultaneously process several jobs in a batch. The weights of jobs are different to each other, since the mould manufacturing is order-oriented production. Jobs arrive at the heat-treatment shop floor in a dynamic way after cutting processing. Effective scheduling is a complex decision-making in a flow shop with two batch machines.

The remainder of this paper is organized as follows: Sect. 2 reviews the related literature. In Sect. 3, we introduce the problem and the notations used in this paper. In Sect. 4, we present the Original MILP model and propose an improved MILP model. In Sect. 5, we develop a heuristic procedure to improve computing efficiency of the improved MILP model. In Sect. 6, we present computational experiments to demonstrate the application of our model and heuristic. Finally, conclusions are made in Sect. 7.

2 Related Literature

Scheduling with batch machine has attracted much attention in recent years. However, most of the literatures focus on single machine [2–6], and parallel batch machines [7–9]. The literatures on scheduling in a flow shop with batch machines can be classified into two categories, with a constant batch processing time and a varying batch processing time.

For the constant batch processing time problems, the processing time of a batch is independent of the jobs which constitute the batch. Reference [10] considered a situation in which the manufacturing system is equipped with batch and discrete processors. Reference [11] considered two scheduling problems for a two machines flow shop where a single machine is followed by a batching machine. Reference [12] proposed a mixed integer linear programming (MILP) model to minimize makespan in a flow shop with two batching machines. Reference [13] addressed a coordinated scheduling problem of transportation and batching processing in the iron and steel industry. Reference [14] considered the same problem as [13] and proposed two genetic algorithm approaches. Reference [15] considered the two machine flow shop serial-batching scheduling problem where the machines have a limited capacity in terms of the number of jobs and proposed two polynomial-time approximation algorithms with a guaranteed performance.

For the varying batch-processing time problems, the processing time of a batch depends on the jobs in it. References [16–19] considered two machines in a flow shop to minimize makespan. MILP models were proposed in [16, 17]. A greedy randomized adaptive search procedure algorithm was developed in [18]. A hybrid discrete differential evolution algorithm was proposed in [19]. Reference [20] considered incompatible job families to minimize total weighted tardiness, and proposed a variable neighborhood search scheme. Reference [21] considered the problem of minimizing total weighted tardiness on re-entrant batch-processing machines with incompatible job families, and proposed a new combined scheduling algorithm. Reference [22] considered fuzzy due dates and some heuristics based on the earliest due date were proposed.

In this paper, we consider the same problem as [12]. We will propose an improved MILP model for the problem. A heuristic procedure based on MILP will also be developed to improve computing efficiency.

3 Problem Description

3.1 Problem Statement

The scheduling problem studied in this paper can be defined as follows.

1. There are n jobs to be processed on two batch machines in a flow shop. Each job should go through quenching process and then tempering process.
2. The jobs differ from each other in release date r_j and weight w_j. The quenching processing time p_1 and the tempering processing time p_2 are assumed to be a constant, respectively.
3. The two machines for quenching and tempering have the same capacity. Each machine can process a batch simultaneously as long as the total weight of the batch does not exceed the machine capacity B.
4. Each machine can process only one batch at a time. Each batch should be processed on one machine at a time.
5. The buffer between two machines is infinite.
6. Once a batch processing machine is started, it cannot be interrupted. Jobs can not be added or removed from a batch while the batch is being processed.

The objective is to minimize makespan. According to the three-field representation of Graham [23], this problem can be described as $F2|B, r_j, W_j, batch|C_{\max}$.

Theorem 1 *Problem* $F2|B,r_j, W_j, batch|C_{\max}$ *is NP-hard.*

Proof Let us consider a relaxed problem. Assumed that the processing time of a job on machine 2 is zero, and all the jobs have the same release date, the relaxed problem is reduced to a bin packing problem. Since bin packing problem has been proved to be NP-hard, and a special case of the problem under study can be reduced to a bin packing problem. Hence the problem under study is also NP-hard. Theorem 1 is proved. □

3.2 Notation

Index:
j: 1, …, n for jobs; where n is the total number of jobs.
b: 1, …, n for batches.

m: 1, 2 for machines.
Parameters:
p_m: Processing time of a job on machine m.
w_j: Weight of job j.
r_j: Release date of job j.
B: Capacity of machine
BigM: large integer.
Decision variables:
X_{jb}: 1, if job j is in batch b; 0 otherwise.
Dependent variables:
P_{bm}: Processing time of batch b on machine m.
S_{bm}: Starting time of batch b on machine m.
C_j: Completion time of job j on machine 2.
Target variable:
C_{max}: Makespan.

4 Mixed Integer Linear Programming Model (MILP)

4.1 Original Model

Reference [12] presented the following MILP Model for the problem $F2\left|B, r_j, W_j, batch\right|C_{\max}$.

$$\text{Minimize } C_{max} \tag{1}$$

Subject to:

$$\sum_{b=1}^{n} X_{jb} = 1, \quad j = 1, 2\ldots n \tag{2}$$

$$\sum_{j=1}^{n} W_j X_{jb} \leq B, \quad b = 1, 2\ldots n \tag{3}$$

$$S_{b1} \geq r_j X_{jb}, \quad b = 1, 2\ldots n;\ j = 1, 2\ldots n \tag{4}$$

$$P_{bm} \geq P_m X_{jb}, \quad b = 1, 2\ldots n;\ m = 1, 2;\ j = 1, 2\ldots n \tag{5}$$

$$S_{bm} \geq S_{b-1,m} + P_{b-1,m}, \quad b = 2, 3\ldots n;\ m = 1, 2 \tag{6}$$

$$S_{b2} \geq S_{b,1} + P_{b,1}, \quad b = 1, 2\ldots n \tag{7}$$

$$\mathrm{C}_{\max} \geq S_{b,2} + P_{b,2}, \quad b = 1, 2\ldots n \tag{8}$$

The objective, minimizing the makespan, is expressed by (1). Constraint (2) requires that each job should be assigned to exactly one batch. Constraint (3) ensures that the total weight of jobs assigned to a batch cannot exceed the machine capacity. Constraint (4) requires the starting time of a batch on machine one must after the jobs of this batch have arrived at the machine. Constraint (5) defines the processing time of each batch on both machine, if there is no job in the batch, the batch processing time is 0; otherwise, the batch processing time is equal to the job processing time. Constraint (6) ensures that the starting time of the batch on machine m must after the previous batch which is assigned on the same machine has completed. Constraint (7) ensures that the starting time of a batch on machine two must after it completes its processing on machine one. Constraint (8) determines the makespan.

4.2 *Improved Model*

$$\text{Minimize}\,\mathrm{C}_{\max} \tag{9}$$

Subject to:

$$\sum_{b=1}^{n} X_{jb} = 1, \quad j = 1, 2\ldots n \tag{10}$$

$$\sum_{j=1}^{n} W_j X_{jb} \leq B, \quad b = 1, 2\ldots n \tag{11}$$

$$S_{b1} \geq r_j X_{jb}, \quad b = 1, 2\ldots n;\ j = 1, 2\ldots n \tag{12}$$

$$S_{bm} \geq S_{b-1,m} + P_m, \quad b = 2, 3\ldots n;\ m = 1, 2 \tag{13}$$

$$S_{b2} \geq S_{b,1} + P_1, \quad b = 1, 2\ldots n \tag{14}$$

$$C_j \geq BigM(X_{jb} - 1) + S_{b2} + P_2, \quad b = 1, 2\ldots n;\ j = 1, 2\ldots n \tag{15}$$

$$\mathrm{C}_{\max} \geq C_j \quad j = 1, 2\ldots n \tag{16}$$

Constraints (9)–(12) are the same as constrains (1)–(4). In constrains (13) and (14), we assume that the batch processing time is equal to the job processing time for all of batches, even if there may be no job in the batch. Since the batch with no job in it will be assigned to the back, these assume will not affect the scheduling result of the jobs. Constraint (15) is used to compute the completion time of each job on machine two. Constraint (16) requires the makespan is not earlier than the completion time of the last job.

5 Heuristic

The MILP Model can be solved by the commercial solver directly, such as CPLEX. However, with setting a good upper bound on the makespan, the computing efficiency will be improved. Then, we can add the following constraint to the Improved Model.

$$C_{max} \leq UB \tag{17}$$

UB is the upper bound on the makespan, which can be obtained by the following heuristic procedure.

Step 1: Sort jobs in increasing order of release dates. Let L be the list of jobs
Step 2: Put the jobs into batches by the sequence of L. If a job does not entirely fit the current batch, start a new batch and put the job in it
Step 3: Set the ready time of each batch equals to the greatest release date of jobs in it
Step 4: Assign batches to the machines by increasing order of ready times
Step 5: the upper bound is the completion time of the last batch on machine two.

Although the scheduling result may not be optimal, the batch sequence is obviously a feasible solution. The optimal makespan will be not larger than the result obtained by the heuristic. Thus, the steps result in an upper bound on makespan of the problem and the upper bound is tight.

Theorem 2 *the complexity of the heuristic is* $O(n \log n)$.

Proof The complexity of the heuristic consists of three parts:

1. Sorting jobs in increasing order of release dates, needs $O(n \log n)$ time cost.
2. Placing all jobs in batches needs $O(n)$ time cost.
3. Allocating batches to machines needs $O(n)$ time cost.

Thus, the complexity of the heuristic is $O(n \log n)$. Theorem 2 is proved. □

6 Computational Experiments

6.1 Small-Size Problem

In this section, we validate the performance of the improved MILP model and the heuristic by a 15 jobs small-size problem which is the same data as using in [12]. The job processing times in machine one and in machine two are 40 and 45 h respectively, and the capacity of machine is 500 kg. The weights (w_j) and release dates (r_j) of the jobs are provided in Table 1. CPLEX 12.3 is used to solve the MILP models. The heuristic is coded in MATLAB 7.0. A Pentium dual-core (2.00 GHz) computer with 2G RAM is used to run all the experiments.

Solving the example by the Original model and the Improved Model without upper bound respectively, we can obtain the same makespan 226 h. The CPU times are 5.1 and 4.0 s respectively. The upper bound of the makespan computed from the heuristic is 290 h and the CPU time is less than 0.01 s. Solving the Improved Model with upper bound, the makespan is also 226 h and the CPU time is 2.6 s. The Gantt chart of the instance is the same by these three models, which is shown in Fig. 1.

6.2 Large-Size Problem

In the section, large-size random instances are conducted to test the performance of the models. The following parameters are considered to generate the test instances.

Number of jobs (n): 10, 15, 20, 25, 30, 35, 40, 60, 80, 100 and 120;
Weight of job j (w_j): rand int(10kg, 50kg);

Table 1 Weight (w_j) and release dates (r_j) for the instance

j	J1	J2	J3	J4	J5	J6	J7	J8
r_j(h)	115	80	69	20	61	53	121	107
w_j(kg)	60	110	70	90	50	50	160	140
j	J9	J10	J11	J12	J13	J14	J15	
r_j(h)	96	83	4	12	40	56	101	
w_j(kg)	60	90	110	160	140	70	110	

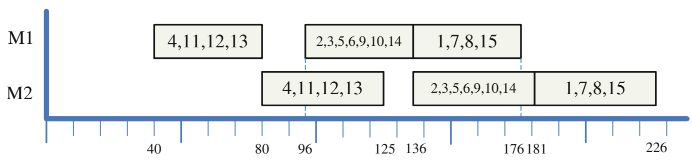

Fig. 1 Gantt chart of the instance

Table 2 Computational results of CPU times (S)

n	10	15	20	25	30	35
Original	3.8	5.2	18.5	29.5	40.2	91.2
Without UB	2.1	2.3	2.6	3.4	4.5	5.5
With UB	1.9	2.0	2.1	2.5	3	3.8

n	40	60	80	100	120	
Original	–	–	–	–	–	
Without UB	6.8	11.9	17.5	27.9	46.2	
With UB	5.3	7.7	12	18.4	32.1	

Capacity of machine (B): 500 kg;
Processing time of a job on machine m (p_m): rand int [10, 40];
Release date of job j (r_j): rand int [0, 30*n*max{p_1, p_2}/(0.8*B)];

For each factor combination, 20 independent instances are generated, resulting in a total of 220 instances. For all the instances, the upper bounds can be computed in less than 0.01 s by the heuristic, which is far less than the CPU times for computing the models. Hence, we only provide the CPU times for solving the models in Table 2. The CPU times for different problem instances are presented in Table 2.

The Original Model only can solve the problem with no more than 39 jobs on CPLEX 12.3. For the instances with more than 40 jobs, we only compute on the Improved Model. Based on the results in Table 2, it is obviously that the performance of the Improved Model is much better than the Original Model. With the upper bound of makespan, the computing efficiency of Improved Model will be improved. It is worth noting that, with the increase of jobs number, the advantages of the Improved Model with upper bound are more obvious.

7 Conclusion

In this paper we improve the existing MILP model for minimizing makespan in a flow shop with two batch machines. The batch scheduling problem we tackled has the following specifications: job release dates, job weights, equal job processing times and limited machine capacity.

Computational experiments show that the Improved Model can obtain the optimal solution and the performance is much better than the Original Model. With an upper bound of makespan, which can be computed from the heuristic, the computing efficiency of Improved Model can be improved.

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The Integration of the 3D Printing Technology and Traditional Chinese Handicrafts

Wen-yuan Wu

Abstract 3D printing is the cutting-edge rapid prototyping technology. The application of this technology has huge impact on the Chinese traditional craft. Here, from the relationship between the technology and the Chinese traditional craft, the advantages of utilization of 3D printing technology on producing handiwork are summarized. The innovated method of the Chinese traditional craft through the 3D printing is analyzed. This makes some ancient crafts, which are facing fail to be handed down from previous generations, could perfectly reappear. Meanwhile, the fact that the 3D printing technology cannot replace the Chinese traditional craft is also discussed.

Keywords Innovation · Integration · Chinese traditional craft · 3D printing

The traditional Chinese crafts are the cultural essence of Chinese nation. They mainly include carving, knit, dye transfer, embroidery, paper-cut, pottery etc. Crafters show the fascination and practical features of traditional handicrafts through their unique skills. However, the handiworks mainly made by hands usually need a long-period producing process with low-efficiency due to the tedious technological process. Nowadays, the artworks purely made by hands with exquisite techniques are expensive. Furthermore, there is always a situation that though the products have high value, no one would pay for the price. So, is there any possibility for us to avoid these problems? Viewing from the past to the present, we can clearly find that both industrial art and art design are benefited from the new technologies and the emerging and development of new production modes [1]. The 3D printing technology based on the new techniques and new materials, as a new manufactory approach, shows advantages and features during the practical application, which well consists with the technological features of traditional Chinese handicrafts. Furthermore, it can make up some shortcoming of traditional handicrafts.

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1 About the 3D Printing Technology

In April 2012, a cover article about the third industrial revolution, published by the UK-famous economic magazine *The Economist*, has triggered a new round 3D printing mania [2]. Actually, the 3D printing is a kind of rapid prototyping technology. It uses virtual 3D digital model as the source file, and applies plastics, metal powder, ceramic materials, resin, wax, sand, food material and other materials to produce the products by fitted adhesive or super laser and melting approaches. Through layer by layer printing, it transforms the model structure into a real object [3]. Thus, it is officially called "additive manufacturing". The 3D printing technology was formally applied in 20 Century 80s. With the continuous development of technology in recent years, the products made by this technology have been widely applied into automobile industry, manufacture industry, aerospace, medical industry, civil construction and other fields as shown in Fig. 1.

As the application fields are varied, the diversity of the materials used by the 3D printing technology determines the different ways for printing. It mainly refers to the way a layer joint another layer during the printing process. According to the product demand and the technical restriction of 3D printing at current stage, the stacking layer is generally realized by the additive or condensation technologies, such as squeezing, sintering, laminating, light etching and polymerizing. The mainstream technology of 3D printing is including SLA, FDM, SLS, 3DP, LOM etc. [4]. However, these cannot live without the basic procedure of 3D printing, that firstly comes up with the virtual model by 3D software or 3D scanner, and transforms it into the common-used Stereo Lithography file (STL) form by Computer Aided Design (CAD) [5], then imports files into Computer Aided Manufacturing (CAM), and divides 3D model into 2D layers with multi-intersecting surfaces. The CAM will construct the prototype according to the manufacturing data, such as materials and forming path. Finally, the data will be transmitted to the rapid formation machine and will be printed by layer depositing. In this way the product

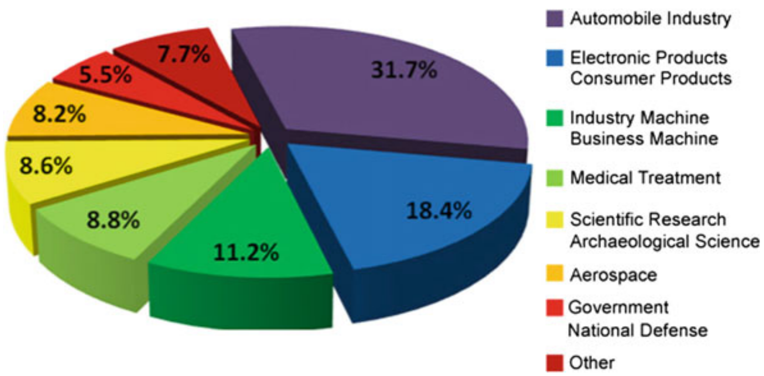
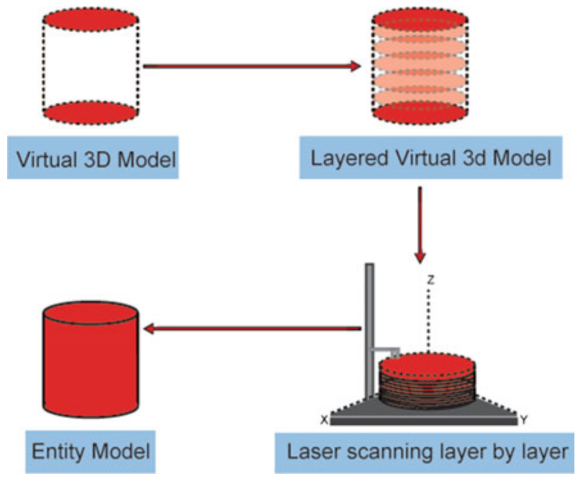


Fig. 1 Distribution diagram of the 3D printing applied in different industries

Fig. 2 Basic procedure of 3D printing



entity is formed. After printing, the surface of the product might be tough, so the product needs to be polished and strengthened by the glue as shown in Fig. 2. If needed, the final product can be painted.

2 The Innovation Impetus of Chinese Traditional Craft from the 3D Printing Technology

2.1 Fearless for Complex Form, Gorgeous for Elaboration Processing

The reason for the traditional Chinese handiworks are so elaborate is that they are made with meticulousness. The craft techniques like embroidering, carving and filigreeing require a high-level of skills of the crafters. The more complicated the decorated stripe is, the more effort will be spent by the crafter, so the craft is more expensive. However, for 3D printer, making a product with exquisite and complicated appearance costs the same time, techniques and money as a simple one [6]. In China, the jewelry industry has already used the 3D printing technology and applied it into the design of jewelry. The 3D printing technology realizes the integration of jewelry design and sample. The product entity can accurately exhibit the design intention of the designer. Also there is a little restriction for printing the shape of the entity. For the repetitive structure, hollow structure, embedded or endothecia structure and complicated liner structure, the 3D printing technology is accurate and prompt and has its own unique advantages, with which the handworks cannot compete [7]. Because the filigree craft adopts precious materials, and the producing process is complicated, it has always been regarded as the court art. After the eight steps of piling, basing, fabricating, knitting, clutching, filling, collecting

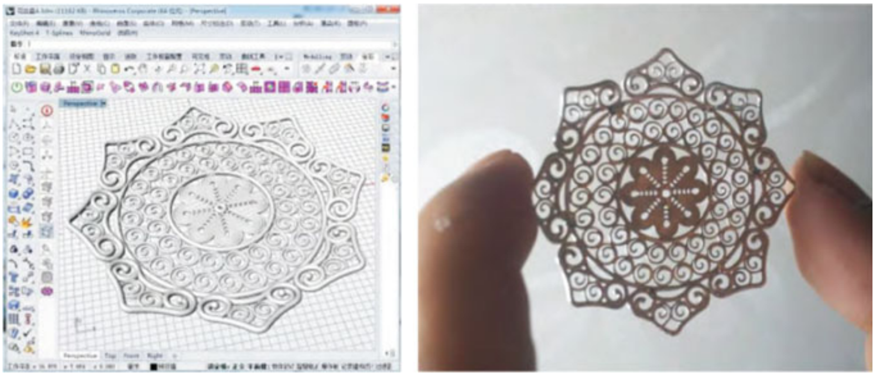


Fig. 3 Filigree disk made in jewelry research center at China University of Geosciences

and welding, the filigree is formed. The researchers in the jewelry research center of China University of Geosciences (CUG) made the filigree disk by the wax spraying 3D printing model with high precision and paraffin wax casting technology as shown in Fig. 3. The resolution of 3D printing machine is in direct proportion to the precision of filigree. Meanwhile, similar technologies have been applied into the repairing of handiworks. It can be seen that from certain extent, the manufactory difficulties of some handiworks, which require high technology previously, have been decreased along with the mature 3D printing technology. Furthermore, it provides a larger design space for handcrafters.

2.2 *Diversified Printing Materials, Strong Multi-vintage*

The research and development of the printing materials are accompanying with the development of 3D printing technology. The normal materials are plastic, resin or paper. Along with the development of technology, metal materials, ceramic materials, and wood materials etc. are emerging. Hereinto, the paper, wood, ceramic, metal are also the normal materials used in the Chinese traditional handcraft. Therefore, this coherence makes the 3D printing and Chinese traditional handcraft can be in harmony each other. Formatec Ceramics is a ceramic manufactory. In December 2012, this company held Ceramics Injection Moulding seminar and came up with Digital Light Processing (DLP) technology as shown in Fig. 4, which is considered as the best current ceramic 3D printing technology [8]. Formatec 3D printer can print out the objects through the DLP projector which illuminates a mixture of light photosensitive resin and ceramic powder. Each layer of the mixture can coagulate under the illumination. Moving the Z axis and continuously supplying the illumination, it can print out the objects layer-by-layer. Followed by degreasing and sintering, the objects can be used. It is a good choice for making small ceramic samples and repairing handiworks.

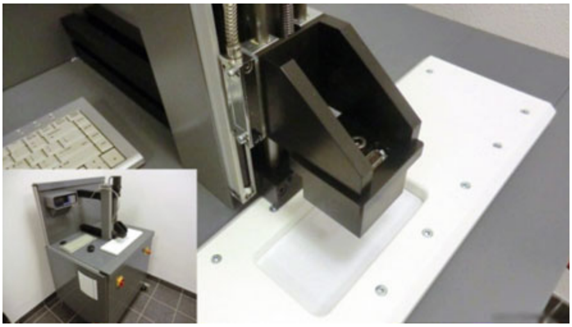


Fig. 4 DLP 3D printer

Fig. 5 Product printed using "Stick"

Wood carving has high level requirement on the quality of the wood and skill of the craftsman. It is better to choose the wood which is after drying treatment or natural withering more than one year. Meanwhile, it also needs to pay attention on their quality. Because wood is a kind of material that is simple and easy for operating, therefore, 3D printing technology also used the wood as the raw materials. The team from the Design for Craft made a filament product used wood pulp, named as Stick. Its appearance is very similar to the wood. Like the normal wood, the Stick can be polished and painted. The team leader said that "This material can be more easily printed out by compared with the wood filament. Furthermore, it can be further treated using the ordinary carpenter's tools" [9]. The product printed by "Stick" is shown in Fig. 5. By compared with the traditional wood carving, 3D printing can completely avoid the problem of selecting materials, and has more creative space for the development of the shaping. Therefore, the diversity of the materials largely affects the development of 3D printing industry. Meanwhile, it also can preferably contribute to the technological innovation of the Chinese traditional craft.

2.3 Enlarge Design Space, Break Through the Traditional Limitations

Traditional handicrafts have two limitations in the manufacturing process. First, because the traditional handicrafts mostly use "Reduction of manufacturing materials" and "equal manufacturing materials", there is limitation on the shaping of handiworks. Shaping ability is limited by the materials and tools. Second, traditional manufactory is a complex process. It is hard to modify the final products. It is also time-consuming work. On the contrast, 3D printing using the "material addition manufacturing" technology, simply changes the multi dimensions manufactory to the two dimensions overlapping from bottom to top. Therefore, it largely reduces complexity of the design and manufactory. Integration and flexibility techniques of the modeling techniques can produce the complicated shapes which were hard to image previously. Meanwhile, 3D printing also can make bizarre structure which cannot be realized by the traditional method.

Another advantage of 3D printing is the convenience, which can initially make some samples during the early design stage and gradually modify them till achieve the finial perfect products. Because it is not necessary to add the cost of manufactory and human resource, the budget for early design stage is obviously decreased. Simultaneously, it also improves the satisfaction of the final products. For instance, the face mask is the important component of the exorcise culture. Normally, the materials are selected from the aspen, willow, and camphor trees. After the selection of materials, blocking, sculpture, coloring, painting, the 5 procedures, more than 20 steps, the final face mask can be made. It is complex process. Ru-bin Wang, the descendants of nuo masks maker, carved nuo masks as shown in Fig. 6. However, it is becoming a simple process since the 3D printing technology used. For the face mask, the sample can be printed out first. Combined with the handicraft technology, the sample can be further modified and making the final face mask more relevant to the exorcise culture. In February 2014, lots of the face masks made by 3D printing technology were exhibited in The New York metropolitan pavilion as shown in Fig. 7 [10]. People were surprised on their realistic form and elegant ornamentation. Therefore, we can develop idea spontaneously from the traditional face mask design. Due to the 3D printing technology is completely aided with computer model, there is more space on the shape design and quickly printing the products. Furthermore, the designer can directly make more complicated and exquisite style and color the product in the computer, then constantly reform and make new advances. Of course, everything should be established based on the respect on the exorcise culture. Similarly, for those traditional technologies which need the assembling, such as the furnace and knitting etc., 3D printing can model by one-step and reduce the assembling procedure, but still keep the handicraft diversification and the complication. 3D printing technology brings huge design space to the traditional techniques through the parametric design and develops the design flexibility.

Fig. 6 Traditional carved mask

Fig. 7 3D printing mask

3 New Design Idea from the Combination of 3D Printing and Chinese Traditional Crafts

Design is the ligament between 3D printing and Chinese traditional crafts. It not only the trigger for applying 3D printing in traditional crafts, but also makes the traditional crafts refine themselves continuously through the science and technology. Meanwhile, the traditional crafts with the design sense are the new idea for the development of present age design. From the whole design field, it can be seen that based on the intension of each countries' traditional crafts and/or traditional cultural, developing the design and creation with the vision of contemporary characterization and aesthetic emotion of contemporary people through the modern science and technology, materials, strategies, is becoming one of the main methods.

During the design process, 3D printing can be built up based on the traditional craft, using deconstruction, transplant, grafting, splicing, mixing skills etc. [11] to refine and innovate. Through the combination of these two methods, different shaping styles can be effectively established, forming the new aesthetic vision.

3.1 The Shape and Structure Innovation Through the Combination of the 3D Printing and Chinese Traditional Crafts

In the Mencius, the shape is explained as the natural instincts. For Chinese traditional craft, it advocates the primitive simplicity and nature, emphasizes people-oriented concept. The crafts are all shaped regularly. However, for the most products of 3D printing, because of their integration and flexibility characterization, they normally show irregular shape, ether have curve shapes or demonstrate the inner hollow structures which cannot be realized by the traditional technique. Although it looks opposite to each other, because one is complex, while anther is simple, actually, they maybe complement each other in the combination of design. A theme exhibition, named as the “expose Shanghai 5—imaginary impossible”, was held in the China-international designers’ products exhibition and trade fair. 18 designers from Shanghai demonstrated products made by the 3D printing through a traditional material, bamboo [12]. The exhibition aimed to discuss the dialectical relationship between the new technology and traditional manufactory and materials. The Virtual and True Chair, which is the product of the designer, Gongwei Xu, was made by the latest 3D printing technology combined with the Stereo Lithography Apparatus (SLA) material and the most traditional material application method as in shown Fig. 8. It aims to discuss the advantages and disadvantages of the 3D printing and traditional processing technology and materials. Bamboo basket, a product of designer, Yu Tang, is an individual custom-made tea set, which was made by

Fig. 8 The virtual and true chair

Fig. 9 Bamboo basket

combining the traditional carve of nature bamboo root with the spatial modelling ability of 3D printing technology as shown in Fig. 9. It discussed the possibility of the mixture between virtual 3D printing and traditional techniques. Therefore, it can be seen that though the 3D printing is lack of the friendliness with the people, this can be fulfilled by the traditional materials and/or traditional techniques due to their natural instincts and cultural essences. The combination of these two methods can naturally create an atmosphere of compromise.

3.2 The Skill Innovation Through the Combination of the 3D Printing Technology and Chinese Traditional Crafts

Besides the shape and structure combination, the skills combination is another new design direction. Currently, a Japanese jewelry company, Kabuku, cooperates with a dyeing company. They built a fashion brand, mOment. All jewelries of the mOment are printed out by 3D printing technology and painted through the Japanese traditional dyeing techniques [13]. The unique 3D design and traditional dyeing make each one has its individual meaning, such as the Cloud of KUMO, which demonstrates the sense of blue sky and white cloud after the storm as shown in Fig. 10. Its technological design reflects the people-oriented concept, which makes the jewelry with the emotion and thought. The skills combination makes the 3D printing and traditional techniques merged harmoniously. Through which the designed products yield unusually brilliant results.

Design innovations are all based on the tradition. They are the evolution of the elements restructuring used their own way after adequately understanding the intelligent of predecessors. We need to observe the new technology from different aspects. More importantly, we need to have change to adapt the impact from the new technology on our traditional techniques cultural heritage.

Fig. 10 KUMO jewelry of the mOment

4 Discussion of 3D Printing Technology Impact on Chinese Traditional Craft

The relationship between human and objects is bind by the design. In the course of human history, the style, function and manufacturing of objects were created and conceived gradually by human according to the necessity of survival. 3D printing technology is developed along with this continually conceiving. 3D printing technology injected fresh blood into the traditional handicraft through its advantages of accurate, quick and creative diversity. However, it still cannot change the blood source of Chinese traditional craft. This fact can be confirmed by the following several aspects:

A. Chinese traditional handicraft is defined as varieties of technologies and arts which are passed generationally, have hundreds of year history and integrated technological process, and are made by natural materials with distinctive national style and local characteristics. From the macroscopical aspect, Chinese traditional handicraft pays more attention on the nature of the materials, but 3D printing always uses artificial materials, debating the natural way of traditional process requirements.
B. Chinese traditional handicraft needs to reflect the distinctive characteristics of style and national emotion, emphasizes the plain, contingency and uniqueness of handiworks. It also pays attention on the crafters' emotion, recuperation of the handiwork, the communion resonance with the texture and simple sense of the materials. However, the 3D printing does not show such unique manufacturability, culture and uniqueness. It only has the complete set of computer models. It can print any handiwork at anywhere, but without any vitality. Handmade reflects the communication between the human and objects, the harmony of life and nature, which cannot be reflected by the machinery products. Therefore, although 3D printing technology can perfectly realize the design idea, it cannot replace traditional crafters' feelings.
C. 3D printing technology supplies the facilitation for copying the handiwork. It is critical to work out the relevant law to protect the intellectual property of the

handiworks. Driven by commercial interests, some mercenary arts practitioners abandoned the profound cultural connotation of arts and crafts. Copy is becoming popular. It not only blows the enthusiasm of the originator, but also challenges moral bottom line of human.

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An Optimal Strategy Research for the Outsourcing of Warranty Repairs

Fang-qi Dong, Zi-xian Liu and Jie Yuan

Abstract A reasonable task allocation for the outsourcing of warranty repairs can improve the quality of warranty service and reduce the average cost of repairs. However, the state-independent or partially state-dependent strategy, based on the traditional static task allocation, can bring about enormous goodwill cost for their incapable to keep the load balance of the different vendors. With the development of IT, the real-time communication between the manufacturer and vendors is more convenience, on this basis we propose a fully state-dependent policy based on the dynamic task allocation for the outsourcing of warranty services and Greedy Heuristics is used as an optimal tool. Experimentation is carried out using a simulation data sets and the results show that the presented method is verified effective and practically applicable.

Keywords Dynamic model · Greedy heuristics · Task allocation · Warranty service

1 Introduction

In recent years, as an important factor that affects market competitiveness and customer satisfaction, product warranty is gradually attracting the close attention of manufacturers. It will occupy a lot of resources if manufacturers operate the product warranty services by themselves. For example, in America's industry of automobile, the manufacturers' warranty costs of domestic and global are about 10–13 billion and 40 billion respectively, ranging from 1 to 5.2 % of sales profits [1], which cause a huge pressure on companies' overall development of production and operations. With the increasing global competition, manufacturers have to focus

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their attention on the development, production and management of the products. As an effective means to improve warranty servicing quality and reduce operation costs and risk, the outsourcing of warranty repairs has become an important trend in product warranty service [2]. To avoid the risk of warranty servicing outsourcing, guarantee the geographical area of the warranty and get ready to provide services rapidly, manufacturers usually allocate warranty repairs to many different maintenance centers [3]. A reasonable warranty repairs allocation strategy enables manufacturers to provide customers with warranty services at a low cost and high efficiency, which has a significant effect on manufacturers' operation and development. There are many researchers abroad studying on this topic.

Chen and Kulkarni [4] indicated two important factors for manufacturers in considering allocating warranty repairs to maintenance centers: one is allocating the warranty repairs in an effective and economical manner; the other is minimizing the excessive waiting time for the customer, which could cause the rapidly decline of customer satisfaction, in other words that is minimizing the manufacturers' goodwill cost. Currently, the researches for product warranty repairs allocation are mainly about the state-independent or partially state-dependent strategy based on static warranty repairs allocation [5], which can be characterized with two points. The first one is static task allocation, which means that the manufacturer assigned the product to the corresponding vendors at the moment of sales and sent it to the vendor for repairing each time it failed. References [3, 4] applied the greedy algorithm under static task allocation to allocate warranty repairs, attaining the numbers of warranty products in each maintenance center. But it worth a deep research on how to allocate warranty repairs dynamically to the vendors for avoiding great repair- fluctuations between them. The other is the state-independent or partially state-dependent strategy, that means the manufacturer allocates the warranty repairs in spite of the center's task and queue information or only according to the existing numbers for repairs. Reference [6] employed dynamic routing to allocate warranty repairs under incomplete information state and built parameters to guide repairs allocation. References [7, 8] made some similar researches about product warranty repairs allocation with priority based on the state-independent strategy.

The related researches about outsourcing of warranty repairs are mainly adopting the state-independent or partially state-dependent strategy, which are resulting from the inconvenient real-time communication between the manufacturer and maintenance vendors [9, 10]. In the era of the big data and cloud computation, the real-time communication between the manufacturer and the vendors is more accurate and timely. On this basis, this paper proposed a dynamic greedy algorithm to allocate warranty repairs under the model of dynamic task allocation. This method has two significant features. The first one is dynamic task allocation. The manufacturer didn't specify the corresponding vendors for an item, as an alternative, when an item failed to work during the warranty time, the manufacturer assigned it to the vendors based on the real-time information of the vendors. The second one is a fully state-dependent policy. The manufacturer can keep abreast of the information at each vendor in the process of allocating and make a better use of it. The proposed method can avoid huge fluctuations between different vendors effectively, which can reduce warranty servicing cost and serve manufacturers significant.

The outline of the paper is as follows. Section 2 introduces dynamic allocation models and dynamic greedy algorithm under complete information. Section 3 compares the average time cost of the two allocation models through simulation experiment, verifying the effectiveness of dynamic greedy algorithm. The conclusions and further research detections are presented in the last part.

2 The Basic Introduction of Task Allocation and Its Algorithm

The static task allocation is a main type of allocation for the outsourcing of warranty repairs. In this model, the manufacturer assigns the product to the corresponding vendors at the moment of sales. For example, the manufacturer needs to assign K identical items to V service vendors, each with an exponential service time rate μ_i. The time between failures for a single item is also exponentially distributed with rate λ, and it is assumed that this information is all known to the manufacturer. Because of its unnecessary for the real-time information of the vendors, the static task allocation can be used in the context where the manufacturer is hard to grasp the accurate information of the vendors, and the state-independent strategy is the main method to solve this problem, such as Greedy Heuristics.

Although with Greedy Heuristic we can achieve the number of items to be serviced for each vendor in static task allocation, the manufacturer has no information about the real-time queuing situation of all the vendors when he assigns the product, which can easily cause huge fluctuations of the queuing lengths of the vendors and result in a lot of goodwill cost for the manufacturer. So it is valuable and important for us to apply a dynamic task allocation model in the outsourcing of warranty services.

In dynamic task allocation model, the manufacturer also need to assign K identical items to V service vendors, the difference is that the manufacturer didn't prearrange the corresponding vendors for the item, as an alternative, when the item failed to work during the warranty time, the manufacturer assigned it to the vendors based on the real-time information, such as the queue length and costs of all the vendors, it means that an item may be sent to different vendors at different failures events. The manufacturer should have an accurate and timely knowledge of all the vendors at the decision time in this model.

Let $X(t) = (x_1(t)\ldots x_i(t)), i = 1\ldots V; t \geq 0$ denotes the number of items undergoing or awaiting repair at all the vendors, which is changing with the coming of new failures or the repair completions of the old items. In this model, at the time of assigning a new failure item, the manufacturer has an accurate and timely knowledge of the real-time length x_i of all the vendors, the service rate μ_i for each vendor and the time λ between failures for a single item is also known to the manufacturer, as the same in the static allocation. Let $c_i(x_i)$ indicates the expected cost when an incoming failed item is sent to vendor i with the queue length x_i at the real time and T indicates the service time, which is submitted to the GAMMA distribution with index (x_i+1,μ) when itfollows the "first come, first served" queue sequence. The probability density function of T is

$$f(T)=\frac{\mu}{\Gamma(k+1)}(\mu t)^k e^{-\mu T} \tag{1}$$

$\Gamma(.)$ is the function of GAMMA, $T>0, \mu>0,$ and K is a positive integer (Fig. 1).

According to the formula (1), the expected service time for the item joining the queue length x_i is

$$E(T|x_i)=\frac{x_i+1}{\mu_i} \tag{2}$$

The manufacturer undertakes all the cost during the warranty service, which contains the fixed cost and the goodwill cost at the same time. The manufacturer should pay a fixed cost c_i to vendor i each time that the item is sent to vendor for repair, and also incurs the goodwill cost h_i per unit time that the item remains at vendor i. Therefore, the expected cost for the manufacturer is

$$c_i(x_i)=c_i+h_i*E(T|x_i)=c_i+h_i*\frac{x_i+1}{\mu_i} \tag{3}$$

The target of task allocation for the outsourcing of warranty repairs is the minimization of the total expected cost per unit cost for the manufacturer. To achieve this goal, we develop a dynamic greedy heuristics with full information for the dynamic allocation of the failure item. The whole process is as follows:

Step1: when a new failure item coming, get the real-time state vector $X(t)=(x_1(t)\ldots x_i(t)), i=1\ldots V; t\geq 0$;
Step2: calculate the marginal cost $c_i(x_i)$ of each vendor and choose $j\in\arg\min_{i=1\ldots V}(c_i(x_i))$;
Step3: assign the failure item to vendor j and update the state vector $X(t)$

Greedy Heuristics is a common method to solve the problem of task allocation, especially when dealing with the convex programming problem. The principle for the decision-making is minimization of the increase of the cost by assigning the failure item to the vendor with the minimum $c_i(x_i)$. To prove the validity of this method under the circumstances of dynamic task allocation for the outsourcing of warranty repairs, a simulation test is carried out.

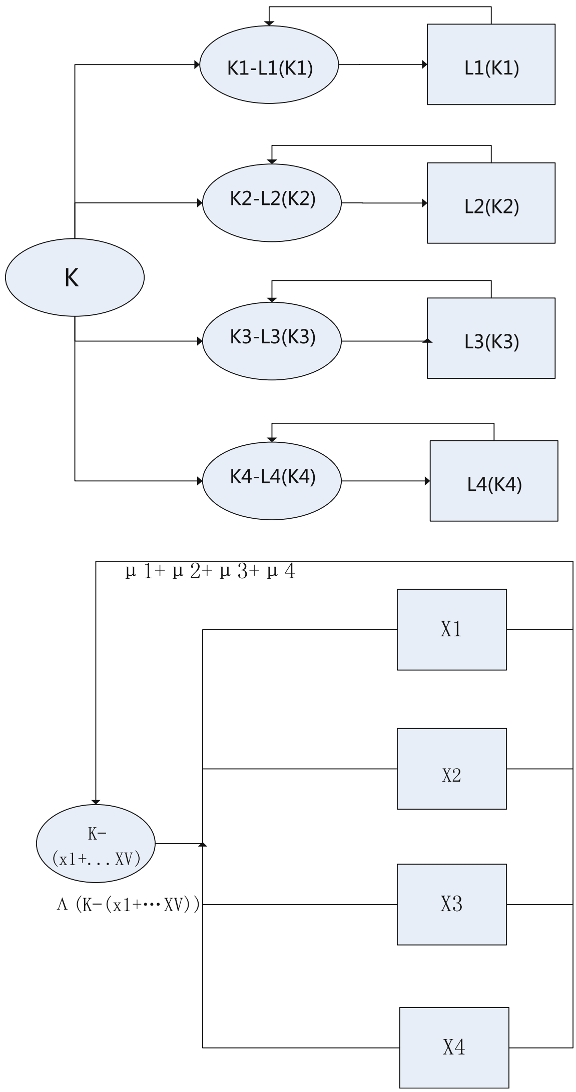

Fig. 1 A static allocation model versus a dynamic allocation model

3 Simulation Study

In this section, we compare the average cost per unit time for our task allocation model with the result of the static allocation, which is achieved by Greedy heuristics under the stable state. First, we need set the value of all the parameters. We assume that the number of items to be assigned is $K = 500$, the failure rate per item per year is $\lambda = 1.2$, and the other parameters for the problem are shown in Table 1.

Table 1 The parameters of all the vendors

Vendor (i)	Fixed cost (C_i)	Goodwill cost (h_i)	Service rate (μ_i)
1	2.3	10	1.056
2	2.3	10	0.881
3	2.3	10	0.789
4	2.3	10	0.689

In Table 1 we assume that the goodwill cost per unit time is the same among all the vendors, since it reflects the loss of goodwill for the manufacturer directly from the customer and independent of the repair vendor used. The service rates of the vendors are different.

With Greedy Heuristic, we can achieve the number of items to be serviced for all the vendors, that is K = [143 129 126 102]. On this basis, we make a data simulation of the actual operation under the stable state for both the static and dynamic task allocation, we have made a statistics about the total cost, the average cost and the operational aspect of all the vendors in the system, the result is as follows.

As can be seen from Tables 2 and 3, through data simulation we have achieved the result of the two kinds of task allocation after two years of stable operation. We have calculated the average service time, the service quantity, the fixed cost and the goodwill cost of all the vendors. From the above comparison, we can summarize that when the total number of items serviced during two years is adjacent, the dynamic task allocation has assigned more items to the vendor with the highest service rata, leading that the average service time of the system is down from 1.194 to 1.123, and about 6 % average service time has been shorten. As a result, the average service cost for an item is declined from 14.24 to 13.53, that means about 5 % product warranty costs has been saved for the manufacturer. Because the number of items and the cost for repair in practice are tremendous, the dynamic task allocation can bring huge profits for the manufacturer.

Table 2 The static task allocation model

Vendor (i)	The service time	Service product quantity	Fixed cost	Goodwill cost	The average cost
1	0.97	328	754.4	3181.6	12
2	1.11	308	708.4	3418.8	13.4
3	1.27	323	742.9	4102.1	15
4	1.52	229	526.7	3480.8	17.5
The average service time		1.194	The average service cost		14.24

Table 3 The dynamic task allocation model

Vendor (i)	The service time	Service product quantity	Fixed cost	Goodwill cost	The average cost
1	0.98	436	1002.8	4272.8	12.1
2	1.08	350	805	3780	13.1
3	1.25	248	570.4	3100	14.8
4	1.41	160	368	2256	16.4
The average service time		1.123	The average service cost		13.53

4 Conclusions

In the era of the big data and cloud computation, the real-time communication between the manufacturer and the vendors is more accurate and timely, so the manufacturer can have a very clear knowledge of all the vendors when assigning the items. We can draw a conclusion from the simulation test that the dynamic task allocation coming from Greedy Heuristic can make a full use of the information from all the vendors and can reduce the service cost for an item in the average sense. What's more, the dynamic task allocation model can also be used in other aspect such as the task allocation among cloud manufacturing, an important direction of the development of manufacturing industries. The drawback of our paper is that we haven't elaborated the principles of mathematics for Greedy Heuristic and the generalization performance of our proposal method is worth more in-depth study.

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Research on a Cutting-Tool Service Design Method

Pei-lu Sun, Ping-yu Jiang and Kai Ding

Abstract Based on the development of industrial Product Service System (iPSS) and the cutting-tool management, this paper proposes an iPSS for cutting-tools, called ct-iPSS. In ct-iPSS, manufacturing enterprises no longer buy the cutting-tools but the cutting-tool-relevant services provided by the cutting-tool manufacturers or the 3rd party service providers. Based on the concept of ct-iPSS, an event-driven cutting-tool service design method is given, which includes four main steps: (1) analyze the cutting-tool service demands coming from the cutting-tool operation activities; (2) identify the service activity and trigger event, whose definition were given in this step; (3) define the service block marks, including service activity marks, event marks and connectors marks; (4) model the cutting-tool service flow, the definition and an example corresponding to the service demands in step 1 were given in this step. It is expected that our methods will help transforming cutting-tool operation activities to service activities and modeling the cutting-tool service flow under the environment of iPSS.

Keywords iPSS · Cutting-tool · Service design · Service flow

1 Introduction

In recent decades, as the socialized manufacturing outsourcing activities explosively arises, cutting-tools which are considered as a kind of strategical consumable resource are becoming more and more important [1]. The cost of cutting-tool usage, management and consumption composes a large amount of enterprise's investment,

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but sometimes still with low utilization efficiency. An investigation conducted by Sandvik shows that in an ordinary workshop 16 % of the machining downtimes are caused by the shortage of cutting tools, 30–60 % cutting-tools are out of control in inventories, and 20 % of the working time is wasted in searching for applicable cutting-tools [2]. This problem is significant and has drawn much attention of enterprises. A new way to use/manage cutting-tools with high efficiency and low cost needs to be discovered. Many researchers and industrial practitioners have discussed a possible scheme combined with the service-dominant logic to solve such problems, i.e., product-service systems (PSS) and industrial product-service system (iPSS) [3–5]. PSS/iPSS integrate the tangible products and its related intangible services as a whole solution to be provided to customers [6]. The customers only need to pay for the usage of PSS/iPSS, and need not to consider the products and its operation logic, which brings them value-added services and cuts down a lot of their initial investments [5, 7]. Some industrial tries have already been conducted by several big cutting-tool manufacturers, e.g. TCM has been providing several kinds of cutting services for SGM (Shanghai General Motors) since 2002 [8].

To investigate and configure PSS/iPSS for customers, the systematic schemes should be designed firstly [9]. Many literatures focused on the service design frameworks or the methodologies of the PPS/iPSS [10, 11]. Luiten used Kathalys Method with five steps to design a sustainable PSS [12]. Akasaka et al. proposed knowledge-based design method to support the acquisition of new PSS design solutions by integrating knowledge accumulated in a knowledge base [13]. Jiang and Zhu studied the modeling and control of the product-service flow for the machine tools [6]. However, few work paid attention to the unified service activity design and service flow design for the cutting-tools.

In this paper, From the PSS/iPSS provider's perspective, we view the cutting-tools as the industrial product, define an iPSS for cutting-tools (ct-iPSS) and discuss how to design the cutting-tool services by designing a unified process flow language to depict the service flow. Firstly, the service design methodology including four steps is proposed. Then the cutting-tool services are divided and defined to induce the service activities and trigger events. Based on that, the schematic service block marks and connectors are defined for building the service flow. The service flow is finally modeled, explaining what resources are used at what time and what place to provide which service activity, and the relationships between it and the upstream or downstream service activities (and other information).

The reminder parts of this paper are organized as follows: Sect. 2 defines the concept of ct-iPSS and the 4 steps to design cutting-tool services. Section 3 discusses the cutting-tool service configuration method, from the service activity to the service flow. Finally, the discussions and conclusions are achieved in Sects. 4 and 5 respectively.

2 ct-iPSS and Cutting-Tool Service Design

2.1 Industrial Product Service System for Cutting-Tool (ct-iPSS)

Definition 1 Industrial product service system for cutting-tool (ct-iPSS for short) is defined as a comprehensive cutting-tool solution deployed by a 3rd party cutting-tool service provider, and this solution integrates intangible cutting service with tangible cutting-tools and can be provided to tool users to satisfy their cutting/machining requirements in the whole cutting-tool's life-cycle. The relationship between the cutting-tool service provider and customer is illustrated in Fig. 1.
Since cutting-tool activities are not the cutting-tool users' core business, they are willing to spend as little time and cost as possible on these non-value-added activities. The cutting-tool service providers are more specialized at the cutting-tool using, and they would like to improve the benefit though integrating the cutting-tool product and technical service. Ct-iPSS seems to be a good solution for the win-win situation between the cutting-tool service provider and the cutting-tool user. To build the service interaction models, some definitions should be given first, e.g., production service, service interaction mechanism, interaction content, etc.

2.2 The Methodology of Cutting-Tool Service Design

The development of ct-iPSS should include three important parts: the design of ct-iPSS, the delivery of ct-iPSS, and the adaption of ct-iPSS. This paper focuses the cutting-tool service design, which is a part of ct-iPSS design. As a new paradigm of cutting-tool applied in the industry, ct-iPSS calls for a novel service design method to adapt the cutting-tool service application environment. In consideration of the delivery, the cost estimation, the tracking and the tracing of cutting-tool service, this paper propose an event-driven cutting-tool service design method, which include four main parts as shown in Fig. 2.

Fig. 1 The relationship between the cutting-tool service provider and user

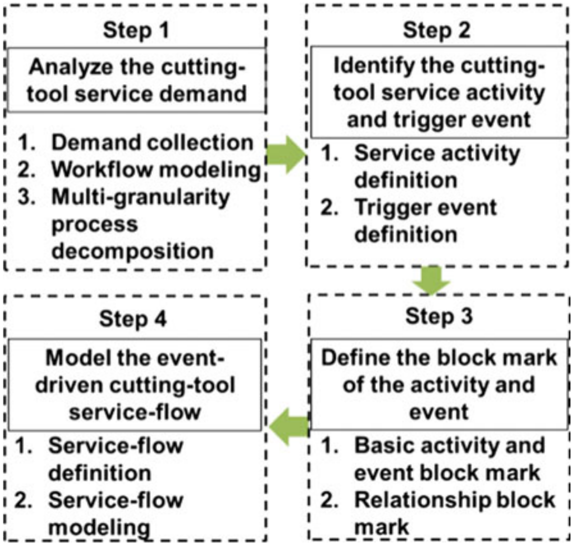


Fig. 2 Four steps of the event-driven cutting-tool service design

3 Cutting-Tool Service Configuration

3.1 Analyzing of the Cutting-Tool Service Demands

The manufacturing enterprises' demands of cutting-tool services focus on mainly four aspects: inventory, delivery, using and monitoring, which are involved the whole life cycle of cutting-tool. Each aspect of their demands includes lots of activities. An activity is regarded as a continuous operation process in this paper. For example, the inventory aspect relate to the stock-in, stock-out, inventory control, etc. The main activities of cutting-tools demands are shown in Fig. 3.

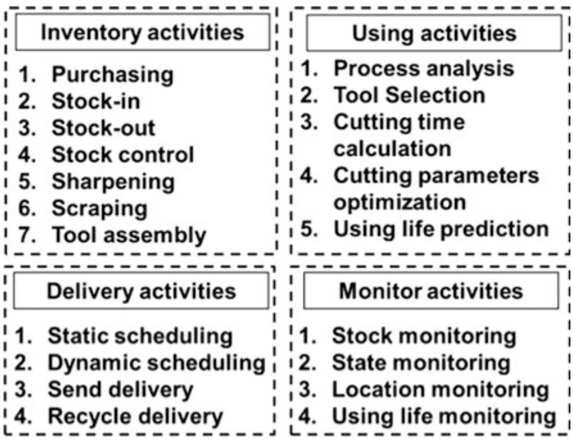


Fig. 3 Main activities of cutting-tools demands

The operation flow of cutting-tool can be rebuilt by the cutting-tool activities. A simple operation flow of cutting-tool is given in Fig. 4. This example includes 8 cutting-tool activities such as cutting-tool purchasing, stock-in, stock-out, etc.

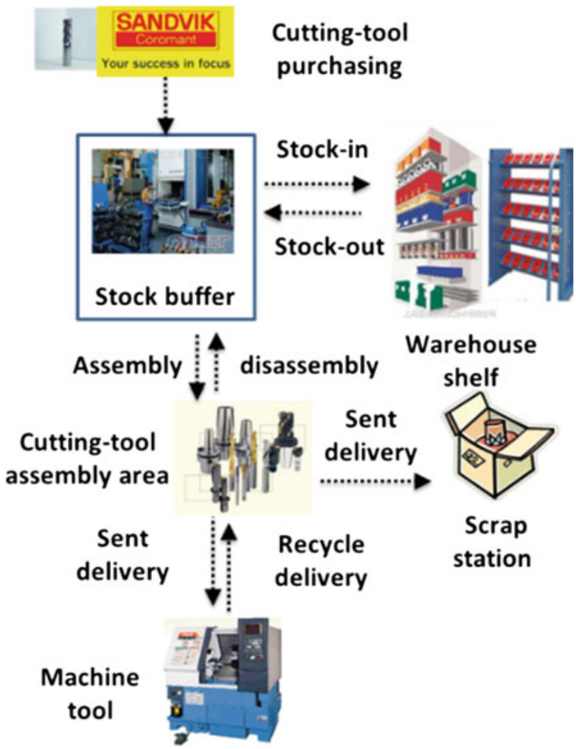
3.2 Identification of the Service Activity and Trigger Event

In Sect. 3.1, the main activities of cutting-tool life cycle were given, which is in view of cutting-tool users. However, in ct-iPSS, most (sometimes even all) of these activities would be executed by the cutting-tool service provider, so we need transform the activities to the service activities.

Definition 2 An *event* is defined as an action or command that happens at a specific time point during a service process. Three kinds of events are defined, i.e., trigger on event, trigger off event, normal event. Trigger on event and trigger off event compose an event pair to indicate the start and end of a common service activity. Normal events are the other events except the trigger on events and trigger off events in service activity. All the events are transient with no duration time.

$$EVT(EVT_{ID}, EVT_{Name}, EVT_T, T_t, L, E) \quad (1)$$

Fig. 4 A operation flow of cutting-tool



where EVT_T represent the event type, $EVT_T \in \{E_{on}, E_{off}, E_{nor}\}$, which represent the trigger on event, trigger off event and normal event respectively; T_t is the event occurrence time; L represents the working position where *the event* is triggered; E is the process executer or operator.

Definition 3 A *service activity* (SA) is defined as an independent series of continuous operations or processes executed at a certain working position with a duration time (due to the trigger time of the trigger on event and the trigger off event in this service activity) during service executing period. It can be decomposed into several independent sub-service activities.

$$SA(SA_{ID}, SA_{Name}, SA_T, EVT_s, st, EVT_d, dt, F, S, L, E) \quad (2)$$

where SA_{ID} is the service activity ID number, which is the unique identification of this service activity *in ct-iPSS*; SA_{Name} is the service activity name; SA_T is the service activity type; EVT_s is the trigger on event; st is the trigger time of the trigger event; EVT_d is the trigger off event; dt is the trigger time of the trigger off event; F is function of this service activity; S is the current state (on or off); L represents the working position where service activity is executed; E is the process executer or operator. The formalization of sub-service activity is the same as service activity.

3.3 Definition of the Service Block Mark

Based on the above definitions, we further propose a graphical model for service processes. We define homologous block mark to correspond to the service activity and event (as shown in Fig. 5).

A block mark of the SA includes a basic SA block and two event blocks, and one of the event block is trigger on event, the other one is trigger is trigger off event.

Except for the definition of service activity and event, we need define the connect relationship of service activity and event. The connect relationship have mainly three types: sequential connection, conditional connection and the

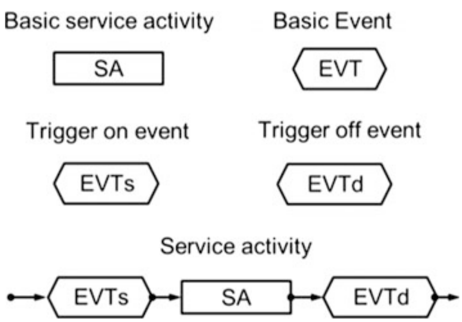
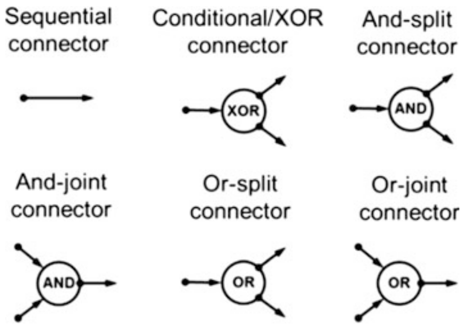


Fig. 5 The block mark of service activity and event

Fig. 6 The connectors of service activities and events



parallel connection. The parallel connection includes the ‘and’ connection and the ‘or’ connection, both of which can be composed to two types of connection: split connection and joint connection. The block marks of the connection relationship, we called connectors, were defined to the homologous sign as shown in Fig. 6.

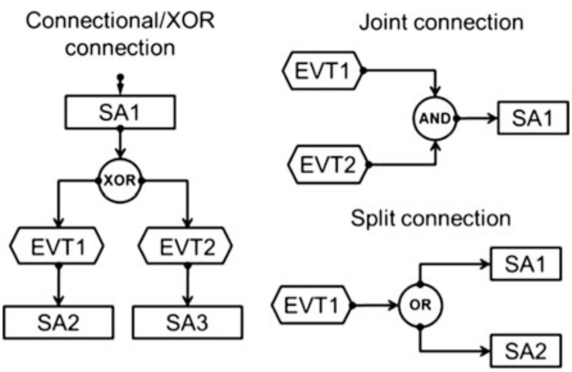
Once the connectors were defined, we can connect the service activities and event conveniently, and we can track and trace the information flow of the service activities and events through establishing the background information database. For the concise reason, the establishment of the background information database would not be discussed in this paper. The basic connection examples of activities and events were shown in Fig. 7.

3.4 Modeling of the Cutting-Tool Service Flow

Definition 4 A *state* is defined as a temporarily stable and unchanged situation of the objects, i.e., before-start, under-execution and after-completion. It should be pointed out that state changes are triggered by events.

Definition 5 A *service flow* is defined as a logic connection of the service activities which corresponds to the consecutive state and position shifting (from one position to another). A service flow can be represented as a multi-variable array.

Fig. 7 The example connection of service activity and events



$$SF(SF_{ID}, SF_{Name}, E_s, SA_s, C_s, T_c) \tag{3}$$

where E_s denotes a finite set of events; SA_s refers a finite set of service activities; C_s is a finite set of logical connectors; T_c belong to C_s, is a function, which maps each connector onto a connector type.

Based on the definition of service flow, we can build the service flow though reorganizing the service activities, events and the connectors. In Sect. 3.1, a cutting-tool operation flow was given, and we can transform the operation flow to a service flow through the service flow modeling method. The graphical service flow transformed from the operation flow is shown in Fig. 8.

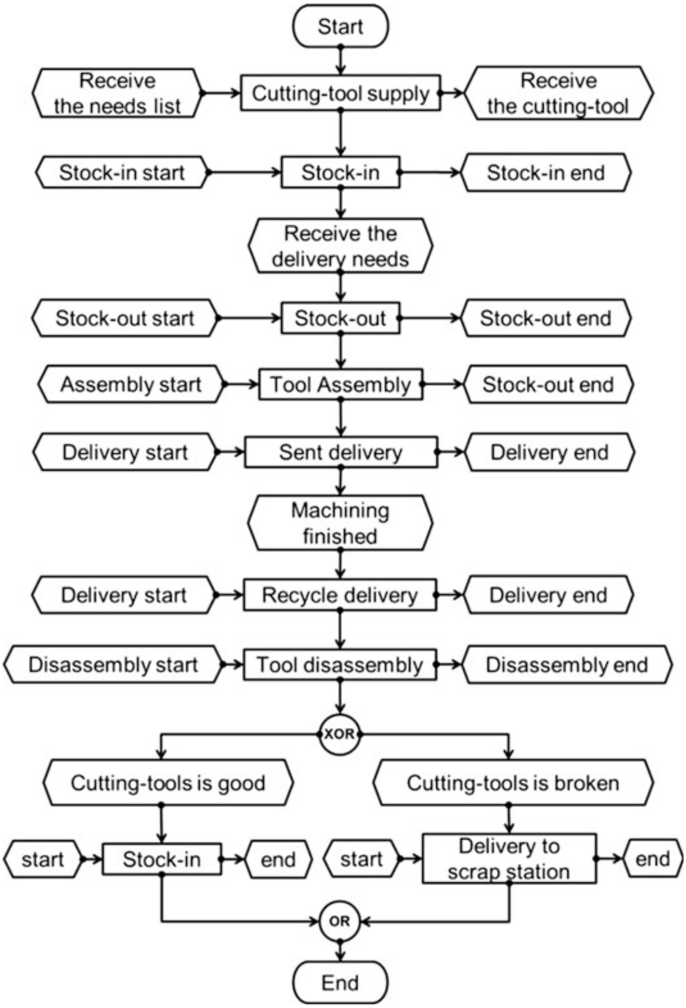


Fig. 8 A service flow of cutting-tool

In Fig. 8, there are 8 service activities corresponding to 8 cutting-tool activities in Fig. 4. However, because of the executer of activities is different, the essence of the activities is changed. The cutting-tool user who is the cutting-tools owner in operation flow, become the cutting-tool service customer in the service flow, who does not own the cutting-tools ever.

4 Discussion

The service design method mentioned in this paper is referring to the workflow modeling methods such as IDEF, petri nets and the EPCs (Event-driven Process Chains) [14, 15], especially the EPCs. However, the traditional EPCs and IDEF just describe and normalize the work executing process, which are not carrying the information flow of these processes. And some researchers applied the petri nets into the EPCs [15], but due to the complexity of petri nets, some of connect relationships can not be clearly described, and the process execution information such as the location and the trigger time of event are still not carried in their research.

The event-driven cutting-tool service design method devotes to provide a basic way to model the cutting-tool service flows which are corresponding to the customers' demands and can carry as much as possible the operational information in service process in order to provide the data support for the ct-iPSS.

5 Conclusion and Future Work

This paper proposed an event-driven cutting-tool service design method, and its four steps was described particularly. Through this method, the design of cutting-tool services in ct-iPSS would be easier and clearer than before. Moreover, because of the service flows contain the main service activities and the information flow of cutting-tools' circulation, it is convenient for the subsequent ct-iPSS configurations such as the cost estimation and the service tracking and tracing etc.

However, it is just a beginning research of ct-iPSS, there are still so much work need to do, such as the treatment of the information flow carried by the service flow, the service-CAD development, the cost estimation, the optimization and the monitoring of cutting-tool service flow, the implantation of ct-iPSS, etc.

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An Enhanced ALC Based on Kriging Model for Multidisciplinary Design Optimization

Du-xian Nie, Ting Qu, Xin Chen, Mei-lin Wang and Guo-quan Huang

Abstract An enhanced augmented Lagrangian coordination(ALC) method based on Kriging model is proposed. The classic speed reducer problem is designed as an example to verify the enhanced augmented Lagrangian coordination method, numerical results show that the enhanced ALC method can not only obtain good optimization results, but also greatly reduce the computational cost and improve the efficiency of optimization.

Keywords Augmented Lagrangian coordination · Kriging model · Multidisciplinary design optimization · Latin hypercube sampling

1 Introduction

Multidisciplinary design optimization (MDO) is used for the design of large and complex engineering systems which are normally composed of a set of linked subsystems. From last century, MDO has been widely used in many areas with complex engineering systems, including aviation, aerospace, automotive manufacturing. Due to the large scale of the complex system to be designed, it is often decomposed into smaller subsystems to perform discrete optimization and management. The design coordination methods are often applied to ensure the coupling among subsystems. Typical MDO methods include concurrent subspace optimization (CSSO) [1], bi-level integrated system synthesis (BLISS) [2], collaborative optimization

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(CO) [3], analytical target cascading (ATC) [4] and augmented Lagrangian coordination(ALC) [5]. Among them, CSSO and BLISS are two-level optimization methods, which involve unavoidable system analysis after each round of iteration, and thus consume large computing efforts. As a result, they are only applied to the design problem containing continuous variables. In addition, their convergence properties have not been theoretically proved. CO is strictly limited to two-level optimization to ensure its convergence and cannot be applied to most of the complex systems which involve multiple levels. ATC is based on hierarchical decomposition of targets, which is mainly used for non-centralized problems with hierarchical structures and belongs to a subclass of ALC. ALC method overcomes the limitations of existing methods. It has the advantages of flexibility and wide application, which is widely concerned by scholars [6]. However, there exist the following deficiencies during the solving process of ALC. The couplings between subsystems make the number of their interaction increased significantly, especially with the optimization variables, objective function and the number of constraints, the number of iterations is significantly increased. Thus, it takes a lot of time to complete the whole optimization process. In order to solve the above problems, this paper intends to introduce the Kriging approximation model [7] in the optimization process, without reducing the accuracy, to construct a calculation, calculation simulation results and the actual results similar to the mathematical model to replace the actual simulation program, and in the iterative process of updating the model, improve the accuracy and the optimization efficiency of ALC method.

The approximate model technology is an important method to solve complex engineering systems multidisciplinary design optimization. At present, the approximate models of the application of the engineering optimization field are polynomial response surface model [8], artificial neural network approximation model [9] and Kriging model [7]. Polynomial response surface model although there are the advantages of computation quantity is small, easy to use, but for engineering tend to have multiple local optima and nonlinear degree higher, the model fitting precision is poor [10]. Artificial neural network approximation model, although it has a good global approximation ability, but the approximate the improvement of model accuracy in largely dependent on more design samples and the neural network training iteration, so a large amount of calculation [11]. The Kriging model as an effective approximation techniques in recent years has been widely used in structure optimization [12, 13], multidisciplinary design optimization [14], aircraft [15] and vehicles [16] in the field of structural optimization, is an estimate of the minimum variance of estimation model, which has features of global approximation and local random error estimation. The Kriging model not only has a better fitting effect on the problem of high nonlinear and local response, but the parameters of its can be determined according to the design sample. Therefore, the problem of large amount of computation in the process of ALC is studied by using the Kriging approximation model, so as to improve the computational efficiency of ALC. The remainder of this paper is organized as follows. The Kriging approximation model is introduced in the second section. The third section is the enhanced ALC method based on Kriging model. The example analysis is in the section. Conclusions are in the last section.

2 Kriging Model

2.1 Mechanism of Kriging Model

The model is derived from the spatial statistics [7], and it is an unbiased estimation model with the smallest variance, and has the statistical characteristics of the global approximation and local random error. In addition, it has better fitting effect of the nonlinear degree and local response to the problem of the local response. Its expression form is

$$y(x) = f(x) + z(x) \tag{1}$$

where, $z(x)$ is a Gauss random function with a mean of 0 and a variance of σ^2, which is the deviation from the global simulation. $y(x)$ to be fitted to the response function. $f(x)$ is an unknown function of design variables, which is equivalent to the overall design of the whole design space and is generally replaced by β. That is

$$y(x) = \beta + z(x) \tag{2}$$

β is an unknown constant, which is estimated by a known response. $z(x)$'s covariance matrix is

$$\mathrm{cov}[z(x_i), z(x_j)] = \sigma^2 \mathrm{R}[R(x_i, x_j)] \tag{3}$$

R is expressed as the correlation matrix. $R(x_i, x_j)$ indicates the correlation function of any two x_i and x_j in the n sampling points, which is often used by Gauss function.

$$R(x_i, x_j) = \exp[-\sum_{k=1}^{m} \theta_k (x_i^k - x_j^k)^2] \tag{4}$$

m is the number of design variables, x_i^k, x_j^k is the first k element for the sample points x_i,x_j, respectively. θ_k is used to approximate the unknown correlation coefficient of the model. After determining the correlation function, the predicted value of the response value x of the unknown $\hat{y}(x)$ is given by (5).

$$\hat{y}(x) = \hat{\beta} + r^T(x) R^{-1}(y - f\hat{\beta}) \tag{5}$$

Here y is a column vector of length n, containing the response values of the sample data. When $f(x)$ is constant, f is the unit column vector of length n. $r^T(x)$ for the unknown position x and n sampling points of the related vector of length n.

$$r^T(x) = [R(x, x_1), R(x, x_2), \cdots, R(x, x_n)]^T \tag{6}$$

In (5), the $\hat{\beta}$ is estimated by (7):

$$\hat{\beta} = (f^T R^{-1} f) f^T R^{-1} y \tag{7}$$

Variance σ^2 and θ_k are estimated by (8) and (9), respectively.

$$\hat{\sigma}^2 = \frac{(y - f\hat{\beta})^T R^{-1} (y - f\hat{\beta})}{n} \tag{8}$$

$$\hat{\theta}_k = \max\{-\frac{[n \ln(\hat{\sigma}^2) + \ln|R|]}{2}\} \tag{9}$$

2.2 *The Accuracy of Kriging Model Checking*

Other sampling points are necessary to check the created Kriging model in order to verify the accuracy of the model and to ensure the validity of the model. There are many methods for model accuracy testing, including maximum error (ME) method, mean square deviation method for prediction, empirical cumulative variance method and squared error coefficient R^2. In this paper, the maximum error (ME) method and the R^2 method are used as the evaluation, and the form is (10) and (11), respectively.

$$MS = \max_{i=1}^{n} |\hat{y}_i - y_i| \tag{10}$$

$$R^2 = \frac{\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2} \tag{11}$$

Here, $\hat{y}_i$ is the first i response approximate model predictive value. y_i is the first i simulation real response. $\bar{y}$ is mean value. The local fitting accuracy of the MS reaction model is smaller, which indicates that the local fitting performance of the approximate model is better. The coefficient of determination value in the range of [0, 1], its value is close to 1 and its fitting precision is higher.

3 An Enhanced ALC Method Based on Kriging Model

ALC method is used to coordinate the process of solving the two layers of internal and external to complete. The internal loop is used to solve the given weight by using the block coordinate descent algorithm to solve the sub problems, and the outer loop is implemented with the weight update coordination. With the weight of the update, the internal loop block coordinate descent algorithm to solve the problem of the sub problem is getting lower and lower. Especially when the number of internal cycles is more, the coupling of the sub problems associated with the penalty term is obviously increased, which makes the coordination with the penalty weight update be more difficult. In order to improve the situation, the Kriging model is adopted to improve the inner loop in order to enhance the efficiency of ALC method. Large scale complex system is decomposed into various sub problems, and the ALC coordination method based on Kriging model approximation technique is shown in Fig. 1.

Its concrete steps are as follows:

Step 1 Set the initial values of the parameters;

Step 2 Sample variables by using Latin hypercube sampling (LHS) according to the variables of the sub problem;

Step 3 To calculate the constraint functions or the objective function value of each sub problem, and obtain the sample response observed values in each sub problem;

Step 4 Create the Kriging model based on the sampling points and response observed values;

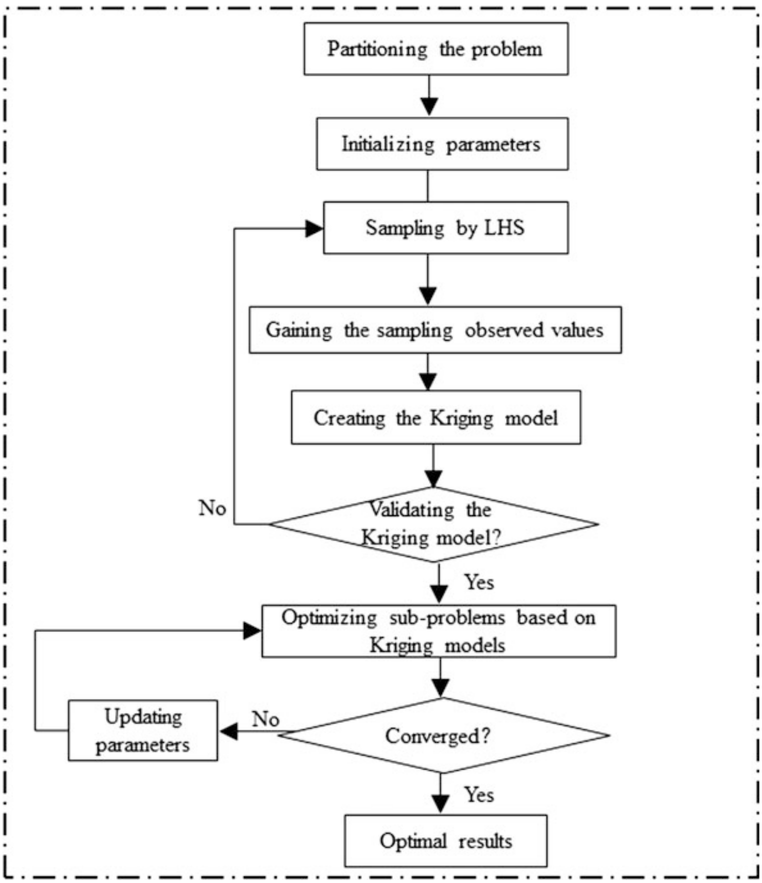


Fig. 1 The solving coordination process of ALC based on Kriging model

Step 5 Evaluate the accuracy of the Kriging model by error analysis. Not meeting the precision conditions, to be returned to Step 2, Reconstruct Kriging model by adding new sampling points;

Step 6 Set values of variables, transfer corresponding variables values to each sub problem as the target of coupling and parameters. The original implicit objective function or implicit constraints of each sub problem are replaced by Kriging approximation model. Optimize each sub problem and obtain the optimal solution;

Step 7 To determine whether or not to meet the convergence condition. If the convergence condition is satisfied then the output is optimized, otherwise, go back to the Step 8;

Step 8 Update penalty parameters and return to Step 6.

In order to verify the effectiveness of the enhanced ALC method, the optimization problem of the speed reducer is solved. This problem comes from the literature [17]. The objective of this case is to minimize the volume of the speed reducer subjected to stress, deflection, and geometric constraints. The design variables are the dimensions of the gear itself x_1, x_2, x_3, and both the shafts x_4, x_5, x_6, x_7. The AIO design problem for the speed reducer is defined by (12).

$$\min_{x_1,\cdots,x_7} f = \sum_{i=1}^{7} F_i \tag{12}$$

$$\begin{aligned}
s.t.\quad & g_1 : \frac{1}{110x_6^3}\sqrt{(\frac{745x_4}{x_2x_3})^2 + 1.69\times10^7} - 1 \le 0,\\
& g_2 : \frac{1}{85x_7^3}\sqrt{(\frac{745x_5}{x_2x_3})^2 + 1.575\times10^8} - 1 \le 0,\\
& g_3 : \frac{1.5x_6 + 1.9}{x_4} - 1 \le 0,\\
& g_4 : \frac{1.1x_7 + 1.9}{x_5} - 1 \le 0,\quad g_5 : \frac{27}{x_1x_2^2x_3} - 1 \le 0,\\
& g_6 : \frac{397.5}{x_1x_2^2x_3^2} - 1 \le 0,\quad g_7 : \frac{1.93x_4^3}{x_6^4x_2x_3} - 1 \le 0,\\
& g_8 : \frac{1.93x_5^3}{x_7^4x_2x_3} - 1 \le 0,\quad g_9 : \frac{x_2x_3}{40} - 1 \le 0,\\
& g_{10} : \frac{5x_2}{x_1} - 1 \le 0,\quad g_{11} : \frac{x_1}{12x_2} - 1 \le 0
\end{aligned}$$

$$
\begin{aligned}
&F_1 = 0.7854x_1x_2^2(3.3333x_3^2 + 14.9335x_3 - 43.0934),\\
&F_2 = -1.5079x_1x_6^2, \quad F_3 = -1.5079x_1x_7^2,\\
&F_4 = 7.477x_6^3, \quad F_5 = 7.477x_7^3,\\
&F_6 = 0.7854x_4x_6^2, \quad F_7 = 0.7854x_5x_7^2.\\
&2.6 \le x_1 \le 3.6, \quad 0.7 \le x_2 \le 0.8,\\
&17 \le x_3 \le 28, \quad 7.3 \le x_4 \le 8.3,\\
&7.3 \le x_5 \le 8.3, \quad 2.9 \le x_6 \le 3.9,\\
&5.0 \le x_7 \le 5.5
\end{aligned}
$$

The problem is decomposed into three sub-problems associated with gear, shaft1 and shaft2, The objective coupling function of the speed reducer system is $f_0 = []$, constraint functions are $h_0 = []$, $g_0 = []$. Three components (gear, shaft1 and shaft2) are coupled through the linking variables x_1, x_2, x_3. The objective function of gear sub-problem p_1 is F_1, the constraint is $\mathrm{G}_1 = [g_5, g_6, g_9, g_{10}, g_{11}]$. It has not local design variables. The objective function of gear sub-problem p_2 is $F_2 + F_4 + F_6$, local design variables are x_4, x_6, the constraint is $\mathrm{G}_2 = [g_1, g_3, g_7]$. The objective function of gear sub-problem p_3 is $F_3 + F_5 + F_7$, local design variables are x_5, x_7, the constraint is $\mathrm{G}_3 = [g_2, g_4, g_8]$. In order to facilitate and do not lose the generality, consider the use of centralized ALC method to solve the problem, the problem is solved by using the enhanced ALC based on the Kriging model, which is shown in Fig. 2.

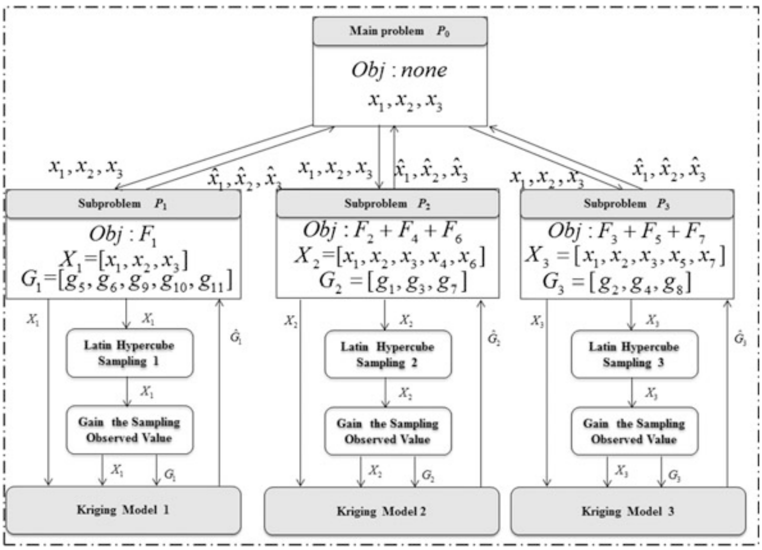


Fig. 2 The solving framework of centralized ALC based on Kriging model for the speed reducer

Fig. 3 Kriging approximation models of the sub-problem p_2

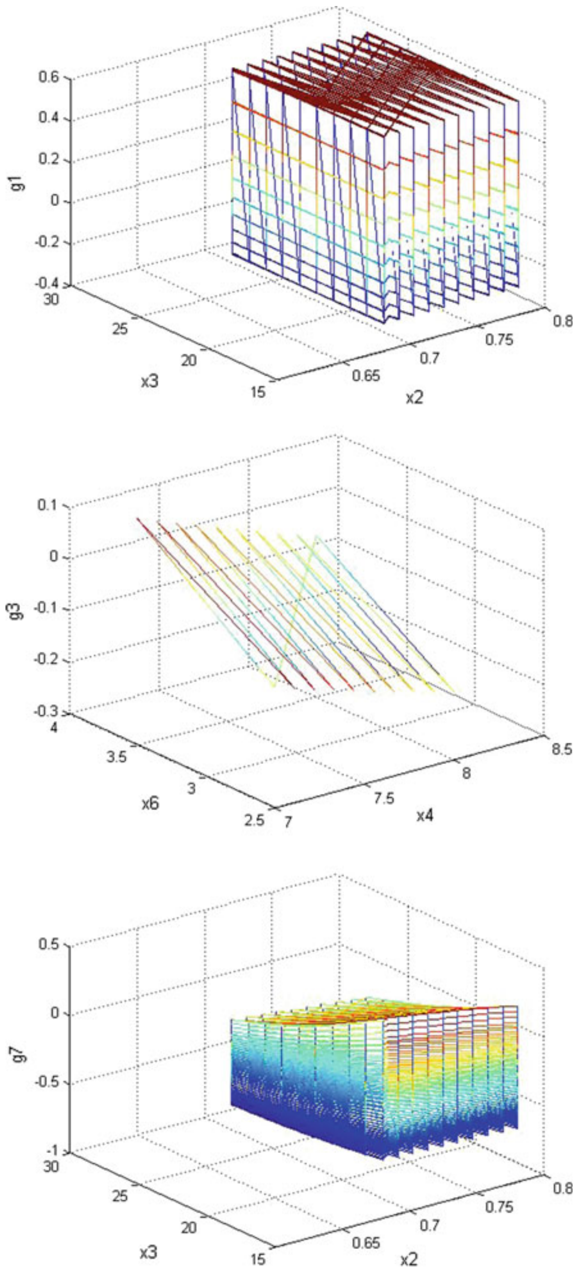
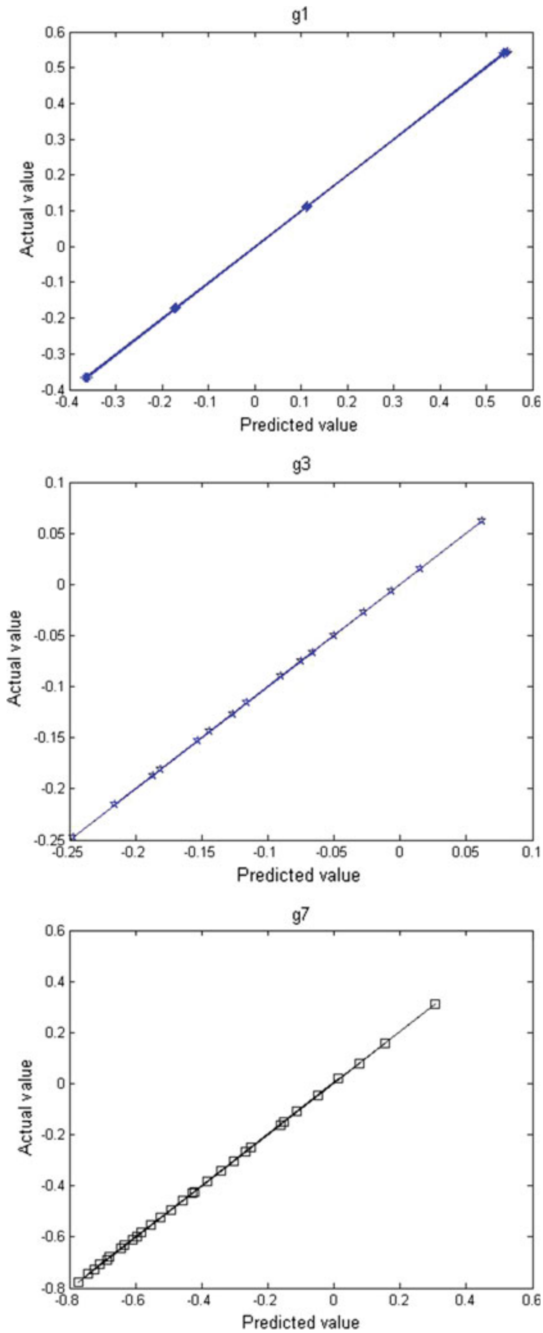


Fig. 4 Error analysis for Kriging approximation models of the sub-problem p_2



The whole experiment is carried out in CPU 2.5 GHz, RAM 4 GB and Matlab7.11 environment. According to the above steps of the enhance ALC method, at first, set parameters as $v = 0$, $\alpha = 0.1, \tilde{f} = 1$, initial weights $w = 0.001$, $\beta = 2.2$, $\gamma = 0.4$. The maximal iterations are set to 1000, and tolerance is $\varepsilon = 10^{-3}$, then, creating the Kriging models of sub problem (shaft1) p_2 is introduced in detail. Select 50 sample points by LHS to create the Kriging models to conduct the sub problem by calculating response observed values of constraint functions $G_2 = [g_1, g_3, g_7]$, and the create models are shown in Fig. 3.

Meanwhile, randomly select 30 sample points to evaluate the created models. Error analysis for the Kriging models of sub problem p_2 is shown in Fig. 4. Evaluation indexes of Kriging Models of the sub-problem p_2 are seen in Table 1.

Under the assumption that the threshold value of the evaluation indexes *ME* is 0.1 and R^2 is 0.9, respectively, Table 1 and Fig. 4 show that the established approximate models meet the requirements.

Five initial points coming from the literature [17] are selected. An enhanced ALC method is adopted to solve the speed reducer problem. The results provided by using the centralized ALC and An enhanced ALC are shown in Tables 2 and 3, respectively.

It can be seen that the results of the enhanced centralized ALC method and the centralized ALC method are very close, in terms of the running time and the number of iterations, the enhanced centralized ALC based on the Kriging approximation greatly improves the efficiency and shortens the time of the optimization compared with the centralized ALC.

Table 1 Evaluation indexes of Kriging models of the sub problem p_2

Kriging models	ME	R^2
g_1	1.21e-002	0.9994
g_3	1.61e-002	0.9989
g_7	1.0400e-003	0.9999

Table 2 The optimal results of the centralized ALC

Initial point	$x_1, x_2, x_3, x_4, x_5, x_6, x_7$	Iterations	Run time (s)	Objective function value
1	3.5001, 0.7000, 17.0000, 7.4879, 7.7153, 3.3941, 5.2867	44	22.68	2994.56
2	3.4991, 0.7000, 17.0001, 7.2914, 7.7153, 3.3806, 5.2867	43	21.73	2995.41
3	3.5001, 0.7000, 17.0000, 7.3050, 7.70233, 3.3502, 5.3066	42	21.59	2994.53
4	3.5001, 0.7000, 17.0000, 7.3013, 7.7153, 3.3695, 5.2867	41	20.98	2994.67
5	3.5000, 0.7000, 17.0000, 7.3004, 7.7153, 3.3502, 5.2867	45	23.39	2994.45

Table 3 The optimal results of the centralized ALC based on Kriging model

Initial point	$x_1, x_2, x_3, x_4, x_5, x_6, x_7$	Iterations	Run time (s)	Objective function value
1	3.5004, 0.7000, 17.0000, 7.3879, 7.7153, 3.3641, 5.2865	22	12.87	2994.66
2	3.4991, 0.7000, 17.0001, 7.3914, 7.7167, 3.3486, 5.2867	20	11.53	2995.87
3	3.4997, 0.7000, 17.0000, 7.3020, 7.70233, 3.3502, 5.3066	21	12.24	2994.73
4	3.5012, 0.7000, 17.0001, 7.3015, 7.7133, 3.3495, 5.2876	19	10.48	2994.97
5	3.5001, 0.7000, 17.0000, 7.3008, 7.7153, 3.3503, 5.2867	23	13.92	2994.49

4 Conclusion

In this paper, the enhanced ALC method based on Kriging model is proposed. At first, we create the Kriging models by using the Latin hypercube sampling method to obtain the sample data, and use the created Kriging models to replace the implicit constraint functions or implicit objective functions of the sub problems. Then, optimize the sub problems and obtain the optimal solution of each sub problem. Finally, using the classic speed reducer problem is designed as an example to verify the effectiveness of the enhanced ALC method. Numerical results show that the enhanced ALC method under the condition not reducing the accuracy of optimization results greatly reduces the computational cost and improves the optimization efficiency. Thus, it provides an effective way to choose for solving process of the ALC method.

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Scatter Search for Truck Scheduling Problem with Product Loading/Unloading Constraints in a Crossdocking System

Yan Ye, Hui Fu, Di Zhang and Jun-wei Xiao

Abstract Truck scheduling is an important optimization problem for successful crossdocking operations. Current efforts less focus on the problem considering the constraints of product unloading and loading sequences in trucks, which makes scheduling optimization more difficult and easily aggravates inefficiency of unsuitable scheduling. This paper proposes an integer programming model for such problem in a multi-door crossdocking system. The objective is to find an optimal door assignment and sequencing of inbound and outbound trucks that minimizes the makespan and satisfies the constraints. For solving it, a scatter search (SS) algorithm is developed. Computational experiments are conducted to evaluate the performance of the proposed SS approach in comparison with genetic algorithm (GA). The computational results show that SS produces better solutions in shorter CPU times for problem instances with different scales.

Keywords Crossdocking system · Loading/unloading sequence · Scatter search · Truck scheduling

1 Introduction

Crossdocking is a commonly used strategy to reduce the supply chain inventory and transportation costs and to provide good customer service. In a typical cross-docking terminal, an arriving inbound truck is assigned to a receiving dock door and then its products are unloaded, sorted, moved and loaded onto outbound trucks assigned to shipping dock doors, with little or no storage. The efficient

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implementation of the process requires optimal truck door assignment and truck sequencing, namely truck scheduling optimization.

The problem has been proved to be NP-hard [1] and has attracted attention of many researchers. McWilliams considered a parcel cross-dock with a fixed network of conveyors, where incoming trucks are scheduled with the objective of minimizing the makespan of parcel transfer operation [2]. He developed local search and simulated annealing algorithm to solve the problem. Liao et al. proposed simulated annealing, tabu search, ant colony optimization, differential evolution, and two hybrid differential-evolution algorithms for inbound truck scheduling under a fixed outbound truck departure schedule [3].

In addition, scheduling inbound and outbound trucks simultaneously in a multi-door crossdocking system is studied by more literature. Chen and Song studied a two-stage hybrid crossdocking scheduling problem where loading or unloading trucks is considered as the tasks of parallel machines at the incoming and outgoing stage [4]. They developed a mixed integer programming model and proposed four heuristics based on Johnson's rule to solve it. The cross-docking scheduling problem was modeled by Bellanger et al. as a three-stage hybrid flowshop, in which trucks and orders were represented as batches. Several heuristic schemes and a branch-and-bound algorithm were proposed to find a schedule minimizing the completion time of the latest batch [5]. Boysen constructed an acyclic directed graph for the truck scheduling at zero-inventory crossdocking terminals and proposed a dynamic programming approach and a simulated annealing procedure to minimize tardiness of outbound trucks [6]. Shakeri et al. studied crossdocking truck scheduling where products are exchanged between trucks and formulated it as a mixed integer programming model [7]. They proposed a two-phase heuristic algorithm to address the problem: a dependency ranking search heuristic for truck sequencing and a door fitness heuristic for door assignment [8]. Lim et al. assumed that trucks are loaded or unloaded during a fixed time window and the capacity of the crossdock is limited [9]. They formulated the problem as an integer programming model with the objective to minimize total transfer distances in the crossdock and designed tabu search and genetic algorithm for its solution. Miao et al. developed similar algorithms for minimizing the operational cost of the product shipments and the total number of unfulfilled shipments [10]. Miao et al. considered the same problem except that each dock door is either exclusively dedicated to inbound or outbound trucks. They built a 0-1 integer programming model and proposed an adaptive tabu algorithm to optimize the problem [11]. Kuo proposed a model for calculating the makespan when given sequence of inbound and outbound trucks based on first come first served. The model was integrated with a variable neighborhood search to optimize truck door assignment and sequencing [12]. For reviews on crossdock scheduling problems, please refer to [13] and [14].

Existing researches mainly assume that products in a truck are processed in any order. In fact, products need to be unloaded or loaded in a particular order since the truck normally picks up them from multiple suppliers or delivers them to different customers along the certain path, which is common in some industries such as less-than-truckload transportation. The sequence requirement makes truck scheduling optimization more difficult. Moreover, it easily aggravates inefficiency of unsuitable scheduling, such as longer waiting time of outbound trucks and heavier traffic congestion in the crossdock.

This paper focuses on the truck scheduling problem with such sequence requirement of handling products. After an integer programming model is proposed, a scatter search (SS) algorithm is developed to solve the problem. SS is an evolutionary method introduced by Glover in 1977 firstly and has been widely used in diverse fields, such as flowshop scheduling and vehicle routing problem [15, 16]. To the best of our knowledge, only one paper published by Tarhini et al. applied SS to the crossdocking field. They studied the crossdock door assignment problem in which there are at least as much dock doors as trucks [17]. However, this paper designed SS for both door assignment and truck sequence with the assumption that the number of trucks exceeds that of dock doors.

The rest of this paper is organized as follows. The mathematical formulation is described in Sect. 2, along with the problem assumption. Section 3 explains the details of the proposed SS algorithm. Experimental results are reported in Sect. 4, followed by concluding remarks in Sect. 5.

2 Mathematical Model

In the considered multi-door crossdocking system, it is assumed that the unloading or loading sequences of products in trucks are known in advance according to determined product pickup and delivery route of each truck. Once a product is unloaded from an inbound truck, it can be immediately moved and loaded to the suitable outbound truck that has been arrived at the dock door, even thought the unloading task of the inbound truck is not fulfilled yet. Each truck is available at time zero, and will not leave the door until it is completely unloaded or loaded, once docked. Moreover, each door is exclusively designated for receiving of shipping beforehand. In order to model the problem mathematically, the following notations are defined:

$S_m = \{1, \ldots, m, \ldots, M\}$	Set of inbound trucks
$S_n = \{1, \ldots, n, \ldots, N\}$	Set of outbound trucks
$S_k = \{1, \ldots, k, \ldots, K\}$	Set of receiving dock doors
$S_l = \{1, \ldots, l, \ldots, L\}$	Set of shipping dock doors
$S_p = \{1, \ldots, p, \ldots, P\}$	Set of all products
S_m^u	Set of products unloaded form inbound truck m
S_n^l	Set of products loaded to outbound truck n
S_{pm}^u	Set of products whose unloading positions are before that of product p in inbound truck m

S^l_{pn}	Set of products whose loading positions are before that of product p in outbound truck n
r_p	Quantity of product p
f_p	Unloading position of product p
g_p	Loading position of product p
t_1	Unit unloading/loading time
t_e	Truck changeover time
t_{kl}	Transfer time of products from receiving dock k to shipping dock l
A_m	Time when inbound truck m enters a receiving dock
L_m	Departure time of inbound truck m
C_n	Time when outbound truck n enters a shipping dock
D_n	Departure time of outbound truck n
U_p	Time when unloading of product p is finished
W_p	Time when loading of product p starts
Z	A big number
T	Makespan (or schedule length)
x_{mk}	1, if inbound truck m is assigned receiving dock k, else 0
y_{nl}	1, if outbound truck n is assigned shipping dock l, else 0
z_{mnkl}	1, if inbound truck m is assigned receiving dock k and outbound truck n is assigned shipping dock l, else 0
$p_{mm'k}$	1, if for inbound truck m and m′ assigned to receiving dock k, m precedes m′, else 0
$q_{nn'l}$	1, if for outbound truck n and n′ assigned to receiving dock l, n precedes n′, else 0.

The integer programming model formulated for the problem is as follows:

$$\begin{aligned} &\text{Minimize} \quad T \\ &\text{Subject to}: \end{aligned} \tag{1}$$

$$T \geq D_{\text{n}}, \quad n \in S_n \tag{2}$$

$$\sum_{k \in S_k} x_{mk} = 1, \quad m \in S_m \tag{3}$$

$$\sum_{l \in S_l} y_{nl} = 1, \quad n \in S_n \tag{4}$$

$$\text{p}_{mm'k} \leq x_{mk}, \quad m, m' \in S_m, \ m \neq m', \ k \in S_k \tag{5}$$

$$\text{p}_{mm'k} \leq x_{m'k}, \quad m, m' \in S_m, \ m \neq m', \ k \in S_k \tag{6}$$

$$\mathrm{q}_{nn'l} \leq y_{nl}, \quad n, n' \in S_n,\ n \neq n',\ l \in S_l \tag{7}$$

$$\mathrm{q}_{nn'l} \leq y_{n'l}, \quad n, n' \in S_n,\ n \neq n',\ l \in S_l \tag{8}$$

$$z_{mnkl} \leq x_{mk}, \quad m \in S_m,\ k \in S_k,\ n \in S_n,\ l \in S_l \tag{9}$$

$$z_{mnkl} \leq y_{nl}, \quad m \in S_m,\ k \in S_k,\ n \in S_n,\ l \in S_l \tag{10}$$

$$z_{mnkl} \geq x_{mk} + y_{nl} - 1, \quad m \in S_m,\ 2k \in S_k,\ n \in S_n,\ l \in S_l \tag{11}$$

$$A_{m'} \geq L_m + t_e - Z(1 - p_{mm'k}) \quad m, m' \in S_m,\ k \in S_k \tag{12}$$

$$C_{n'} \leq D + t_e - Z(1 - q_{nn'l}), \quad n, n' \in S_n,\ l \in S_l \tag{13}$$

$$\mathrm{U_p} \geq A_m + \sum_{v \in S^u_{pm}} r_v t_1 + r_p t_1, \quad p \in S_p,\ m \in S_m \tag{14}$$

$$W_p \geq C_n, \quad p \in S^l_n \tag{15}$$

$$W_p \geq W_v + r_v t_1, \quad v \in S^l_{pn} \tag{16}$$

$$W_p \geq U_p + t_{kl} z_{mnkl}, \quad p \in S^u_m \cap S^l_n,\ m \in S_m,\ n \in S_n,\ k \in S_k,\ l \in S_l \tag{17}$$

$$L_m \geq U_p, \quad p \in S^u_m \tag{18}$$

$$L_m \geq U_p, \quad p \in S^u_m \tag{19}$$

The objective is to minimize the makespan, as shown in (1). Constraint (2) specifies that the makespan is the maximum completion time of all outbound trucks. Constraints (3) and (4) ensure each truck is exactly assigned to one dock door. Constraints (5)–(8) define the logic relationships between x_{mk} and $p_{mm'k}$ as well as between y_{nl} and $q_{nn'l}$. Constraints (9)–(11) ensure that both x_{mk} and y_{nl} are equal to 1 when the value of z_{mnkl} is 1, otherwise x_{mk} or y_{nl} is equal to 0. Constraints (12) and (13) specify the time dependencies between two different inbound/outbound trucks assigned to the same receiving/shipping door, that is, the docking time of one truck on the door is after the leaving time of the other truck, which precedes the former truck, plus the truck changeover time. Constraint (14) states that each product in an inbound truck can be unloaded only after the truck has docked and all products, whose unloading positions are before its unloading position, have been unloaded. Constraints (15) and (16) define similar relationship for product loading. Furthermore, Constraint (17) states that the starting time of loading a given product is after the completion time of its unloading plus its transfer time in the terminal. Constraints (18) and (19) ensure that each inbound or outbound truck cannot leave the assigned door until its products are all unloaded or loaded.

3 Development of a Scatter Search Algorithm

Scatter search is a global search strategy that is founded on the premise that systematic designs and methods for creating new solutions afford significant benefits beyond those derived from recourse to randomization [18]. It uses a framework for search diversification and intensification, which normally consists of five main components: diversification generation method, improvement method, reference set update method, subset generation method, and solution combination method. The framework is very flexible because each component can be implemented in a variety of ways and degrees of sophistication. The implementation of these methods in the proposed scatter search algorithm is described in detail as follows.

3.1 Diversification Generation Method

The diversification generation method is aimed to generate a collection *P* of *Psize* diverse solutions as initial population and consists of two phases.

First, *Psize* inbound and outbound truck sequences serviced by the crossdock are built. Each sequence uses the positive integer number coding of all inbound or outbound trucks. In order to assuring the diversification of sequences, the diversification generator proposed in [19] is used. For instance, when there are 6 inbound trucks and 6 outbound trucks, a seed solution shown in Fig. 1 is created at random. Its left represents the service sequence of inbound trucks and the right represents that of outbound trucks. P(1) shows respective positions of these trucks. Form P(1), P(2) is determined by the method in [19]. For each number in P(2), an inbound or outbound truck can be drawn from the seed according to its correspondence with P(1). Then, a new truck sequence is produced.

If there are M inbound trucks and N outbound trucks, based on the above method and a seed, the number of total truck sequences is determined by

$$DIVNUM = 4 \cdot [M/2] \cdot [N/2] \tag{20}$$

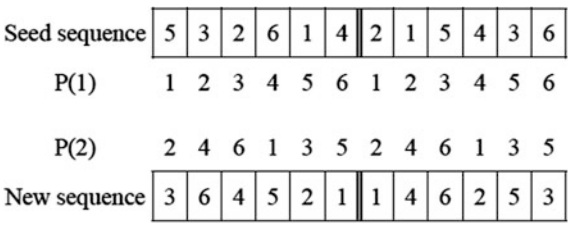

Fig. 1 Generation of a new truck sequence by applying diversification generator to a seed sequence

where [*M*/2] indicates the greatest integer smaller than or equal to *M*/2. By comparing *DIVNUM* and *Psize*, there exist two situations:

(1) If *DIVNUM* is less than *Psize*, the initial population is created by randomly generating [Psize/DIVNUM] + 1 seed sequences and applying the above method to each seed.
(2) If *DIVNUM* is not less than *Psize*, the initial population is created by randomly selecting *Psize* sequences from *DIVNUM* truck sequences.

Secondly, for each truck sequence generated above, an adapted approach from that in [12] is used to assign dock door and calculate operations time for each truck. Each inbound/outbound truck in the sequence is successively assigned to the first vacant receiving/shipping door and its docking time is recorded. Considering products unloading/loading sequence requirement, the starting time for unloading each type of product in a docked inbound truck is calculated as the docking time of the truck plus the unloading time of all preceding products. Similarly, the starting time for loading each type of product in a docked outbound truck is the maximum of its unloading complete time plus transfer time in crossdock and the docking time of the truck plus the loading time of all preceding products. The leaving time of each truck is calculated as the complete time of unloading/loading all products in it. Finally, both truck sequence at each door and the makespan are obtained.

3.2 Improvement Method

The improvement method is generally used to improve the initial solutions or solutions generated by combination method. In our work, reversing the elements between two randomly selected points is applied to the inbound part, outbound part, and both parts of a truck sequence, which can produce three new sequences. Door assignments and makespans corresponding to them can be obtained based on the above method. If the makespan of at least one new sequence is less than that of the original sequence, it is replaced with the new one.

3.3 Reference Set Update Method

The reference set update method constructs an initial reference set (*Refset*) from the initial population and updates it during iterations. The *Refset* comprises two subsets: a subset *Refset1* with *b1* high quality solutions and a subset *Refset2* with *b2* diverse solutions. All solutions in *Refset* are sorted by their makespans in an ascending order.

The *Refset1* is formed by choosing *b1* truck sequences with minimal makespan. To build *Refset2*, the difference between truck sequences is defined as the number of their dissimilar elements. For example, there are two sequences: 213645324615 and 215436364125. Their difference is 7. For each truck sequence in *P-Refset*, the minimum of the differences between it and the sequences in *Refset* is calculated. The sequence with the maximum of these minimum differences is selected. If the number of such sequences is more than one, the sequence with maximal makespan is added to *Refset*. The process is repeated *b2* to obtain *Refset2*.

When updating *Refset*, the static update strategy [18] is used. That is, new *Refset* is built from the original *Refset* and new truck sequences generated by the combination and improvement methods. If it is the same as the original *Refset*, terminate the algorithm.

3.4 Subset Generation and Solution Combination Method

The subset generation method builds a number of subsets based on the reference set and the solutions in each subset are used in the combination method to generate one or more new solutions. In this study, every pair of two truck sequences in *Refset* is used to form a subset. Then, as the combination method, ordered crossover operator is respectively applied to inbound part and outbound part of truck sequences in a subset to produces two new sequences. If the sum of subsets or new sequences is greater than *Psize*, then select *Psize* subsets or sequences randomly.

4 Experimental Results

We examines the performance of the SS algorithm proposed for solving the integer programming model of the crossdocking truck scheduling, in comparison with the genetic algorithm (GA). Both algorithms are coded in VC++ and all the experiments are performed on a personal computer with Pentium Dual 2.5 GHz CPU and 1.99G RAM under Windows XP professional.

The parameters of SS and GA are shown in Table 1. In GA, the roulette wheel selection, ordered crossover and reverse mutation operator are used. The algorithm

Table 1 Parameters of SS and GA

Algorithm	Parameter	Values
SS	*Psize*	100
	b_1	7
	b_2	3
GA	Population size	100
	p_c	0.9
	p_m	0.1
	Maximum iteration	200
	Number of the best solution not improved	5

terminates when the best solution is not improved within 5 iterations or it has run 200 iterations.

We generate test instances in this study since there are no benchmark instances available to evaluate the performance of the algorithms for the considered problem. We choose a representative layout of a crossdock with two parallel sets of docks located at opposite terminals. One set is used for inbound trucks and the other is used for outbound trucks. The transfer time from a receiving dock to a shipping dock is proportional to their rectilinear transfer distance according to the topology. Product types in a truck and their unloading or loading positions are generated randomly. The total number of inbound product types is the same as that of outbound product types. The quantity of each type of product is uniformly generated in the interval [2, 6]. Unit unloading/loading time and truck changeover time are constant.

Test instances are divided into three categories, including small, medium, and large scales. Each category contains three instances. For each instance, the SS and GA approaches are run 10 times and the detailed results are presented in Table 2. The second column of Table 2 shows the instance sizes, denoted by K-M-L-N-TP. TP is the maximum number of product types in an inbound or outbound truck. The performance of SS and GA are evaluated by the *Best objective* (value), *Average objective*, and *Average CPU time* of the ten replications. The last column shows the gap of SS and GA in computational time, which is calculated by:

$$Gap = (time^{GA} - time^{SS})/time^{GA} \times 100\% \tag{21}$$

From Table 2, the SS approach outperforms GA in terms of the solution quality in all test instances. Moreover, it can be observed from the *Gap* column that the calculation time of SS is reduced by more than 70 % compared with GA. This implies that SS has a great advantage in speed.

Table 2 Results of SS and GA on problem instances with small, medium and large sizes

Categories	Problem instances	GA			SS			Gap (%)
		Best	Average	CPU time (s)	Best	Average	CPU time (s)	
Small	3-9-3-9-3	140	144.5	8.731	134	137.9	0.181	97.929
	3-12-3-12-3	208	214.1	7.867	193	201.8	0.231	97.064
	3-15-3-15-3	243	254.9	6.692	224	236.9	0.258	96.152
Medium	8-30-8-30-5	395	402.1	12.32	380	393.8	0.453	96.322
	8-45-8-45-5	574	592.3	19.301	548	575.6	1.556	91.936
	8-60-8-60-5	819	830.9	12.245	791	818.2	1.949	84.087
Large	15-80-15-80-10	1414	1430.6	25.964	1394	1421.8	5.743	77.883
	15-90-15-90-10	1568	1584.2	59.15	1567	1582.6	10.7	81.910
	15-110-15-110-10	1963	1977.6	52.633	1932	1971.4	13.774	73.831

5 Conclusion

This research is focused on optimizing the dock door assignment and sequence of inbound and outbound trucks in a multi-door crossdock under the constraints of unloading and loading products in trucks in a given order.

The formulation of the problem is not found in the literature.

First, an integer programming model is built for the problem. Based on the model, a scatter search (SS) approach is then proposed. SS has seldom been explored for crossdocking settings and the approach is an important contribution of this research. Finally, experimental results of test instances with different sizes show that the SS algorithm is efficient when compared with GA.

It is assumed that all trucks are available at time zero in this work. The cross-docking truck scheduling when trucks arriving after the start of the schedule will be our future work. In addition, integrating other metaheuristics into SS will be considered to provide higher optimization performance.

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Joint Optimization of Condition-Based Repair-by-Replacement and Spare Parts Provisioning Policy with Random Maintenance Time and Lead Time

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Abstract A joint strategy, referred to as periodical condition-based repair-by-replacement and continuous reviewed (S,s) type spare provisioning policy, is presented for continuous deteriorating systems with a known number of identical repairable components. Maintenance consists of replacing all failed and/or deteriorated components, and then deteriorated components being repaired off-line. With assumptions of random repair time, random lead time for spare parts ordering and imperfect maintenance effect, a stochastic simulation model is developed to determine the jointly optimal strategy. The objective function of the model represents the average cost per component per unit time over an infinite time span, while inspection interval, preventive replacement threshold, spare part inventory levels and repair capacity are chosen as decision variables. The optimal result is obtained using integrating approach with discrete event simulation and genetic algorithm (GA). Simulation results indicate that there are trades-off among maintenance policy, spare parts inventory and repair capacity.

Keywords Joint optimization · Condition-based repair-by-replacement · (S,s) type spare provisioning policy · Repair capacity · Random maintenance time · Random lead time

1 Introduction

Maintenance optimization is a great interesting research topic which arouse great interest among scholars for its primary purpose is to find an effective implementation of preventive maintenance policies to maximize system availability and/or to minimize system maintenance costs has been extensively studied. For review of

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maintenance models for single-unit and multi-unit systems, see references [1, 2]. Many of today's technological systems, such as aircrafts, nuclear power plants, military installations and advanced industrial and medical equipments etc., involve high level of complexity in their maintenance and operation and require high level of availability and reliability. Meanwhile, the complexity of the system leads to its complicated, expensive and time-consuming maintenance activities. Components of certain equipment are more likely to be stocked than complete components if the major unit of equipment is expensive, and repair may be preferred to replacement if it is possible. Therefore, for a repairable system, it is wise to replace its failed components immediately and repair them off-line to reduce the length of system downtimes caused by corrective and/or preventive maintenance, which is defined as a repair-by-replacement policy [3].

On the other hand, a prompt maintenance relies on the availability of spare parts in order to reduce failure downtime and costs. That is to say, maintenance and inventory management are strongly interconnected and should both be considered simultaneously when optimizing a company's operations. This topic also have been extensively studied by many researchers [4–9]. For instance, reference [4] presented a spare ordering policy for preventive replacement with age-dependent minimal repair and salvage value considered. Reference [5] proposed an integrated condition-based replacement and spare part? Provisioning policy for deteriorating systems.

For a repairable system with repair-by-replacement policy, its inventory comprises two types of spare parts, one type is the repaired component, the other is the new component which replenishes the inventory for the elimination of un-repairable component. Therefore, the availability of spare parts not only is subject to the maintenance frequency and quantity, ordering frequency and quantity, it is also influenced by the maintenance capabilities (generally refers to the number of maintenance or repair equipment). Furthermore, the complexity of the spare parts makes its price very expensive and the lead time is becoming extended. Too early and/or too many orders will cause excessive ordering and holding costs. On the contrary, shortage of spare parts may occur, which can result in high failure probability and cost. Therefore, it is necessary to consider the related spare supply policy and spare related holding and downtime cost while studying the maintenance and replacement policy.

Furthermore, the complexity of the system and its spare parts can also incur a non-neglectable repair time and a long lead time for spare parts ordering. In many previous studies, these parameters are deterministic and considered as given values. However, in practice the time required for complete replacement is a random variable dependent on the deteriorate level of the unit [10]. Additionally, a random lead-time for delivering the spare unit could not be neglected [11]. In the early research, the authors usually assumed that the system after repair is "as good as new". However, this assumption is not always true in practice applications. The fact that many items may not be assumed to have returned to their initially perfect state after repair, that repair effect may be dependent on the deterioration level before repair [12]. Reference [13] proposed an age-replacement policy with age-based minimal repair and random lead time of the spare order for a system subject to shocks. In Ref. [10] models, it is assumed that both the expected inter-maintenance time and the expected maintenance time depend on the maintenance threshold. Both perfect maintenance and imperfect maintenance can be handled by these models.

Systems comprising a known number of identical components are common in areas such as industrial production, military, and the medical industry. Examples include wind turbines in a wind power farm, a fleet of identical trucks, a fleet of battleships, and identical terminals in a computing centre. Comparing with systems with many non-identical components, the deterioration of components in these multi-unit systems is usually independent, and there are natural similarities of their maintenance, such as the same preparations for maintenance, the same spare parts, maintenance techniques, and maintenance equipment.

In this study, a continuous deteriorating system comprising a known number of repairable identical components is studied. A joint strategy, referred to as periodical condition-based repair-by-replacement and continuous reviewed (S,s) type spare provisioning policy is presented for it. With assumptions of random repair time [10], random lead time [13] and imperfect maintenance effect [14], a stochastic simulation model is developed to determine the jointly optimal strategy. Integrating approach with discrete event simulation and genetic algorithm (GA), the optimal inspection interval, preventive replacement threshold, spare part inventory levels and repair capacity are determined jointly in order to minimize the average cost per component per unit time over an infinite time span.

2 Modeling

2.1 System Characteristics

The system comprising N identical components, in which each unit contains a repairable critical component deteriorating gradually. The general assumptions for each unit $i (i = 1, 2, \cdots, N)$ are as follows:

(1) The deterioration state of unit i at time t can be described by a scalar random variable $x_t^{(i)}$. This variable increases monotonically over time when the unit is deteriorating.
(2) When $t = 0$, unit i is considered to be in the new state, and so $x_0^{(i)} = 0$. Unit i is considered to have failed as soon as its deterioration state exceeds a critical level $D_f^{(i)}$. At that point, it incurs mandatory maintenance immediately.
(3) The increments of deterioration state of unit i between two consecutive time components,$\Delta x^i_{(k-1,k)}$, are considered nonnegative, stationary, and statistically independent, they follow the same distribution as the probability density function $f_i(x)$. Consequently, the distribution of the increments during z time components is $f_i^{(z)}(x)$, where $f_i^{(z)}(x)$ the zth convolution of is $f_i(x)$.

2.2 Maintenance and Spare Parts Strategy

The proposed condition-based repair-by-replacement policy is a periodical control limit policy with the preventive maintenance threshold D_p for the deterioration levels of the components, and the inventory policy is of the periodical reviewed (*S*, *S*) policy, where *S* is the maximum stock level and *s* is the reorder level. The related assumptions and the possible decisions of the condition-based replacement and the spare order are given as follows:

(1) Both the state of each unit and the inventory are inspected periodically with a fixed inspection interval $T(T = k_T \Delta t, k_T \in N)$. The inspection cost is C_i. It's instantaneous and non-destructive inspection.
(2) At each inspection point, if the deterioration state of unit i satisfies $x_i \geq D_f^{(i)} (i \in \{1, 2, \cdots, n\})$ and the spare unit is available, it is replaced correctively; If $D_p^{(i)} \leq x_i < D_f^{(i)} (i \in \{1, 2, \cdots, n\})$ and the spare unit is available, it is replaced preventively. The replacement is replacing the failed and degraded components by spares (repaired or new). It is assumed that the replacement time is negligible. The cost of the preventive (respectively, corrective) replacement is C_p (respectively, C_c). In most real situations, it can be considered that $C_c > C_p$. If no spare unit is available in the inventory, all the replacements are delayed with a downtime cost C_d per unit time and an order of spare components be placed immediately. Once the spare components arrive, the delayed replacement will be performed.
(3) After replacement, all the failed components are eliminated. The degraded components are sent to a repair shop with c parallel identical servers that are able to handle all types of repair jobs. It is assumed that the repair time of a component is exponentially distributed with mean $1/\mu_r$. The repair cost per unit time per component is C_r. After repair, the deterioration level of the component i, y_i, may not be assumed to have returned to their initially perfect state, but it may be dependent on its deteriorating level before repair x_i. The improved incremental $x_i - y_i$ is a random variable in $(0, x_i)$ and follows the normal distribution $N(x_i/\mu, \sigma^2)$.
(4) An order for spare components is placed when the inventory level is less than s to replenish the inventory to the maximum stock level S. The ordering cost for a spare part is C_s. The repair time of a component is exponentially distributed with mean $1/\mu_s$. When the repaired and/or new spare components arrive and the delayed replacement is finished, the remained spare parts are stocked in the inventory with a holding cost per unit time per component C_h.

Let the triple (n_0, n_p, n_c) denote the system state, in which n_0 is the number of components need not to be replaced, n_p is the number of components need to be preventively replaced and n_c is the number of components need to be correctively replaced (hence $n_0 + n_p + n_c = N$). The initial system state is $(N, 0, 0)$.

Equivalently, we denote the state of the spares as (s_n, s_r), in which s_n is the number of new spare parts and s_r is the number of repaired spare parts. The initial inventory state is (S,0). Let SL be the current inventory state (hence $SL = s_n + s_r$).

According to the proposed strategy, the decision tree at each decision point is as shown in Table 1. In this table, $N_{cr}, N_{pr}, N_{cd}, N_{pd}$ denote the number of components need to corrective replacement, preventively replacement, delayed corrective replacement and delayed preventively replacement, respectively.

2.3 Modeling

According to the presented policy, it can be seen that different maintenance and inventory parameters can incur different maintenance decision results and costs. Therefore, in order to minimize the average cost per component per unit time over an infinite time span, the optimal inspection interval, preventive replacement threshold, spare part inventory levels and repair capacity should be chosen. The optimization of the proposed policy can be defined as a constrained optimization problem if the average cost rate AC_∞ can be represented a function of T, D_p, S, s, c as following:

$$\begin{aligned} AC_\infty &= \min f(T, D_p, S, s, c) \\ \text{s.t. } T &= 1; 2; 3; \ldots \\ 0 &< D_p < D_f \\ S, s &= 1; 2; 3; \ldots \\ c &= 1; 2; 3; \ldots \end{aligned} \tag{1}$$

$$\begin{aligned} f(T, D_p, S, s, c) &= \lim_{t_m \to \infty} \frac{C_m + C_{sp}}{t_m N} \\ C_m &= C_i N_i + C_c N_c + C_p N_p + C_d \sum_{j=1}^{t_m} N_d(t) + C_r \sum_{j=1}^{t_m} N_r(t) \\ C_{sp} &= C_s N_s + C_h \sum_{j=1}^{t_m} N_h(t) \end{aligned} \tag{2}$$

where N_i, N_c, N_p, N_s are the total numbers of inspections, corrective replacements, preventive replacements and ordered spares over the time span t_m. $N_d(t)$, $N_r(t)$, $N_h(t)$ are the numbers of failed components, repaired components and spares in the inventory at time t.

Table 1 Maintenance decisions

System and inventory states	Decision making			Maintenance results	After repairing
(n_0, n_p, n_c) (s_n, s_r)	$n_p + n_c = 0$			$N_{cr} = 0$ $N_{pr} = 0$ $N_{cd} = 0$ $N_{pd} = 0$	(n_0, n_p, n_c) (s_n, s_r)
	$n_p + n_c > 0$	$n_p + n_c \leq SL$	$n_p + n_c \leq s_n$	$N_{cr} = n_c$ $N_{pr} = n_p$ $N_{cd} = 0$ $N_{pd} = 0$	$(n_0 + n_p + n_c, 0, 0)$ $(s_n - n_p - n_c, s_r + n_p)$
			$n_p + n_c > s_n$	$N_{cr} = n_c$ $N_{pr} = n_p$ $N_{cd} = 0$ $N_{pd} = 0$	$(n_0 + n_p + n_c, 0, 0)$ $(0, SL - n_c)$
		$n_p + n_c > SL$	$n_c \leq SL$	$N_{cr} = n_c$ $N_{pr} = SL - n_c$ $N_{cd} = 0$ $N_{pd} = n_p - (SL - n_c)$	$(n_0 + SL, n_p - SL + n_c, 0)$ $(0, n_p - SL + n_c)$
			$n_c > SL$	$N_{cr} = SL$ $N_{pr} = 0$ $N_{cd} = n_c - SL$ $N_{pd} = n_p$	$(n_0 + SL, n_p, n_c - SL)$ $(0, 0)$

3 Solution

3.1 Discrete Event Simulation

It is not analytically tractable to obtain optimal maintenance policies, especially a joint optimal policy. Simulation is used to analyze the joint policies presented in this study. By simulating a large number of system life histories using discrete event simulation approach, the ensemble averages of the concerned quantities for the calculation of the policy performance criteria can be estimated. Each simulated history can be considered as a virtual experiment in which the unit deterioration processes are followed in their evolution throughout the life cycle. In this approach, the Monte Carlo simulation is used to simulate the process requires to model the deterioration of components.

Due to the stochastic characteristic of the Monte Carlo simulation, results of a simulation are instable and cannot be the final optimal value. Therefore, we simulate the deterioration processes and its evolution many times for each set of decision variables to ensure the stability of simulation solutions. Variance controlling technology is used to control the number of simulations and the average simulation value is regarded as the optimal value. A simulation process is as follows:

Let $\left(n_o^{j-1}, n_p^{j-1}, n_c^{j-1}\right)$ denote the system state at the beginning of the jth time unit $t_j\left(t_j = j\Delta t, j = 1, 2, 3, \cdots, m\right)$. At this time, there are N_{cd}^{j-1} corrective replacements and N_{pd}^{j-1} preventive replacement are delayed. The inventory state is $\left(s_n^{j-1}, s_r^{j-1}\right)$. Then the total inventory is $SL^{j-1} = s_n^{j-1} + s_r^{j-1}$. At first, the deterioration processes of all components require to be modeled as follows:

$$x_j = x_{j-1} + \Delta x_j \tag{3}$$

where Δx_j is a random increment of the deterioration level of the unit j during the period of a unit time, and it is generated random according to the given distribution.

Next, identify whether new events occur during the time unit. All possible events are:

(1) Inspection event. If $t_j \% T = 0$, the system needs a new inspection and $N_i = N_i + 1$. After inspection, we can get the new system state. If there are NOP^j components operational well at the previous time components but which can satisfy preventive replacement condition at this time, and NOF^j components are operational well at the previous time components but fail at this time, the system state becomes $\left(n_o^{j-1} - NOP^j - NOF^j, n_p^{j-1} + NOP^j, n_c^{j-1} + NOF^j\right)$.

(2) Replacement event. Combining with the system and inventory states, replacement activities are scheduled and the system and inventory states are modified according to the decision rules in Table 1. After that, the total replacement numbers are increased.
(3) Repair event. The components which need to preventive repaired is sent to the repair center. Comparing the repair capacity with the repair requirement, arriving events of repaired components is scheduled after random repair times which is generated random according to the given distribution. The number of repaired components can be calculated as:

$$NR = \begin{cases} n_p^j & 0 < n_p^j < c \\ c & n_p^j \geq c \end{cases} \quad (4)$$

(4) Arriving event of repaired components. The repaired components are sent to the inventory and the number of repaired spare parts is modified $s_r^j = s_r^j + NR$. The delayed replacement event is triggered immediately.
(5) Ordering event. If the total inventory is below the reorder level s or the stockout occurres when replacement is required, an ordering event should be scheduled. The ordering number is $NS = S - SL$. An arriving event of new components is scheduled after random lead time which is generated random according to the given distribution.
(6) Arriving event of new components. The new components are sent to the inventory and the number of new spare parts is modified $s_a^j = s_a^j + NS$. The delayed replacement event can also be triggered immediately by this event.

3.2 *Optimization*

An optimization algorithm should be used to determine the optimal values of the decision variables. Genetic algorithms (GAs) are powerful optimization techniques, inspired by the principles of natural selection and species evolution. Due to their robustness and easy customization, GAs have been successfully applied to a wide range of problems. Many researchers have proposed the use of GA as an optimization tool for maintenance scheduling activities, such as references [15–17].

The established model in this paper is a nonlinear, hybrid multi-variable and single-objective optimization model. Therefore, we choose as an optimization algorithm in this study to derive the decision variables jointly. In the optimization algorithm, technologies of two random point arithmetic crossover, single point real-value mutation and legalization of solution are adopted to ensure the accuracy of the solution.

4 Results and Discussion

4.1 Numerical Examples

Taking a system containing 5 components as a case, numerical experiments are presented to show the characteristics of the proposed condition-based repair by replacement-order policy. The increments of deterioration levels between two consecutive times follow the Gamma distribution $\Gamma(0.86, 1244.59)$. The repair time and the lead time follow the exponential distribution Exp(0.2) and Exp(1) respectively. The improved incremental of unit with a deterioration state x_i follows the normal distribution $N(0.5x_i, 0.026x_i)$. The other cost parameters are set as: $C_i = 50$; $C_p = 5000$; $C_c = 15000$; $Ci = 50$; $Cd = 600000$; $Ch = 100$; C_s=100000 and $D_f = 1500$. Figure 1 shows an example of the evolution of the optimization process. The optimal values of the decision variables are $T = 15$, $Dp = 1084, S = 5, s = 1, c = 2$, corresponding to the minimal cost rate 251365.658333.

4.2 Analysis

Comparing with the optimal results in reference [18] with the deterministic repair time and lead time, the minimal cost rate has increased more due to the random factors. In order to decrease the replacement frequency, the optimal inspection interval become larger. However, the preventive replacement threshold decreases to ensure a low failure probability. The variation of inventory and repair parameters is more conducive to ensure Adequate spare parts for replacement.

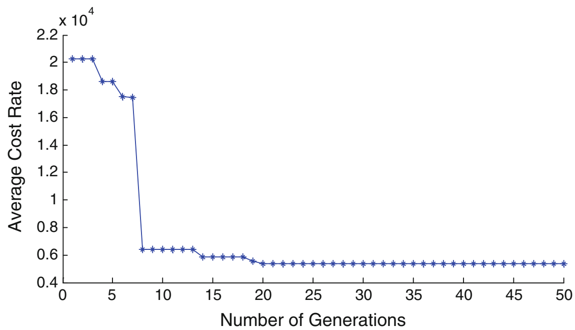

Fig. 1 An example of optimization result of GA

5 Conclusion

In this study, a continuous deteriorating systems with a number of repairable identical components is focused. A joint strategy, referred to as periodical condition-based repair-by-replacement and continuous reviewed (S,s) type spare provisioning policy is presented for it. All failed and/or deteriorated components are replaced by spare parts in the inventory, repaired or new, and repaired off-line. With assumptions of random repair time, random lead time for spare parts ordering and imperfect maintenance effect, a stochastic simulation model is developed to determine the optimal inspection interval, preventive replacement threshold, spare part inventory levels and repair capacity to minimize the average cost per component per unit time over an infinite time span. Integrating discrete event simulation with genetic algorithm, the optimal result is obtained. Simulation results show that system availability can increase significantly due to the downtime reduction under the combination of repair-by-replacement. Furthermore, the maintenance cost decreases correspondingly. The results of sensitivity analysis indicate that trades-off among maintenance policy, spare parts inventories and repair capacity are existing.

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The Error Fluctuation Evaluation for Key Machining Form Feature of High-Value Difficult-to-Cut Part

Yan Wang, Ping-yu Jiang and Qi-quan An

Abstract To analyze the phenomenon of huge difference of performance quality machined by same equipment and machining procedure, an error fluctuation evaluation method is proposed. A formalized error propagation equation is established to model the error propagation relationship between quality characteristic and each process error based on machining error propagation network (MEPN). Based on this, two sensitivity analysis indices are defined to indicate the interactive effects of each process error on the quality. On the basis of real-time machining condition monitoring and in-process quality measuring, the Support Vector Regression (SVR) is introduced to solve the sensitivity analysis index of the parts in a same batch. Further, the error fluctuation coefficient is proposed to indicate the fluctuation of key Machining Form Feature (MFFs) and further evaluate the stability of Multistage Machining Processes (MMP). Finally, a deep-hole machining process of aircraft landing gear part is used to verify the proposed method.

Keywords Machining error propagation network · Multistage machining processes · Sensitivity analysis · Support vector regression

1 Introduction

Due to the complicated interactive effects in the Multistage Machining Processes (MMP) of high-value difficult-to-cut part, the part quality (such as dimension quality, form and position quality and surface quality) at a single stage is determined not only by the machining elements of the current stage, but also by the quality of upstream stages [1–4]. The aircraft landing gear part is a kind of high-value part and usually manufactured in a small-batch production pattern.

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However, due to the characteristics of complex structure, small batch, difficult-to-cut material, high material removal and high quality requirement, how to complete the machining of aircraft part with high quality and further ensure the dynamic stability of its multistage machining process (MMP) has become an issue that must be overcome. And above all, the key to ensure the dynamic stability of MMP is how to reduce and control the error fluctuation of quality. A large number of research has been done on the error source diagnosis and error fluctuation analysis. Conventionally, the statistical process control method (SPC) is used to monitor the quality fluctuation and identify the error source in single-stage manufacturing process [5, 6]. However, large amounts of sample data are needed in SPC to ensure the credibility of statistics. Obviously, as there are few samples available in small-batch production and inadequate information about the quality of parts, the SPC based on normal distribution cannot accurately identify the decisive error source. It is infeasible to quantitatively analyze the error fluctuation of aircraft landing gear part and identify the error fluctuation sources by the measuring index based on statistical features.

Sensitivity analysis is to study how the uncertainty in the output of a mathematical model or system can be apportioned to different sources of uncertainty in its inputs [7]. Thus, the sensitivity analysis method is always used in the manufacturing field, such as reliability design, fault diagnosis and so on. Lu [8] proposed the a sensitivity analysis model on multi-layer perceptron (MLP) neural networks (NN), which eliminates distortions on the sensitivity measures due to dissimilar input ranges with different units of measure for input features of both continuous and symbolic types in NN's practical engineering applications. Based on the sensitivity analysis method, Zhang [9] presented a practical and efficient method for testing the reliability sensitivity of vehicle components with non-normal distribution parameters. Zhu [10] proposed the theory of performance sensitivity distribution, in which a sensitivity Jacobian matrix is used to describe the effects of the component tolerance on the system performance. Based on that matrix, Caro introduced a method to analyze the sensitivity of a design with robustness indices [11]. For the process design, in order to improve process plan selection, Abellan-Nebot proposed a methodology to identify critical fixtures and manufacturing stations/operations based on a sensitivity analysis of candidate process plans [12]. In addition, based on the stream of variation (SoV) model, a sensitivity analysis method is proposed to evaluate the sensitivities of dimensional features of a cylinder head to its fixture deviations (the departures of the actual values from the nominal values) [13]. However, there are few contributions on the error fluctuation analysis without much quality information.

Therefore, combined with sensitivity analysis theory, this paper proposes an error fluctuation evaluation method to indicate the effect of error sources on the quality and evaluate the stability of multistage machining processes in small batch production. Finally, we discuss how the proposed approach analyzes and evaluates the error fluctuation via a case study of the deep-hole machining process of an aircraft landing gear part.

2 Error Fluctuation Model of Single Quality Characteristic

2.1 Error Propagation Equation

In order to analyze the error fluctuation level, it is necessary to explore the error mechanism of generating, expressing and propagation in MMP. The machining error propagation network model (MEPN) [14, 15] proposed in authors' early paper can depict the error propagation relationships between quality characteristics and error sources which include the running state of machining elements (MEs) in current stage and the quality state of upstream machining form features (MFFs). Figure 1 shows the extended MEPN of single quality characteristic.

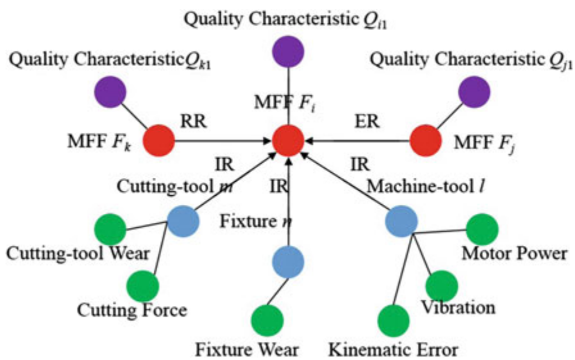
The topological node relationship in MEPN qualitatively expresses the error propagation relationship. But it is not capable to quantize these error propagation relationships by data analysis. In order to make a quantitative description for the error propagation relationship, an error propagation equation, as shown in Eq. (1), is proposed to model the nonlinear relationship between single quality characteristic and error sources.

$$q(k) = f(x_1, x_2, \cdots, x_n) + \xi(k) \quad (1)$$

where $q(k)$ represents the measurement of quality characteristic k, $f(\mathrm{x})$ represents the function relationship between quality characteristic k and each error factor, x_n represents the running state of nth ME or quality characteristic, n denotes the number of error sources, $\xi(k)$ represents the random error affecting quality characteristic k in machining process.

Assume that the input error sources in the ideal working condition of multistage machining system is expressed as $x^* = (x_1^*, x_2^*, \ldots, x_n^*)$, the deviation $\Delta q(k)$ of quality characteristics k between ideal state and actual state can be formalized as the following equation:

Fig. 1 Extended MEPN of single quality characteristic



$$\begin{aligned}\Delta q(k) &= f(x_1, x_2, \ldots, x_n) - f(x_1^*, x_2^*, \ldots, x_n^*) \\ &= F(x_1 - x_1^*, x_2 - x_2^*, \ldots, x_n - x_n^*) \\ &= F(\Delta x_1, \Delta x_2, \ldots, \Delta x_n)\end{aligned} \tag{2}$$

where F(x) represents the function relationship between the quality characteristic k and error factors, Δx_i represents the departure of error factor i between the ideal state and the actual state. By analyzing the nodes relationship in MEPN, the error propagation equation of quality characteristic k can be established.

2.2 *Sensitivity Analysis Index of Single Quality Characteristic*

In a stable machining process, the fluctuation of error factors in machining system can lead to the quality fluctuation. The different system state and quality requirements differentiate the sensitivity of error sources on the quality. The greater sensitivity indicates that there is an increasing trend of change in machining quality. Meanwhile, there is a different sensitivity of each error source on the machining error of quality characteristic. The larger sensitivity indicates that the error factor plays a more important role in the machining process of the quality characteristic, and effective control of the error factor can maintain the stability of machining process. Therefore, two error fluctuation sensitivity indices are proposed to indicate the impact of all error sources on the quality characteristic and the impact of each error sources on the quality characteristic, respectively. The definitions of two sensitivity analysis indices are given as follows.

Definition 1 The sensitivity of quality characteristic k refers to the change trend in current state of machining system. The greater sensitivity shows that the quality is more unstable under the current machining status. The sensitivity S_k is calculated as follows:

$$S_k = \left|\frac{\partial F(\mathbf{x})}{\partial \mathbf{x}}\right| = |\nabla_{\mathbf{x}} F(\mathbf{x})| \tag{3}$$

where $\mathbf{x} = (x_1, x_2, \ldots, x_n)$ represents the deviation vector of all error factors effecting the quality characteristic k, $\nabla_{\mathbf{x}} F(\mathbf{x})$ represents the gradient of function $F(\mathbf{x})$ at the point $\mathbf{x}$.

Definition 2 The sensitivity of quality characteristic k to error factor i refers to the change speed of quality characteristic k when the error factors have tiny changes, which can be calculated by the following equation. The faster the error factor i changes, the more important it is for keeping the stability of the quality. The sensitivity S_k^i is calculated as follows:

$$S_k^i = \left| \frac{\partial F(\mathbf{x})}{\partial x_i} \right| = |\nabla_{x_i} F(\mathbf{x})| \tag{4}$$

where ∂x_i represents the deviation of the error factor i in machining system, $\nabla_{xi} F(\mathbf{x})$ represents the gradient of function $F(\mathbf{x})$ at the point x_i.

2.3 Solving Sensitivity Analysis Index

In order to calculate the two sensitivity of quality characteristic indices, it is necessary to clear the error propagation relationship in the MMP. On the basis of shop-floor data of multiple parts in the same batch, solving the sensitivity analysis index is transformed into fitting the multivariate nonlinear error propagation relationship. For multivariate nonlinear fitting problem, the commonly used method is intelligent learning algorithm, such as artificial neural network (ANN), support vector regression (SVR) and so on. Considering the condition of small sample and the complexity of training sample, the support vector regression is chose to fit the nonlinear error propagation relationship.

In the SVR, a nonlinear mapping function $\varphi(\cdot)$ is chosen to map the data from low-dimensional space to high-dimensional space. Then, the sample data is fitted into linear function in high-dimensional space corresponding to the error propagation relationship in low-dimensional space. The optimized linear function $F(\mathbf{x})$ in high-dimensional space is given as follows:

$$F(\mathbf{x}) = \omega^T \varphi(\mathbf{x}) + b \tag{5}$$

where ω denotes the weight of the linear relationship, b denotes the offset in the function. Considering the characteristic of few parameters, nonlinear mapping and less numerical difficulties, the radial basis function is chosen as the kernel function to fit the error propagation relationship, and the fitting function $F(\mathbf{x})$ is shown as the following equation:

$$F(\mathbf{x}) = \sum_{i=1}^{\mathrm{N}} \left(\alpha_1 - \alpha_1^*\right) K(\mathbf{x}, \mathbf{x}_i) + b = \sum_{i=1}^{\mathrm{N}} \left(\alpha_1 - \alpha_1^*\right) \exp - \left\{ \frac{\|\mathbf{x} - \mathbf{x}_i\|^2}{2\delta^2} \right\} + b \tag{6}$$

where α_i and α_i^* represent the Lagrange multipliers, $\|\mathbf{x} - \mathbf{x}_i\|$ represents the norm of $\mathbf{x} - \mathbf{x}_i$. By the support vector regression analysis of machining data, the nonlinear fitting relationship between quality characteristic and error sources. According to the definition of the sensitivity of single quality characteristic, the error fluctuation sensitivity of quality characteristic k can be calculated as follows:

$$\mathbf{S}_k = \sum_{i=1}^{N} \left(\alpha_i - \alpha_i^*\right) \frac{(\mathbf{x}_i - \mathbf{x})}{\delta^2} \exp\left(-\frac{\|\mathbf{x}_i - \mathbf{x}\|^2}{2\delta^2}\right) \tag{7}$$

The angel between the vector $\mathbf{S}_k$ and the unit vector $\mathbf{e} = (e_1, e_2, \cdots, e_i, \cdots, e_n)$ $(e_1 = e_2 = \cdots = e_i = \cdots = e_n, |\mathbf{e}| = 1)$ is introduced to calculate the sensitivity of error sources on the quality characteristic k. The scalar sensitivity S_k of error sources on the quality characteristic k is calculated as follows:

$$S_k = \begin{cases} \arccos\left(\frac{\mathbf{S}_k \mathbf{e}}{\|S_k\|\|\mathbf{e}\|}\right) & \mathbf{S}_k\mathbf{e} \geq 0 \\ \pi - \arccos\left(\frac{\mathbf{S}_k \mathbf{e}}{\|S_k\|\|e\|}\right) & \mathbf{S}_k\mathbf{e} < 0 \end{cases} \tag{8}$$

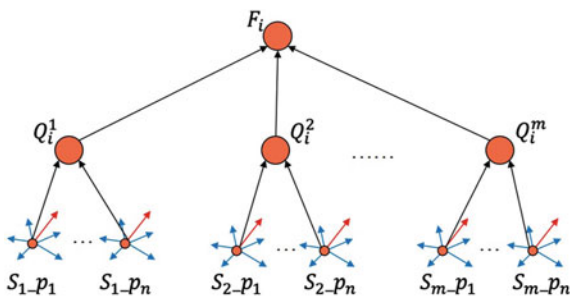
Similarly, the sensitivity of error source i to quality characteristic k can be obtained by calculate the angel between the vector $\mathbf{S}_k$ and the unit vector $e^i = (e_1^i, e_2^i, \cdots, e_i^i, \cdots, e_n^i)$ $\left(e_i^i = 1,\ e_j^i = 1\,(j \neq i)\right)$ Thus, the scalar sensitivity S_k^i of error source i to quality characteristic k can be calculated as follows:

$$S_k^i = \begin{cases} \arccos\left(\frac{\mathbf{S}_k \mathbf{e}^i}{\|\mathbf{S}_k\|\|\mathbf{e}^i\|}\right) & \mathbf{S}_k\mathbf{e}^i \geq 0 \\ \pi - \arccos\left(\frac{\mathbf{S}_k \mathbf{e}^i}{\|\mathbf{S}_k\|\|\mathbf{e}^i\|}\right) & \mathbf{S}_k\mathbf{e}^i < 0 \end{cases} \tag{9}$$

3 Error Fluctuation Evaluation of Key MFFs

Based on the aforementioned description, the sensitivity of quality characteristics affiliated with the MFFs are used to further analyze the error fluctuation of key MFFs. Figure 2 shows the analytical structure of the key MFF F_i. According to Fig. 2, it can be seen that the error fluctuation of quality characteristic of different parts in same batch determine the error fluctuation of MFF. In order to quantitatively evaluate the fluctuation level, the error fluctuation sensitivity of MFF F_i is defined in Eq. (10).

Fig. 2 The analytical structure of the key MFF F_i



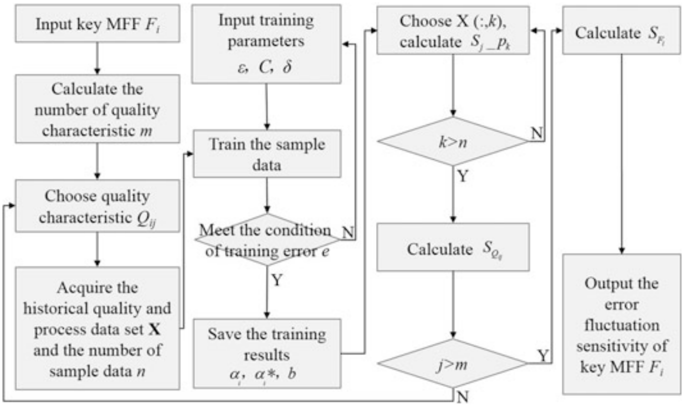


Fig. 3 The algorithm flowchart of error fluctuation sensitivity of key MFFs

Definition 3 Error fluctuation sensitivity of MFF F_i refers to the overall error fluctuation evaluation of all quality characteristics affiliated with MFF F_i. The greater the sensitivity value of MFF is, the more unstable the machining process is. The sensitivity S_{F_i} can be calculated by the following equation:

$$S_{F_i} = \frac{1}{mn} \sum_{j=1}^{m} \sum_{k=1}^{n} S_m\_p_n \tag{10}$$

where m denotes the number of quality feature affiliated with MFF F_i, $s_m\_p_n$ represents the error fluctuation sensitivity of quality feature m of nth part.

To achieve the calculation of error fluctuation sensitivity analysis, the algorithm flowchart is proposed as following Fig. 3. Error fluctuation sensitivity characteristic reflects the difference of stability of different MFFs, these indicators pointed out the subsequent adjustment direction of the machining process and equipment parameters.

4 Case Study and Disscussions

Limited by experimental conditions, the quality and process data of one outer cylinder part are collected from practical machining process. On the basis of that, the data of other 12 parts are generated by computer simulation. The deep-hole machining process is chosen to verify the availability of the error fluctuation sensitivity analysis method. Table 1 shows the shop-floor data of deep-hole machining process of 13 outer cylinder parts.

Due to huge difference of data standard and dimension, the process data is normalized before solving the error fluctuation sensitivity. The radial basic function

Table 1 The process data of the deep-hole machining

No.	Q (mm)	P_1	P_2 (mm)	P_3 (W)	P_4	P_5 (°C)	P_6 (mm)	P_7 (mm)
1	0.17	0.3067	0.05	232.22	0.3446	1.86	0.30	0.02
2	0.34	0.7828	0.14	236.40	0.2861	3.58	0.18	0.32
3	0.20	0.5630	0.08	256.29	0.3983	2.98	0.24	0.24
4	0.24	0.6070	0.12	226.14	0.7347	3.14	0.22	0.18
5	0.43	0.4202	0.16	289.00	0.8204	2.87	0.26	0.36
6	0.33	0.6729	0.14	236.40	0.2861	2.36	0.18	0.42
7	0.20	0.5630	0.14	256.29	0.3983	2.98	0.24	0.35
8	0.17	0.6070	0.16	246.66	0.6093	3.14	0.16	0.08
9	0.34	0.4202	0.16	289.00	0.1608	2.87	0.26	0.46
10	0.32	0.5630	0.32	246.66	0.4642	2.77	0.26	0.12
11	0.28	0.3268	0.16	245.38	0.4312	2.88	0.22	0.34
12	0.32	0.8762	0.20	262.70	0.4642	2.77	0.26	0.18
13	0.02	0.3323	0.22	290.28	0.6291	3.04	0.28	0.06

based SVM is used to train the error propagation relationship based on the normalized process data. In the SVR, the parameters $\varepsilon = 0.03$ $C = 1000$ $\delta = 0.4$ are set by experience. Figure 4 shows the relative error of training result.

As shown in Fig. 4, the training error of model has been reduced to 0.03 after machining the 11th part. The parameter displacement in SVR b = 0.6476 and Table 2 shows the value of $(a_i - a_i^*)$. Figure 5 shows the regression curve of quality data.

As shown in Fig. 6, it can be seen that the average error fluctuation sensitivity of deep-hole machining process is 1.2351, and the deep-hole machining process of 5th part has the biggest sensitivity. Aimed at 5th part, the sensitivity of each error factors on quality can be obtained according to Eq. (4). Figure 7 shows the sensitivity distribution of deep-hole machining process of 5th part. Besides, it can be

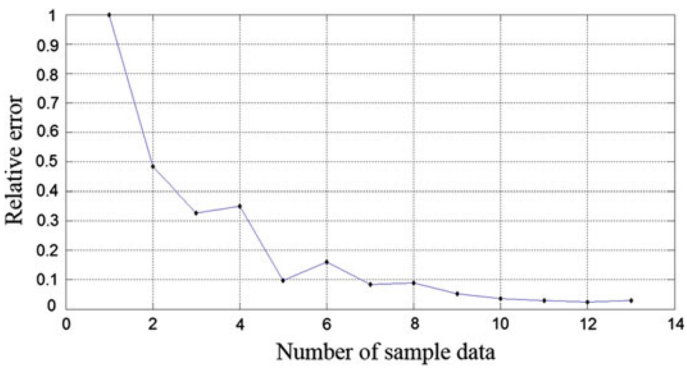


Fig. 4 The relative error of training result

Table 2 The training results of SVR

i	$(a_i - a_i^*)$	i	$(a_i - a_i^*)$
1	−0.1526	8	−0.2932
2	0.1717	9	0.2894
3	−0.1012	10	0.0916
4	−0.0001	11	0.0895
5	0.9045	12	0.0838
6	0.1188	13	−1.0764
7	−0.1277		

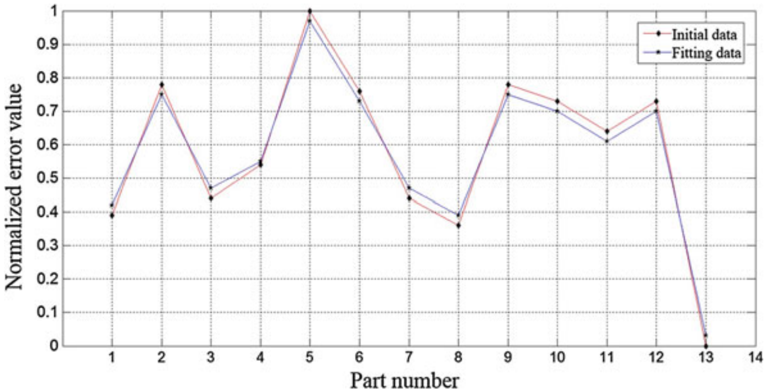


Fig. 5 The fitting curves of deep-hole diameter in the outer cylinder part

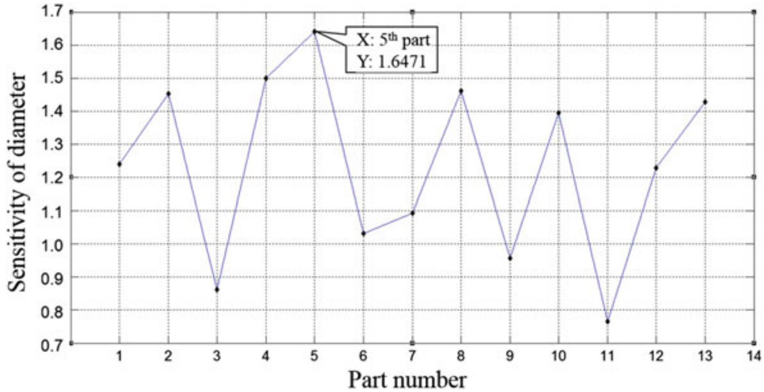


Fig. 6 The distribution of error fluctuation sensitivity of 13 parts

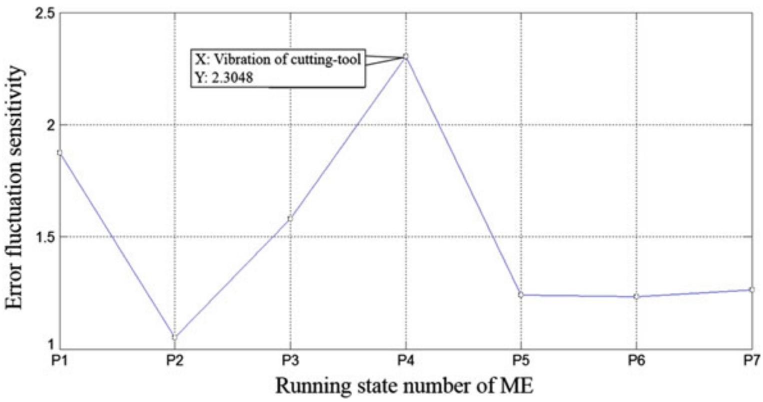


Fig. 7 The sensitivity distribution of deep-hole machining process of 5th part

seen that the vibration of cutting tool has the largest error fluctuation sensitivity in the deep-hole machining process of 5th part. Thus, the vibration of cutting tool plays a more important role than other error factors. On the basis, the error fluctuation sensitivity of key MFFs can be calculated according to the analytical structure shown in Fig. 3, the results are shown in Fig. 8. It can be seen that the key MFF turning deep-hole 1 has the biggest sensitivity value in the batch machining process. The reason is that the diameter of the deep-hole feature is key quality requirement. Thus, the machining of turning deep-hole should be paid more attention.

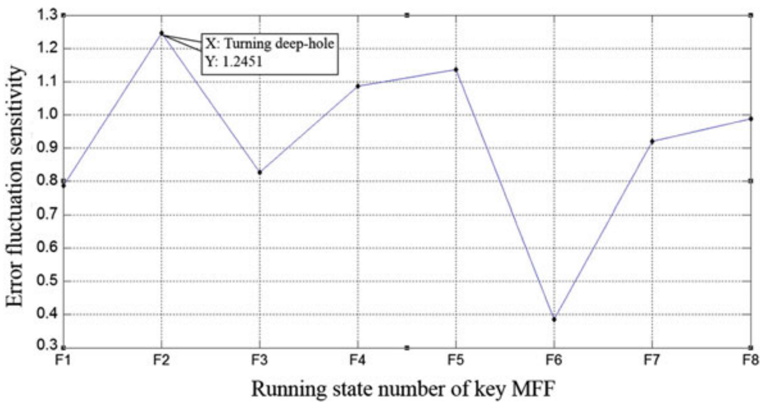


Fig. 8 The error fluctuation sensitivity of key MFFs

5 Conclusion

Combined with sensitivity analysis theory, this paper proposes an error fluctuation sensitivity model to quantitative describe the effect of error factors on the machining quality in the multistage machining process of high-value difficult-to-cut part. In the proposed error fluctuation sensitivity model, the error propagation relationships are abstracted from the node relationship in machining error propagation network. The support vector regression (SVR) is introduced to learn the nonlinear error propagation relationship between the quality and error factors. The error fluctuation sensitivity of single quality characteristic and the error fluctuation sensitivity of error factor to quality characteristic are proposed to discuss the effect of each error factor to quality. On the basis, the error fluctuation sensitivity index of key MFF is proposed to capture the error propagation relationship from part level. Finally, the proposed approach analyzes and evaluates the error fluctuation via a case study of the deep-hole machining process of an outer cylinder part from aircraft landing gear.

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Study on Performance Evaluation of Product Warranty Service System Based on Balanced Score Card and System Dynamics

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Abstract With the development of the warranty activities, warranty service quality is becoming more and more important to influence customers' satisfaction and how to evaluate warranty service has become a hot research topic. To determine the effectiveness of warranty service from multi-criteria, this paper proposes the balanced score card to model the product warranty performance system. On this basis, the system dynamics method is developed and converted to product warranty performance system. After the main performance indicators are obtained, the system dynamics is designed and simulated.

Keywords Balanced score card · Performance evaluation system · Product warranty · System dynamics

1 Introduction

Nowadays, customers pay more attention to the product warranty service, which drives industries concentrate on warranty service system. Whether the warranty service system is competitive or not can evaluate through developing a product warranty performance evaluation system. And also warranty service performance is the basic part of control and monitor process. Through comparing the actual performance and the standard, the managers can determines the degree of variation, then take actions to correct the performance. So warranty service performance is becoming a hot research topic. Literatures focus mainly on warranty cost [1], customer satisfaction [2], time and operating efficiency during the warranty service process [3]. Little if any attention is given to multicriteria performance. Also the warranty literature surprisingly neglects the area of performance measurement based on the market perceptive. So it is a challenge and an appeal to develop a

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warranty performance evaluation system which highlights the interrelationships among different performance factors.

Many companies have been considering on performance management with Balanced Scored Card which is a fashionable method on the evaluation of performance [4, 5]. A Balanced Scored Card contains four perspectives: finance, customers, internal processes, and learning and growth. These indicators are interconnected with cause-and-effect relationships. And System Dynamics can solve these problems. System dynamics method is a quantitative method often used to study the complex social economic system, which is based on feedback control theory, and by means of computer simulation technology. Santos proposed to illustrate performance measurement by using system dynamics in detail [6], and Elena used system dynamics to explore causal relationships between different actors in after sales system [7].

Considering the relationships between performance indicators due to interactions and feedback loops, warranty service performance system follows the basic law of system dynamics modeling, so decide to study warranty performance evaluation using the basic theory and approach of system dynamics. The framework of the paper is as follows. Section 2 analyzes the causal relationships existing within the Balanced Scored Card. And according to the system dynamics modeling steps, defines quantified characteristic variables, and makes the causal feedback loop diagram. Then using theories and methods of system dynamics model build the stock and flow diagrams and logic equations. Section 3 makes simulation on the model using Vensim software, and analyses the simulation results. And Sect. 4 makes some conclusions of the paper.

2 Warranty Performance Evaluation Model

2.1 The Causal Relationships of Performance Indicators Based on BSC

The Balanced Score Card is a methodological tool with a multidimensional focus that makes possible to integrate corporative strategies with the company's own operation in order to determine the organizational objectives, assessing business performance through management indicators. The financial, customers, processes, and learning perspectives allow the company to use the BSC for warranty management [8]. The target of BSC applied to warranty management is to transform strategic objectives in the sales area into specific action plans based on key and contrastable management indicators, developed based on the four perspectives of the methodology as follows:

(1) *Financial perspectives*
It measures financial terms. Finance Profit generates by the revenue from the market sales and also by the warranty cost. The customer satisfaction may

improve the sales by appealing new customers and customer retention. And warranty cost may decrease through improving the internal process of warranty.

(2) *Perspectives of customers*
It evaluates the way in which the company generates value for the customers. It seeks to measure the impact and satisfaction that the company generates on its customers. In this article we assume the quality reliability and reliability of maintenance and repair activity influence customer satisfaction.

(3) *Perspectives of learning and growth*
The objective is to assure the capacity of adaptation and long-term renovation of the company, as well as to keep knowledge of the areas considered as basic competencies. Learning and growth can be measured by quality reliability and reliability of maintenance and repair activity, which can be improved by investment of warranty and quality [9, 10].

(4) *Perspectives of internal process*
It considers the operational processes of warranty service management. The process consists an overall service actors such as manufactures, technical assistance center and so on. The efficiency and effectiveness can also be an important indicator for the performance evaluation. And can be improved by the warranty investment.

From the analysis above, designed the main framework describe the warranty service system factors and relations. The model designed in Fig. 1 describes the causal feedback loops among the whole warranty service system mainly from four perspectives. It clearly explains the complex relationships. Through analysis the causal feedback loop, we can conclude that warranty service performance indicators are interconnected with cause-and-effect relationships and can't be evaluated simply

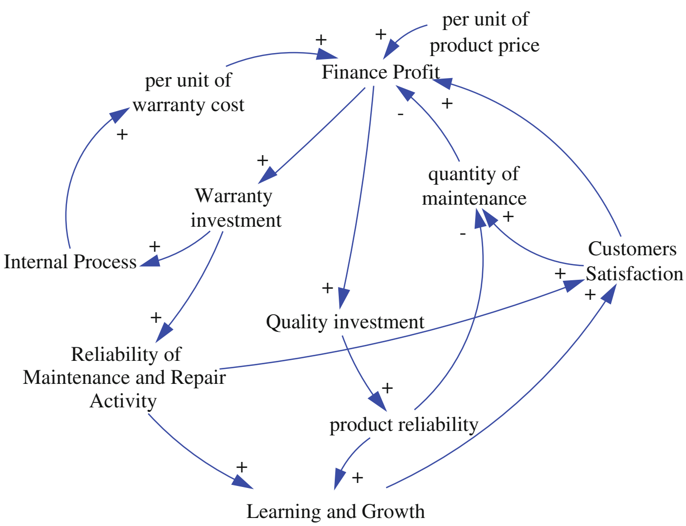


Fig. 1 Causal feedback loop

by sum of the score. Also the previous period performance impacts the current performance. For example the profit at time t-1 can influence the investment both the warranty and quality at time t. So the causal feedback loop of warranty service performance can be modeled through following the basic law of system dynamics.

2.2 Design SFD for Performance Evaluation System

Causal feedback loop reflected the system changes that are the feedback structure. But the qualitative description is not sure that the variable change mechanism in the loop. In order to further made it clear that the quantity of relations between system elements, it is necessary to establish the corresponding dynamic model of system dynamics. The mechanism can be described by stock and flow diagrams. Stock and flow are two basic variables. Stock is accumulated, flow reflect the stock changes with time, the difference between inflow and outflow accumulated over time, resulting in stock. Stock flow diagram (SFD) is more essence to describe the system than causal feedback loop. It not only can clearly reflect the logical relationship between system elements, but also can make clear further accumulation effect of each variable in the system and the rate change.

Stock and flow diagrams are the organic combination of basic variables and symbols. According to the relationships between the indicators of warranty performance system, designed the stock and flow diagram. It can reflect the characteristics of the different variables which make mechanism more clear, that can't be reflected by the causal loop. And then through further quantify the stock and flow diagram, the simulation purpose of performance evaluation realized. The stock and flow diagram of warranty performance as shown in Fig. 2.

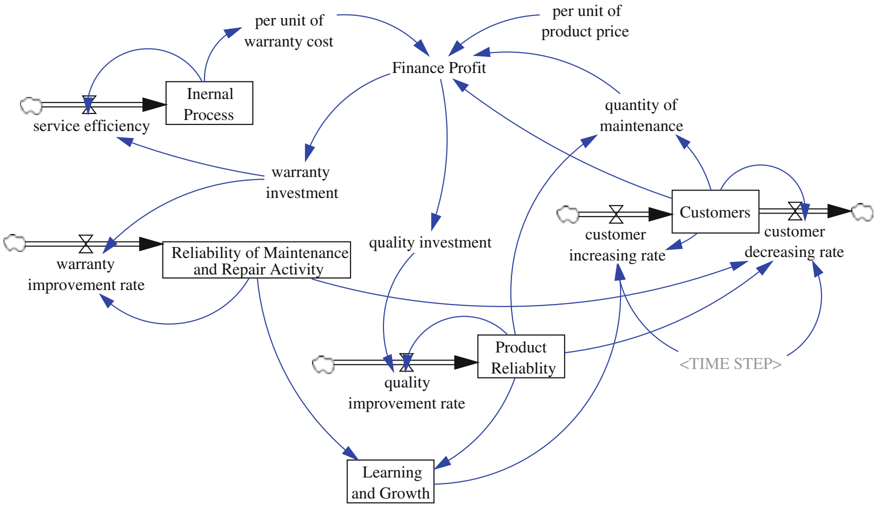


Fig. 2 Stock and flow diagram

After design the stock and flow diagram. Then the next step is to make functions depending on the relationship of each variable and the type of each variable. The main equations are as follows:

Finance Profit = Customers * per unit of product price-per unit of warranty cost * quantity of maintenance
Customers = INTEG (customer increasing rate-customer decreasing rate, 1000)
Learning and Growth = Product Reliability + (1 − Product Reliability) * Reliability of Maintenance and Repair Activity Internal Process = INTEG (service efficiency, 0.1)

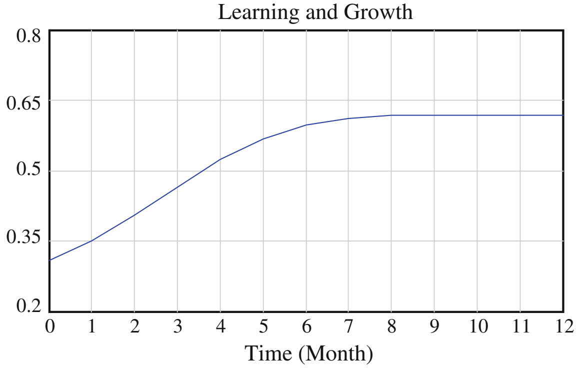
To make sure the model is OK, we should test it through a dimensional consistency test and an extreme test. On the premise of having practical significance, dimensions must unify. Using Vensim software for dimensional consistency check proved that each dimension is unified. Extreme test is mainly used to test whether the equation model is stable and reliable, whether it can reflect the changing rule of the real system in any extreme cases. Using Vensim software for extreme cases, prove that the model is stable and reliable.

3 Simulation Study

Using Vensim software for the warranty performance evaluation system, the cycle for the time running are 12 months. And unit for time is month. The simulation results are shown in Figs. 3, 4, 5 and 6.

In Fig. 3, the learning and growth performance is increasing with time. Learning and growth can be reflected by two factors. One is about product reliability improvement; another is the reliability of maintenance and repair activity. The causal loop diagram is quality investment → product reliability → learning and growth → customers' satisfaction → finance profit → quality investment. Warranty investment → reliability of maintenance and repair activity → learning and growth → customers' satisfaction → finance profit → warranty investment.

Fig. 3 Learning and growth



In Fig. 4, with the improvement of product reliability and reliability of maintenance and repair activity, appealed new customers and customer retention which expand the market share. The causal loop diagram is product reliability → learning and growth → customers' satisfaction → finance profit → quality investment → product reliability. Reliability of maintenance and repair activity → learning and growth → customers satisfaction → finance profit → warranty investment → product reliability.

In Fig. 5, the financial performance profit increase with time. Factors affect the finance profit include sales, product price, warranty cost, quantity of maintenance. In warranty system, warranty cost is a main part of warranty management. Quantity of maintenance decreases with the increase of product reliability, that's why many companies devote to quality investment. Warranty cost can decrease with the internal process, with cooperate well with logistics among manufactures and the technology assist centers. The causal loop diagram is product reliability → quantity of maintenance → finance profit → quality investment → product reliability. Product reliability → learning and growth → customers' satisfaction → finance profit → quality investment → product reliability. Internal process → per unit of warranty cost → finance profit → Warranty investment → Internal process.

Fig. 4 Customers

Fig. 5 Finance profit

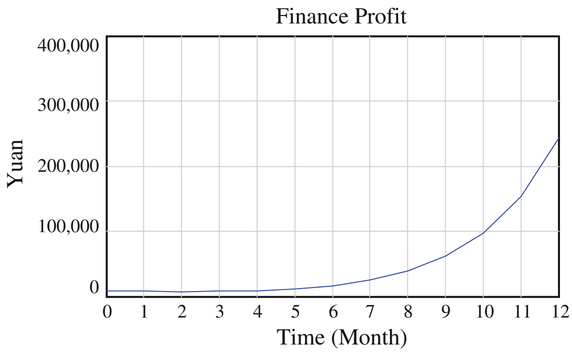
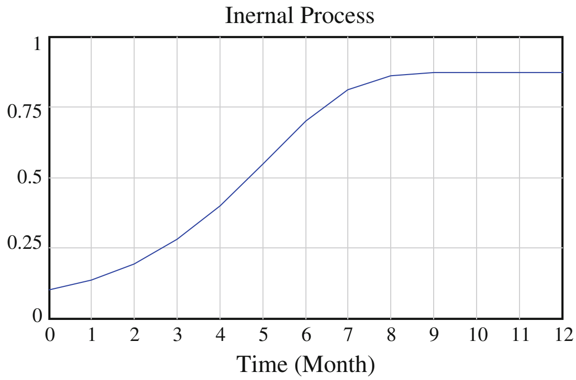


Fig. 6 Internal process



In Fig. 6, the internal process performance is increasing with time. The causal loop diagram is Finance Profit → Warranty investment → Internal process. That is if the industry's cash flow into warranty investment, which can integrate the social network. Such as the technology investment of information sharing can improve service efficiency, reduce unnecessary cost, then more finance profit.

The warranty performance evaluation system simulation quantified the connection between the four indicators. This explained the warranty system can't be measured through only one indicator, and can't be evaluated through all of them without considering their interactions.

4 Conclusions

The article focuses on warranty service performance evaluation based on Balanced Score Card and system dynamics. According to the system dynamics process, sure the boundaries of the system and the components of the elements of the system identify causal-loop diagram and define variables, establish SFD model and logic equations, then simulation running and analyses the simulation results.

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Studying Cost Allocation in Joint Distribution for E-Commerce—A Small to Medium Size Logistic Firm's Perspective

Ming Dong, Ai-ping Wu and Hua Li

Abstract This paper aims to construct a joint distribution model that suits the third-party logistics SMEs, and to propose a cost allocation model. It sees the joint distribution as a cooperative game, so that we can use Shapley value to calculate an initial allocation plan; then it considers four factors affecting the contribution of a participant, namely goods volume, amount of special items, initial investment and the risk of packaging delay, so as to determine the degree of contribution of each participating enterprise in the process of joint distribution; finally, according to the different degree of contribution it adapted the cost allocation value. A numerical example has been given at the end and implications of the model have been discussed.

Keywords Cost allocation · E-Commerce · Logistic firms · Joint distribution · Shapley value

1 Introduction

E-Commerce distribution is an advanced form of integrated distribution, building upon modern information, automation and management technology [1]. The E-Commerce distribution industry in China has been characterized by a couple of leading companies and many small to medium sized companies competing in the same market; and the co-existence of E-Commerce enterprise logistics and third party logistics [2]. The SMEs in logistics suffer from a relatively low efficiency and high cost thus unsatisfactory services. Their investment on the distribution system failed to meet the basic return on investment criteria and from another perspective,

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redundancy in infrastructures is widely seen. The situation is worsening by the increasing presence of international distribution companies such as Fedex and DHL who possess highly efficient distribution systems [3].

For these SMEs, how to integrate and share the storage infrastructures, information and network resources becomes an important issue. There are successful examples of such integrated distribution system for SMEs in developed countries, such as 7–11 convenience store in Japan [4]. Nemoto applied the joint distribution model into the context of E-Commerce, adopting a case study on the central commercial zone in Tokyo [5]. The joint distribution system can increase the distribution efficiency, reduce the logistic cost, alleviate traffic problems therefore reduce the carbon emission. For these purposes, the Ministry of Finance and the Ministry of Commerce has initiated 22 joint distribution trial centers around China. On the research side, Wei and Sun proposed the specific joint distribution mode and operating procedure, proving that the above initiatives by the government is appropriate in both the short and longer term [6].

This paper believes adopting a joint distribution model not only requires considering the demand side of the industry, but also requires considering the demand for last mile distribution. For example, Zhang examined the new trend in last mile joint distribution by using the case of Jingdong College Operation Center, Ali Mini Post Office and Tmall Community Service Station, which has provided rich empirical evidence to support the joint distribution model [7]. Under reasonable joint distribution modes, what are the fair and efficient cost allocation mechanism among participant so that each of them is satisfied to continue the cooperation becomes one of the key issue in the prevalence of joint distribution mode [8].

More specifically, there are broadly two ways to solve the cost allocation issue: one basing on cooperative gaming model [9, 10] and the other one basing on data envelope analysis (DEA) model [11] (or a combination of both, for example, see [12]). Ju et al. [13] reviewed the most commonly used methods in determining the cost and revenue allocation in joint distribution alliances, highlighting, again, the importance to find a good cost allocation solution.

2 Joint Distribution Model

The joint distribution model in this paper consists of upstream E-Commerce enterprises, third party small to medium size logistic companies, and consumers. These participants form a platform where storage and distribution resources are shared. The model can be illustrated by Fig. 1.

In this model, the E-Commerce enterprises distribute the goods to the 2nd order joint distribution station via the small to medium size logistics firms. After the goods collecting, recording and order processing, the distribution plan has been made and transportation has been scheduled. Goods then will be delivered to the 1st order joint distribution station. That is to say, the joint distribution refers to the distribution between the 2nd order joint distribution station of region A and B.

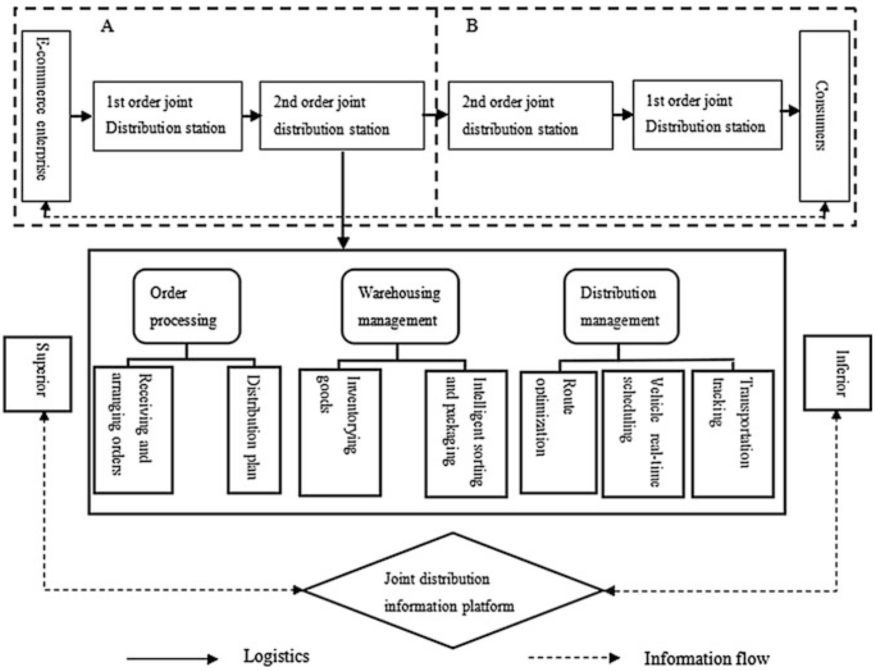

Fig. 1 The joint distribution model

3 Cost Allocation in Joint Distribution

3.1 Shapley Value in Joint Distribution

Cost allocation for small to medium size logistic firms in E-Commerce distribution is a typical cooperative gaming relationship.

Suppose there are n participants forming a set $\mathrm{N} = \{1, 2, 3, \ldots, \mathrm{n}\}$, and $S \subseteq N \cdot c(S)$. is the characteristic function of joint distribution alliance, it refers to the minimum cost of the joint distribution alliance. By setting $c(\varphi) = 0$, $c(i)$ refers to the cost of non-joint distribution, and (N, c) is a *n-participant* cooperative game. In this paper the feasible payoff vector should meet the following three conditions: (1) in the joint distribution alliance, the cost allocation of each one of participants should be no more than the cost of non-joint distribution; (2) the total cost of joint distribution should be no more than the total cost of non-joint distribution; (3) in the joint distribution alliance, the sum of cost of each participants should be equal to the total cost of joint distribution. There are many solutions that satisfy the three conditions, however, the following section will aim to find the most reasonable solution. Shapley value is the unique solution:

$$\varphi_i(c) = \sum_{S \subseteq (N-i)} w(|S|)[c(S \cup i) - c(S)], \quad i = 1, 2, \ldots, n \tag{1}$$

$$w|s| = \frac{(n - |s|)!(|s| - 1)!}{n!} \tag{2}$$

In the above formula $\varphi_i(c)$ refers to the allocated cost of participant i, $\phi(C = \{\varphi_1(c), \varphi_2(c), \ldots, \varphi_n(c)\})$ is an allocation solution. $w|S|$ can be regarded as a weight factor, and $|S|$ is the number of elements in sub set S.

3.2 Adapted Shapley Value in Joint Distribution

The Shapley Value method has met the individual rationality criteria by assuming that each participant has an equal importance weight factor $\overline{\lambda} = \frac{1}{n}$. However, in reality, participant firm will NOT always have the same λ_i. Therefore, a better way to determine the λ_i to measure the participant's contribution to the joint distribution alliance should be proposed. In other words, the Shapley Value needs to be adapted and amended.

This paper considers the following four aspects when adapting the original Shapley Value:

(1) Goods volume: the more goods being distributed by the joint distribution from one participant firm, the more contribution it does to the economy of scale, thus more contribution to the whole system.
(2) Special goods: distributing special goods will require additional sorting and packaging processes, incurring more cost. So the more special goods one participant firm distribute, the more cost it will generate thus more negative effect to the alliance, resulting a lower contribution.
(3) Initial investment: it refers to the contributed devices, capital, labor and technology one participant firm brings to the alliance. The more initial investment one firm has made, the more contribution it has done to the whole alliance, and therefore such firms should afford less cost as a reward.
(4) Risk of packaging delay: when distributing jointly, between the 1st and 2nd order joint distribution station, there might be delays brought about by the different efficiencies form participant firms because of goods arriving at different times. The more delays one firm incurs, the more risk and cost it has brought to the alliance thus the lower contribution it has made.

The adapted importance λ_i can be obtained by applying an AHP analysis considering the above four aspects.

Based on the rationale of the adaptation, $\varphi_i(c)$ is the cost that should be afforded by participant i in the ideal case, in reality the cost afforded by participant i is $\varphi_i'(c)$ and the importance weight is λ_i, then the amount of adaptation $\Delta\lambda_i = \lambda_i - \frac{1}{n}$, because $\sum_{i-1}^{n} \lambda_i = 1$ so $\sum_{i=1}^{n} \Delta\lambda_i = 0$. Based on the real meaning of the above equations, the actual adaptation for participant i is given by $\Delta\varphi_i = c(N) \times (-\Delta\lambda_i)$ therefore the final cost afforded is given by $\varphi_i'(c) = \varphi_i(c) + \Delta\varphi_i$ obviously $\sum_{i-1}^{n} \varphi_i'(c) = c(N)$, that is, the sum of adapted cost for each participant firm equals to the total cost of the joint distribution alliance.

3.3 Numerical Example

Now imagine a joint distribution alliance $N = \{1, 2, 3\}$ consisting of three logistic firms—A, B and C. Their cost of non-joint distribution $c(1)$, $c(2)$, $c(3)$ is correspondingly 11,000, 8000 and 9500 *yuan*. The joint distribution cost $c(1, 2)$ when only A and B participate is 12,000 *yuan*. Similarly $c(1, 3)$ is 14,000 *yuan* and $c(2, 3)$ is 11,000 *yuan*. The joint distribution cost $c(1, 2, 3)$ of A, B and C participating is 18,000 *yuan*. According to the Shapley value method in collaborative gaming, and according to formula (1) and (2), the cost allocated for firm A is shown in the Table 1.

Adopting a similar procedure it can be calculated that the participant B and C will be allocated the cost of 4416 and 6167 *yuan*. Taking goods volume, special goods, initial investment and risk of packaging delay as the criteria layer and the importance weights of logistics firms as the objective layer, an AHP analysis can gives the importance weights of logistic firms as follows: 0.346, 0.321 and 0.333. According to the adapted Shapley value calculation, we have obtained the amendments on cost as: −234, 216 and 18 *yuan*. Therefore, the final cost for A, B and C are: 7183, 4632 and 6185 *yuan*.

Table 1 Cost allocated to participant A

S	{1}	{1, 2}	{1, 3}	{1, 2, 3}
$c(S)$	11,000	12,000	14,000	18,000
$c(S\backslash 1)$	0	8000	9500	11,000
$c(S) - c(S\backslash 1)$	11,000	4000	4500	7000
$\|S\|$	1	2	2	3
$w\|S\|$	1/3	1/6	1/6	1/3
$w\|S\|[c(S) - c(S\backslash 1)]$	3667	667	750	2333

Cost allocated to A: 7417 *yuan*

4 Discussion

From the above numerical example we could see that after participating in the joint distribution, the total cost for these three logistic firms are lower and the cost for each firm is much lower too. After the adaptation and amendment, the cost for more important firm is lowered, making the cost allocation plan more reasonable.

Although the above allocation solution can ensure the three pre-conditions for Shapley Value can be well met, the final cost for joint distribution may be higher than the non-joint distribution if one participant firm contribute too little to the alliance. Similar issue also exists in Wang and Chen's work in 2013 [14], as well as Wang et al.'s work in 2009 [15].

This paper proposes a preliminary explanation for this phenomenon: due to the differentiated scale, efficiency and therefore contribution among participant firms, there benefits captured (the reduction in cost afforded) from the alliance will also vary. If the cost reduction brought by the joint distribution can NOT cover the increased cost allocated due to the low contribution in the adaptation of Shapley Value, it might be true that for some participant firm the cost of joint distribution will be even higher than the non-joint distribution. For example, the risk of packaging delay and initial investment do not exist in non-joint distribution conditions.

This preliminary explanation implies that in the formation of a joint distribution alliance, benefits can only be guaranteed when each participant firm's contribution to the alliance is higher than a certain threshold. Therefore this can be used as criteria to evaluate the potential benefit/loss of participating a joint distribution alliance. On the other hand, reducing the risk of packaging delay and increasing the initial investment can both increase the efficiency of joint distribution therefore can increase the contribution to the alliance by this particular participant firm. This can be used as a motivating device for participants in a joint distribution alliance.

5 Conclusion

In this paper we have discussed the cost allocation for joint distribution alliance in the context of E-Commerce. This context is characterized by the co-existence of leading logistic firms and many small to medium size logistic firms competing in the same market. Joint distribution is one of the strategies used by these small to medium logistic firms to reduce cost and improve efficiency. In this process, the cost allocation for each participant firm is seen as one of the most important issue. We adopted a cooperative gaming perspective, and used the Shapley Value to propose a solution. Furthermore, we have identified the limitations of original Shapley Value and have made adaptation according to the particular context. The criteria we used are based on the following four influential factors, namely the goods volume, special goods, initial investment and risk of packaging delay.

These four factors are weighed by using an AHP approach. Finally, we illustrated our proposed model and solution by a numerical example. We also discussed some of the implications of our proposed model. Looking beyond the paper, currently researches into joint distribution are generally at higher level. It is expected to see more studies into the specific aspects such as the motivation and other supporting mechanisms for joint distribution in the future, making it more practical.

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Pre-releasing Strategy Based on Workload Control

Hong-Yang Zhong, Jian-Jun Liu, Qing-xin Chen, Ning Mao and Yuan-Fei Tang

Abstract Bottle blowing machine manufacturers adopt a hybrid production mode that combines pre-releasing and make-to-order production. However, pre-releasing decision making depends too much on personal experience resulting in inefficiency. In order to improve the efficiency, this paper proposes a heuristic pre-releasing order strategy for bottle blowing machine manufacturers. The strategy establishes a mathematical model for pre-releasing in bottle blowing machine manufacturers, and works out the solution to the established mathematical model with branch and bound algorithm. Simulation studies are conducted to verify the effectiveness of the proposed strategy. It shows that the results are promising as compared to the experience strategy.

Keywords Bottle blowing machine · Pre-releasing strategy · Workload control

1 Introduction

Plastic industry makes great achievements to the Gross Domestic Product of China in recent years, as we can see in [1, 2]. However, there still exist some critical problems to be solved in the manufacturing of plastic products, especially in the manufacturing of bottle blowing machine, which serves as the upstream of plastic production. Most of the domestic bottle blowing machine manufacturers remain in an unstable state and face the threat of bankruptcy, which is the result of frequent tardiness and high energy consuming of bottle blowing machine manufacturing. Thus, plastic industry is facing growing pressure to improve delivery accuracy as well as energy efficiency, given a mounting concern about the severe competition in plastic market of China.

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Different from the typical Make-to-Order (*MTO*) enterprises, the bottle blowing machine manufacturers take a pre-releasing strategy, a hybrid production strategy which combines the concept of Make-to-Storage and Make-to-Order production, as the production mode. This gives rise to a phenomenon that bottle blowing machines that sell well are produced in off-seasons in order to make up for the production capacity shortage in boom seasons, while the unpopular types of machines are produced only by orders. Additionally, the technics of some parts required by orders are highly flexible, resulting in the uncertainty of parts' technical routines. Therefore, the uncertain environment not only complicates the production control of manufacture, but also causes the imbalance of workload distributed over timeline.

The majority of bottle blowing enterprises in China take traditional production planning methods as the basis of production control, such as Material Resource Planning (*MRP*), Just-in-time (*JIT*). While these traditional production plan and control methods are not suitable to the MTO enterprises as is shown in [3–6], for most of them are developed in the repetitive production environment.

Workload control (*WLC*) concept is one of new Production Plan and Control (*PPC*) concept that has been designed specifically for the needs of Make-to-Order environment with high complexity [7]. The basic principle of *WLC* is keeping the task queue of every machine in the shop floor at reasonable length, in order to make sure the minimum of average waiting time and total flow time of tasks, and finally achieving the balance of workload of the whole manufacturing system. There are three hierarchical control levels of *WLC* [8], which are order entry level, job releasing level, and job dispatching level (Fig. 1).

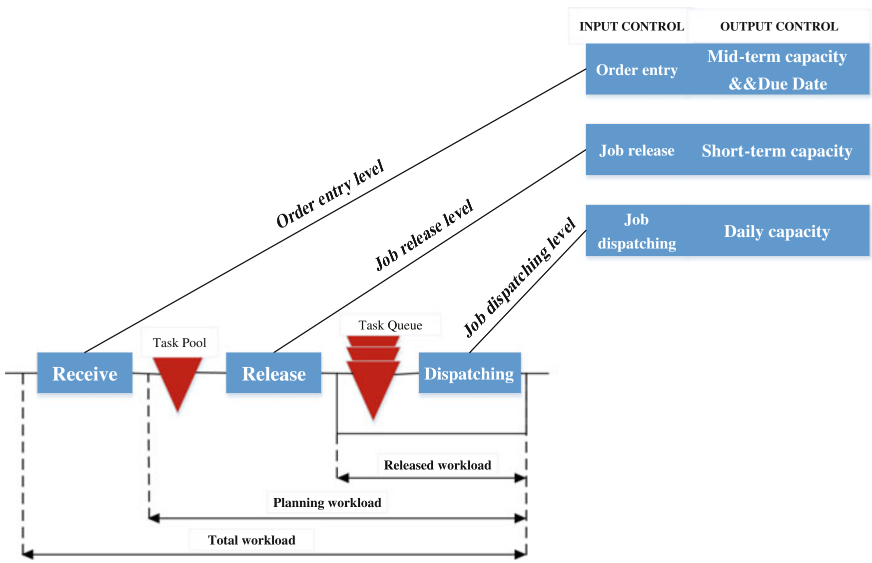

Fig. 1 Hierarchical control structure of workload control concept

In the order entry level, the acceptance of arriving orders is determined, and due date is set for each accepted order, So that the production lead time remains in a predetermined value. In the job release level, the accepted orders that wait in the task pool are reviewed and released for the next period of production. The input control decisions, however, are: when to release the jobs; how many jobs to release; and which jobs to release [9]. In the job dispatching level, the queue length before each work center is kept limited to ensure the workload balance of each work center [10].

2 Pre-releasing Strategy

2.1 *Essential Principles of Pre-releasing Strategy*

From the former section, we can arrive at a conclusion that Workload Control (*WLC*) concept is a production plan control method proposed specifically for the order-oriented enterprises. In a hybrid production environment as bottle blowing machine enterprise, which takes pre-releasing strategy as a workload control approach, however, the decision making is much more complicated(Fig. 2). In recent years, the issues about order entry level have arouse much attention. A multi-layer production planning and control structure is proposed for typical job shops in the application of [11], a decision support system about customer inquiry is developed in the application of [12], and a multi-level job release control model is proposed in [13–15]. As the top level in the whole production planning and control system of Bottle Blowing Machine, order entry level is the key to control the source of the overall workload of enterprise. There are two important decisions that need to be made in the order entry level: (1) The combination and number of pre-releasing order; (2) The optimization of critical procedure routines.

Suppose there are M types of manufacturing units, each one of them $j \in J = \{1, 2, \ldots M\}$ is a general flow shop; pre-releasing decision period of enterprise is T; unit workload calculation cycle is T'; there are Z well-sold types of bottle blowing machine represented by $c \in C = \{1, 2, \ldots Z\}$, in decision period, whose quantity

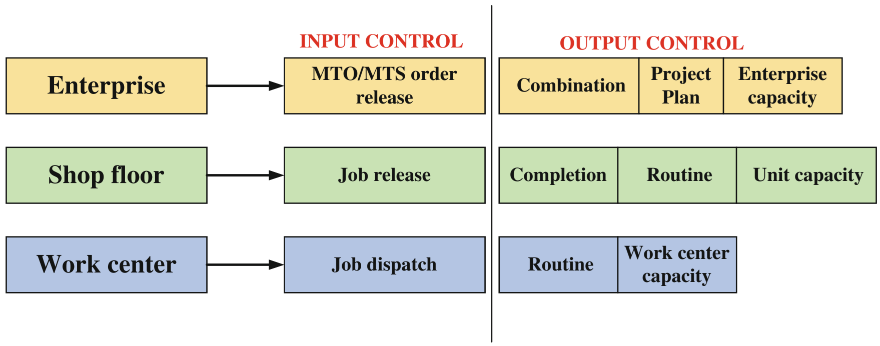

Fig. 2 Hierarchical control structure of bottle blowing enterprise

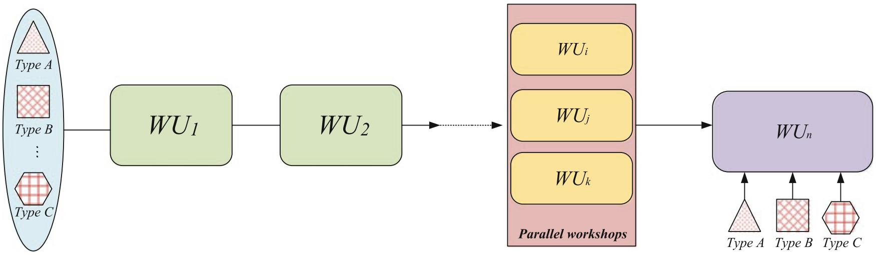

Fig. 3 Work unit flow shop

limit is k_c; A_j represents the workload limit of unit $j \in J = \{1, 2, \ldots M\}$ in a calculation cycle. The technical routine of a part is not fixed, but flexible, for example, the predetermined routine of part P (Fig. 3) is $\{WU_1 \to WU_2 \to WU_3 \to \cdots WU_n\}$, where the technics of shop WU_2 and WU_3 are not specifically sequenced. The optimized routine can be rearranged by $\{WU_1 \to WU_3 \to WU_2 \to \cdots WU_n\}$ according to the instant workload distribution of shop floor. Considering uncertainty of orders, product structural complexity, and diversity of processing routine of bottle blowing enterprise, the pre-releasing strategy is proposed to balance the workload. The keys of pre-releasing model are: (1) The total workload calculation of each unit; (2) The number of pre-releasing order.

The basic principles of pre-releasing strategy are shown in Fig. 4. Suppose the quantity limit, due date and pre-releasing decision period of well-sold bottle blowing machine are identical. The main steps of periodic pre-releasing decision include: (1) determine the well-sold machine and its production limit based on market requirement; (2) calculate the workload of each unit on the timeline; (3) construct the mathematical model for the pre-releasing strategy and decide the optimal quantity of pre-releasing orders for each unit. When a new order arrives, the pre-releasing order model will be triggered to modify the quantity of pre-releasing order (Fig. 3). However, the quantity modification of orders caused by emergency is not the focus of this paper, so it will not be discussed in detail.

2.2 *Calculation of Workload in Units*

The workload of a unit comes from these three sources (Fig. 5): (1) orders in process; (2) orders to be released; (3) reserved orders. In this section, we focus on the calculation of the pre-releasing and customer orders to be released in the unit.

However, the difficulty of workload calculation lies in the accuracy of Earliest Released Date (*ERD*) of each part in a unit. Based on the ERD, the workload requirement period, which means the time zone of workload requirement, can be calculated. The end time is referred to as Latest Operation Completion Date (*LOCD*). *ERD* is equal to the Material Arriving Date (*MAD*). As for the universal

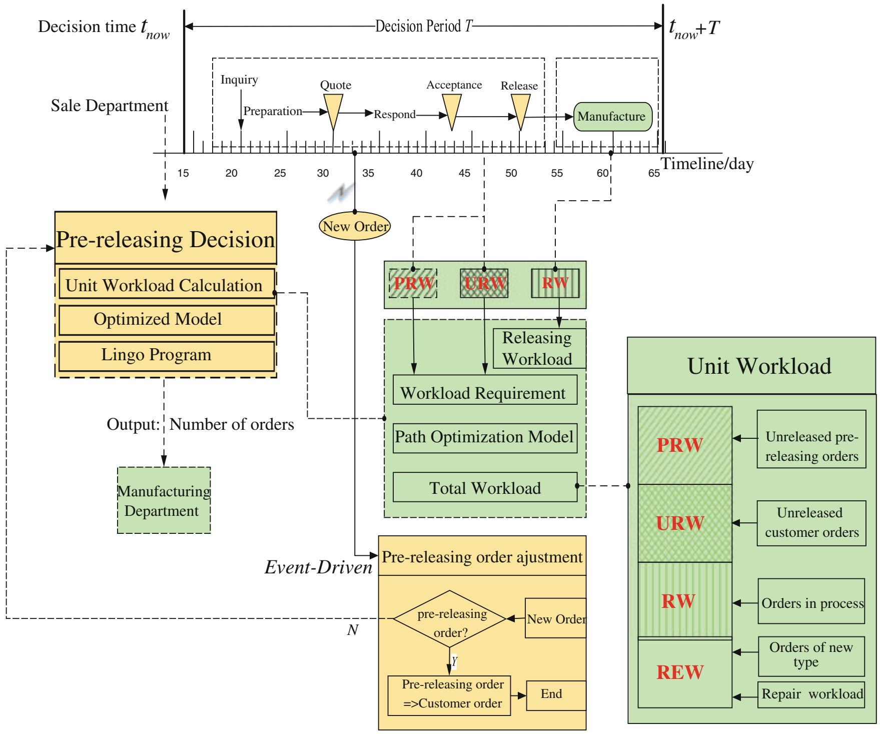

Fig. 4 Pre-releasing order decision structure

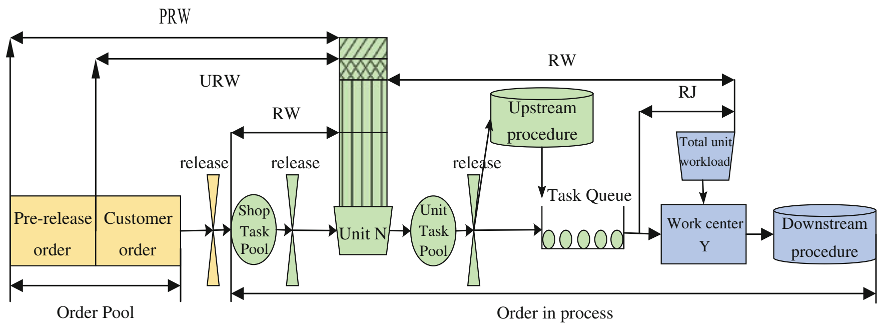

Fig. 5 Workload sources diagram in a unit

parts, the *ERD* is based on the *LOCD* of all the customized parts, which is referred to as the reverse sequenced $\text{Max}\{LOCD_A \ldots LOCD_n\}$. On the contrary, the pre-releasing orders only contain universal parts, so the *ERD* of pre-releasing parts is set after the confirmation of the *ERD* of customized parts, according to the sequence of each unit average duration (Fig. 6).

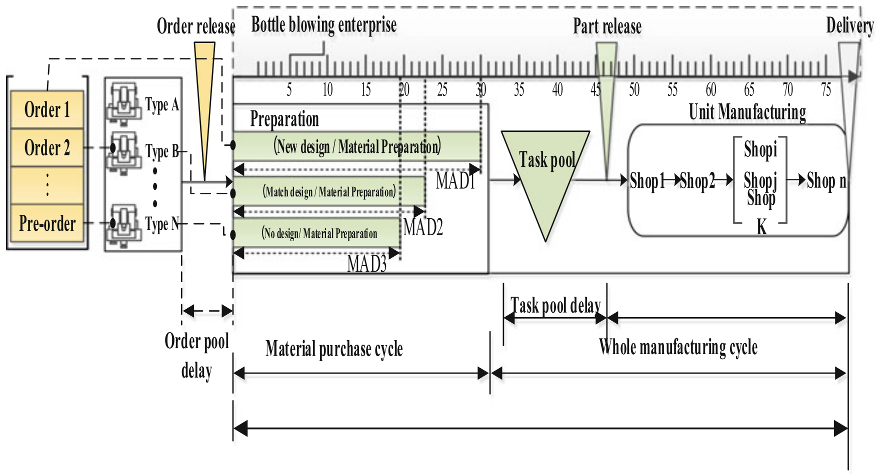

Fig. 6 *ERD/LOCD* calculation

The proposed method can only be used to get the initial value of parts' *ERD/LOCD*. The final value of parts' *ERD* is only effective after the verification of parts, which takes the direct releasing strategy, regardless of the order pool delay. The average durations of parts are distinguished between universal parts and customized parts. The universal parts' average duration is relatively accurate for the reason that the production is much more skillful, while the customized parts are influenced by the requirement of customers, so the workload requirement period is on the basis of average duration expectation to make sure the accuracy of workload requirement period.

The average duration expectation of customized parts can be achieved on the basis of historical statistics. Suppose a typical customized parts technical routine consists of M units, the average duration of one unit $j \in J = \{1, 2, \ldots M\}$ is the weighted average of each unit duration, the formula is shown in (1), where PT_{wm}^{j} stands for the average duration of unit j, PT_{k}^{j} stands for the duration of sample k, and n is the number of statistical samples. Then the average duration probability distribution of unit j is achieved based on the random state evolution model, and finally the average duration expectation of unit j can be achieved by formula (2), where P_{j,S_i} stands for the probability of average duration PT_{wm}^{j}. Besides, the statistical duration can continue to be amended to conform to the prevailing circumstances.

$$PT_{wm}^{j} = \frac{\sum_{k=1}^{n} (PT_{k}^{j})^2}{\sum_{k=1}^{n} PT_{k}^{j}} \tag{1}$$

$$PT_j = \sum_{i=1}^{n_j} P_{j,S_i} \times PT_{mw}^j \tag{2}$$

The workload of orders to be released to unit j at time t: suppose the parts collection V_{tnow} contains D types of customized parts and D' types of universal parts. Order $i(i \in V_{tnow})$ contains R_i types of parts, the number of each type of part $l \in I_4 = \{1, 2, \ldots R_i\}$ is r_{il}. Firstly, the workload requirement period *(ERD, LOCD)* of part l is achieved on the basis of certain rules. Secondly, the technical routine of part l is optimized according to the model below: Suppose the technical routine of part $l \in I_4 = \{1, 2, \ldots R_i\}$ is $[N_1 \to N_2 \to N_3 \to \cdots \to N_n]$, where each unit has no constraint with the others. So the multi-process routine of part l can be transformed as $\left\{N_1 \to N_2 \to \begin{bmatrix} p_{k,k} & \cdots & p_{k+s,k} \\ \vdots & \ddots & \vdots \\ p_{k,k+s} & \cdots & p_{k+s,k+s} \end{bmatrix} [N_k, N_{k+1}, \ldots, N_{k+s}] \to N_n\right\}$, where $p_{k,k} = \{0, 1\}$ represents the probability of workshop N_k sequenced by k, $p_{k,k+s} = \{0, 1\}$ represents the probability of workshop N_k sequenced by $k + s$, and $p_{k,k}$ is up to the workload of N_{k-1} at completion time. The workload rate $\left[\frac{TotWL_{k,t}}{A_k} \ldots \frac{TotWL_{k+s,t}}{A_{k+s}}\right]$ of $[N_k, N_{k+1}, \ldots, N_{k+s}]$ at completion time of N_{k-1} is calculated and sequenced in ascending order. If the workload rate of N_{k+1} is the lowest, $p_{k,k+1} = 1$, the technical routine of other units can also be optimized in this principle. Then, the optimal technical routine of parts between units is $[N_1 \to N_2 \to N_{k+1} \to N_k \ldots N_n]$.

In summary, on the basis of the technical routine, *ERD* of parts and duration in each unit of parts, the workload requirement period can be achieved. The workload requirement period of Order O in unit j is as formula (3): suppose order O contains p_o kinds of parts. The number of each part $l \in I_1 = \{1, 2, \ldots p_o\}$ is p_o and the workload requirement $PC_{ol,j}$ of order in a unit is identical, γ stands for the economical batch coefficient.

$$C_O TWL_j = \sum_{l=1}^{p_o} PC_{ol,j} \times n_{ol} \times \gamma \tag{3}$$

2.3 Mathematical Model of Pre-releasing Strategy

When all parts of customer order are released, and the technical routines are optimized in the former proposed principle to balance the workload of each unit. There are chances of existing imbalance in some units. In order to make sure of a further balance of workload, pre-releasing orders have to be released. In this section, the target of pre-releasing strategy is to make the units with inadequate workload reach their workload upper bound, improving delivery accuracy and energy efficiency. Thus, based on the integer programming model, the mathematical model of pre-releasing strategy is as follows:

$$\text{Min} \quad z = \alpha\left(1 - \left(\sum_{j=1}^{\varpi} \frac{RW_j}{A_j}\right)/\varpi\right) + \beta\left(ROL_\varepsilon / \sum_{j=1}^{\varpi} A_j\right) \tag{4}$$

$$\text{s.t} \quad RW_j = RoTWL_j + \sum_{\varepsilon=0}^{z} x_\varepsilon C_\varepsilon TWL_j + \sum_{O \in O_1} C_O TWL_j + \text{Re}TWL_j \leq A_j \quad j \in J \tag{5}$$

$$\begin{cases} x_1 \leq k_1 \\ x_2 \leq k_2 \\ \cdots \\ x_\varepsilon k_\varepsilon \quad \varepsilon \in \{1, 2, \ldots, Z\} \end{cases} \tag{6}$$

Formula (4) is the objective function, this objective function is a compromising function of the workload rate in units at decision period and the minimum influence of pre-releasing order on the next decision period. Because the workload rate should be as high as possible, on the other hand, the influence of pre-releasing orders on the next decision period should be reduced to minimum for the short-sighted features of pre-releasing decision. In formula (4), ROL_ε is the total workload of ε type of bottle blowing machine on the future decision period, α and β are the weight coefficients. When the enterprise is in boom seasons, the value of α should be higher than β, while the value of α should be lower than β in off seasons; Formula (5) is the constraint to make sure the workload in units would not exceeds the upper limits; the RW_j is the total workload of unit j, A_j is the upper bound of unit j; $C_o TWL_j$ stands for the workload of order O in unit j, O_1 is the number of customer orders to be released; $ReTWL_j$ is the reserved workload of unit j; In Formula (6), x_ε represents the decision variable that means the number of ε type bottle blowing machine is x_ε; Z represents the number of well-sold type bottle blowing machine; k_ε represents the upper bound of ε type bottle blowing machine in this pre-releasing decision period.

3 Experiment Design

3.1 Pre-releasing Decision System

The former established mathematical model is a nonlinear integer programming model, which can be solved by branch and bound algorithm. Therefore, this paper takes *Microsoft Visual Studio 2010* as the system developing interface, *SQL Server 2008 R2* as the database, and *Lingo* to work out the solution of this mathematical model. The system structure is as shown in Fig. 7. This system can work out the optimal combination of pre-releasing orders and their optimal technical routine,

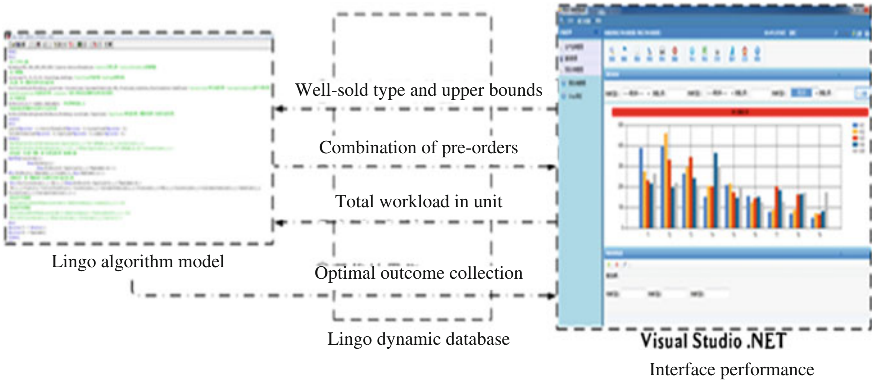

Fig. 7 Pre-releasing decision system

based on the upper bound of well-sold types of machine and the actual workload in enterprise. This system can provide significant decision support for the future development of enterprise.

3.2 *Parameter Settings*

In order to testify the effectiveness of the proposed algorithm, a numerical example is presented based on *Microsoft Visual Studio 2010*, *SQL Server 2008 R2*, and *Lingo11*. There are five types of well-sold bottle blowing machine in Table 1. The upper bound and technical routine are identical. Average duration and standard hour is also given in Table 2. Suppose the workload of orders in process is identical and the reserved workload is given in Table 3. The enterprise is in a boom season, the value of weight coefficient $\alpha = 0.8$, the value of weight coefficient $\beta = 0.2$.

Table 1 Experiment design

Type	Machine components and alternative technical routine		
	Part ID Technical routine	Upper bound	MAD
A	A-C $1 \rightarrow \begin{bmatrix} 2 \\ 3 \end{bmatrix} \rightarrow 4 \rightarrow 5$	5	4
B	B-C $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5$	6	6
C	C-C $1 \rightarrow 2 \rightarrow \begin{bmatrix} 4 \\ 3 \end{bmatrix} \rightarrow 5$	5	4
D	D-C $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5$	0	10
E	E-C $1 \rightarrow 2 \rightarrow 4 \rightarrow 3 \rightarrow 5$	0	14

Table 2 Average duration requirement in unit (day/h)

Part ID	WU_1	WU_2	WU_3	WU_4	WU_5
A-C	6/32	3/28	12/65	3/17	4/24
B-C	7/39	5/27	10/58	6/37	5/25
C-C	7/28	6/29	13/69	6/23	5/27
D-C	7/32	5/21	9/55	6/27	5/26
E-C	7/37	5/19	10/59	6/31	5/27

Table 3 Reserved workload and upper bound

Unit	T_1	T_2	T_3	T_4	A_j	Threshold
WU_1	206/42/24	206/42/24	130/35/20	247/30/25	600	1.1
WU_2	278/46/22	182/38/25	160/28/20	240/34/25	650	1.2
WU_3	250/40/25	160/37/20	140/37/30	210/41/20	640	1.1
WU_4	220/36/20	170/25/18	160/28/20	115/35/20	650	1.1
WU_5	211/42/32	219/19/20	201/20/15	167/27/23	600	1.2

4 Results and Discussion

Simulation experiment is conducted based on the parameter setting of the former section, and then the optimal combination of orders is achieved by the branch and bound algorithm. The combination is as follows: Type A: 4; Type B: 5; Type C: none. Adjustment is made to comply with the needs of market and the rule of lower risks, and the revised combination is as follows: Type A: 3; Type B: 3; Type C: 3. Although the pre-releasing strategy depending on personal experience could raise the workload rate in units, the combination would not be beneficial to the workload balance in units, worse still, it will result in more reserved workload in the decision period to come. So the pre-releasing order combination based on pre-releasing decision system can not only enhance the workload rate and workload balance in units, but also improve delivery reliability and make little influence on the future decision period. As is shown in Fig. 8, pre-releasing order combination based on pre-releasing decision system has better performance than that depending on personal experience.

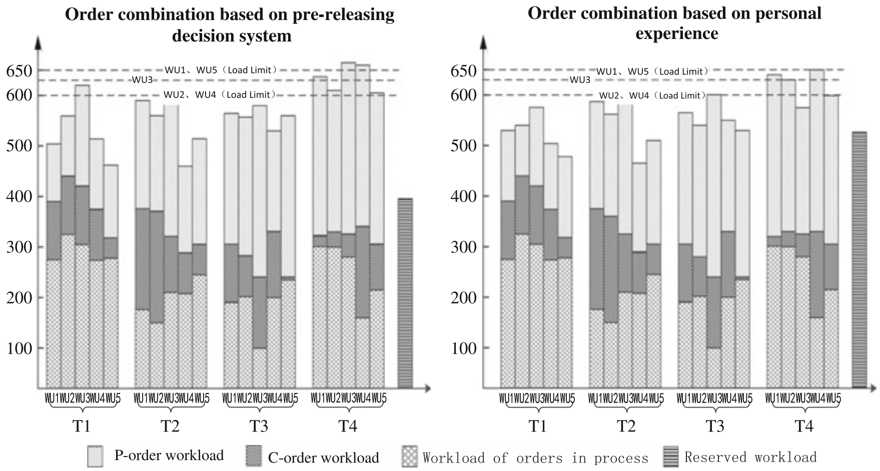

Fig. 8 Comparison of two method of pre-releasing strategy

5 Conclusion

The proposed workload control approach has a distinguishing characteristics compared to the pre-releasing strategy depending on personal experience, especially in the workload balance in units that ensures delivery reliability of enterprises. Through simulation experiments, the presented results of the former proposed approach has superior performance than pre-releasing dependent on personal experience. Having fully considered the features of bottle blowing machine manufacturing, this paper proposes a workload calculation method, and constructs a pre-releasing optimized mathematical model. Besides, a pre-releasing decision system that based on the mathematical model is developed to work out the optimal pre-releasing order combination, simulation experiments are conducted to validate the effectiveness of the system.

Since the parameter settings of this paper are static, the dynamic variability of parameter settings is further to be investigated for and more adaptability to production. Additionally, a hybrid push and pull production approach can be developed based on pre-releasing strategy based on workload control.

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Kitting Application for Automotive Mixed Model Assembly Line

Zhao-yang Yang, Guo-jun Zhang, Hai-ping Zhu, Hui-zhou Zhu and Hui Ying

Abstract A bottleneck appeared due to the lack of storage space at assembly stations when a new model start to be produced on a mixed model assembly line of an automotive company. To solve the problem, engineers plan and implement kitting to replace the line stocking as the material supply system of the mixed model assembly line. The completed kitting system achieve the advantage by meeting the space requirement, decreasing non-value additional work time of operators, improving the working environment, enhancing administration of assembly line and increasing product quality.

Keywords Mixed model assembly line · Material delivery · Kitting

1 Introduction

Manufacturers of automotive vehicles are facing two challenges, one is more and more fierce competition, the other is higher and higher demands of customers. In order to survive in the market, manufacturers have to try their best to satisfy the customers while limiting their costs. So it is very necessary to make their assembly systems suitable for mass customization. Each vehicle from the line could be different from others because of various types, specific options and one particular variant part of multiple models requested by a customer. It means that a specific part

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must be on the line at the right time. There are two common material supply systems in assembly systems to achieve this cause, line stocking and kitting.

Bozer and McGinnis [1] firstly introduced this problem. They presented a descriptive model by which kitting and line stocking can be compared easily based on multiple criteria at an early decision stage. The authors demonstrated the model by an example and discussed new research directions for kitting.

Ding [2] performed a case study at a US tractor plant that had successful implemented a kitting process. Based on the project Ding made a conclusion that the JIT-systems dealing with larger parts can benefit from kitting.

Brynzer and Johansson [3] discussed the design and performance of kitting systems, based on a number of case studies. Some factors are considered, including the location of the kitting system, work organization, picking method, batching policy for picking, picking information and equipment used. The related performance measures are picking efficiency and picking accuracy.

Carlsson and Hensvold [4] analysed a business case and tried to replace line stocking with kitting at Caterpillar BCP-E, Leicester. Their study showed that kitting would decrease line side storage, inventory value, replenishments beside the line, and operator walking times, at the same time increase the number of part handlings, space and time for kitting.

Hua and Johnson [5] identified factors that might have effect on the selection between kitting and line stocking among a number of issues, such as product property, storage and handling of material, production control, performance measures, and implementation, based on a case study of an electronics assembly company.

Ding [6] presented a kitting application in an engine assembly line of SAIC GM Wuling Automobile Company Ltd. The application demonstrate that the benefits of kitting includes production line layout optimization, guarantee of product quality, improvement of production line output capability, realization of the engine lean Manufacturing.

Cao [7] introduced the case of Shanghai General Motor. In order to alleviate the bottleneck resulted from the lack of work space, they planed and implemented a kitting system which increases the work space, decrease non-value added work and enhance assembly quality.

Caputo and Pelagagge [8] studied and compared three basic policies, kitting, JIT kanban-based continuous supply and line stocking, An ABC analysis was performed to develop hybrid policies. They provided some quantitative decision tools to select the suitable material delivery policy at an early decision stage, and explore trade-offs among the three feeding policies.

Caputo and Pelagagge [9] further proposed a methodology to evaluate and select policies of materials delivery for shop floor. They studied kitting, JIT kanban-based continuous supply, line stocking, and class-based hybrid policies. Descriptive models were developed which were used to design material delivery systems and evaluate their performances. A case study was utilized to test the method. The result indicated the method was capable as a decision making tool. Hybrid feeding policies might be preferable to a single feeding policy.

Limère, Landeghem, Goetschalckx, Aghezzaf and McGinnis presented a mathematical cost model which was used to evaluate the assignment of parts for kitting or line stocking. They tested the model with the case data from an automotive company in Belgium. The results showed that hybrid policies, i.e. kitting some parts while stocking others in bulk at the line, could achieve the exclusive use for either material delivery system [10].

In this paper, kitting is applied at a mixed model assembly line of an automotive company to solve the bottleneck problem of lack of storage space beside line caused by new model coming on the assembly line.

2 Problem Description

2.1 Process of S2 Line in the Assembly Workshop

The S2 line in an assembly workshop of an automotive company was founded in 2006. Now it can make four models, and there are several configurations for each model, e.g. high configuration, low configuration and so on. With a variety of production parts and the highly complicated assembly process, the S2 line is a typical mixed model assembly line.

S type of layout is applied in this S2 line, and the line consists of: the Trim line 1, the Trim line 2, the ground line, the receiving line, the commercial line, the instrument assembly line, the door line and the mechanical line. This classification is based on the requirement of the process. The main process layout of the S2 line is illustrated in Fig. 1.

The production program of the work shop: 39 finished cars should be assembled per hour, the equipment running rate is 98 %, and the rated standard time of workstation is 90s.

2.2 The Process Characteristics of S2 Line

Currently, the technology of vehicle assembly trends to large-scale, high efficiency, high quality, modularity automation, intelligent information, Digitization, low energy consumption, less pollution and high attention to logistics etc.

Especially, the S2 line has also its own characteristics as following: Apply the pull production based on the theory of lean manufacturing; Improve the production efficiency and reduce the production cycle by using modularization technology; Conduct the real-time monitoring by modern information management technology; Improve the automation level and the assembly quality by using the robot technology; Make full use of the factory stereo space, shorten the assembly line and improve the sustainable production capacity; Ensure the assembly quality by establishing and improving the quality control system; Reduce the pollution by recycling the industrial wastewater.

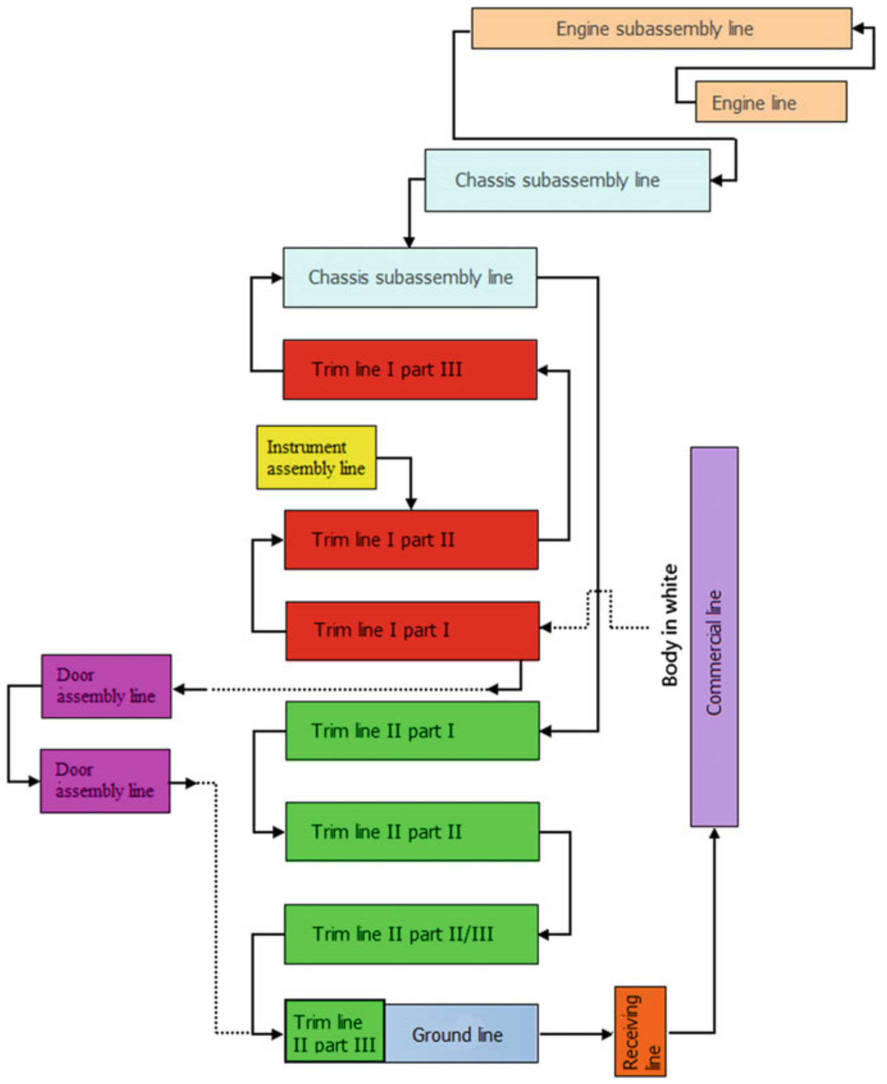


Fig. 1 The process layout of the S2 line

2.3 *Problem Encountered*

Although the future development trend of the car assembly technology is considered when designing the S2 line of the vehicle assembly workshop, it has been a long time since the factory was built. The rapidly development of the assembly technology makes the S2 line not so advanced as other newly built assembly line in terms of information technology, intelligent technology and logistic technology.

Especially, the traditional logistic cannot meet the requirement of line-side space under the hybrid flow shop. Therefore, it is urgent to optimize the material supply model before new models of vehicles are produced at this line.

The S2 mixed flow production line is producing a new model, engineers encounter a problem here, i.e. The space at assembly stations is inadequate for material stocking. The result of analysis and research demonstrates that 125 parts could not stocked beside line, and the supermarket area is insufficient either. Therefore, the traditional material supply mode has been unable to meet the requirements of mixed flow production.

3 Solutions Comparison and Decision

Due to the lack of space to stock all the required parts at the assembly line for making a new model, the material supply system for S2 line is reformed. Three solutions are proposed: synchronizing outside the factory, ordering inside the factory and kitting.

According to the real situation, analyze and compare the supply modes of material with respects to cost, demand of logistics area and demand of logistics operators, shown in Tables 1, 2 and 3.

From cost analysis above, no matter the synchronizing outside the factory or the ordering inside the factory, the annual operating cost has to be invested, the longer the system operates, the higher the annual operating cost is needed.

Table 1 Investment comparison of three supply solutions

Solution cost	Synchronizing outside the factory	Ordering inside the factory	Kitting
Fixed investment cost	0	General	High
Annual operating cost	High	General	0

Table 2 Area comparison of the three solutions

Solution	Synchronizing outside the factory	Ordering inside the factory	Kitting
Requirement for area	Need new area	Need larger new area	0
Follow-up benefit	When new vehicle model comes, readjustment of line-side is needed, more area may be needed	When new vehicle model comes, readjustment of line-side is needed, more area may be needed	It can produce 6 models. When new model comes, no new area is needed

Table 3 Number of operators comparison of the three solutions (single shifting production)

Solution		Synchronizing outside the factory	Ordering inside the factory	Kitting
Before implement	Supplier	10		
	Manufacturer	6		
After implement	Supplier	10	21(+11)	0 (−10)
	Manufacturer	6	6	16(+10)

Although the kitting Solution needs a high fixed investment, it needs no new annual operating cost. So this Solution reduces the cycle of return on investment.

Therefore, the kitting Solution is the best in terms of cost.

In can be seen from the Table 2, both the synchronizing outside the factory solution and the ordering inside the factory solution need to extend the factory building and even so, they may not satisfy the newer requirement of newer model.

So the kitting Solution is also the best in view of logistic area demand.

Taking the situation of single shifting production as an example, From the demand of logistics operators, it can be found that, based on the number of operators before, the solution of synchronizing outside the factory needs no more operator; the solution of ordering inside the factory needs 11 more operators of logistics provider, 6 more operators of manufacturer; kitting Solution can reduce 10 operators of logistics provider, needs 10 more operators of manufacturer.

Therefore, the solution of ordering inside the factory needs most operators. Both the synchronizing outside the factory Solution and the kitting Solution need 16 operators, and there is no change for the number of operators before and after the two Solutions are implemented, That means no new budget for operators comes into being for the two solutions.

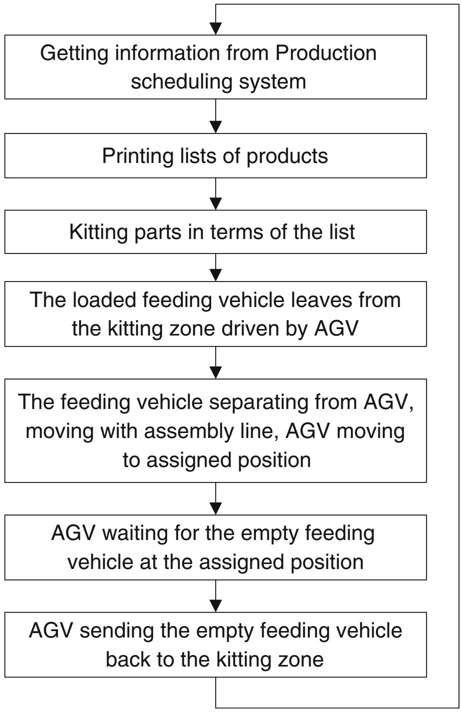
In conclusion, in terms of cost, demand of logistics area and demand of logistics operators, the kitting Solution is the best choice to solve the bottleneck of new vehicle coming on line.

4 Kitting Application

4.1 A. Implementation of Kitting for S2 Line

Instead of tradition assembly line, kitting process separates on-line assembly from picking of components. Picking workers print the production list according to information from the production scheduling system, and then put the components of one product on corresponding feeding vehicle in terms of the production list. The feeding vehicle, moving at the same speed with the product, transports the components to the assigned position at the required time. When all of the components

Fig. 2 Flow chart of kitting



are used up, the feeding vehicle quits at the assigned position and enter the next cycle. The procession is shown as Fig. 2.

Considering limitation of S2 line layout, demand of manufacture condition and long term solution of the company, eight kitting zones are designed for kitting variant parts. Figure 3 shows the completed kitting zone. Table 4 shows the main product process of each kitting zone.

4.2 Benefits of the Kitting System for S2 Line

Owe to kitting system, great benefits are gotten:

(1) Solving the bottleneck problem of new product coming onto line
It can solve the problem of shortage of line area by transferring the material to kitting zone for new product.

(2) Improving the working environment and administration of assembly line
Because of a large amounts of material pilled beside the assembly line, the environment of assembly line was very crowded in the past time. With the kitting system, the work space beside the assembly becomes tidy, kanbans

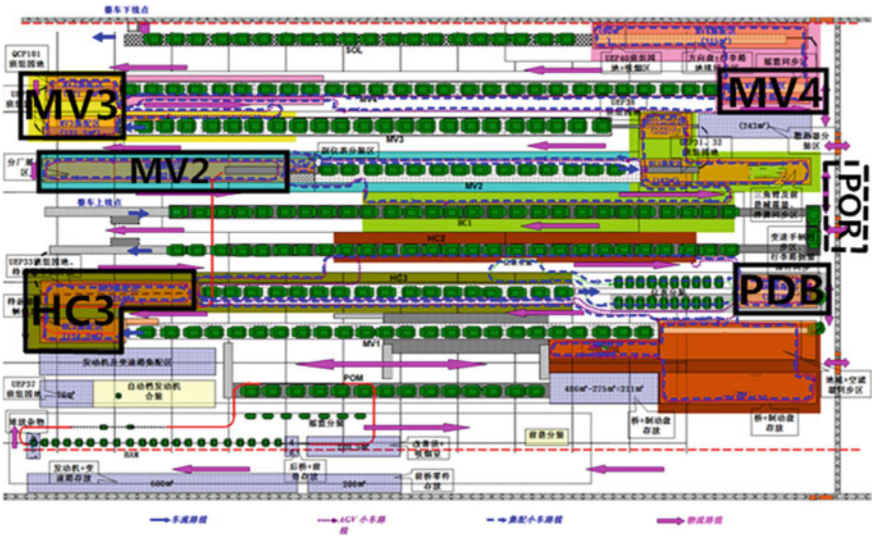


Fig. 3 Sketch of the kitting zone

become more eye-catching, the sight of operators becomes wider, the level of administration is increased.

(3) Decreasing additional work time, enhancing product quality

Illustrated by the case of team 31 group B, Table 5 shows differences of work time for 13 work position between with and without kitting system.

It can be seen from Table 5 that there are 8 work positions, 61.54 % of all work position, where work time decreases. The total work time decreases with 37 s, about 41.11 % of tact time. As the result of investigating, the main reason for decreasing of work time is that process of picking is removed with kitting system. In the same time, the assembly quality is improved by decreasing mistakes of picking.

Table 4 Main product process of kitting zone

Kitting zone	Product process
MV2	Group 38, kitting trim II part I
MV3	Group 38, kitting trim II part II
MV4	Group 40, kitting trim II part III
HC1	Group 31, kitting trim I part I
HC2	Group 32, kitting trim I part II
HC3	Group 33, kitting trim I part III
PDB	Group 33, kitting instruments
POR	Group 35, kitting doors

Table 5 Work time of team 31 group B for a kind of product

Work position	Work time without kitting (s)	Work time with kitting (s)	Difference (s)
B015L	77	77	0
B018L	95	80	−15
B018R	97	80	−17
B019L	71	90	+19
B021L	90	81	−9
B021R	76	82	+6
B022L	85	83	−2
B022R	88	84	−4
B023L	93	101	+8
B024L	96	87	−9
B024R	74	90	+16
B026L	90	72	−18
B026R	92	80	−12
Total time	1124	1087	−37

5 Conclusion

By means of investigating and analyzing, engineers transform the S2 mix model assembly line of an automotive company with kitting system. For the bottleneck problem of new model production in mix model assembly line due to space limitation, kitting is a ideal solution for increasing work space, decreasing non-value additional work time of operators and improving work environment greatly. According to information from the workshop, the completed kitting system works well.

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Study on Performance Evaluation and Improvement for the Discrete Manufacturing Enterprises Under the Integration Framework

Jia-kun Sun, You-quan Xu and Fu-peng Yin

Abstract In today's highly competitive business environment, manufacturing enterprises need to evaluate their operations and make decisions quickly and get on with it, the formation of the manufacturing performance evaluation system is discussed. Requirement analysis for performance evaluation is explored, then the technique method is proposed: the system of manufacturing performance indicators is modeled with the reference to the concept of MRP, manufacturing data is acquired on the basis of the integration of the management systems at different stages of the product life-cycle; According to the distribution of the data, the gaps between the reality and the simulation results in manufacturing systems are identified by comparison; With value stream map as a bridge between the evaluation result and the potential improvement of the enterprise business, through the application of factor analysis and ANP, it is to provide the basis and reference path for the improvements.

Keywords Discrete manufacturing · Production data · Manufacturing performance evaluation · Improvement

1 Introduction

As an important part of manufacturing, discrete manufacturing has the characteristics of a wide range of parts and components, flexibility of manufacturing processes and equipment configuration, the dynamic changes in the production process

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products, logistics, equipment, production is not balanced and so on [1]. With the social and economic development, market competition is more intense [2, 3], in today's highly competitive business environment, manufacturing enterprises need to evaluate their operation and make decisions quickly and get on with it. Manufacturing performance evaluation help improve business processes reengineering and supply chain management, it can also help find deficiencies of the existing system, the potential of the production system so as to improve their operational capacity.

2 Background

In terms of evaluation indicator system, it has developed from a single financial evaluation indicator system to the system including quality time and flexibility, etc., and it has been an issue of increasing concern for the researchers and the business community that how to give a comprehensive assessment according to industry, region, type of business and other features, combining with different indicators of manufacturing performance. British manufacturing surveyed showed a growing number of enterprises used non-financial indicators, especially the indicators of quality and marketing activities, customer satisfaction, employee productivity and the quality level was considered an as the important indicator for surveyed companies [4]. Reference [5] modeled the objectives and performance indicators, and it used semantics to describe the objectives and performances, it tried to find a formatted evaluation indicator by computing of the semantic expression for businesses. Based on international manufacturing strategy survey (IMSS) database [6], manufacturing performances were divided into time, flexibility, financial and quality in modular customization by using factor analysis, and it also established structural equation model (SEM) to research relationship between the competitive priorities and the manufacturing performance, currently, there is no perfect solution to promote each other and alternately reflects both the relationship between the various indicators of the performance evaluation system.

As for the evaluation methods, Zhu, Liu, etc. [7, 8] summarized three methods of manufacturing performance evaluation, including constructing comprehensive performance indicators, using AHP to determine the indicator weight and data envelopment analysis of multiple input and output, performance evaluation model was proposed based on process analysis. Reference [9] calculated the deviation coefficient of order lead time and efficiency coefficient of the production system by two-dimensional variables, and uses the results to evaluate the manufacturing flexibility, and it can also explain the flexibility in different situations and the degree of improvement in terms of flexibility.

In order to objectively and fairly evaluate the manufacturing performance, scientific and rational evaluation indicator and evaluation criteria should be identified; the appropriate evaluation method is to be selected. In the actual operation, due to the business management complexity of various departments within the enterprises, it usually makes the evaluation criteria and evaluation methods lack of objectivity. Due to the stochastic nature of manufacturing systems and the complexity of production sites, a variety of qualitative analysis is far from effective performance evaluation, and is also difficult to identify the key factors [10], therefore, effective quantitative evaluation methods should be input, and all these analysis must be based on the real-time data from production sites. As for the implementation and application of the evaluation, Koc and Bozdag [11] studied the relationship between the application of advanced manufacturing technology and manufacturing performance parameters in small and medium enterprises, but this kind of study could only provide a general guidance to the manufacturing industry enterprise operation. Some researchers [12] tried to develop an integrated performance measurement system to integrate a variety of measurement methods, while this system is basically used as a monitoring tool, and there is no closed-loop feedback to support the improvement of the manufacturing performance. The data of manufacturing performance evaluation usually comes from production statistics, focusing on ex-post evaluation of production efficiency, there is a lag between the performance indicator and the real dynamic operation of the production efficiency, to some extent, the evaluation result is usually unable to provide efficient path guidance for the improvement of the operations of the manufacturing enterprises.

3 Requirement Analysis for Manufacturing Performance Evaluation

For discrete manufacturing enterprises, with the integration of the relative management systems of technology, manufacturing, procurement and other aspects in product lifecycle as the basis, based on data from the production management system, enterprise modeling system and methodology as the reference, study a workable performance indicator system, evaluation methods and processes, orienting to production strategy, reflecting customer demand and supporting the continuous improvement of the enterprise operations, which can be applied in the enterprise to provide a theoretical reference path and theoretical guidance for the improvement of the manufacturing performance.

3.1 Manufacturing Performance Evaluation Indicator System Modeling

In the process of manufacturing performance evaluation, performance indicator system is the foundation and key sector,production data related to the materials, equipments, technologies, personnel management, production process and other factors, can clearly reflect products, factory, process and resources (P^3R)

structure [13], it can also reflect the characteristics of the manufacturing enterprises. With the data related to the manufacturing from the management systems in the product life cycle as the basis, it needs to study that how to analyze the indicator attributes, set indicator range of the target value, determine the data sources of the indicator values, evaluation frequency, performance score based on indicator calculation, construct the performance indicator system in line with the business characteristics and development trend of the enterprises, according to the business environment, the regional and industry characteristics.

3.2 Multi-level, Multi-dimensional Mixed Performance Evaluation Method and Influencing Factors Analysis

The manufacturing performance evaluation process is ready for corporate executives, middle management and workshop management, the departments involved including manufacturing, procurement, quality inspection, sales, after-sale service and so on [14]. Different departments have different requirements and evaluation standards for manufacturing performance evaluation, at the same time, a lot of variables, may contain discrete variables and global variables. It needs to study how to define the performance indicators, influencing variables and functions of system-level and sub-level, and the data needed to exchange between the system and their subsystems, and application of multilevel evaluation method. It also needs to study the establishing method of model and the relationship between the models of different levels, to study the relationships among multiple attributes of different models.

3.3 Analysis of Manufacturing Performance Indicator and Improvement Method

At present, many performance evaluation systems focus on the evaluation itself, and did not set up the relation between the performance indicator and the improvement point or the improvement domains. The purpose of the evaluation is to continuously improve the management level and help improve the decision-making ability of the management level. It needs to examine how to establish the relationship between the performance indicator system and the areas of improvement on the basis of the traditional industrial engineering methods such as time and motion studies, process analysis, site management and quality control methods, it needs to study the factors that affect the manufacturing performance are, based on the integration of the management information systems in the whole product life cycle, so that the manufacturing performance is improved.

4 Technique Mehtod

4.1 System Design of Manufacturing Performance Indicators

With the reference of the concept of MRP [15], the production purpose is to produce effective output to meet market demand, which is the independent requirements, while the other indicators such as scrap, rework, on-time delivery rate is similar to the dependent requirements, as shown in Fig. 1. Therefore, based on the market demand according to their manufacturing strategy in time, quality, cost, flexibility requirements, performance indicators can be refined to the performance indicator on timely delivery, product quality, customer satisfaction, employee morale as well as efficiency and utilization, which can be treated as the specific guidance for manufacture. Analytic hierarchy process is used to determine the performance indicator system of manufacturing system, as shown in Table 1.

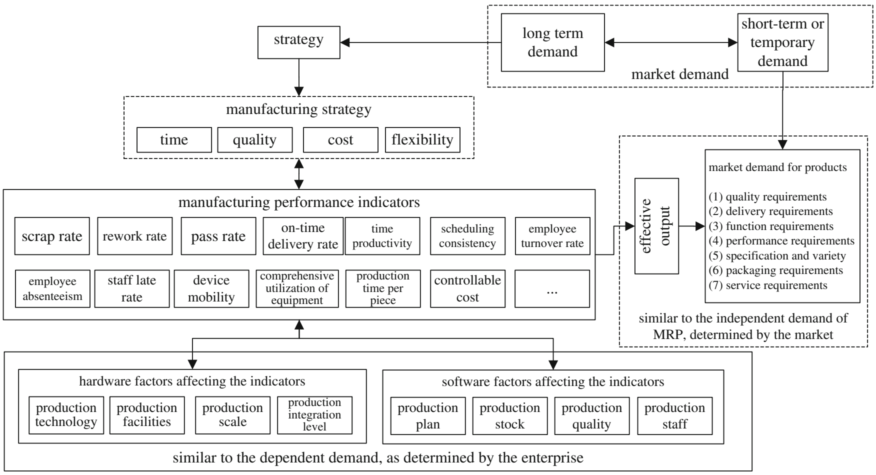

Fig. 1 Design of manufacturing performance indicator system

Table 1 Manufacturing performance indicators

Product quality	Customer satisfactory	Employee morale	Efficiency and utilization	Manufacturing cost
Scrap rate Rework rate First qualified rate	On-time delivery rate Time productivity Scheduling consistency	Employee turnover rate Absenteeism level Late rate	Availability rate Comprehensive utilization Production line balancing rate	Task time Variable cost Ratio to material used Inventory fund occupancy rate

4.2 Production Data Acquisition and Simulation

Production data acquisition is the basis for manufacturing performance evaluation, while the collected data is preliminary analyzed and processed to provide direct preparation for the performance evaluation, and the data must be obtained from the manufacturing process associated management system. So, first of all, the integration PLM and other management information systems are to be first implemented, including: production planning system, human resources management system, process planning system, project management system, the data gotten including machine tools, machining parts, working conditions, workers, equipment, quality data, and so on. In order to ensure the quality of the data, sample variables, sample size, sampling error need to be adjusted according to the characteristics of the object to ensure data availability, and the data also should be verified to ensure the quality of data acquisition.

The data obtained is to input SPSS to fit to analyze the distribution form, then through the simulation, the influence of different indicator changes on the performance indicator and the range of influence is studied, simultaneously, the rationality of simulation conditions is also examined, to adjust indicator data to re-examine the changing direction of the indicators, to identify gaps between the key performance indicators and the simulation indicators, to determine the room for potential improvement of manufacturing performance.

4.3 Manufacturing Performance Improvement Approaches and Their Impact on Performance Indicators

The purpose of the evaluation is to improve, the improvement methods of traditional basic industrial engineering are mainly concentrated in process analysis, action analysis, time study, etc. As for modern improvement methods, it needs to analyze and deduce the relationship between the performance indicators and improvement points or fields in different business links through the application of factor analysis method and ANP, combining with value stream map based on the data acquired from the integrated systems, so as to provide the basis and reference path for the improvements (Fig. 2). In detail, the time, quality, cost and flexibility of manufacturing strategy can be treated as the control factor layer, and their weight can be obtained through AHP method. The indicators from the process, manufacturing, procurement and other aspects can be conducted as a network layer, thus the non weighted matrix is constructed. According to the corresponding weights, weighted super matrix is constructed and the limit vectors of each rule are added up in accordance with the criteria weights. Based on the calculation results, the importance of different indicators can be determined according to the order of centrality indicator. The key indicators to promote the manufacturing performance can be found in line with the sort of the causes.

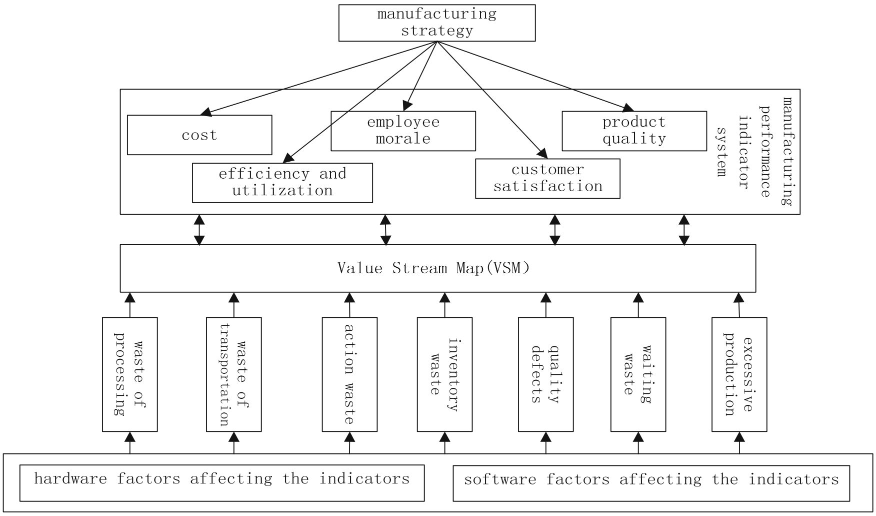

Fig. 2 The reference path for manufacturing performance improvement

5 Summary

Through the research on manufacturing performance system and evaluation method, it is to establish a manufacturing performance evaluation system based on production strategy, which can reflect the demand at different levels, in different part of the business and support continuous improvement. At the same time, with the value stream map itself as a bridge communicating the evaluation and improvement, to establish the relationship between the evaluation indicators and the improvement point or improvement area, to provide the reference path for the practical application of the enterprise to improve the production efficiency, enhance the competitiveness.

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Healthcare Service Hidden Quality Cost Estimation Based the SERVQUAL and QFD Method

Ni-ni Gao and Yang Zhang

Abstract In order to make hospital realize the importance of the hidden quality cost in healthcare, this paper study the estimation method of healthcare hidden quality cost. SERVQUAL and QFD method were combined together to estimate the hidden quality cost in healthcare and apply the method in a case hospital. The related data was got by the investigation questionnaire. The method provide a tool to hospital manager to estimate hidden quality cost due to patient dissatisfaction, and the result can help hospital manager find out the key factors influencing the hidden quality cost.

Keywords Healthcare · Hidden quality cost · SERVQUAL · QFD

1 Introduction

Healthcare's quality is a prominent issue, the quality of care influence the hospital revenue, so the quality cost bring more and more researcher to concern. Although some has realized the importance of quality cost, more pay attention to the explicit cost, the hidden cost are always omitted, which take up more part in the total quality cost. In order to make more hospital pay attention to the hidden quality cost, this paper mainly tries to estimate the hidden quality cost in healthcare.

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2 Literature Review

Feigenbaum [1] first attempts to categorize the quality costs into three main categories: prevention cost, appraisal cost and failure cost, that is the PAF model. The PAF model neglects the hidden quality cost, so the model doesn't reflect the total quality cost. And many attempts have been made to improve the PAF model and study the hidden quality cost. Different authors have different opinions about the content of hidden quality cost.

Porter and Rayner [2] recognize the importance of tangible and intangibles, and divide the quality cost into tangible factory costs, tangible sales costs and intangible costs, and the intangible costs that can only be estimated, such as loss of customer goodwill, delays caused by stoppages and rework and loss of morale amongst staff. Modarres and Ansari [3] add two more dimensions to PAF model introduced by

Table 1 The classification of hidden quality cost estimation method

Researcher	The content of hidden cost	Estimation method
Sansalvado and Brotons [8]	Total hidden quality cost in enterprise	Develop model based on fuzzy logic, linear and possibilistic regression and Crosby's Quality Management Maturity Grid
Zhang [9]	Total hidden cost in enterprise	Customer dissatisfaction will lead to enterprise value variation, estimate the hidden quality cost using the Discounted Cash Flow method based on the enterprise value theory
Albright and Roth [10]	The loss due to poor quality products	Symmetric Taguchi quality loss function
Kim and Liao [11]	The loss due to poor quality products	Asymmetric quality loss function
Li [12]	Hidden service quality cost	The modified quality loss functions
Fink and Gillett [13]	Customer dissatisfaction cost of waiting	Combines the M/M/1 queuing model with the Taguchi loss function
Moen [14]	Intangible quality cost	Quality function deployment method
Wang and Jiang [15]	Hidden quality cost	Hidden quality cost is the function of sales revenue
Sellés et al. [16]	Hidden loss due to a delay in the completion of a certain building	Combine the fuzzy logic and expert on technique
You et al. [17]	Hidden cost of airline unpunctuality	The hidden cost of airline unpunctuality is the function of delay duration
Cook et al. [18]	Quality reputation loss	Quality reputation loss is the sum of the added cost of funding, loss of share prices falling and the loss of customer losing
Tannock et al. [19]	Disruption costs due to quality loss	Simulation approach

Feigenbaum, they are the cost of quality design and the cost of inefficient utilization of resources. Dahlgaard et al. [4] calssified the quality costs as visible and invisible costs, invisible cost are the costs due mainly to the loss of goodwill and additional costs incurred due to internal inefficiencies. Giakatis et al. [5] identified the hidden quality costs are the manufacturing loss and the design loss, they are large and they cannot be overlooked. Yang [6] offered to supplement traditional P-A-F model with hidden external quality costs that are composed of two costs categories: extra resultant quality costs and estimated hidden quality costs. Snieska et al. [7] conclude the content of hidden external failure quality costs, including the related to loss of customers' goodwill, the related to possible loss of lost brand value and the related to loss of organization's lost image. From the above, we can get that the content of hidden quality cost is abundant, different method should be used to estimate different hidden quality cost.

A lot of researcher has tried to estimate the hidden quality cost, it is summarized in Table 1.

From Table 1, we can get that most of the literature focus on the hidden quality cost estimation in manufacturing, just few of about service, and almost no hidden quality cost estimation in healthcare. However, service quality is very different from manufacturing quality, the estimation method is not quite fit for the service sector. For service sector, especially for hospital, the content of quality is very abundant, any quality problem will lead to the patient dissatisfaction and lead to hidden cost. It is impossible to measure all the hidden quality cost, this paper is to estimate the hidden cost caused by customer dissatisfaction.

3 Methodology

The paper uses a hybrid of two well-known quality methods including SERVQULAL and QFD to estimate the hidden quality cost. Because the content of hospital quality is abundant, any quality problem will lead to patient dissatisfied and hidden quality cost occur. In order to reflect hospital quality systematically, the paper using the SERVQUAL method, which including five dimension as the input of QFD. The input of QFD is customer's requirement, if the patient's requirement is satisfied, there have no hidden quality cost exist; otherwise, hidden quality cost will occur. The less satisfied they felt, the higher the hidden quality cost. So the degree of satisfaction influence the hidden quality cost. At the same time the importance of each requirement is different, the more important, the less satisfied with the requirement, the higher the hidden quality cost. So the hidden cost is determined by the weight of the patient's requirement and the degree of satisfaction.

Suppose the patient's requirement set is $D = (D_1, D_2, \ldots D_n)$, and the importance attached to each requirement, that is the weight of each requirement is $W = (w_1, w_2, \ldots w_n)$. If the larger the requirement weight, the more the hidden cost caused by the requirement, on the contrary, the smaller, the less.

The patient will go to the competitor when they felt dissatisfied, then a loss will occur. Actually, The hidden quality cost is determined by quality perception difference. The difference between the company's and their chief competitor's performance is denoted R_i, which is a performance index. If $R_i < 0$, it means that the company's performance is better than their chief competitor and a loss will never happen, the hidden quality cost is zero even if the customer is dissatisfied and the weight of the requirement is big. Because the customer has no better choice if he leaves the company. If the $R_i > 0$, it means the hospital's performance is worse than the chief competitor's, which will lead to the customer dissatisfied and leave the hospital. There will be a loss and the hidden quality cost occurs.

Both the weight of requirement and the performance difference influence the quantity of hidden quality cost, so we call $Q_i = R_i * w_i$ the cost index. It is shown in detail in Table 2.

The difference investigate questionnaires is design in a Likert scale five-point format ranging from "quality completely agree" (1) to "quality completely disagree" (5). Suppose the performance gap reach the maximum, that is to say, the $R_i = 5$, the maximum cost index is $Q_i = 5w_i$. The maximum loss T_{max} due to unsatisfied customer lost is calculated according to the method adapted by Jones & Williams, it is shown in Table 3.

So, the hidden cost rate I can be described as follow:

$$I = \frac{T_{\max}}{R_{i,\max} * \sum_{i=1}^{n} w_i}$$

The hidden quality cost for the unsatisfied customer's service requirement over the analyzed period can be expressed as the hidden cost rate times the sum of cost indexes. Following is the formula.

Table 2 Calculation weight related to hospital service hidden quality cost

SERQUAL indicator	Requirement weight	Customer perceptions gap						Performance difference	Cost index
		0	1	2	3	4	5		
Requirement indicator 1	w_1							R_1	$R_1 * w_1$
Requirement indicator 2	w_2							R_2	$R_2 * w_2$
Requirement indicator 3	w_3							R_3	$R_3 * w_3$
…	…							…	…
Requirement indicator n	w_n							R_n	$R_n * w_n$
Total	$\sum_{i=1}^{n} w_i$								$\sum_{i=1}^{n} R_i * w_i$

Table 3 Loss due to unsatisfied customer lost (adapted by Jones and Williams)

1	Average value of each sale of service	Value
2	Average retain profit	x
3	Sales during the period selected for analysis	x
4	How many customers the organization has	x
5	Average periodicity of purchases	x
6	Number of satisfied customers	x
7	Number of unsatisfied customers(U)	x
7A	Number of unsatisfied customers who are not intended to buy repeatedly	x
7B	Number of unsatisfied customers who are intented to buy repeatedly	x
8	Number of purchases of product of satisfied and unsatisfied with intensions to buy customers during analyzed period (line6 × line5 + line7B × line5)	x
9	Loss of customers's purchases due to unsatisfying (line7A × line5)	x
10	Loss of income due to unsatisfied customers (line9 × line2)	x
11	Average costs of attraction of new customer	x
12	Costs of replacing of unsatisfied customers by others (line9 × line11)	x
13	Total loss (line12 + line10)	x

$$E_m = I * \sum_{i=1}^{n} R_i w_i$$

where m is the number of service.

For all the service, the total hidden cost is calculated as

$$THQC = \sum_{j=1}^{m} E_m$$

4 Case Study

In this paper we take a third-class hospital as an example to estimate the hidden quality cost.

Firstly, we analyze the patient's requirement according to the SERVQUAL five dimensions model, and get 27 patient's requirement. Then in order to get the weight of requirement the questionnaires were done. The question option in the questionnaires were designed in a Likert scale seven-point format ranging from "very unimportant" (1) to "very important" (7). A total of 200 questionnaires were distributed to patient in different age groups, and 171of them were received, usable responses were 167, comprising a response rate of 84 %. The weight of requirement was got by the following formula, The result is shown in Table 4.

Table 4 Calculation weight related to hospital service hidden quality cost

SERQUAL requirement indicator		Requierment weight w_i	The case hospital P_i	Competitor P_{ic}	Performance difference R_i	Cost index w_i*R_i
Tangibles	Hospital facility	5.23	4.21	4.17	0.04	0.21
	Hospital environment	5.78	1.62	0.88	0.74	4.28
	Layout of the hospital	5.71	1.68	2.24	−0.57	−3.25 → 0
	Advancing level and Completeness of equipment	6.09	4.6	3.75	0.85	5.18
	Medical staff wearing	5.54	4.35	4.2	0.15	0.83
Assruance	Doctor's professional Knowledge and technical level	6.63	1.88	4.38	−2.5	−16.59 → 0
	Service attitude	6.28	2.2	0.86	1.33	8.35
	Timely and properly treatment	6.51	4.12	4.46	−0.34	−2.22 → 0
	Moral standards	6.49	2.54	4.57	−2.03	−13.16 → 0
	Service courtesy	5.76	1.31	2.7	−1.38	−7.95 → 0
	Reliability	6.22	1.38	0.96	0.42	2.61
Reliability	Service commitment	6.25	2.9	2.36	0.54	3.37
	Provide exact time of treatment	6.08	2.72	1.67	1.05	6.38
	Provide service on time	6.08	4.38	3.8	0.58	3.53
	Inform the medical result in Time	6.16	3.3	1.49	1.8	11.08
	Try all the best to solve the Problem	5.93	0.69	3.35	−2.66	−15.77 → 0
	Transparency of charges	6.23	3.88	2.78	1.11	6.92
	Describe all service in detail	6.01	0.92	1.24	−0.31	−1.86 → 0

(continued)

Table 4 (continued)

SERQUAL requirement indicator		Requierment weight w_i	The case hospital P_i	Competitor P_{ic}	Performance difference R_i	Cost index w_i*R_i
Responsiveness	Fast treatment	6.24	3.08	4.84	−1.76	$-10.98 \rightarrow 0$
	Don't use busying as an excuse and provide service in time	5.97	0.48	3.82	−3.33	$-19.88 \rightarrow 0$
	Answer question in time	6.01	2.13	4.85	−2.72	$-16.35 \rightarrow 0$
	Respond complaints and suggests immediately	5.84	4.25	1.37	2.88	16.81
Empathy	Medical staff know about patient's condition very well	6.21	4.79	4.55	0.25	1.55
	Medical staff take good care of patient	5.65	0.84	3.64	-2.8	$-15.83 \rightarrow 0$
	Provide personalized service	5.42	4.68	3.57	1.11	6.02
	Know about the problem patient concern	5.71	3.42	1.93	1.49	8.5
	24-h service	5.78	1.64	0.86	0.78	4.51
	Total	161.81				90.13

$$w_i = \frac{n_{i1} \times 1 + n_{i2} \times 2 + n_{i3} \times 3 + n_{i4} \times 4 + n_{i5} \times 5 + n_{i6} \times 6 + n_{i7} \times 7}{n_{i1} + n_{i2} + n_{i3} + n_{i4} + n_{i5} + n_{i6} + n_{i7}}$$

Where *n* is the number of every option; i the requirement.

Then the hospital's performance is investigated, at the same time, we select the largest competitor as the other investigation object. Because the feeling or needs of different people are different, we let the average value of investigate result on behalf of the performance difference. The investigation result of the hospital and the competitor are shown in Table 4. According to the result, the performance difference between the case hospital and the competitor are calculated. And then the cost index of every requirement is calculated, the result is shown in Table 4.

Selecting a disease as example, the maximum loss in a month is T_{max} is 435,000 yuan, so the hidden cost rate I is:

$$I = \frac{T_{\max}}{R_{i,\max} * \sum_{i=1}^{n} w_i} = \frac{435{,}000}{5 \times 161.81} = 537.67$$

The hidden quality cost is:

$$HTC = I * \sum_{i=1}^{n} R_i w_i = 537.67 \times 90.13 = 48{,}460.2$$

We also can get the hidden cost every dimension:

$$HTC_{tangible} = I * \sum_{i=1}^{n} RW_i = 537.67 \times 10.5 = 5645.54$$

$$HTC_{assruance} = I * \sum_{i=1}^{n} RW_i = 537.67 \times 10.96 = 5892.86$$

$$HTC_{reliability} = I * \sum_{i=1}^{n} RW_i = 537.67 \times 31.28 = 16{,}818.32$$

$$HTC_{responsiveness} = I * \sum_{i=1}^{n} RW_i = 537.67 \times 16.81 = 9038.23$$

$$HTC_{empathy} = I * \sum_{i=1}^{n} RW_i = 537.67 \times 20.58 = 11{,}065.25$$

From the result, we can know that, among the five dimension, the hidden cost value of reliability is the greatest one, following it is empathy, and then responsiveness, assurance, tangible is the last. So we also can get the hidden quality cost influential factor mainly is realiability, empathy and responsiveness.

5 Conclusion

Healthcare service quality influence the total hospital costs and revenue in a large extent, in order to make hospital manager realize the importance of hidden quality cost, this paper integrating SERVQUAL into QFD to estimate the hidden quality cost caused by patient dissatisfaction. The result show that the hidden quality cost due to patient dissatisfaction is large, and at the same time we get the key factors influencing the hidden quality cost is reliability, empathy and responsiveness.

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Research on Quality-Oriented Outsourcing Decision Architecture for Small-Batch Parts of Multistage Machining Processes

Pu-lin Li and Ping-yu Jiang

Abstract Service-oriented collaborations are widely used in manufacturing industry and more and more enterprises outsource the non-core business. But it's difficult to control the quality of multistage machining processes (MMP) parts for small-batch. This paper proposes a quality-oriented outsourcing decision system (QODS) for small-batch parts of MMP. First describe the framework of QODS, which consists of the error propagation network and enterprise relationship network. Then the authors invest the synergy of two complex networks and analyze the dynamic characteristics and vulnerability of the composite network to make the QODS stronger and smarter. Finally, the data mining and deep learning based on big data in QODS are used to decide more suitable outsourcing relationship. The QODS provide a new outsourcing decision mode for small-batch parts of MMP. Moreover, the enterprises can identify potential quality risks and try to avoid them, which are hard to observe in the traditional outsourcing system.

Keywords Quality-oriented outsourcing decision system · Multistage machining processes · Small-batch

1 Introduction

At present, global competition in the manufacturing engineering sector is becoming fiercer and fiercer and the enterprises have recognized the trend to promoting more service-oriented collaborations in manufacturing industry. Many small and medium enterprises start to provide professional manufacturing services for the product manufacturers in outsourcing collaborations. More and more enterprises, especially the equipment manufacturers, will outsource the non-core business. Equipment

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parts are almost small-batch processing so research on decision of outsourcing collaborations considering the quality control is a thorny issue. What's more, due to lack of quality characteristic data, it will be difficult to apply the traditional statistical process control (SPC) to the quality control in small-batch of MMP mode.

Much research has been done on the manufacturing network and some important achievements have been made. A new networked mode called social manufacturing (SM) was proposed to well organize plenty of distributed enterprises [1, 2]. Outsourcing tasks related to machining processes and parts is becoming one of the most significant manufacturing service activities during the production procedure [2]. However, the SM was not taken the outsourcing process quality as a decision factor. Also a quality information tracking model based on inter-enterprise quality tracking and control were proposed [3] but the model was not concerned on small-batch of MMP parts. A machining error propagation network has been done to explore the inherent mechanism of machining error propagation for improving product quality in multistage machining processes [4].

Through analyzing manufacturing network and quality control method in enterprises collaboration, a quality-oriented outsourcing decision system for small-batch parts of multistage machining processes is proposed in this paper. The QODS may explore the rule of the quality characteristic variation propagation along the outsourcing chain, so it can achieve proactive prediction of the outsourcing parts quality. At last, data mining and deep learning based on big data will be used in modifying the QODS after each outsourcing, which will contribute to selecting the proper collaboration in the future.

2 Quality-Oriented Outsourcing System for Small-Batch Parts of Multistage Machining Processes

The quality of the outsourcing parts is influenced by many factors, such as the error of machine tools, cutters and fixtures. Even the machining error from precious process may affect the current one. The QODS for small-batch parts of MMP is composed of two basic network architectures. The first one is the error propagation network. Each part has its own processing, which is the inherent property. It rarely changes when a batch of parts' production orders are given. So research on the error propagation network can make it clear that how the former errors and the machining conditions affect the final quality. The other network is the service-oriented enterprise relationship network. Once an enterprise wants to outsource a batch of parts, it can decide the optimal outsourcing relationship in the network, which means higher quality, lower cost and faster made.

Figure 1 shows the two basic networks and their relationship. The error propagation network belongs to the outsourcing parts, where circles means the quality attributes and triangles the initialized machining conditions (the machine tool, the cutter and the management level). And we can take all the manufacture resources as a pool in the enterprise relationship network. Different enterprises in the pool may

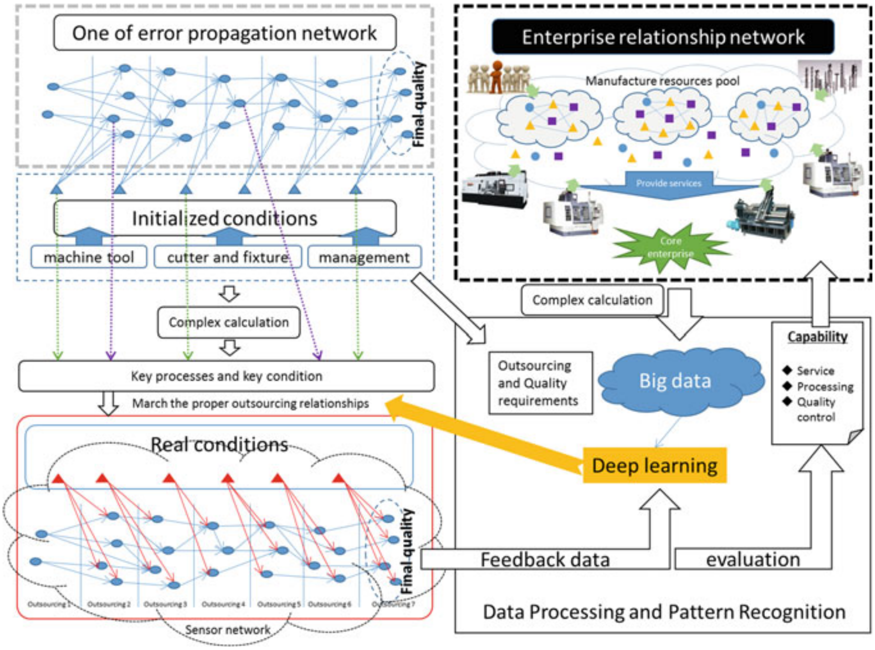

Fig. 1 Two basic networks and their relationship

have different contacts. We extract a sub-network where a core enterprise, such as an equipment manufacturer, dominates the manufacture. The core enterprise will not only concern about the final quality, but also the processing quality defects because it may cause unknown risks.

After calculating the complex of the error propagation network, we can figure out the key machining processes and key machining conditions. Then the sensitivity of the final quality will be analyzed, and the proper outsourcing relationships will be decision by deep learning from the big data, which is abstracted from the enterprise relationship network. So we can replace the conditions to the real ones. The service capability, processing and quality control capability of the outsourcing enterprise will affect the final quality. Also a sensor network is needed to track the processing quality. With doing this outsourcing, a data feedback system will be used to modify the pattern recognition effect in deep learning. In the end, the evaluation of the outsourcing enterprises may adjust the enterprise relationship network both in structure and weight.

Figure 2 shows a converged network where two outsourcing chains in a manufacturing network. As we can see, the enterprise of B serves two MMP parts. It means that B has the same capacity in the two error propagation networks. Supposing node C is out of control in the complex network, the node B will replace it. The final quality of part 1 will change along with the conditions differences. After reassessing the capacity of node B, we can predict the final quality accurately

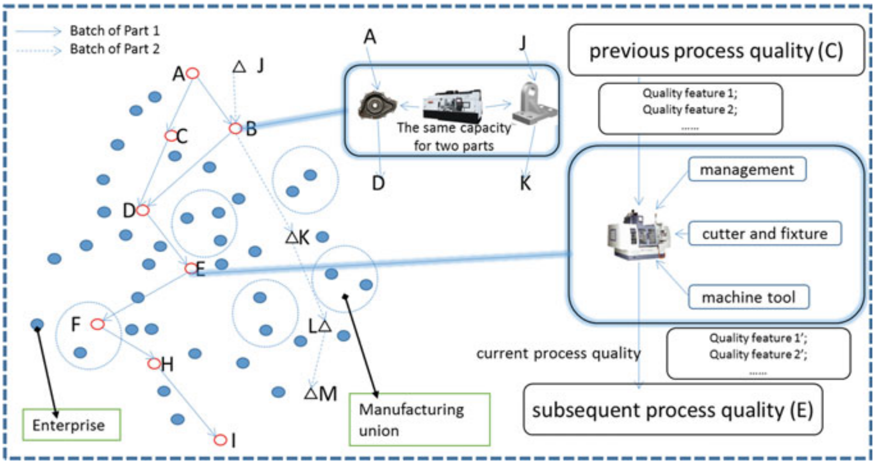

Fig. 2 A converged example of two networks

in using the error propagation network. So the unreliability of enterprise C makes effects on the final quality of part 2 although the node B isn't in part 2's error propagation network.

3 Key Enabling Technology

3.1 Dynamic Characteristics and Vulnerability Analysis Based on Complex Network Theory

The manufacturing network becomes more and more interconnected and interdependent with the development of the intelligent manufacturing. The complex analysis has become an important subject and some achievements have been made in manufacturing network. There are solutions to considering the outsourcing quality, but quite few studies have been published on processing quality controlling in outsourcing network. Once a nonconforming part was found, it will affect the subsequent processing. Even it may affect the final quality and the delivery time. So risks and vulnerability analysis of the quality-oriented outsourcing network is required [5].

Figure 3 shows a methodical framework for Dynamics characteristics and vulnerability analysis on QODS. Phase 1 aims at reaching a clear definition of quality-oriented outsourcing network. The processing characteristics of outsourcing parts should be studied. Then error propagation networks of MMP Parts and the manufacturing relationship network should be modeled and analyzed. The types of networks' failures and interdependencies will be discussed in Phase 2. Phase 3 is the most important where dynamics characteristics and vulnerability analysis will

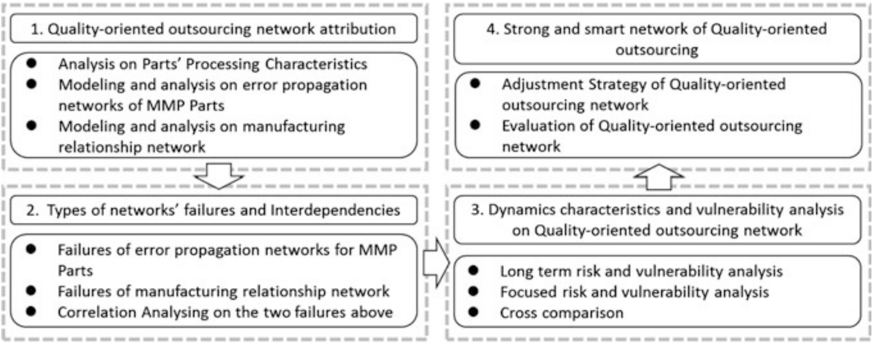

Fig. 3 A methodical framework for dynamics characteristics and vulnerability analysis on QODS

be argued on quality-oriented outsourcing network. In the final Phase, a strong and smart network of quality-oriented outsourcing is proposed.

3.2 *Data Mining and Deep Learning Based on Big Data*

With the big data era's coming, deep learning, a new research field of machine learning is used to analyze and process data efficiently [6]. Big scale data sets are the key to succeeding in deep learning. So it is to be solved that the big data mining and deep learning applied in the QODS.

As shown in Fig. 4, the history outsourcing data, machining data in the enterprises, feedback data from final quality and process planning data are taken as the

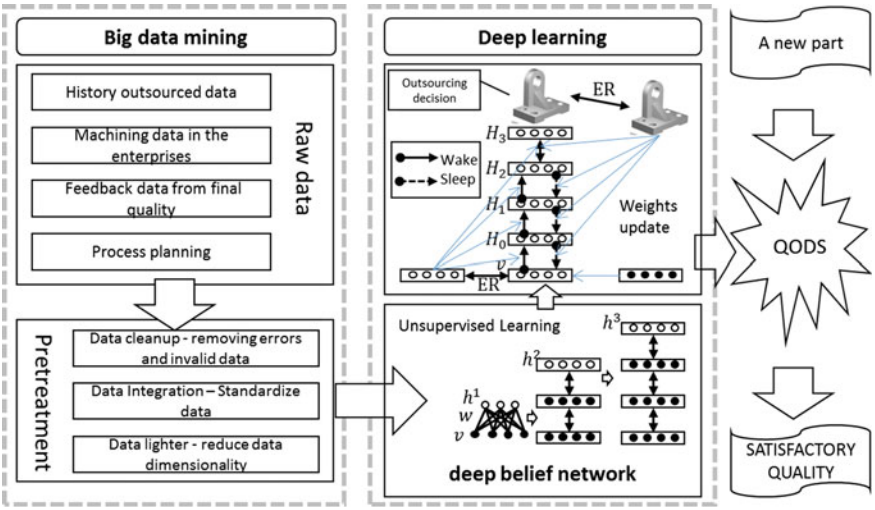

Fig. 4 Framework of data mining and deep learning

raw data. All the data will be cleaned up, integrated and be lighter to avoid the curse of dimensionality. Then the deep belief network (DBN) is introduced to simulate the data distribution of outsourcing relationship data input, and extract quality requirements features automatically layer by layer in using Layerwise Pre-Training Algorithm [7]. The Wake-Sleep Algorithm, which is an unsupervised learning algorithm for a multilayer neural network, will be used in trimming generative and recognition weights. This model can be used to predict whether the new outsourcing relationship can meet the quality requirements or not.

4 Conclusions

This paper proposed the quality-oriented outsourcing decision architecture for small-batch parts of multistage machining processes. We describe the framework of QODS, which consists of the error propagation network and enterprise relationship network. Then we invest the synergy of two complex networks and analyze the dynamics characteristics and vulnerability of the composite network to make the QODS stronger and smarter. Finally, we use data mining and deep learning based on big data in QODS to decide more suitable outsourcing relationship. The QODS provided a new outsourcing decision mode for small-batch parts of MMP. In this way, the enterprise can identify potential quality risks, which is hard to observe in the traditional outsourcing system and then try to control them. Therefore, it merits further study considering the quality in the manufacturing outsourcing decision.

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The Coordination of Supply Chain with Random Fluctuation Price and Price-Dependent Demand

Si-yao Tang, Jiang-tao Mo and Tian-yuan Liu

Abstract In this paper, we investigate the coordination of a two stage supply chain that consists of a supplier and a retailer, where the price is random fluctuations due to market environment, and influences demand. The study have showed that, the buyback contract can coordinate the supply chain, but cannot guarantee the profits of the member increased. And by combined the buyback contract with the wholesale price contract, the supply chain can be coordinated perfectly and achieved a win–win situation for the members of the supply chain. Further, numerical example is presented to verify the theoretical results and extensive sensitivity analysis of coordinate parameters is performed to evaluate the impact on the supply chain performance.

Keywords Buy-back contract · Price-dependent demand · Price fluctuation

1 Introduction

In real life, the demand of some products will be affected by the price, if the price is relatively low, it is easy to attract a large number of customers to buy. Otherwise it is difficult to stimulate the purchase of customers. That is the customer's demand for the products is affected by price, which is often referred to as price sensitive product.

In recent years, the supply chain of price sensitive products has received a lot of attention of scholars. In 1955, within studied the model of supply chain underprice dependent demand, and analyzed the order quantity and pricing strategy [1]. Mills established the supply chain model of the demand function as the price addition or the price multiplication, obtained the optimal retail price and order quantity of supply chain [2]. Jamernegg and Kischka established classical newsvendor model

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for price independent as well as price-dependent demand respectively. Based on the service constraint and loss constraint, investigate the existence of solutions of two kinds of models [3]. Sana has set up a EOQ model demand which function is $\eta(p) = \eta_0(p_h - p)(p - p_l)^{-1}$, where η_0 is the expected demand, p is a random variable, the optimal order quantity in the demand function is obtained by using the maximum profit of the unit time, numerical examples were presented and the model main parameters were sensitivity analysis [4].

The global market competition is becoming increasingly fierce, almost all enterprises are competing as members of a supply chain. Because of the "double marginal effect" in the supply chain, the local optimization of the enterprise's own interests will lead to the system suboptimal solution. Supply chain node enterprises need to improve the overall competitiveness of the supply chain through the coordination and cooperation between each other. Therefore, coordination among the members of a supply chain is an essential strategic issue. There are many supply chain coordination contracts existing in the literature, including for example, revenue sharing contracts, buyback contracts, quantity discount contracts, price elasticity contracts, option contracts etc. The coordination capacity of those contracts is subject to the specific supply chain management background. Tsay has gave a detailed study of the contracts in supply chain coordination [5]. Buyback contract refers to, after the selling season, the supplier repurchase the unsold products to of the retailer at a reasonable price. In order to stimulate the retailer to increase the order quantity, it is a common contract in the coordination of uncertain demand system, which is a kind of risk sharing mechanism, and can play a role incentive to order. It's biggest feature is that it can be flexible to eliminate the "double marginalization" in the random demand system. Pastemack first proposed repurchase in the supply chain coordination research, Points out that if the retailer is not restricted to return the unsold products at wholesale price, or do not allow the retailer to return is not an ideal solution, the supply chain coordination could be realized only if allowed to return, and only return a fraction of the cost [6]. Taylor [7, 8] pointed out that the buyback contract can encourage retailers to increase the order quantity of products, improve the supply chain entire interests, but different repurchase price has influence on the supply chain benefits for both sides. Padmanabhan and Png [9] studied two echelon supply chain consisting of one manufacturer and two competing retailers, to show that the buyback contract can prevent competition among retailers, so as to improve the efficiency of the supply chain. Zhao et al. [10] used the buyback contract to coordinate the supply chain model that the price dependent demand and determined by the retailer, analyzed the effect of uncertainty on coordination, the results show that, demand uncertainty is a key factor affecting the applicability of supply chain contract. The price sensitive products supply chain can be divided into two types, one is the price is exogenous, that price is a constant, the other is the price is endogenous, is a decision variable, the role of a contract in two different types of supply chains is different. Saha and Goyal [11] researched a two echelon supply chain coordination under stock and price induced demand by using joint rebate contract, wholesale price discount contract and cost sharing contract, found analytically that the manufacturer's and the retailer's preferences among the three contractual forms are not always aligned. Emmons and Gilbert [12] pointed out that only when the product sales price unchanged, the repurchase contract can coordinate the supply chain, but when the sales price changes and subject to the seller's decision, the purchase contract cannot coordinate the supply chain. Chiu et al. [13] found when the price dependent demand, buyback contract cannot coordinate the supply chain, and designs the generalized buyback contract, namely the supplier given the retailer a sales target, suppliers to repurchase the remaining products outside of the target, discovered that the contract can also coordinated price multiplication and price addition two different demand function of supply chain. Chen and Bell [14] use two different repurchase price (one for the unsold products repurchase, another for customer return products repurchase) in the buyback contract to coordination the supply chain stochastic demand depends on price and consider customer return, found this type of buyback contract compared to using only one repurchase price in the buyback contract agreement is easier to implement, and can achieve the perfect coordination.

In real production, there is a way of existence except for the exogenous and endogenous two forms, that is, under the combined action of many factors, the price fluctuates around value, which is the manifestation of the law of value. Tiemei Gao et al. [15] through the empirical method to confirm: by the influence of many factors, the price of our country presents the characteristics of fluctuation. Therefore, the research on the supply chain coordination of the price fluctuation has a positive effect on improving the level of enterprise inventory management and enhancing the comprehensive competitiveness of enterprises. In order to describe the fluctuation phenomenon, also consider modeling of convenience, we use a random variable to express the price, assuming that the price is a random variable, and called for "prices fluctuate randomly". The main purpose of this paper is to study the coordination of the supply chain that demand depend on random price, analysis of the condition of supply chain coordination, the method of choosing the coordination parameters is given to realize the profit of supply chain.

2 Model Description and Assumptions

In this paper, we set up a supply chain including one retailer and one supplier, both the retailer and the manufacturer are risk neutral and the demand information on the final product is symmetric. The supplier offer a single product to the retailer. The product market demand is random, is associated with the selling price of products, and sale price random fluctuation. Consider out of stock loss and residual product salvage value, when in short supply, the retailer will face a shortage of loss; When supply exceeds demand, the rest of the product exist the salvage value.

Following notations are used in the development of the model.

p	Unit sale price at the retailer end, is a random variable in $[p_l, p_h]$ with $p > 0$ and $p_h < a/b$, determined by the market environment. PDF: $f(x)$, CDF: $F(x)$, p_0 is the mean sale price
D	The market demand, depend on sale price with function $D = a - bp$, and a is the upper limit of demand, b is a price related elasticity variable of demand
w	Unit wholesale price
c	Unit production cost
s	Unit cost of underage
h	Unit cost of overage
Q	Order quantity of the retailer
w_b	Unit repurchase price under buy back contract

The parameters in the model satisfy the following inequality conditions:

$w > c$	The condition for supplier to obtain profits
$c > w_b$	The condition for supplier to obtain profits
$p_l - w > -s$	Retailer selling products will get more profits than facing out of stock even in the lowest sale price

3 Development of the Mathematical Model

3.1 Centralized Decision Model

Under the centralized decision-making, the member enterprises in the supply chain can be seen as belonging to the same economic entity relations of cooperation. Decision maker can have all the information of the supply chain, the goal is to make the supply chain profit maximum, that is, optimal the supply chain total expects profit. The supply chain's total profit under the centralized decision can be expressed as

$$
\begin{aligned}
E\Pi_c(Q) = & \text{ Expected sales revenue} - \text{Production cost} \\
& + \text{Expected salvage} - \text{Expected shortage cost}
\end{aligned}
$$

The mathematical expression is as follows:

$$
E\Pi_c(Q) = pE[\min(Q, D)] - cQ + hE[(Q - D)^+] - sE[(D - Q)^+] \tag{1}
$$

Since:

$$E[\min(Q,D)] = (a - bp_h) + b\int_{\frac{a-Q}{b}}^{p_h} F(x)dx$$

$$E[p\min(Q,D)] = p_h(a - bp_h) - \int_{\frac{a-Q}{b}}^{p_h} F(x)(a - 2bx)dx - Q\int_{p_l}^{\frac{a-Q}{b}} F(x)dx$$

$$E[(Q-D)^+] = Q - (a - bp_h) - b\int_{\frac{a-Q}{b}}^{p_h} F(x)dx$$

$$E[(D-Q)^+] = bp_h - bp_0 - b\int_{\frac{a-Q}{b}}^{p_h} F(x)dx$$

Therefore, the supply chain's profit function given in (1) can be written as follows.

$$E\Pi_c(Q) = -Q(c-h) - Q\int_{p_l}^{\frac{a-Q}{b}} F(x)dx + (s-h)b\int_{\frac{a-Q}{b}}^{p_h} F(x)dx - \int_{\frac{a-Q}{b}}^{p_h} F(x)(a-2bx)dx - sb(p_h - p_0) + (p_h - h)(a - bp_h)$$

Under centralized decision, supply chain optimization system is

$$P_1:\ \begin{cases} \max E\Pi_c(Q) \\ s.t.\ a - bp_h < Q < a - bp_l \end{cases}$$

Theorem 1 *Under centralized decision, the optimal order quantity Q_c^* of the supply chain is determined by the following formula:*

$$(c-h) + \int_{p_l}^{\frac{a-Q_c^*}{b}} F(x)dx = \left[s - h + \frac{a - Q_c^*}{b}\right]F\left(\frac{a-Q_c^*}{b}\right) \qquad (2)$$

Proof Let $h(Q) = E\Pi_c'(Q)$, so that

$$\begin{aligned} h(Q) &= -(c-h) + \int_{p_l}^{\frac{a-Q}{b}} F(x)dx = \left[s - h + \frac{a-Q}{b}\right] F\left(\frac{a-Q}{b}\right) \\ h'(Q) &= E\Pi_c''(Q) = -\frac{1}{b}\left[s - h + \frac{a-Q}{b}\right] f\left(\frac{a-Q}{b}\right) < 0 \end{aligned} \tag{3}$$

Because of $h(a - bp_h) > s - c + p_l > 0$ and $h(a - bp_l) = -(c - h) < 0$.

Then $h(a - bp_h)h(a - bp_l) < 0$, and (3) shows that $h(Q)$ is on the reduction of function of Q, according to the existence of zero point theorem, the existence $Q_c^* \in (a - bp_h, a - bp_l)$, to meet $h(Q_c^*) = 0$, namely (3) established.

Due to Q_c^* is the only stationary point, and also Q_c^* is the maximum point of $E\Pi_c(Q)$. That is, Q_c^* is the only optimal solution of the problem P_1, it is under centralized decision, retailer's optimal order quantity is Q_c^*.

3.2 The Situation Under Wholesale Price Contract

Under wholesale price contract, the supplier per unit of product at the price w delivery to the retailer, the wholesale price is greater than the production price, namely $w > c$. The retailer decides the order quantity of the product according to the market demand and the wholesale price to maximum profit, and the supplier make to order.

The retailer's expected profits can be expressed as:

$$\begin{aligned} E\Pi_r(Q) = &-Q(w-h) - Q\int_{p_l}^{\frac{a-Q}{b}} F(x)dx + (s-h)b\int_{\frac{a-Q}{b}}^{p_h} F(x)dx \\ &- \int_{\frac{a-Q}{b}}^{p_h} F(x)(a-2bx)dx - sb(p_h - p_0) + (p_h - h)(a - bp_h) \end{aligned}$$

Similarly, expected profit of the supplier is given as:

$$E\Pi_s(Q) = (w-c)Q$$

The optimization problem for the retailer is:

$$P_2: \begin{cases} \max\ E\Pi_r(Q) \\ s.t.\ a - bp_h < Q < a - bp_l \end{cases}$$

Theorem 2 *Under wholesale price contract, the retailer's optimal order quantity is determined by the following formula:*

$$(w-h) + \int_{p_l}^{\frac{a-Q_r^*}{b}} F(x)dx = \left[s - h + \frac{a-Q_r^*}{b}\right] F\left(\frac{a-Q_r^*}{b}\right) \tag{4}$$

The proof method is similar to the proof of Theorem 1, in order to simply we omit it.

Theorem 3 *The order quantity of the retailer in the centralized decision is more than the order quantity of the retailer in the wholesale price contract, namely $Q_c^* > Q_r^*$. and the total expected profit of supply chain in centralized decision is greater than that in decentralized decision making. Namely,*

$$E\Pi_c(Q_c^*) > E\Pi_r(Q_r^*) + E\Pi_s(Q_r^*).$$

Proof Let $T(Q) = [s - h + \frac{a-Q}{b}]F(\frac{a-Q}{b}) - \int_{p_l}^{\frac{a-Q}{b}} F(x)dx + h$

Then $T'(Q) = -\frac{1}{b} f(\frac{a-Q}{b})(s - h + \frac{a-Q}{b}) < 0$

That is, $T(Q)$ is a reduction function on Q, because of $T(Q_c^*) = c$, $T(Q_r^*) = w$ and $c < w$, then $T(Q_c^*) < T(Q_r^*)$, so that $Q_c^* > Q_r^*$.

Next we will discuss the total expected profit of supply chain under centralized decision is greater than is greater than under decentralized decision.

$E\Pi_c(Q) = E\Pi_r(Q) + E\Pi_s(Q)$, and Q_c^* is the only maximum point of $E\Pi_c(Q)$, because $Q_c^* > Q_r^*$, so that Q_r^* is different from Q_c^*. Then $E\Pi_c(Q_c^*) > E\Pi_c(Q_r^*) = E\Pi_r(Q_r^*) + E\Pi_s(Q_r^*)$.

In summary, the Theorem 3 shows that, when supply chain using single wholesale price contract cannot make supply chain coordination, which is due to the double marginalization effect, that is, supply chain in both sides consider their marginal benefit maximization, while ignoring the whole supply chain of the marginal benefits. The following will discuss buyback contract of supply chain coordination.

3.3 The Situation Under Buyback Contract

Under buyback contract, the supplier per unit of product at the price w delivery to the retailer, And commitment to repurchase the unsold products at w_b which is higher than the residual value, so as to stimulate the retailer to increase the order quantity.

The retailer's and the supplier's expected profits can be expressed respectively as following:

$$E\Pi_{rb}(Q) = -Q(w - w_b) - Q\int_{p_l}^{\frac{a-Q}{b}} F(x)dx + (s - w_b)b\int_{\frac{a-Q}{b}}^{p_h} F(x)dx$$
$$-\int_{\frac{a-Q}{b}}^{p_h} F(x)(a - 2bx)dx - sb(p_h - p_0) + (p_h - w_b)(a - bp_h) \quad (5)$$

And

$$E\Pi_{sb}(Q) = (w + h - c - w_b)Q + (w_b - h)[a - bp_h + b\int_{\frac{a-Q}{b}}^{p_h} F(x)dx] \quad (6)$$

The optimization problem of the retailer is:

$$P_3 : \begin{cases} \max E\Pi_{rb}(Q) \\ s.t.\ a - bp_h < Q < a - bp_l \end{cases}$$

Theorem 4 *Under the buyback contract, the optimal order quantity Q^*_{rb} of the retailer satisfy the following equation:*

$$(w - w_b) + \int_{p_l}^{\frac{a-Q^*_{rb}}{b}} F(x)dx = \left[s - w_b + \frac{a - Q^*_{rb}}{b}\right]F\left(\frac{a - Q^*_{rb}}{b}\right) \quad (7)$$

Proof Let $l(Q) = E\Pi'_{rb}(Q)$, then

$$l(Q) = E\Pi'_{rb}(Q) = -(w - w_b) - \int_{p_l}^{\frac{a-Q}{b}} F(x)dx + \left[s - w_b + \frac{a - Q}{b}\right]F\left(\frac{a - Q}{b}\right)$$

$$l'(Q) = -\frac{1}{b}\left(s - w_b + \frac{a - Q}{b}\right)f\left(\frac{a - Q}{b}\right) < 0 \quad (8)$$

That is, $l(Q)$ is a monotone function, and because:
$l(a - bp_h) > s - w + p_l > 0$ and $l(a - bp_l) = -(w - w_b) < 0$

Then $h(a - bp_h)h(a - bp_l) < 0$, From (8) we know that $l(Q)$ is a reduction of function on Q, according to the existence of zero point theorem, there existence only one point $Q^*_{rb} \in (a - bp_h, a - bp_l)$, to meet $h(Q^*_{rb}) = 0$, namely Eq. (7) established.

Due to Q^*_{rb} is the only stationary point on $(a - bp_h, a - bp_l)$, then Q^*_{rb} is the maximum point of $E\Pi_{rb}(Q)$. That is, Q^*_{rb} is the only optimal solution of the problem P_3. Namely, in buy back contract, retailer's optimal order quantity is Q^*_{rb}.

In this situation the retailer's expected profits is $E\Pi_{rb}(Q^*_{rb})$, and the supplier's profits is $E\Pi_{sb}(Q^*_{rb})$.

Theorem 5 *If the contract parameter w_b satisfy*

$$\frac{w - c}{w_b - h} = 1 - F\left(\frac{a - Q^*_c}{b}\right) \tag{9}$$

then buyback contract can coordinate the supply chain.

Proof By substituting Substitution (9) into (7), we get

$$(c - h) + \int_{p_l}^{\frac{a - Q^*_{rb}}{b}} F(x)dx = \left[s - h + \frac{a - Q^*_{rb}}{b}\right] F\left(\frac{a - Q^*_{rb}}{b}\right) \tag{10}$$

Compared (10) and (2), we obtain $Q^*_{rb} = Q^*_c$.

Substitution (9) into (5) and (6) respectively, then the supply chain's total profit is $E\Pi_{rb}(Q^*_{rb}) + E\Pi_s(Q^*_{rb}) = E\Pi_c(Q^*_c)$, that is, supply chain coordination.

Theorem 5 shows that when the repurchase price satisfy (9) under the buyback contract, supply chain coordination. However, it is not a guarantee that the supply chain members can obtain a higher profit than under the wholesale price contract.

To this end, the next we will combine the buyback contract with wholesale price contract, so that the system increased profits can be freely distributed among members:

Let $w_b - h = \lambda$, from (9) we obtain:

$$\lambda = (w - c)\left[1 - F\left(\frac{a - Q^*_c}{b}\right)\right]^{-1} \tag{11}$$

Substitution (11) into $E\Pi_{rb}(Q^*_{rb})$ and $E\Pi_{sb}(Q^*_{rb})$, one gets

$$E\Pi_{rb}(Q^*_{rb}) = E\Pi_c(Q^*_c) - \lambda\phi, \quad E\Pi_{sb}(Q^*_{rb}) = \lambda\phi \tag{12}$$

where $\phi = (a - bp_h) + b\int_{\frac{a - Q^*_c}{b}}^{p_h} F(x)dx - F(\frac{a - Q^*_c}{b})Q^*_c$, and $\phi > 0$.

By (12), we know when the buyback contract coordinate the supply chain, $E\Pi_{sb}(Q_{rb}^*)$ is an increasing function on λ, that is to adjust the value of λ, can make the supply chain's expected profit arbitrary allocation between the members of the supply chain.

Theorem 6 *When* $w_b = \lambda + h$, $w = \lambda[1 - F(\frac{a-Q_c^*}{b})] + c$, *and* λ *in the range of* $[\lambda_{\min}, \lambda_{\max}]$, *the supply chain achieve a win-win situation, where*

$$\lambda_{\min} = E\Pi_s(Q_r^*)\phi^{-1}, \quad \lambda_{\max} = [E\Pi_c(Q_c^*) - E\Pi_r(Q_r^*)]\phi^{-1}.$$

Proof When $E\Pi_{rb}(Q_{rb}^*) \geq E\Pi_r(Q_r^*)$ and $E\Pi_{sb}(Q_{rb}^*) \geq E\Pi_s(Q_r^*)$, one gets $\lambda_{\min} \leq \lambda \leq \lambda_{\max}$.

Under the buyback contract, when $\lambda_1 = \lambda_{\min}$, The supplier's profits is equal to the profits under wholesale price contract, the increased system profits all owned by retailer. And when $\lambda_1 = \lambda_{\max}$, The retailer's profits is equal to the profits under wholesale price contract this time the increased system profits all owned by supplier. The above discussion shows that, when the price is a random variable, and effects demand. Buyback contract can coordinate the supply chain, but cannot guarantee the supply chain profits increase. However, if the repurchase price and the wholesale price have different combinations, it will be able to achieve the perfect coordination of supply chain.

4 Numerical Example

The values of the parameters in appropriate units for the model are considered as follows. Production cost $c = 3$, wholesale price $w = 8$, cost of underage $s = 2$, cost of overage $h = 2$, the upper limit of demand $a = 100$, and price related elasticity variable of demand $b = 2$, Product price p to meet the uniform distribution in $[10, 50]$. Using the method of the model, the optimal ordering strategy and the related expected profit of the supplier in the wholesale price contract can be obtained by simulation calculation:

$Q_r^* = 51.8336$, $E\Pi_r(Q_r^*) = 469.4708$, $E\Pi_s(Q_r^*) = 259.1681$. At this time, the total profit of supply chain is $E\Pi(Q_r^*) = 728.6389$. And the optimal order decision of the retailer on centralized decision is $Q_c^* = 73.1672$, the total profit is $E\Pi_c(Q_c^*) = 776.9159$. Numerical simulation results are consistent with the Theorem 3. From Figs. 1 and 2 we know that, the order's influence on the expected profit of supply chain, explains the existence of the optimal ordering quantity, and the centralized optimal decision-making order quantity is larger than the optimal decentralized decision making to order.

Under the buy-back contract, if $w_b = 7.4669$, the supply chain coordination, at this time, the retailer's expected profit is $E\Pi_{rb}(Q_c^*) = 593.9979$, the supplier's expected profit is $\Pi_{sb}(Q_c^*) = 182.9179$. From the numerical results, we can know

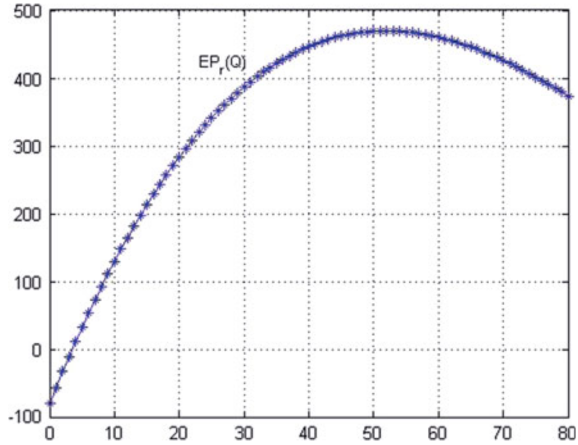

Fig. 1 The effect of the order quantity on the expected profit of supply chain under centralized decision

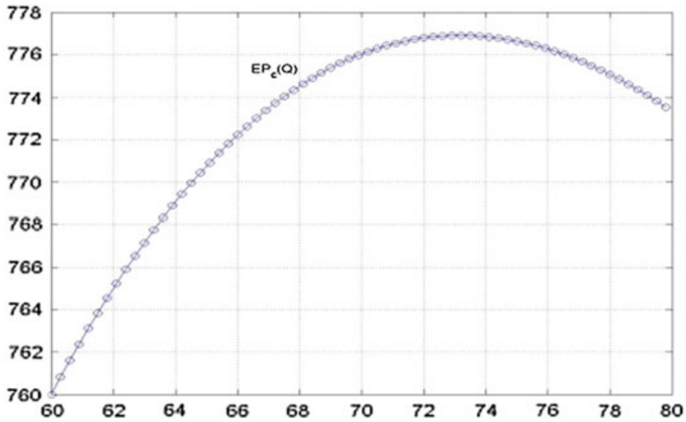

Fig. 2 The effect of the order quantity on the expected profit of retailer under decentralized decision

that $E\Pi_{rb}(Q_c^*) > \Pi_r(Q_r^*)$, and $E\Pi_{sb}(Q_c^*) < E\Pi_s(Q_r^*)$, such an example cannot achieve a win-win situation.

Under the buyback price and the wholesale price joint contract, as long as the profit distribution ratio of λ fell within the range of $[7.7458, 9.1887]$, the supply chain can achieve a win-win situation. For example, when $\lambda = 8.4673$, $w_b = 6.4673$ and $w = 10.7441$. At this time, the expected profit of the supplier and the retailer separately are $E\Pi_{rb}(Q_c^*) = 493.6093$, $E\Pi_{sb}(Q_c^*) = 283.3066$. We can know that $E\Pi_{rb}(Q_c^*) > E\Pi_r(Q_r^*)$ and $E\Pi_{sb}(Q_c^*) > E\Pi_s(Q_r^*)$, and such an example can achieve a win-win situation.

Table 1 The impact of λ on w_b, w, Π_{rb} and Π_{sb}

λ	w_b	w	Π_{rb}	Π_{sb}
7.7458	5.7458	10.0843	517.7478	259.1681
7.8901	5.8901	10.2162	512.9201	263.9958
8.0344	6.0344	10.3482	508.0924	268.8235
8.17870	6.1787	10.4802	503.2647	273.6512
8.3230	6.3230	10.6121	498.4370	278.4789
8.4673	6.4673	10.7441	493.6093	283.3066
8.6116	6.6116	10.8761	488.7816	288.1343
8.7559	6.7559	11.0080	483.9539	292.9620
8.9001	6.9001	11.1400	479.1262	297.7897
9.0444	7.0444	11.2719	474.2985	302.6174
9.1887	7.1887	11.4039	469.4708	307.4451

Table 1 lists the effects of λ's value changes on the repurchase price and the wholesale price, as well as the expected profits of the retailer and the supplier:

From Table 1, when the value of λ in the interval $[7.7458, 9.1887]$, the profit of supplier and retailer will be increase in the joint contract than in the wholesale price contract. When $\lambda = 7.7458$, the supplier will achieve all the increasing profit of supply chain; When $\lambda = 9.1887$, the retailer will achieve all the increasing profit. As the wholesale price increases, the repurchase price of the remaining products will increase, which is willing for retailer to accept.

5 Conclusion

Today quite a few scholars have studied the supply chain coordination problems with the demand influenced by the price. Most assumed that the price was endogenous and be determined by the retailer, or the price was fixed exogenous variable, while few studied the coordination of supply chain where the price was exogenous random variable and influenced demand. In this paper, we investigate the coordination of a two stage supply chain that consists of a supplier and a retailer, where the random fluctuation price is subject to market environment, and influences demand.

The results have showed that, when the price is random, the buyback contract can coordinate the supply chain, but cannot guarantee the profits of both increased. But if the buyback contract combined with the wholesale price contract, it can achieve perfect coordination of supply chain. The conclusion of this article is feasible in theory, and it can provide theory basis for the coordination problems of supply chain with the exogenous random price and demand influenced by price.

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On the Coordination of Supply Chain with Demand Uncertainty Under the Combination of the Wholesale Price Contract and Option Contract

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Abstract In this paper, we studied the coordination of the supply chain consisting of one retailer and one supplier, where the market demand is uncertain. The combination of the Wholesale Price Contract and Option Contract is used to solve the problem that market risk is borne independently by the supplier. The theoretical analysis shows that the strategy can share the risk between members of the supply chain, i.e., the supplier's risk reduced, and the supply chain system profit can be rationally distributed, the supply chain can be coordinated and a win-win situation can be achieved by choosing appropriate option price. Finally, the numerical examples were given to verify this conclusion.

Keywords Option contract · Supply chain coordination · Wholesale price · Win-win

1 Introduction[1]

Wholesale price contract, which refers to a price contract jointly signed by the retailer and the supplier, according to the product market demand and wholesale price, the retailer determines his order quantity, and then the supplier organizes production; the flexible terms with specific transaction are not contained in the contract. The wholesale price contract is the simplest and the most common type of contract. Peraki and Roels determined an efficient lower bound on various structure supply chain under the wholesale price contract [1]. Kouvelis and Zhao studied the impact of bankruptcy cost on supply chain, and got a strategy for decision makers

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to deal with financial constraint in the wholesale price [2]. Xu and Zhao studied the effect of backup supply on supply chain, and extended the supply chain to dual channel mode that the manufacturer can sell its product directly to consumers under the wholesale price contract [3]. The wholesale price contract is easy to operate in practice. It can reduce the cost of enterprise management and fully guarantee supplier's interests. However the retailer has to individually bear the uncertain demand risk, it not only affect the supply chain performance but also not conducive to establish a long term partnership. Lariviere and Porteus had done a detailed exposition for the wholesale price contract and the supply chain operation, and proved that the supply chain could not be coordinated only by using the wholesale price contract [4]. In the study of supply chain coordination, the wholesale price contract is only used as a benchmark to evaluate the performance of supply chain coordination.

Under the option contract, the retailer purchases a certain number of product usage rights in advance, and then exercises the option partly or totally after learning the demand information [5]. The paper of coordinating supply chain with option contract can be divided into two categories: one is the retailer just order option which calls option order quantity. For example, Ritchken and Tapiero introduced the option mechanism into inventory research to reduce the risk of product price and quantity fluctuation [6]. Wang and Liu studied the problem of the channel coordination and risk sharing in retailer-led supply chain through an option contract [7]. Hou and Qiu studied the option contract design for a supply chain under the price-dependent stochastic demand, and obtained the setting of the optimal option purchased price had nothing to do with the sale price, but it was determined by the bargaining power of both parties [8]. Chen, Hao and Li studied the problem of the coordination of supply chain composed of a risk neutral supplier and a loss-averse retailer, which coordinated supply chain in option contract and achieved the Pareto Optimality [9]. Another papers, which use option contract to coordinate the supply chain where the retailer not only orders options but also orders a certain quantity (the initial order quantity) of products with wholesale price contract, which combines options with wholesale price contract. For example, Lili, Zhang and Liu studied the channel coordination and risk sharing by establishing a call option contract model, and they proved a win-win situation for supply chain members can be achieved by using the option contract [10]. Liu, Chen and Zhai established a Stackelberg game model and discussed the effects of option exercise price and production ratio on the supply chain performance [11]. Sun and Xu established an agricultural product model under the perfect competition market, which improved the supply chain integrated performance by using the option contract in case that supplier had only one chance to put into production and the output is random [12]. Wang and Tsao constructed asupply chain contract model based on the bidirectional option contract from retailer's perspective, and analyzed the impact of different parameters on the retailer's decision-making behavior [13]. Wang, Chu and Wang anayzed the risk of introducing options based on the traditional newsboy model, and derived two important parameters for buyer to estimate the risks of introducing options [14].

Literature [5–9] only considered the option order method, we could know that the risk of uncertain market demand was partly transferred to supplier and the supply chain performance was improved, but literature [7, 8] didn't discuss the supply chain members how to achieve a win-win situation. Literature [10–14] adopted the ordering form with combination of wholesale price and option, it decreased the trading flexibility and reduced the supplier's production risk, such that it could make the supply chain as a whole better able to respond to the uncertainty, literature [12–14] also didn't discuss that the supply chain members how to achieve a win-win situation.

Under the uncertain environment of market demand, this paper applies the wholesale price contract and the option contract to the supply chain coordination whose objective is to reduce the supplier's risk appropriately, and to distribute the supply chain profit in system rationally, and to coordinate the supply chain and achieve a win-win situation. Firstly, considering the decentralized decision situation, we respectively determine the optimal profit of the retailer and the supplier. Secondly, considering the centralized decision situation, we optimize the supply chain total profit. Finally, we coordinate the retailer's order decision and the supplier's production decision by adopting the portfolio order strategy with wholesale price and options. After analysis and discussion, we conclude that the supply chain integrative performance can be realized, the supply chain system profit can be rationally distributed, the expected revenue of the retailer and supplier are both increased, and the increased profit can be rationally distributed, and a win-win situation is achieved by choosing appropriate option purchased price and exercised price.

2 Notations and Assumptions

We consider a one-period two-echelon supply chain composed of one supplier and one retailer who produces and sales the production with a long production lead time under an uncertain market environment. Before the start of selling season, the supplier provides his wholesale price w, option purchase price w_o and option exercise price w_e, and the retailer determines the wholesale price contract order quantity Q and the option order quantity q according to the supplier's production M and price parameters, then the supplier determines his optimal production. At the beginning of the season, because the product that were supplied by the supplier needs to first meet retailer's wholesale price contract, if the actual market demand is higher than retailer's order quantity with wholesale price contract, the retailer will exercise the option, if the market demand is not satisfied, the retailer will have a shortage.

To express clearly, following notations are used in the development of the model:

D The random demand for the market with the PDF $f(x)$, CDF $F(x)$

p Unit sale price of the product;

c Unit manufacturing cost of the product;
s Unit purchase price of the spot market product;
g_r Unit shortage cost of the product for retailer;
g_s Unit shortage cost of the product for supplier;
v Unit salvage value of the product;

To meet the practice, the mathematical model is developed on the following basic assumptions:

1. Without loss of generality, we require that $p > s > w > c > v$;
2. To make option contract is attractive to retailer, we should ensure that $p + g_r > w_o + w_e$;
3. Avoiding that the supplier takes the product residual treatment and doesn't meet the retailer's options, we should ensure that $w_e > v$;
4. To make wholesale price contract is also attractive to retailer, we should ensure that $w_o + w_e > w$;
5. To make supplier's shortage loss is more than his production cost, we assume $g_s - c > 0$;
6. To simplify the model analysis work, we assume that $(p + g_r - w_e)(c - v) - (p + g_r - v)w_o \leq 0$.

3 Model and Decisions Analysis

3.1 The Wholesale Price Contract

Under the wholesale price contract, the retailer determines his order quantity to maximize his profit according to the market demand and the wholesale price, and the supplier uses the make to order production mode to supply products.

With the wholesale price contract, the retailer's expected profit is

$$E\prod\nolimits_r^d = pE\min(Q, D) + v(Q - D)^+ - g_r(D - Q)^+ - wQ \tag{1}$$

Theorem 1 *Under the wholesale price contract, the retailer's optimal order quantity Q_d^* satisfies*

$$Q_d^* = F^{-1}\left(\frac{p + g_r - w}{p + g_r - v}\right). \tag{2}$$

Proof Taking the first and second order derivatives of $E\prod_r^d$ with respect to Q, we have

$$\frac{\partial E\prod_r^d(Q)}{\partial Q} = (p+g_r-w)-(p+g_r-v)F(Q),$$
$$\frac{\partial^2 E\prod_r^d(Q)}{\partial Q^2} = -(p+g_r-v)f(Q).$$

From assumption (1), we obtain that there exists a unique solution

$$Q_d = F^{-1}\left(\frac{p+g_r-w}{p+g_r-v}\right)$$

and $Q_d > 0$ to equation $\frac{\partial E\prod_r^d(Q)}{\partial Q} = 0$.Since $f(x) > 0$,we have $\frac{\partial^2 E\prod_r^d(Q)}{\partial Q^2} < 0$, that $E\prod_r(Q)$ is a concave function of Q, therefore, the retailer's optimal order quantity satisfies Eq. (2).

The supplier's expected profit is

$$E\prod_r^d(Q_d^*) = (w-c)Q_d^* - g_s(D-Q_d^*)^+ \quad (3)$$

3.2 Centralized Decision Model

Under the centralized decision situation, we can know the retailer and the supplier belong an economic entity, which objective is to determine the optimal production to maximize the whole profit of the supply chain. When $M < Q+q$, it can result in sales opportunities loss; when $M > Q+q$, this can result in overstock of the production loss, therefore, for making the supply chain profits optimal, it leads to $M = Q+q$.

The supply chain system expected profit is given by

$$\begin{aligned} E\prod_c &= pE\min(D,Q+q) + vE(Q-D)^+ \\ &+ vE[q-\min((D-Q)^{+,q)]^+ - g_rE(D-Q-q)^+} \\ &- g_sE(\min[(D-Q)^{+,q]-Q)^+ - c(Q+q)} \end{aligned}$$

By the equation $M = Q + q$, the expected profit of supply chain system can be written as

$$E\prod\nolimits_c (M) = (p + g_r - c)M - (p + g_r - v)\int\limits_0^M F(x)dx - g_r\mu \tag{4}$$

Theorem 2 *Under the centralized decision situation, the supply chain system optimal production* M_c^* *satisfies*

$$M_c^* = F^{-1}\left(\frac{p + g_r - c}{p + g_r - v}\right) \tag{5}$$

Proof Taking the first order derivative of $E\prod_c$ with respect to M, we have

$$\frac{\partial E\prod_c (M)}{\partial M} = (p + g_r - c) - (p + g_r - v)F(M)$$

By assumption (1), there exists a unique solution

$$M_c = F^{-1}\left(\frac{p + g_r - c}{p + g_r - v}\right)$$

to equation $\frac{\partial E\prod_c(M)}{\partial M} = 0$ and $M_c > 0$. Since $f(x) > 0$ we obtain $\frac{\partial^2 E\prod_c(M)}{\partial M^2} < 0$, i.e., $E\prod_c(M)$ is a concave function of M, therefore, the supply chain system optimal production M_c^* satisfies Eq. (5).

3.3 The Retailer's Decision with Wholesale Price and Option

Assumed that M is the supplier known production and $M > 0$. When $M < Q$, the supplier purchases products from spot market to meet retailer's wholesale price contract order quantity; when $M \geq Q$, the product firstly meet wholesale price contract and then the rest for option contract. Hence, the retailer's profit is given by

$$\begin{aligned} E\prod\nolimits_r &= pE\min(D, Q + \min((M - Q)^+, q)) \\ &+ vE(Q - D)^+ - w_e E\min[(D - Q)^+, \min((M - Q)^+, q)] \\ &- g_r E((D - Q)^+ - \min((M - Q)^+, q))^+ - wQ - w_o q, \end{aligned} \tag{6}$$

In order to achieve supply chain coordination, we assume that the supplier's production is $M = M_c^*$, the retailer wishes to determine the wholesale price contract order quantity Q^* and the option purchased quantity q^* to maximize his expected profit.

Theorem 3 *Under the wholesale price and option contracts, if* $0 < M_c^* < Q$, *the retailer's optimal order quantity* Q_1^* and q_1^* *satisfy the following conditions*

$$Q_1^* = M_c^*, \quad q_1^* = 0. \tag{7}$$

Proof When $0 \le M_c^* \le Q$, taking the first order derivative of $E\prod_r$ with respect to Q, we get

$$\frac{\partial E\prod_r}{\partial Q} = (p + g_r - w) - (p + g_r - v)F(Q)$$

From assumption (1), there exists a unique solution

$$Q_1 = F^{-1}\left(\frac{p + g_r - w}{p + g_r - v}\right)$$

and $Q_1 > 0$ to equation $\frac{\partial E\prod_r}{\partial Q} = 0$. From assumption (1) and $F^{-1}(x)$ is monotonically increasing, we have $M_c^* > Q_1$. Again since $\frac{\partial E\prod_r}{\partial q} < 0$, $\frac{\partial^2 E\prod_r}{\partial Q^2} < 0$ and $q \ge 0$, thus the retailer's optimal order quantity satisfy Eq. (7).

Theorem 4 *Under the wholesale price and option contracts, if* $Q < M_c^* < Q + q$, *the retailer's optimal order quantity* Q_1^* *and* q_1^* *satisfy the following condition*

$$Q_2^* = 0, \quad q_2^* = M_c^*. \tag{8}$$

Proof From assumption (3), (4) and $F(x) > 0$, we have $\frac{\partial E\prod_r}{\partial Q} < 0$, $\frac{\partial E\prod_r}{\partial q} < 0$ and $Q \ge 0$, $Q < M_c^* < Q + q$, therefore, the retailer's optimal order quantity satisfy Eq. (8).

Theorem 5 *Under the wholesale price and option contracts, if* $M_c^* \ge Q + q$, *the retailer's optimal order quantity* Q_3^* and q_3^* *satisfy the following conditions*

$$Q_3^* = F^{-1}\left(\frac{w_o + w_e - w}{w_e - v}\right), \quad Q_3^* + q_3^* = F^{-1}\left(\frac{p + g_r - w_o - w_e}{p + g_r - w_e}\right) \tag{9}$$

Proof Taking the first order derivative of $E\prod_r$ with respect to Q and q, we have

$$\frac{\partial E\prod_r}{\partial Q} = (p+g_r-w)-(p+g_r-w_e)F(Q+q) - (w_e-v)F(Q)$$
$$\frac{\partial E\prod_r}{\partial q} = (p+g_r-w_o-w_e)-(p+g_r-w_e)F(Q+q)$$

From assumption (2)–(4), then it follows that there exists a unique group of solution to equation set

$$\frac{\partial E\prod_r}{\partial Q} = 0, \quad \frac{\partial E\prod_r}{\partial q} = 0,$$

we have

$$Q_3 = F^{-1}\left(\frac{w_o+w_e-w}{w_e-v}\right), \quad Q_3+q_3 = F^{-1}\left(\frac{p+g_r-w_o-w_e}{p+g_r-w_e}\right)$$

From assumption (3) and (4) we obtain $Q_3 > 0$, by assumption (2) and (4) we know that $q_3 > 0$. Again from assumption (6), it leads to $M_c^* \geq Q_3 + q_3$. Further taking the second order derivative of $E\prod_r$ with respect to Q and q, we get

$$A = \frac{\partial^2 E\prod_r}{\partial Q} = -(p+g_r-w_e)f(Q+q)-(w_e-v)f(Q),$$
$$B = \frac{\partial^2 E\prod_r}{\partial q^2} = -(p+g_r-w_e)f(Q+q) = \frac{\partial^2 E\prod_r}{\partial Q\partial q} = C.$$

Since $f(x) > 0$, then it follows that

$$A<0, \quad \begin{vmatrix} A & C \\ C & B \end{vmatrix} = (w_e-v)(p+g_r-w_e)f(Q)f(Q+q) > 0,$$

i.e., $E\prod_r$ is a concave function of Q and q, thus the retailer's optimal order quantity satisfy Eq. (9).

As stated above, when $M = M_c^*$, we have the retailer's optimal order quantity subject to

$$E\prod_r(M_c^*, Q^*, q^*) = \max\{E\prod_r(M_c^*, Q_i^*, q_i^*), \quad i = 1,2,3\} \tag{10}$$

and $Q_1^* + q_1^* = M_c^*$, $Q_2^* + q_2^* = M_c^*$, $Q_3^* + q_3^* < M_c^*$.

3.4 The Supplier's Decision with Wholesale Price and Option

After the retailer has made a purchase decision, the supplier wishes to determine the production M to maximize his expected profit, the supplier's expected profit is

$$\begin{aligned} E\prod\nolimits_s(M) = {} & wQ^* + w_o q^* + vE(M - Q^* - \min((D-Q^*)^+, q^*)))^+ \\ & + w_e E\min[(D-Q)^+, \min((M-Q)^+, q)] - cM \\ & - g_s E(\min[(D-Q)^+, q] - (M-Q)^+)^+ - sE(Q^* - M)^+ \end{aligned} \tag{11}$$

Theorem 6 *Under the wholesale price and option contracts, the supplier's optimal production M^* satisfies*

$$M^* = \begin{cases} Q^*, & 0 \le M_2 \le Q^*, \\ M_2, & Q^* < M_2 < Q^* + q^*, \\ Q^* + q^*, & M_2 \ge Q^* + q^* \end{cases} \tag{12}$$

where $M_2 = F^{-1}\left(\frac{w_e + g_s - c}{w_e + g_s - v}\right)$.

Proof When $M < Q^*$ and $M \ge Q^* + q^*$, from assumption (1), we have

$$\frac{\partial E\prod_s}{\partial M} = s - c > 0, \quad \frac{\partial E\prod_s}{\partial M} = -(c - v) < 0,$$

i.e., $E\prod_s$ is strictly monotone increasing such that $M < Q^*$ and strictly monotone decreasing subject to $M \ge Q^* + q^*$. Therefore, the maximum values can only be obtained in $Q^* < M < Q^* + q^*$.

When $Q^* < M < Q^* + q^*$, we take the first order derivative of $E\prod_s(M)$ with respect to M, we have

$$\frac{\partial E\prod_s(M)}{\partial M} = (w_e + g_s - c) - (w_e + g_s - v)F(M),$$

by assumption (1) and (5), there exists a unique solution

$$M_2 = F^{-1}\left(\frac{w_e + g_s - c}{w_e + g_s - v}\right) \tag{13}$$

to equation $\frac{\partial E\prod_s(M, Q^*, q^*)}{\partial M} = 0$ and $M_2 > 0$. Again since $f(x) > 0$, we obtain $\frac{\partial^2 E\prod_s}{\partial M^2} < 0$, i.e., $E\prod_s$ is a concave function of M, thus the supplier's optimal production satisfies Eq. (13).

3.5 Supply Chain Coordination

To achieve the supply chain coordination, we need set the appropriate contract parameters to stimulate retailer's optimal order quantity and supplier's optimal production are consistent with the optimal production in centralized situation. At the same time, the supply chain members can achieve a win-win situation through selecting appropriate contract parameters.

Theorem 7 *If the option contract parameters* (w_o, w_e) *satisfy the following conditions*

$$w_e \geq p + g_r - g_s \tag{14}$$

and

$$w_e = \frac{(p + g_r)(w_o + v - c) - w_o v}{v - c}, \tag{15}$$

the supply chain coordination can be achieved.

Proof From Eqs. (5), (13) and (14), we have

$$\frac{w_e + g_s - c}{w_e + g_s - v} \geq \frac{p + g_r - c}{p + g_r - v},$$

i.e.,$F(M_2) \geq F(M_c^*)$, it leads to

$$M_2 \geq M_c^* \tag{16}$$

The conditions of the supply chain coordination are $M^* = M_c^*$ and $Q^* + q^* = M_c^*$. This problem will be discussed in following situations.

1. When $(Q^*, q^*) = (Q_1^*, q_1^*)$, by (7), we can know that $Q_1^* + q_1^* = M_c^*$. From (12), we have $M^* = Q^* = M_c^*$;
2. When $(Q^*, q^*) = (Q_2^*, q_2^*)$, by (8), it leads to $Q_2^* + q_2^* = M_c^*$, then combining with (12) and (16), we have $M^* = M_c^*$;
3. When $(Q^*, q^*) = (Q_3^*, q_3^*)$, by (15), we can obtain

$$\frac{p + g_r - c}{p + g_r - v} = \frac{p + g_r - w_o - w_e}{p + g_r - w_e},$$

i.e., $F(Q_3^* + q_3^*) = F(M_c^*)$, one gets $Q_3^* + q_3^* = M_c^*$, then combining with (12) and (16), we have $M^* = Q_3^* + q_3^* = M_c^*$.

As stated above, if the option contract parameters $(w_o\ w_e)$ satisfy (14) and (15), the supply chain coordination can be achieved.

Theorem 8 *If the option contract parameters* (w_o, w_e) *satisfy the following conditions*

$$\begin{cases} w_o = \lambda(c - v), \\ w_e = (1 - \lambda)(p + g_r) + \lambda v, \end{cases} \tag{17}$$

where $\lambda > 0$ is an parameter, then we have the following properties:

(a) When $\lambda \le g_s/(p + g_r - v)$, the supply chain coordination can be achieved, and the expected profit of supply chain system can be divided between the retailer and the supplier arbitrarily.
(b) When $\lambda_{\min} \le \lambda \le \min(g_s/(p + g_r - v), \lambda_{\max})$, it can achieve a win-win situation, where

$$\lambda_{\min} = \frac{E\prod_R^D (Q_d^*) + (w - c)Q^* - \Delta}{E\prod_c (M_c^*) - \Delta},$$

$$\lambda_{\max} = 1 - \frac{E\prod_s^d (Q_d^*) - (w - c)Q^*}{E\prod_c (M_c^*) - \Delta},$$

$$\Delta = [(p + g_r - c)Q^* - (p + g_r - v)\int_0^{Q^*} F(x)dx - g_r\mu].$$

Proof

(a) For $\lambda \le g_s/(p + g_r - v)$, we have $\lambda(p + g_r - v) \le g_s$ it leads to $(1 - \lambda)(p + g_r) + \lambda v \ge p + g_r - g_s$, then combining with (17), we have $w_e \ge p + g_r - g_s$ and (15) is always holds. Based on Theorem 7, the supply chain coordination can be achieved.

Substituting $Q^* + q^* = M_c^*$ and (17) into (6), we have

$$E\prod_r (\lambda) = \lambda E\prod_c (M_c^*) + (1 - \lambda)\Delta - (w - c)Q^* \tag{18}$$

Substituting $M^* = M_c^*, Q^* + q^* = M_c^*$ and (17) into (11), we obtain

$$E\prod_s (\lambda) = (1 - \lambda)E\prod_c (M_c^*) - (1 - \lambda)\Delta + (w - c)Q^* \tag{19}$$

where $\Delta = [(p + g_r - c)Q^* - (p + g_r - v)\int_0^{Q^*} F(x)dx - g_r\mu]$, and then the expected profit of supply chain system can be divided between the retailer and the supplier arbitrarily.

(b) From $\lambda_{\min} \leq \lambda \leq \min(g_s/(p+g_r-v), \lambda_{\max})$ and the result a), one easily derives that the supply chain can achieve coordination, by $\lambda \geq \lambda_{\min}$, we have

$$\lambda E \prod\nolimits_c (M_c^*) + (1-\lambda)\Delta - (w-c)Q^* \geq E \prod\nolimits_r^d (Q_d^*)$$

according to (18), we obtain

$$E \prod\nolimits_r (\lambda) \geq E \prod\nolimits_r^d (Q_d^*) \tag{20}$$

by $\lambda \leq \lambda_{\max}$, we have

$$(1-\lambda)E \prod\nolimits_c (M_c^*) - (1-\lambda)\Delta + (w-c)Q^* \geq E \prod\nolimits_s^d (Q_d^*),$$

according to (19), we obtain

$$E \prod\nolimits_r (\lambda) \geq E \prod\nolimits_r^d (Q_d^*) \tag{21}$$

From (20) and (21), we can know that the retailer and the supplier are willing to accept the option contract, they achieve a win-win situation.

Based on Theorem 8, when $\lambda = \lambda_{\min}$, from (18) and (19) We have $E \prod_r(\lambda) = E \prod_r^d(Q_d^*)$, and $E \prod_s(\lambda) = E \prod_c(M_c^*) - E \prod_r^d(Q_d^*)$, and then the supplier obtains all increased expected profit of the supply chain system; when $\lambda = \lambda_{\max}$, from (18) and (19), we have $E \prod_s(\lambda) = E \prod_s^d(Q_d^*)$ and $E \prod_r(\lambda) = E \prod_c(M_c^*) - E \prod_s^d(Q_d^*)$, then the retailer obtains all increased expected profit of the supply chain system.

4 Numerical Example

To illustrate the problem intuitively, a numerical example is given to test the coordination effect of the supply chain. The model parameters are listed as follows: $p = 10$, $w = 7$, $s = 6$, $c = 4$, $v = 3$, $g_r = 3$, $g_s = 6$, Assume that the distribution of demand D follows uniform distribution in the interval $[0, 200]$. Under the wholesale price contract, from (2), (1) and (3), we have the retailer's optimal order quantity is $Q_d^* = 120$, the retailer's optimal expected profit is $E \prod_r^d(Q_d^*) = 60$, and the supplier's optimal expected profit is $E \prod_s^d(Q_d^*) = 264$; Under the centralized decision, from (5) and (4), we have the supply chain optimal production is $M_c^* = 180$, and the supply chain optimal expected profit is $E \prod_c(M_c^*) = 510$; Let $w_o = 0.6\, w_e = 7$, from (10), (12) and (11), under wholesale price and option contracts, we can know that the retailer's optimal ordering quantity with the wholesale price contract is $Q^* = 30$, the retailer's optimal option purchased quantity is $q^* = 150$, the retailer's optimal expected profit is $E\prod_r(M_c^*, Q^*, q^*) = 195$, the supplier's optimal production is $M^* = 180$, the supplier's optimal expected profit is $E\prod_s(M_c^*, Q^*, q^*) = 315$; Based on Theorem 8, we obtain that the profit distribution parameters of achieving a win-win situation between retailer and supplier are $\lambda_{\min} = 0.3600$, $\lambda_{\max} = 0.6907$. It's obvious $E\prod_r(M_c^*, Q^*, q^*) + E\prod_s(M_c^*, Q^*, q^*) = E\prod_c(M_c^*)$, $E\prod_r(M_c^*, Q^*, q^*) > E\prod_r^d(Q_d^*)$, $E\prod_s(M_c^*, Q^*, q^*) > E\prod_s^d(Q_d^*)$, it follows that the supply chain achieves perfect coordination.

Figure 1 describes the impact on the retailer's order decision, the supplier's production, and the supply chain order decision with different values of w_e under the wholesale price and option contracts. It shows that the retailer's total order quantity and the supplier's production decrease when the option exercise price decreases, but the supplier's production decision is not affected in centralized decision. Figure 2 describes the impact on the interval $[\lambda_{\min}, \lambda_{\max}]$ of the supply chain members achieve a win-win situation.

Table 1 shows the change of the supply chain profit when w_e changes 7.1–7.4. It states that the retailer's expected profit increases and the supplier's expected profit decreases when the option exercise price decreases under the wholesale price and the option contracts, but the whole expected profit of the supply chain is not affected in centralized decision, The expected profit of the retailer and the supplier all realize increase through using the wholesale price and option contracts.

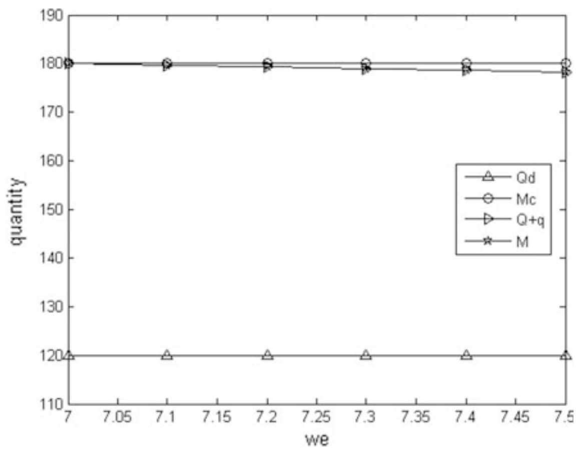

Fig. 1 The impact of w_e on order and production decision

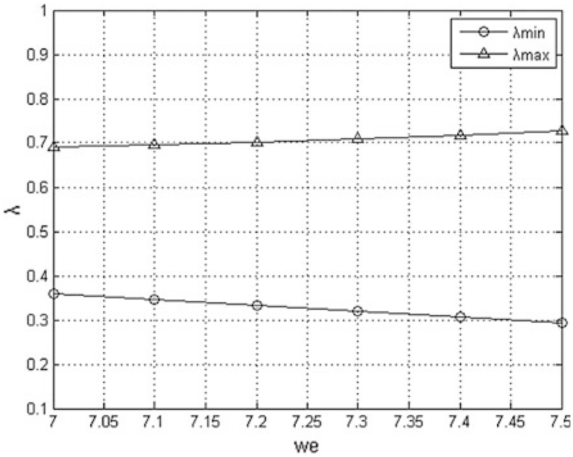

Fig. 2 The impact of w_e on interval $[\lambda_{\min}, \lambda_{\max}]$

Table 1 The impact of w_e on the profit of supply chain

w_e	Wholesale price contract			Wholesale price and option contracts			Centralized decision
	$E\prod_r^d$	$E\prod_s^d$	$E\prod_r^d + E\prod_s^d$	$E\prod_r$	$E\prod_s$	$E\prod_r + E\prod_s$	$E\prod_c$
7.1	60	264	324	188.0529	321.9442	509.9971	510
7.2				181.4450	328.5431	509.9881	
7.3				175.1530	334.8193	509.9723	
7.4				169.1558	340.7931	509.9490	

5 Conclusion

In this paper, a one to one supply chain coordination model is constructed based on the wholesale price and option contracts in an uncertain market environment. Conclusions are drawn by analysis as follows. First, it is concluded that the supply chain can realize the integrative performance by adopting the wholesale price and option coordination mechanism, which can stimulate retailer's optimal order quantity and supplier's optimal production are consistent with the optimal production in centralized situation. Second, the study shows that the supply chain member's profits aren't less than the profit of decentralized decision and the increased profit can be rationally distributed after coordination between both sides by choosing appropriate option purchased price and exercised price.

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Study on Warranty Repair Facilities' Multi-echelon Location-Allocation Based on LORA and Queuing Theory

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Abstract The efficiency on delivery of warranty service plays a critical role in the customers' buying decisions making. Adopting a good way to locate the repair facilities not only provide customers with sufficient post-sale services, but also decrease cost for manufactures. Focusing on this problem, we put forward a multi-objective models, combining multi-echelon location-allocation problem with queuing theory, for allocating warranty service facilities meanwhile, improving customer satisfaction through shortening queuing waiting time. And because our model belongs to NP-hard problem, we adopts Genetic Algorithm to solve a random numerical example, achieving the Pareto optimal solution on how to locate the facilities and how to arrange relevant devices and resources on each echelon facilities. Because of our model's feasibility and generality, its analysis and solutions have practical implications as the basis on warranty repair facilities locating problems.

Keywords Warranty repair facility · Multi-echelon location-allocation · LORA · Queuing theory · Genetic algorithm

1 Introduction

In today's competitive market, almost all the durable products are sold with a warranty. A Warranty is a guarantee or promise which the product manufacture provides assurance to the buyer that specific functions or conditions of the product that they sold are true or will happen during the 'the warranty period'. It specifics that manufactures need to take measures, such as repair, replace or provide monetary credit to buyers in the case of product failure during the warranty period. According to Murthy et al. [1], though the profit margin for warranty service is

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roughly 30 % compared to 10 % on the initial sale on the whole, different manufactures achieve obvious differentiated profits since their warranty service support are not equally effective. Delivery of warranty service in a cost efficient manner might be the critical reason that give rise to this situation and then, in recent years, the trend of its logistics research on the warranty service, especially its related location allocation problem has seen enormous growth.

The literature pertaining to location allocation problem is wide in its scope and long in history. Hakimi [2] developed one of the earliest P-median models by finding the optimum location of a switching center in a communication network. He also mentioned that his work can be easily concerned with building a hospital or a police station, and with these sorts of situation, the best place to build the station would be a 'median' of the corresponding graph with weights. Hodgson [3, 4] proposed the Flow Capturing Location Model in 1990, and perfected his previous FCLM combined with P-median for dealing with two types of demand respectively, he examined his model in a small test network using synthetic demand data, to prove his model's availability. Current et al. [5] introduced the Maximum Covering/Shortest Path problem with multiple criteria programming, extending the concept of 'coverage' from facility location analysis to network design. Bapna et al. [6] extended Current's model to Maximum Covering/shortest Spanning Subgraph Problem, applying an integer-programming to balance the perspectives of coverage and cost in his facility location problem, and then develop a heuristic solution for this problem. All of these classical works focus on just one echelon facility location allocation, but nowadays, some of the products are more likely a complex system, which is composed of many components, like subsystems, modulars and parts, therefore existing the following cases, for instance, that some of the components are rarely failed but repaired in need of high-end and expensive devices, under this kind of situation, manufactures tend to apply multi-echelon facilities for cost savings on the premise of not greatly influence service level. For today's multi-echelon repairable item system, the previous works seem not to be perfectly suitable.

Therefore, there are many researchers working on these problems, and the most famous series studies are related to LORA, level of repair analysis. According to Brick and Uchoa's concept [7], LORA is an analysis methodology used to determine the optimal location of facilities and devices for the maintenance of technical systems components and the more appropriated repair policies. Crabtree and Sandel [8] are the first researches suggested LORA for logistics of US army. Baros and Riley [9] proposed an integer programming formulation for the level of repair problems of multi-echelon multi-indenture level systems and implemented the branch-and-bound method to solve it. However, his solution must subjected many simplified assumptions, which enhanced difficulties to adopt the real cases. Bousseta [10] also proposed an integer programming model for this problem, and compared with Barros's work, his formulation presented lower generality. Based on these problems, Brick and Uchoa [7] developed a very generic mixed-integer programming model for the discrete location of facilities and installation of capacitated resources and show its applicability to LORA problems. The drawback was that in his study he assumed that failed products were always sent to the right echelon facility to repair, but in the real cases, most of failed ones first arrived the nearest facility to seek service whether the facility was the suitable echelon or not. So, taking failed products' transshipments between echelons into consideration is more consistent with the actual situation.

In addition, some studies combined the multi-echelon location allocation problems on warranty repair with inventory systems [11], but few of them focused on one of original intentions of these problems, namely cost savings on the premise of enhancing customer satisfaction. So we put forward a multi-objective models, combining multi-echelon location-allocation problem with queuing theory, for allocating warranty service facilities meanwhile, improving customer satisfaction through shortening queuing waiting time. And because this model belongs to NP-hard problem, we adopts genetic algorithm to solve a random numerical examples, achieving the Pareto optimal solution on how to locate the facilities and how to arrange relevant devices and resources on each echelon facilities.

This paper is organized as follows. In the Model Formulation section, we put forward a multi-objective models under warranty repair, combining two-echelon location-allocation problem with queuing theory. The two-echelon location-allocation problem is based on LORA, and takes failed products' transshipments between echelons into consideration, and applying the finite-source queuing theory for enhancing customer satisfaction through decreasing queuing waiting time. In the Algorithm section, we simply present how to use genetic algorithm to solve this NP-hard problem. In the Numerical Example section, we examine a random numerical examples, and adopt simulated annealing genetic algorithm to achieve the Pareto optimal solution. We end the paper with a Conclusion section.

2 Model Formulation

2.1 Two-Echelon Model with LORA

We consider failed products under these situations, repairs can be performed on the nearest repair center, or if these repairs cannot be done on the repair center, they will be transshipped to the higher echelon repair center who are possessed with corresponding equipment. Take military naval vessel as an instance, its maintenance can be performed at its marine base, or at its OEM once big problems exist. Other examples like electronic products, autos, complex systems are sort of similar to this example. A repair network should connect echelons of repair centers, mostly it will have two echelons, here we call them Distributed echelon and Central echelon, where the former are the nearest repair centers. This partition method conforms to Alfredsson's [12] two-echelon model, meanwhile, a repair network with too many echelons will give rise to the increasing management cost. Therefore, this section presents an integer programming model for the two-echelon location-allocation problem. And the following model can be easily expanded to multi-echelon models, here we won't dwell on them.

There is also the question of which types of repair tasks should be performed on the Distributed echelon or Central echelon respectively. Many products can be into tree structures, under level of repair analysis, both Saranga [13] and Basten [14] divided products into subsystems, modulars, and parts, and Brick and Uchoa [7] discussed a more generic partition method, he called it the relation contain-contained(father-son), namely depending on the repair resources available at the places where the repair system are deployed, he divided the products into Line Replaceable Units (LRU) and Shop Replaceable Units (SRU). In addition, there exists Liu et al.'s [15] research on customized warranty, with dividing configurable laptop into CPU, memory, power supply etc. Therefore, the two-echelon repair network with LORA discussed in this paper, should clear out structures of products in the first place, and then can specify which failed parts of them should be repaired on which echelons of repair network. Figure 1 depicts part of the generic tree structure of a complex product.

In Fig. 1, any of the subsystems, modulars, or parts may contain other components of their own class, namely a subsystem may contain other subsystem, modular may contain other modular, and part may contain other part as well. And we assume that modular cannot contain any subsystem and part cannot contain any modular or subsystem for the sake of explicating the structure clearly. Any subsystems, modulars or parts on terminal notes in this figure means they are repairable unit but cannot be further divided. Because if they can be further divided into other subcomponents, then repairing its subcomponents is always cost-saving in real cases, which is not conforms to our analysis based on LORA. For the reasons given above, we assume that any repair of product failures can be traced down to their termination notes of tree structures. We use I to denote terminal repair task set. Note that any subsystems, modular, or parts can be the terminal tasks.

We've already mentioned that define $i \in I$ as all the terminal repair task set. Define $j \in J$ as demand point where generates different types of terminal repair task i. Warranty always follow the life cycle of a product. According to Khawam et al.'s point, there are three phases during the life cycle of a product. And the

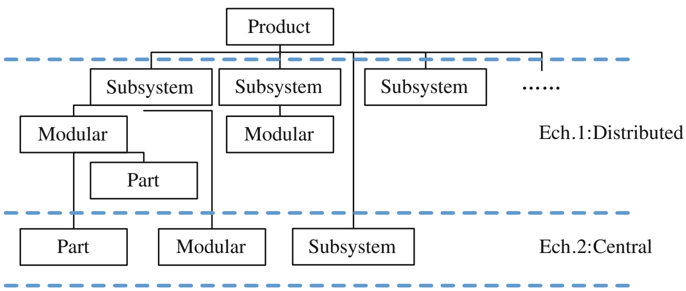

Fig. 1 The Tree Structure of Certain Product

second phase where a product experiences a steady state when the number of them under warranty and returned for service remains roughly constant, takes up a big part of the life cycle. In this paper, we focus on the steady-state phase of the warranty life cycle and all the cost we discuss followed are discounted to this period. So we define w_{ij} as the number of tasks $i \in I$, demanded at $j \in J$. Then w_{ij} in the warranty period L, with steady failure hazard γ_i is, $w_{ij} = d_j \int_0^L \gamma_i dt$, where d_j is the number of products at demand point $j \in J$.

Define $m_D \in M_D$ as the alternative places for Distributed echelon depicted as Ech. 1 in Fig. 1 and $m_C \in M_C$ as the alternative places for Central echelon depicted as Ech. 2 in Fig. 1. Define $o \in O$ as the service options when failed products come to the repair center and we will discuss it in the next part. The C_{ijm_Do} is the cost for task $i \in I$, generated at demand point $j \in J$, performing the service option $o \in O$ in the Distributed echelon site $m_D \in M_D$, and $C_{ijm_Dm_Co}$ is the cost for task $i \in I$, generated at $j \in J$, that is cannot be repaired at site $m_D \in M_D$, then transshipped to the Central echelon site $m_C \in M_C$, performing the service option $o \in O$. These two parameters will be discussed in the next part as well. Define f_i as the resources and devices to finish corresponding terminal task $i \in I$. Define F_{m_D} and F_{m_C} as the fixed costs to set up the Distributed and Central repair center respectively which is discounted to the warranty life cycle we mentioned before. Five sets of Boolean decision variables are defined below: y_{ijm_D} equals 1 if task $i \in I$, generated at $j \in J$, seeks the service at the site $m_D \in M_D$ and y_{ijm_C} equals 1 if task $i \in I$, generated at $j \in J$, seeks the service at the site $m_C \in M_C$ both according to the shortest path principle. x_{m_D} equals 1 if there is a Distributed repair center constructed at the site m_D, and x_{m_C} equals 1 if there is a Central repair center constructed at the site m_C. z_{im_D} equals 1 if the task $i \in I$ can be repaired at the site m_D.

Based on the above analysis, we combine P-median model that firstly proposed by Hakimi [2] with LORA, formulating an integer programming for two-echelon location-allocation model as follow.

$$\mathrm{P_1}: \min \sum_{i \in I} \sum_{j \in J} \sum_{m_D \in M_D} \sum_{m_C \in M_C} \sum_{o \in O} w_{ij} \left[C_{ijm_Do} y_{ijm_D} + (1 - z_{im_D}) C_{ijm_Dm_Co} y_{ijm_C} \right] x_{m_D} x_{m_C} + \sum_{m_D \in M_D} x_{m_D} F_{m_D} + \sum_{m_C \in M_C} x_{m_C} F_{m_C}$$

$$s.t. \quad \sum_{m_D \in M_D} y_{ijm_D} = 1, \quad \forall i \in I, \quad \forall j \in J \tag{1}$$

$$\sum_{m_C \in M_C} y_{ijm_C} = 1, \quad \forall i \in I, \quad \forall j \in J \tag{2}$$

$$x_{m_D} - y_{ijm_D} \geq 0, \quad \forall m_D \in M_D, \quad \forall i \in I, \quad \forall j \in J \tag{3}$$

$$x_{m_C} - y_{ijm_C} \geq 0, \quad \forall m_C \in M_C, \quad \forall i \in I, \quad \forall j \in J \tag{4}$$

$$x_{m_D} - z_{im_D} \geq 0, \quad \forall m_D \in M, \quad \forall i \in I \tag{5}$$

$$\sum_{m_D \in M_D} x_{m_D} = n_D \tag{6}$$

$$\sum_{m_C \in M_C} x_{m_C} = n_C \tag{7}$$

$$F_{m_D} = \sum_{i \in I} f_i z_{im_D}, \quad \forall m_D \in M_D \tag{8}$$

$$F_{m_C} = \sum_{i \in I} f_i \tag{9}$$

$$z_{im_D} = \{0,1\}, \quad y_{ijm_D} = \{0,1\}, \quad y_{ijm_C} = \{0,1\}, \quad x_{m_D} = \{0,1\}, \quad x_{m_C} = \{0,1\} \tag{10}$$

Constraint set (1) and (2) ensures that any task $i \in I$, generated at the demand point $j \in J$ can only seek service at just one repair center from every echelon. Constraint set (3) and (4) ensures that if there is no facility on the alternative site, then any task cannot seek service from here. Constraint set (5) ensures that only and if only there is a facility at site m_D, then task i can perform service here, note that the difference between seek service and perform service. Constraint (6) and (7) denotes that there will be n_D Distributed and n_C Central repair centers to set up. For simplified the model, we assumed that any fixed costs to set up repair center are composed of the devices to perform corresponding tasks, then constraint (8) denotes that what types of devices should be deployed at each Distributed repair center, here we use constraint (9) to denote that any Central repair center can perform all types of tasks, like the OEM. These assumptions conform to Brick's research. And constraint set (10) ensures that z_{im_D}, y_{ijm_D}, y_{ijm_C}, x_{m_D}, x_{m_C} are Boolean decision variables.

2.2 Transshipment

Many studies with LORA potentially or explicitly assumed that the failed products were always sent to the right echelon facility to repair. However, in the real cases, most of failed ones first arrived the nearest facility to seek service whether the facility was the suitable echelon or not. Meanwhile, there are some failures that are difficult to expect or identify, compelling the customers make the first choice to seek the nearest repair center. For instance, the vessels when breaking down on the sea will be tugged to the nearest repair factory whether it can be repaired or not. Once the repair cannot be done, then the product should seek or be sent to the higher echelon repair center. In this paper, we call this process as Transshipment. Meanwhile, we assume that repair center will adopt Free Replacement Warranty

Table 1 Queuing time

C_{ijm_Do}	o_1: repair $= c_{jm_D} + cs_i$ (11)
	o_2: transship $= c_{jm_D}$ (12)
$C_{ijm_Dm_Co}$	o_1: repair $= c_{m_Dm_C} + cs_i$ (13)

policy to implement the repair service for products under warranty, which is a common assumption in this research area. Therefore, service options $o \in O$ include two alternatives, one is replacing the failure the failure unit, and the other is transshipping it to the higher echelon repair center. Define c_{jm_D} as the cost occurred on the route between demand point j and site m_D and $c_{m_Dm_C}$ as the cost of failed product transshipped between site m_D and higher echelon site m_C. Define cs_i as replacement cost to perform task i. Table 1 presents corresponding cost when two echelon repair centers adopt the service option, namely the formulations of C_{ijm_Do}, $C_{ijm_Dm_Co}$.

2.3 Queuing Model

We believe that on one hand the objective of location-allocation problem is for cost savings, in the other hand under warranty service, improving customer satisfaction, especially shortening repair servicing time also counts for much. So in this part, we combine the previous model with queuing theory, putting forward a multi-objective models for allocating two-echelon warranty service facilities meanwhile, improving customer satisfaction through shortening queuing waiting time.

We consider that the number of arrivals from the demand points is finite, and to every type of task, every repair center as single service unit, so it will forms several independent Finite-Source Queues with single server since every task generated from the demand point only seeks the nearest repair center to perform the service. Based on our modeling scenario, we build the other objective function as follow.

$$P_2\colon \min \sum_{i\in I}\sum_{j\in J}\sum_{m_D\in M_D}\sum_{m_C\in M_C}\sum_{o\in O} w_{ij}\left[T_{ijm_Do}y_{ijm_D} + (1 - z_{im_D})T_{ijm_Dm_Co}y_{ijm_C}\right]x_{m_D}x_{m_C}$$

Similar with previous conclusions, we define T_{ijm_Do} as the total time for task $i \in I$, generated at demand point $j \in J$, performing the service option $o \in O$ in the Distributed echelon site $m_D \in M_D$, and $T_{ijm_Dm_Co}$ as the total time for task $i \in I$, generated at $j \in J$, which is cannot be repaired at site $m_D \in M_D$, then transshipped to the Central echelon site $m_C \in M_C$, performing the service option $o \in O$. Table 2 presents the formulations of T_{ijm_Do}, $T_{ijm_Dm_Co}$.

Table 2 Repair cost

T_{ijm_Do}	o_1: repair $= t_{jm_D} + rt_{im_D}$ (14)
	o_2: transship $= t_{jm_D}$ (15)
$T_{ijm_Dm_Co}$	o_1: repair $= t_{m_Dm_C}$ (16)

In Table 2, t_{jm_D} is the time spend between demand point j and Distributed echelon site m_D, and it should be in direct proportion to distance between demand point j and Distributed echelon site m_D. Similarly, $t_{m_D m_C}$ is the time spend between site m_D and higher echelon site m_C and in direct proportion to its distance as well. We assume that the average rate of performing repairing for same type of task at the Distributed repair center is the same μ_i because they all are in the same echelon repair system of one OEM. And we also consider that the failure type detection time is so short compared with the whole service time that any failed product arrival at the Distributed repair center where cannot perform the repair will immediately be transship to the Central site. So we define rt_{im_D} as the total average time spend on repairing for task $i \in I$, performing service at Distributed site m_D. Here we assume that the time spend on repairing at Central repair center is extremely short compared with the transshipment time since we believe that Central repair center are possessed with enough service unit, namely the average servicing rate is so large that we won't consider it in the following equations. And in real cases, the failed products that need to be transshipped always just account for a small faction, so the previous assumption will not affect the result.

Define L_{im_D} as the mean number of task $i \in I$ at the Distributed site $m_D \in M_D$, γ_{im_D} as the birth and death rate of task $i \in I$ at the Distributed site $m_D \in M_D$, and p_{im_D} as probability of zero number of task $i \in I$ at the Distributed site $m_D \in M_D$. And D_{im_D} denotes the number of task $i \in I$ performing repair servicing at the site $m_D \in M_D$. According to Gross's [16] conclusions with our parametrical settings, we obtain some constraint sets as follows.

$$rt_{im_D} = \frac{L_{im_D}}{\gamma_{im_D}}, \quad \forall m_D \in M_D, \quad \forall i \in I \tag{17}$$

$$D_{im_D} = \sum_{j \in J} d_j y_{ijm_D} z_{im_D}, \quad \forall m_D \in M_D, \quad \forall i \in I \tag{18}$$

$$\gamma_{im_D} = \gamma_i (D_{im_D} - L_{im_D}), \quad \forall m_D \in M_D, \quad \forall i \in I \tag{19}$$

$$L_{im_D} = D_{im_D} - \frac{\mu_i}{\gamma_i}(1 - p_{im_D}), \quad \forall m_D \in M_D, \quad \forall i \in I \tag{20}$$

$$p_{im_D} = \left[\sum_{k=0}^{D_{m_D}} \frac{D_{im_D}!}{(D_{im_D} - k)!} \left(\frac{\gamma_i}{\mu_i} \right)^k \right]^{-1}, \quad \forall m_D \in M_D, \quad \forall i \in I \tag{21}$$

3 Algorithm

From the two objective functions above we can see that they are similar with the P-median and its extended models, but the terms in these functions are nonlinear in the assignment variables. And the constraints ot the model are obviously more complex than the other location-allocation problems, thus the problem we discussed is more difficult than the P-median and other location-allocation problems, which is already a notorious NP-hard problem. In this research area, there are many studies applying intelligent algorithms, such as simulated annealing, genetic algorithm, Tabu search, etc. to find the satisfactory solutions. Thus we adopt genetic algorithm to solve our problem, and applying simulated annealing algorithm as an attempt to alleviate the problem of pre-mature convergence, which is the drawback of standard genetic algorithm. Since we are dealing with a multi-objective problem, we update the best chromosome between generations based on the Pareto optimal solution, namely the values of two objective functions both should be better in the next generation. Readers who are interested in these algorithms can find details in Ponsich's [17] and Hui's [18] works.

4 Numerical Example

We use the previous algorithm to solve a random numerical example based on our multi-objective model. And the algorithm is written in Matlab and run on a personal computer with Intel Core i7-2635QM and 4G memory. This numerical example randomly produce 30 demand points with 6 types of tasks, selects 3 Distributed repair centers from 8 random alternative sites, and 1 Central repair center from 4 random alternative sites. The initial parametrical settings of this algorithm are as follows. Set population size as 30, and number of iteration as 300. Figure 2 presents the iteration process of this algorithm when solving our problem. Figure 3 use a graph to present one of Pareto optimal solution on our problem.

In Fig. 2, we can see that under the Pareto optimal solution, the current optimal fitnesses for P_1 and P_2 are [368,856.08, 161,241.67]. In Fig. 3, the scale of demand points denotes their different random sizes. More importantly, the ratio of types of task are randomly produced, and with their corresponding repair device fixed cost as $f_i = [2104, 3673, 2976, 1604, 1903, 2676]$, this algorithm reaches a conclusion that we should deploy f_1, f_3, f_4, f_5, f_6 repair devices at the Distributed repair centers, and f_2 repair device at the Central repair center. Note that if the result were that all the repair devices should be deployed at the same echelon, then the numerical example would prefer one-echelon location-allocation scheme, thus the model and its solutions are generic to standard location problems and two-echelon location problems.

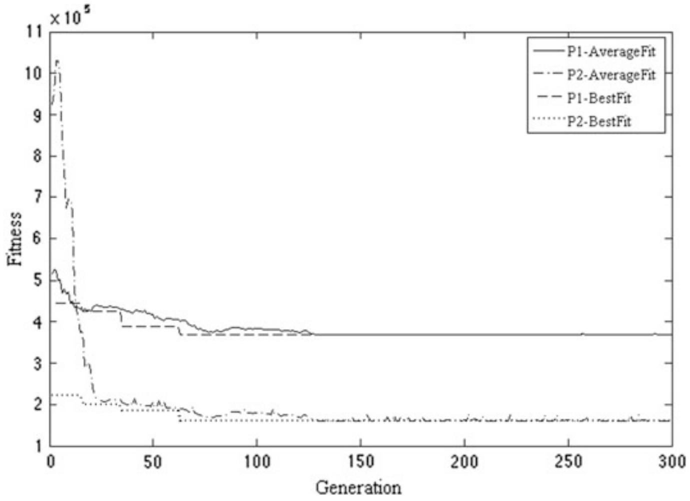

Fig. 2 Iteration process

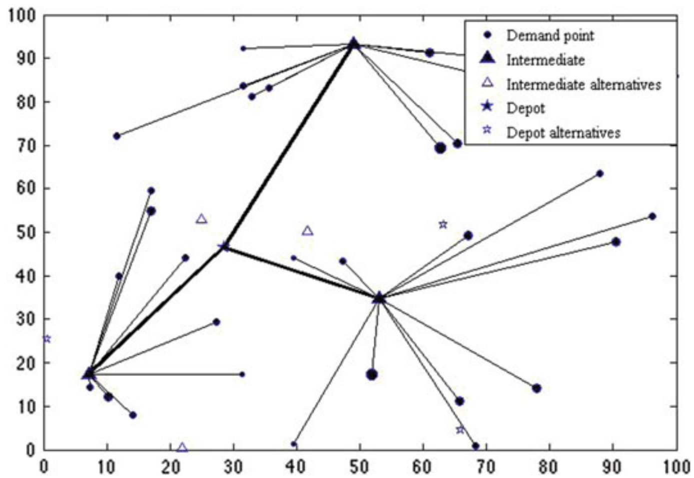

Fig. 3 Result

5 Conclusion

The efficiency on delivery of warranty service plays a critical role in the customers' buying decisions making. Adopting a good way to allocate the repair facilities not only provide customers with sufficient post-sale services, but also decrease cost for manufactures. Focusing on this problem, this paper puts forward a multi-objective models, combining two-echelon location-allocation problem with queuing theory.

The two-echelon location-allocation problem is based on LORA, and takes failed product transshipments between echelons into consideration, and applying the finite-source queuing theory for enhancing customer satisfaction through decreasing queuing waiting time. And because this model belongs to NP-hard problem, we adopts simulated annealing genetic algorithm to solve a random numerical example, achieving the Pareto optimal solution on how to locate the facilities and how to arrange relevant devices and resources on each echelon facilities.

Nevertheless, our proposed model still has some limitations that we may consider in our future works. First of all, it doesn't take spare stock, namely the inventory system into consideration, which apparently affects the queuing time and customer satisfaction a lot. Secondly, our proposed model can extend to be more generic one that even contains third party maintenance facilities which nowadays plays a critical role in warranty service delivery. Thirdly, our model should consider the stochastic process of LORA, which means that the failure hazards of terminal tasks are actually randomly distributed on time. These enhancements can make our model and its solutions more grounded in reality.

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An Equipment Offering Degree Evaluation Method for Weapon System-of-Systems Combat Network Based on Operation Loop

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Abstract Equipment offering degree evaluation plays a fundamental role in requirements analysis of weapons and equipment demonstration. An equipment offering degree evaluation method for weapon system-of-systems combat network (WSOSCN) based on operation loop is proposed. After discussing the WSOSCN model and its generation algorithm, a measure called equipment offering degree index is put forward to evaluate the contribution of single equipment in a WSOSCN. A case is studied to analyze the offering degree of different type of nodes. And different edge connection probability increased strategies are considered to illustrate the influence of edge connection probability on equipment offering degree evaluation. Results show that decision entities play the most essential role in a WSOSCN and high level command & control (C2) center is of more significance than the leaf C2 center. Results also show that in the early period of WSOS development, enhancing the connection between armaments has important implications.

Keywords Equipment offering degree evaluation · Operation loop · Weapon system-of-systems combat networks

1 Introduction

In information age, confrontation between weapon system-of-systems (WSOS) has replaced the platform-centralized warfare and become the main operating pattern in the future [1–3]. WSOS is composed of interconnected weapons and equipments according to special structure [4, 5]. It is to satisfy the certain strategic demand and combat mission especially in the information condition. Weapon system-of-systems combat network (WSOSCN) is a complex network composed of our equipment and

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enemy targets. The problem of equipment offering degree evaluation plays a fundamental role in requirements analysis of weapons and equipment demonstration.

Many studies have been devoted to evaluate the equipment contribution of a WSOSCN. Liu et al. [6] put forward the concept of military value to assess equipment importance; Chang et al. [7, 8] proposed an analysis method based on grey target theory to solve the problem of key technology contribution rate of weapon system of system; Yu et al. [9] adopted value-focused method to evaluate equipment offering degree and Bai et al. [10] built equipment contributing rate model to using SEA; Golany et al. [11] formulated resource constrained network optimization models to address military countermeasure developing problems; Shuteng Zhang presented equipment contributing rate analysis method based on task. However, the existing method always pay more attention to individual capability of single equipment and ignore the interactions with other armaments in the whole combat systems [12].

In this paper, a weapon system-of-systems combat network model is proposed. According to the operation loop concepts, a new equipment offering degree evaluation index based on operation loop is presented. A case is studied to validate the application efficiency of the equipment offering degree evaluation index in supporting the WSOS architecture design and optimization.

2 Weapon System-of-Systems Combat Network Model

2.1 Concepts of Operation Loop

The modern combat cycle theory deems that combat operation is a cycle involving observation, orientation, decision and action (OODA). Jeffrey [13, 14] presented an information age combat model, which classified the forces in the battlefield into sensors, decision organs, influence organs and targets. Cares believes that military operation is a loop process that sensors detect and find the target then transfer the information to decision organs, decision organs judge the battlefield and command the influence organs to attack the target. Tan et al. [15] put forward the concepts of operation loop, which is defined as a closed loop formed by the sensors, decision organs, influence organs and targets for the sake of accomplishing specific operational tasks. Figure 1 shows operation loops.

1. Sensor Entity(S): Weapons and equipments that carry out reconnaissance, monitoring and early warning missions, such as reconnaissance satellites, radar and etc.
2. Decision Entity(D): Weapons and equipment that carry out control and command missions, such as C4ISR, aerospace information system and control center etc.

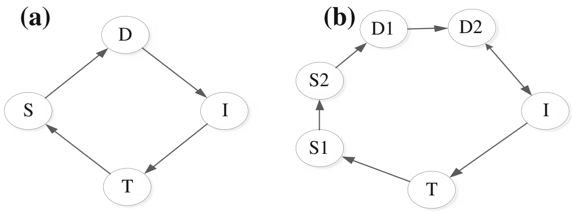

Fig. 1 Operation loops: **a** a simple operation loop, **b** an operation loop with several sensors and decision-makers

3. Influence Entity(I): Weapons and equipment that carry out fire attack and electromagnetic interference missions, such as fighter, frigates and electromagnetic interference radar etc.
4. Enemy Target(T): The enemy infrastructure, weapons and equipment.

It is worth noting that the different operational objectives and combat missions bring about many different operation loops. The operation loops sharing operation entities constitute a complex combat network [15].

2.2 Networked Modeling of Weapon System-of-Systems Combat Networks

WSOSCN can be abstracted into a complex network, which is expressed as $G = (V, E)$, where $V = \{v_1, v_2, v_3, \ldots, v_n\}$ is the set of vertices, and $E \subseteq V \times V$ is the set of unordered pairs of vertices, i.e., weaponry edges. The weaponry nodes is divided into sensors, decision entities, influencers and enemy targets, $V = S \cap D \cap I \cap T$. The collection of sensors $S = \{v_1^s, v_2^s, v_3^s, \ldots, v_k^s\}$ represents all the sensor entities; the collection of decision makers $D = \{v_1^d, v_2^d, v_3^d, \ldots, v_l^d\}$ represents all the decision-maker entities; the collection of influencer $I = \{v_1^i, v_2^i, v_3^i, \ldots, v_p^i\}$ represents all the influencers and the collection of enemy targets $T = \{v_1^t, v_2^t, v_3^t, \ldots, v_q^t\}$ represents all the enemy targets. $N = |V|$, $K = |S|$, $L = |D|$, $P = |I|$ and $Q = |T|$ represent the numbers of all the weaponry nodes, all the sensor entities, decision-maker entities, influence entities and enemy targets respectively. Therefore, we obtain $N = K + L + P + Q$.

2.3 Generation Algorithm for Weapon System-of-Systems Combat Networks

In the real world, a weapon system-of-systems combat network is consisted of hundreds of armaments and the interaction between armaments is complicated and various. However, we can study the law and rules hided in the combat system-of-systems, and generate an approximation combat network to portray the combat system-of-systems.

Figure 2 shows an algorithm of generating a weapon system-of-systems combat network.

3 Single Equipment Offering Degree Evaluation Model

Many studies have been devoted to explore the operational efficiency of a combat network of weapon system-of-systems and a variety of measures have been proposed such as characteristic path length, degree distribution, clustering coefficient and centrality. However, all the measures only partly reflect the ability of networks and consume a lot of computation time. These days, [1] put forward a spectral measure of operational efficiency based on operation loop (operation loop evaluation index, OLEI), which has a definite physical meaning and a simple mathematical formulation. Physically, OLEI characterizes the redundancy of alternative operation loops by quantifying the weighted number of closed walks of all lengths. Mathematically, OLEI can be derived from the graph spectrum as an average eigenvalues.

3.1 Introduction of Operation Loop Evaluation Index

In a weapon system-of-systems combat network $G = (V, E)$, the alternating sequence of nodes and edges $w = v_0 e_1 v_1 e_2 \ldots e_k v_k$ is called walk, $v_i \in V, e_i = \langle v_{i-1}, v_i \rangle \in E$, and k is the length of walk w. In a simple graph, walk w can be simplified as $v_0 v_1 \ldots v_k$, denoted as $w = \langle v_0, v_1, \ldots, v_k \rangle$. If $v_0 = v_k$ in $w = \langle v_0, v_1, \ldots, v_k \rangle$, w is called closed walk. According to the conception of operation loop, we can know operation loops are closed walks. Let $A(G) = (a_{ij})_{N \times N}$ be the adjacency matrix of WSOSCN G, where $a_{ij} = 0\, or\, 1$ and $a_{ij} = 1$ means there exists a directed edge between edge e_i and e_j, otherwise $a_{ij} = 0$. It follows immediately that $A(G)$ is a real matrix with eigenvalues $\lambda_1, \lambda_2, \ldots, \lambda_i$, The set $\{\lambda_1, \lambda_2, \ldots, \lambda_i\}$ is called the graph spectrum of G.

In to destroy this target entity by cooperation of own armaments. It is an operation loop, target entity can be regarded as the origin and end of the walk. The efficiency of operation loop represent the capability of own armaments destroying the targets. If a target entity is covered by n alternative operation loops, it means we have n methods intuitive that the more the alternative operation loop presents, the higher the target damage probability. This observation leads us to consider the redundancy of alternative operation loops as a measure of the operational efficiency of the WSOSCN. Although it would be ideal to define this redundancy as the

Fig. 2 Generation algorithm for weapon system-of-systems combat networks

Algorithm 1 Generation Algorithm for Weapon System-of-systems Combat Networks

Input:

L : Max layer of the C2 network;
M : Span of the C2 network;
m_0 : Initial number of C2 network;
$S-num$: The number of the sensor entity;
$I-num$: The number of the influence entity;
$T-num$: The number of the enemy target entity;
P_{detect} : The probability of sensor entity detecting enemy target;
P_c : The probability of successful communication;
$P_{destroy}$: The probability of influence entity destroying enemy target;

Output:

G_{wsoscn} : Automatic creation weapon system-of-systems combat network;

Other notation:

$C2_i$: The collection of C2 entities in the i_{th} layer of the C2 network;
$C2$: The collection of the whole C2 entities;
S : The collection of the whole sensor entities;
I : The collection of the whole influence entities;
T : The collection of the whole enemy targets

$l \Leftarrow 1$;
Create m_0 C2 entities;
Add each new created C2 entity into collection $C2_l$;
Create $S-num$ sensor entities;
Add each new created sensor entity into collection S;
Create $I-num$ influence entities;
Add each new created influence entity into collection I;
Create $T-num$ enemy targets;
Add each new created enemy target into collection T;
While $l < L$ **do**
  For each C2 entity a in collection $C2_l$ **do**
    Create M C2 entities;
    Add each new created C2 entity into collection $C2_{l+1}$;
    Update $C2$;
    Add edges between each new created C2 entities and its parent C2 entity a;
  End Loop
  $l = l + 1$;
End while
For each enemy target t in collection T **do**
  Generate directed edges starting from t towards sensor entities in collection $C2$ with a probability P_{detect} randomly;
End Loop
For each sensor entity s in collection S **do**
  Generate directed edges starting from s towards C2 entities in collection $C2$ with a probability P_c randomly;
End Loop

Fig. 2 (continued)

For each sensor entity i in collection I **do**
Generate directed edges starting from i towards enemy targets in collection T with a probability $P_{destroy}$ randomly;
End Loop
Update G_{wsoscn};

number of alternative operation loops of different lengths for all targets, this measure is very difficult to calculate. Here we propose to measure the redundancy of alternative operation loops as the scaled number of closed walks of all lengths.

In graph theory, closed walks are directly related to the sub graphs of a graph. For instance, a closed walk of length $k = 2$ corresponds to an edge, and a closed walk of length $k = 3$ represents a triangle. Noting that a closed walk can be trivial, i.e., containing repeated vertices, leading to the length of a closed walk being infinite. As for WSOSCN, considering shorter operation loops have less information loss and have higher operational efficiency, i.e. shorter closed walks have more influence on the redundancy of alternative routes than longer closed walks. Hence, we define a weighted sum of numbers of closed walks $S = \sum_{k=0}^{\infty} n_k/k!$, where n_k is the number of closed walks of length $k > 0$ and $n_0 = N$. This scaling ensures that the weighted sum does not diverge. Denote by $n_{ij}^{(k)}$, the number of walks from v_i to v_j of length $k > 0$. Then we have $n_k = \sum_{i=1}^{N} n_{ii}^{(k)}$. Denote by $a_{ij}^{(k)}$ the element in the kth power of A. In a simple graph with no multi edges or self-loops, it follows from the definition that

$$n_{ij}^{(k)} = a_{ij}^{(k)} \tag{1}$$

Then we obtain

$$n_k = \sum_{i=1}^{N} n_{ii}^{(k)} = trace(A^k) = \sum_{i=1}^{N} \lambda_i^k. \tag{2}$$

Therefore, we have

$$S = \sum_{k=0}^{\infty} \frac{n_k}{k!} = \sum_{k=0}^{\infty} \sum_{i=1}^{N} \frac{\lambda_i^k}{k!} = \sum_{i=1}^{N} \sum_{k=0}^{\infty} \frac{\lambda_i^k}{k!} = \sum_{i=1}^{N} e^{\lambda_i}. \tag{3}$$

However, when N is large, S will be a big number. Therefore, we employ natural logarithm to rescale S, then we obtain

$$S' = \ln(S) \tag{4}$$

In this paper, we adapt S' as operation loop evaluation index.

3.2 Offering Degree Index of Single Equipment

It's a plain fact that if we remove an equipment from our WSOS, the operational effectiveness on enemy targets will decrease. The more decreasing means the more important the removed equipment is. Therefore, the offering degree index of a single equipment v_i can be represented as follows.

$$Od(v_i) = \frac{S'_{G_0} - S'_{G'_{-v_i}}}{S'_{G_0}} \tag{5}$$

where S'_{G_0} is the operation loop evaluation index of initial weapon system-of-systems combat network, while $S'_{G'_{-v_i}}$ is the changed weapon system-of-systems combat network of which the equipment v_i and related edges are removed.

The detailed algorithm for solving single equipment offering degree of weapon system-of-systems is presented in Algorithm 2, as showed in Fig. 3.

4 Numerical Results Analysis

Different kinds of combat entities (sensor entities, decision entities, influence entities) play different roles in the battlefield. To what extent does a certain combat entity contribute to the operational efficiency of a WSOSCN is an interesting and meaningful issue, which can help with the optimization design of a WSOSCN. To illustrate the influence of detection, communication and destroy probability on the offering degree of different types of nodes, three scenarios are put forward: scenario of detection probability increasing, scenario of communication probability increasing and scenario of destroy probability increasing. Next, we will introduce them in detail.

4.1 Offering Degree of Different Type of Node

A WSOSCN G is generated according to **Algorithm** 1. Input parameters are set as follows: Max layer of the C2 network $L = 3$; Span of the C2 network $M = 4$; Initial number of C2 network $m_0 = 1$; The number of the sensor entity $S\_num = 25$; The number of the influence entity $I\_num = 20$; The number of the enemy target $T\_num = 20$; The probability of sensor entity detecting enemy target $P_{\det ect} = 0.5$; The probability of successful communication $P_c = 0.5$; The probability of influence entity destroying enemy target $P_{destroy} = 0.5$. Figure 4 shows the generated WSOSCN.

Fig. 3 Solving algorithm for single equipment offering degree of weapon system-of-systems

Algorithm 2 Solving algorithm for single equipment offering degree of weapon system-of-systems

Input:

G_0: Initial weapon system-of-systems combat network;

N: The number of all the weaponry nodes

Output:

Od: The solution list of single equipment offering degree

Other notation:

G'_{-v_i}: Changed Weapon System-of-systems Combat Network after removing node v_i;

$S'(G_0)$: Operation loop evaluation index of Initial weapon system-of-systems combat network;

$S'(G'_{-v_i})$: Operation loop evaluation index of Changed weapon system-of-systems combat network after removing node v_i;

$Od(v_i)$: Offering degree of equipment v_i;

$i \Leftarrow 0$; $Od \Leftarrow \varnothing$;

Calculate the operation loop evaluation index of initial weapon system-of-systems combat network $S'(G_0)$;

While $i < N$ **do**

Removing node v_i and related edges from G_0;

Update G'_{-v_i};

Calculate the operation loop evaluation index of changed weapon system-of-systems combat network $S'(G'_{-v_i})$;

Calculate $Od(v_i)$;

Add $Od(v_i)$ to Od;

Update Od;

End while

Figure 5 shows the single equipment offering degree of different nodes type in the WSOSCN. Figure 6 shows a clear ranking of offering degree of different nodes type for the operational efficiency of the WSOSCN. In more specific, decision entities contribute the most, and next is the sensor entities, while the influence nodes rank the lowest place. As for the decision entity, high level C2 center is of more significance than the leaf C2 center. This is consistent with common sense, for the C2 center plays a role of brain in military operations and almost all the information must be through its processing. When destroyed, it will lead to paralysis of the entire combat system-of-systems. It's also generally believed that intelligence reconnaissance and acquisition plays a more and more important role in the modern

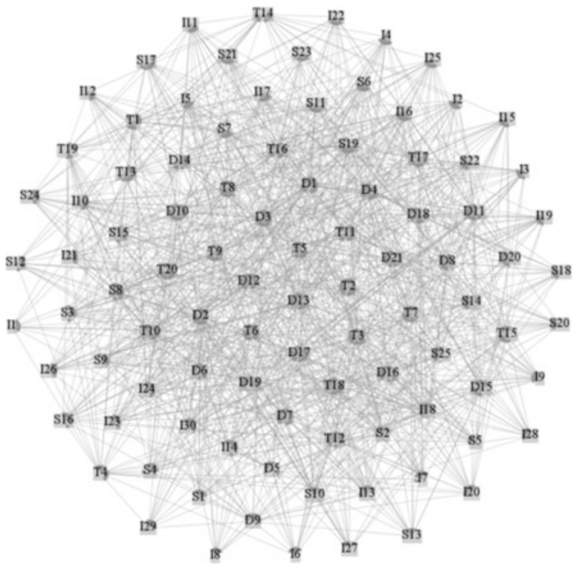

Fig. 4 A weapon system-of-systems combat network generated by **Algorithm** 1

information war. It explains why sensor entity's offering degree is higher than that of influence entity to some extent.

4.2 Influence Analysis of Edge Connection Probability

To illustrate the influence of edge connection probability on the offering degree of different types of nodes (sensor, decision-maker and influence), three edge connection probability increased strategies are considered: (i) Increasing the probability of sensor entity detecting enemy target $P_{\det ect}$; (ii) Increasing the probability of

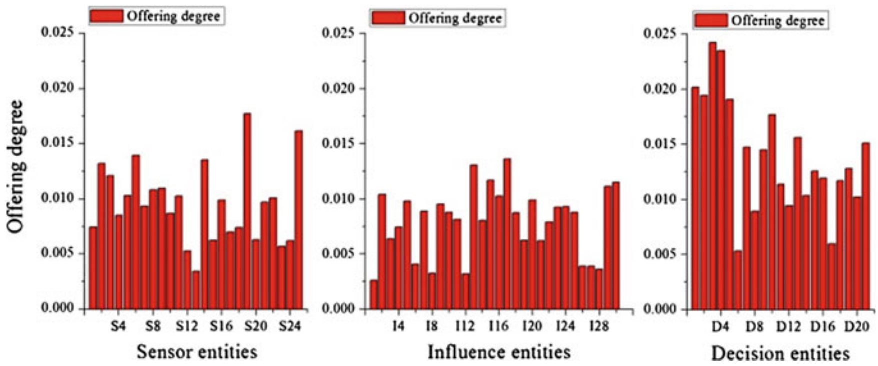

Fig. 5 Single equipment offering degree of different nodes type in a WSOSCN

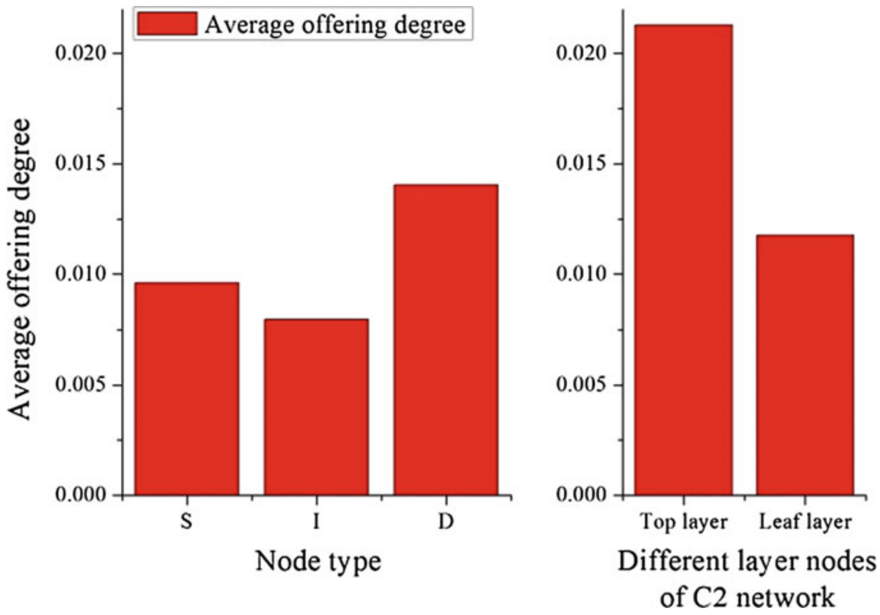

Fig. 6 Average equipment offering degree of different nodes type in a WSOSCN

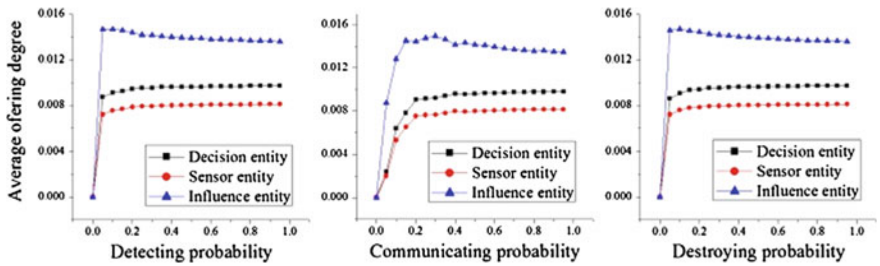

Fig. 7 The average offering degree of decision, sensor and influence entity with the increase of detecting communicating and destroying probability

successful communication P_c; (iii) Increasing the probability of influence entity destroying enemy target $P_{destroy}$.

As shown in Fig. 7, the offering degrees of sensor and influence entity begin to increase dramatically and gradually stabilize with the increase of detecting,communicating and destroying probability. However, as for decision entity, the offering degree of decision entity increase sharply in the initial period and then decrease slowly with the increase of detecting,communicating and destroying probability. The result is interesting and has some meaningful guidance for the construction and development of weapon system-of-systems. That's to say, in the early period of WSOS development, enhancing the connection between armaments has important implications while when the weapon system-of-systems has constructed a quite perfect combat system, the benefit of enhancing the connection between armaments is not so obvious.

5 Conclusions

In this paper, we study an equipment offering degree evaluation method for weapon system-of-systems combat network based on operation loop. The concepts of operation loop are introduced. Then we discuss the weapon system-of-systems combat networks (WSOSCN) model and give an algorithm of how to generate a WSOSCN. A measure called equipment offering degree index is put forward to evaluate the contribution of single equipment in a WSOSCN. A case is studied to analyze the offering degree of different type of nodes (sensors, decision entities, influencers). Results show that decision entities play the most essential role in a WSOSCN and high level command & control (C2) center is of more significance than the leaf C2 center. Moreover, to illustrate the influence of edge connection probability on the offering degree of different types of nodes, three edge connection probability (detecting probability, communicating probability and destroying probability) increased strategies are considered. Results show that in the early period of WSOS development, enhancing the connection between armaments has important implications while when the weapon system-of-systems has constructed a quiet perfect combat system, the benefit of enhancing the connection between armaments is not so obvious.

The proposed networked modeling and equipment offering degree methods of weapon system-of-systems based on operation loop provides a new perspective for the study of WSOS. It has certain significance for the study of WSOS optimization and evolution.

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Study on the New Structure of the Solar Blind Ultraviolet Detector

Yong Xia and Xing-zhao Liu

Abstract Four square metal electrodes are prepared by electron beam evaporation system, respectively between the electrodes reverse insertion of a zener diode regulator tube by molecular beam epitaxy on (0001)—plane sapphire substrates growth β-Ga_2O_3 films, in gallium oxide thin film preparation four 50 um square area. The solar blind UV detector was prepared, measured the V-I curve, is connected with a zener diode by experiment data, it is shown that the solar blind ultraviolet detector of dark and light signals ratio reached nearly 50 times, its performance is not weaker than additional MSM fork electrode structure solar blind ultraviolet detector. Solar blind ultraviolet detector assisted by Zener diode structure has good performance, structure is more simple and greatly reduce the difficulty of fabrication process, compared with the traditional MSM fork to the electrode structure. The miniaturization of the device can be easily realized, is very suitable for developing large area solar blind ultraviolet detection array.

Keywords Molecular beam epitaxy · UV detector · Zener diode

1 Introduction

Monoclinic gallium oxide [1], a wide band gap semiconductor material, and is transparent conductive oxide, its band gap is about 4.8–4.9 eV, and the band gap corresponding solar blind ultraviolet (less than 280 nm) and therefore monoclinic Ga_2O_3 particularly is suitable for solar blind UV detector.

Usually in solar blind ultraviolet detection technology can be widely used in the combustion process detection, ultraviolet leak check, mine fire alarm [2] and missile warning [3] strikes and other fields, development prospect is very broad.

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At present, the AlGaN, ZnMgO and β-Ga_2O_3 films are the materials of the solar blind ultraviolet detector. Bandgap of AlGaN ternary alloy material by changing the material of Al component to carry on the adjustment, but the main problem is high Al group of AlGaN epitaxial thin films was more difficult to prepare, with material Al fraction increases, the quality of epitaxial thin films will be degraded significantly, thus limiting the further development of AlGaN materials in solar blind ultraviolet.

MgZnO is also one of solar blind UV sensitive materials in recent years, compared to AlGaN, MgZnO material can also band gap width between the 3.3–7.8 eV. The adjustment [4] can be regulated in a larger scope and optical properties is more outstanding, promising to research system covering most of the band of the UV detector, however, due to the need for high Mg component, MgZnO is difficult to grow a single hexagonal wurtzite structure to meet the ultraviolet solar blind detection, which in a large extent limits the MgZnO material in the field of solar blind ultraviolet detector development.

Compared with AlGaN and MgZnO and β-Ga_2O_3 materials which have excellent optical properties, chemical stability and high mechanical strength, band gap width up to 4.8 eV, do not need to adjust the band gap by doping, can have good adaptation of solar blind ultraviolet detection demand [5].

2 Methodology

In this paper, we use the SVT company MOS-V-2 type molecular beam epitaxy system to prepare the β-Ga_2O_3 thin film, and with RF plasma auxiliary equipment. In the experiment, the purity of Ga was 99.9999 % and the purity of O_2 was 99.999 %. The process parameters of the specific molecular beam epitaxy growth β-Ga_2O_3 thin film are shown in Table I.

For traditional MSM fork finger electrode structure of Ga_2O_3 thin film solar blind ultraviolet detector, inter digital size reduce in proportion, inter electrode resistance does not occur too big change, just with reduced size, cross the fingers of the electric field strength increased significantly, so that the photocurrent performance a slight upward trend.

Table 1 Process parameters of GA_2O_3 thin film by molecular beam apitaxy

Parameter	Growth condition
Background vacuum (Pa)	5.6×10^{-6}
Substrate temperature (°C)	760
Gallium source temperature (°C)	940
Oxygen flow (ml/min)	1
Radio frequency source power (W)	300
Radio frequency source reflection power (W)	6

As the size of the device is reduced, the area of the device is reduced, and the response of the device is increased. In the time of the device response characteristics, according to the proportion of shrinking device sizes, although carrier between the electrodes and the transition time is significantly shortened, but the final test device rise time and fall time basically unchanged.

Interdigitated electrode structure can be applied to large area solar blind ultraviolet detector array after scaling, but with interdigital electrode dimension reduction, strip width and spacing will become very small, from the point of view of the process will be to device processing manufacturing to bring considerable difficulties.

So we passed the preliminary theoretical exploration of [6], and find out new structure of Zener diode auxiliary solar blind UV detectors.

In the β-Ga_2O_3 film prepared on, we made the light area of 50 mm × 50 mm, a new UV detector has four square electrodes, four electrodes on the electrode, respectively 0 electrode 1, an electrode 2 and an electrode 3, an electrode 0 and an electrode in zener diode the 1 is inserted between the reverse zener diode, in 2 and 3 between the electrode inserted into the reverse, the input current at the electrode 3 and the electrode 0 into a constant, measured 2 and 1 electrode potential between the electrodes, and calculate the potential difference between 1 and 2 U_{21} electrode, its working principle is shown in Fig. 1 among them, W = 40 m, L = 6 m (according to the corresponding size of the traditional MSM interdigital electrode of solar blind ultraviolet detector to decide).

In the preparation of extension of β-Ga_2O_3 films, we prepared traditional interdigital electrode structure and model of the assistance of Zener diode structure pattern by photolithography, then Lithography good film will be plated a layer thickness of about 20 nm of Ti by electron beam evaporation method and on top of the steaming we plate a layer thickness of about 20 nm metal Al and its structure schematic diagram as shown in Fig. 2.

The plated electrode samples turn into acetone, ethanol and deionized water stripping metal, then dried by nitrogen.

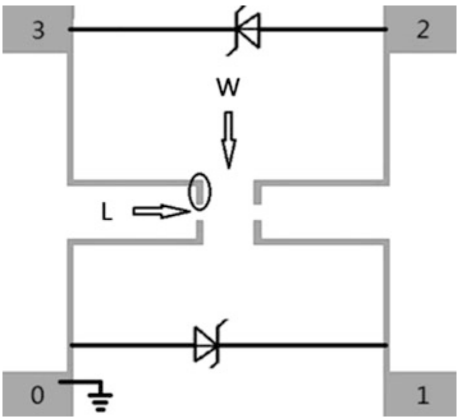

Fig. 1 Principle of Zener diode auxiliary solar blind UV detectors

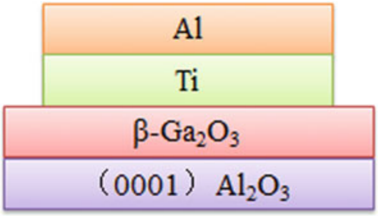

Fig. 2 The structure of the solar blind ultraviolet detector

In order to make the metal electrode and the oxide thin film have good ohmic contact, we put the good sample into the rapid annealing furnace, and then in the nitrogen environment for 500 °C fast annealing for 5 min.

The solar blind ultraviolet detector subject to the same light area (50 mm × 50 mm) fork and blind UV detectors without zener diode assisted solar were placed in the optical power density 0, 12, 23, 38, 53, 76, 115 μW/cm^2,

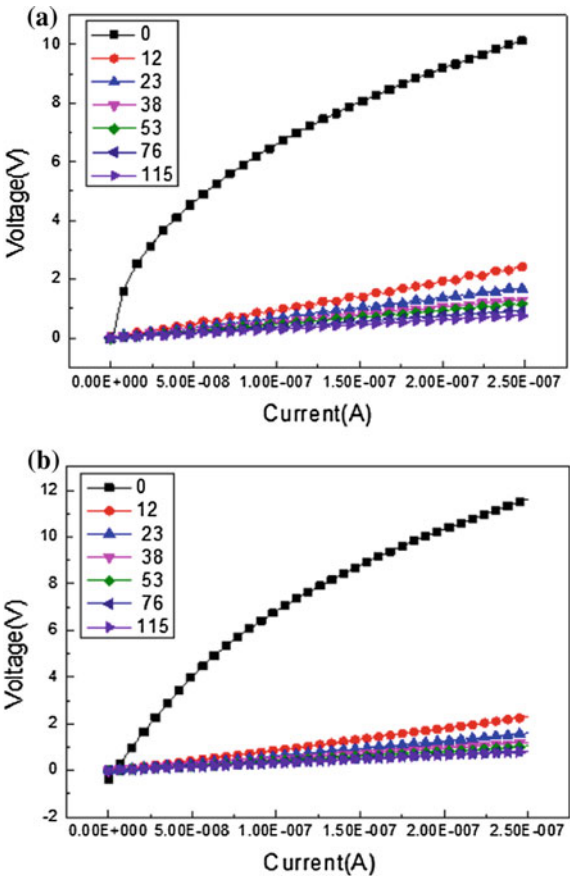

Fig. 3 **a** V-I characteristics of the conventional cross finger electrode structure of the gallium oxide solar blind ultraviolet detector **b** no V-I characteristics of Zener diode auxiliary structure of gallium oxide solar blind UV detector

respectively wavelength 254 nm UV illumination, with constant input current, output voltage detection measured traditional fork finger electrode structure of solar blind ultraviolet detector and no zener diode assisted V-I characteristic of solar blind UV detector. The experimental results are shown in Fig. 2.

From Fig. 3 shows, no matter traditional fork to electrode structure detector or no assistance of Zener diode detector, the input voltage increases with the increase of input current and narrow with UV light power change with the increasing trend.

And the new structure of the detector can be compared with the detector of the structure of the cross finger electrode even when the diode is not joined.

From the experiment we know, no acceptance zener diode assisted gallium oxide model, blind UV detector and traditional fork refers to the electrode structure of gallium oxide solar blind ultraviolet detector performance difference.

To this end, we also produced a special Gazina diode assisted, blind violet detection and no diode Gazina's on the blind UV detector, respectively, the input of constant current, measure the output voltage U_{21} for comparison, as shown in Figs. 4 and 5.

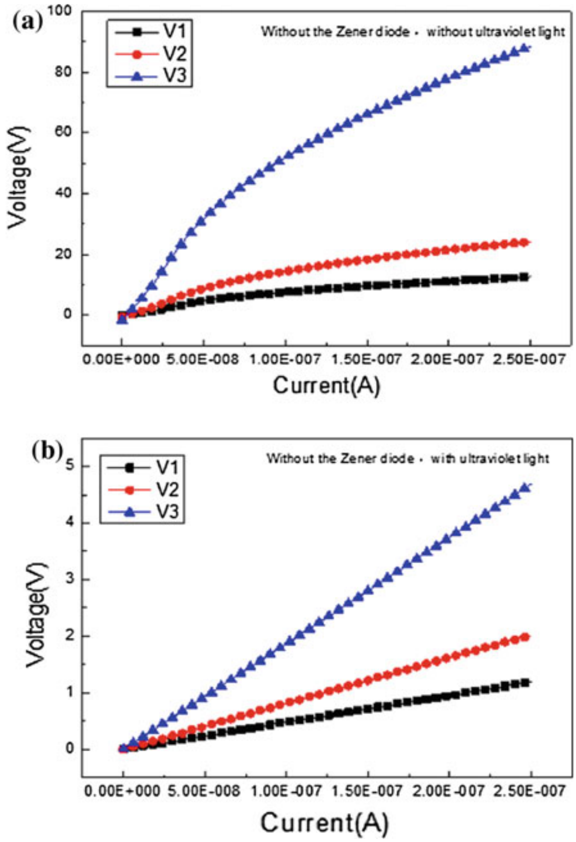

Fig. 4 **a** With UV light, the device changes in electrode potential with the input current when not connected zener diode. **b** Without UV irradiation, the device changes of electrode potential with the input current when not connected zener diode

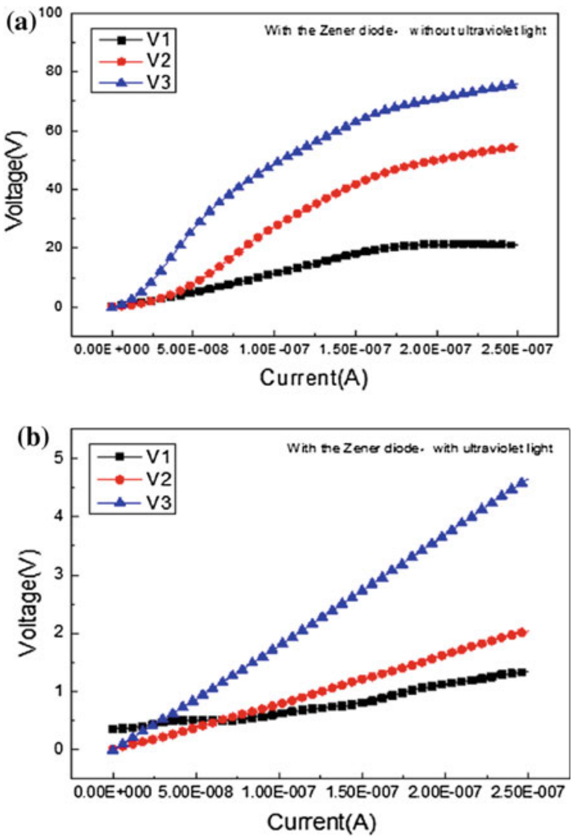

Fig. 5 **a** With UV light, change after the zener diode device connected with the input current of the electrode potential. **b** Without UV irradiation, changes after the zener diode device is connected with the input current of the electrode potential

From Figs. 4 and 5. In the experimental results, we can see that external zener diode, sample devices by and not subject to ultraviolet irradiation and U_{21} changes to significantly greater than without the addition of Zener diode device sample.

From Fig. 6 we can see that to the input current of 250 nA, for example, no external zener diode is connected device in 76 μW/cm^2, UV irradiation U_{21} is about 0.82 V, no UV light environment, U_{21} is about 12 V, the difference is 11.18 V.

External the two zener value 22 V zener diode device in 76 μW/cm^2 UV irradiation U_{21} is about 0.7 V, no UV light environment, U_{21} is about 34 V, the difference is 33.3 V; see, zener diode introduced could pull device signal light and dark between the signal difference, on the device performance is improved obviously, which is realized through the voltage stabilizing effect of the zener diode.

When the device is subjected to UV irradiation, electrode and electrode between the 2 voltage U_{32} and electrode and electrode 0 voltage U_{10} are very small, is unable to achieve the reverse breakdown voltage of the zener diode and Zener temporarily intervene role. When off UV irradiation, due to the rise of Ga_2O_3 thin film resistor, voltage U_{10} and U_{32} also began to increase when zener diode reverse breakdown voltage is reached.

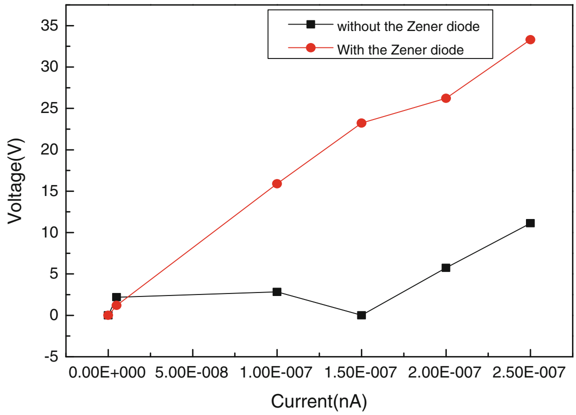

Fig. 6 (no) Difference between the optical signal of UV detector zener diode assisted with dark signal

Zener diode began to intervene in the role, U_{10} and U_{32} was stable in zener diode voltage value of 22 V, electrode 2 potential is forcibly pulled, and 1 on the potential electrode was forced to pull low, this, from Fig. 5b can be very easy to see. From Fig. 6 that through an external zener diode supporting role, J detector dark with the ratio of the signal and the light signal reached nearly 50 times, in terms of performance is not weak on the fork to electrode structure in the photoconductive detectors.

3 Results

To sum up: zener diode assisted solar blind UV detector with a constant current source as the working power supply, when exposed to different intensities of UV irradiation, the output voltage signal will change corresponding.

Through auxiliary function of Zener diode, the device can obtain better performance, the signal light and dark signal difference with the traditional MSM fork refers to the electrode structure of solar blind ultraviolet detector.

The most important is, from the process point of speaking, the structure is more simple compared with the traditional fork refers to the electrode, and the manufacturing process is less difficult, easier to implement device miniaturization, very suitable for the development of for large area solar blind ultraviolet detector array.

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A Mechanism Model of Resource Investment and Evaluation Level of Energy-Saving and Emission-Reduction in Coal Mine

Jin-feng Wang, Zan Chen, Li-jie Feng and Xue-qi Zhai

Abstract In view of the strong nonlinearity of the resource investment and evaluation level of Energy-saving and Emission-reduction (ESER) in coal mine, this paper firstly established the input index system, then established a mechanism model of ESER resources and ESER level based on SVR, used genetic algorithm (GA) to optimize the parameters of the SVR model, and introduced the Cross-validation to improve the process for the best SVR model. The performance of the improved model is measured against particle swarm optimization algorithm. The results showed that: the model using improved GA-SVR fitted better with the nonlinear relationship between ESER resources and ESER level, and this model also had a stronger effectiveness and generalization ability.

Keywords Action mechanism · Coal mine · Energy-saving and emission-reduction · Genetic algorithm · Support vector machine

1 Introduction

China's coal production is generally accompanied by "high energy consumption, high pollution", so coal production enterprises pay more and more attention to the Energy-saving and Emission-reduction (ESER) to ease the pressure on the environment and energy, and have achieved some results through improving the technical equipment and energy-saving measures etc. However, due to the energy

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saving and emission reduction resource investment in coal mine is blind, the environmental and energy problems of coal industry in China are still very serious. It is found that this is a lack of effective standards of ESER level, low investment efficiency and serious waste of resources, so that the environment and energy problems of enterprises cannot be effectively improved. Therefore, how to analyze the impact of resource investment on ESER level in coal mine to improve the efficiency of ESER has become an urgent problem to be solved in the coal industry.

In recent years, there are a few studies on mechanism model of resource investment and evaluation level of ESER in coal mine, related research mainly concentrated in the index system establishment and efficiency evaluation. Li [1] combined with the actual situation of coal enterprises to design the framework of energy saving audit evaluation index system; Jin [2] used DEA to evaluate the efficiency of energy saving and emission reduction of many China's small and medium enterprises; Liao [3] designed the energy, environment, and economic input-output table and model system, which provided a new ESER input-output statistical method.

From the traditional regression analysis to neural network, ant colony algorithm and other intelligent algorithms have been applied to the field of coal mine in recent years [4, 5]. The regression analysis methods often used the complex expression to fit finite sample so that it cannot be generalized, and have lower prediction ability, being difficult to describe the nonlinear relationship between the resource investment and evaluation level of ESER in coal mine. Conventional neural networks and other intelligent algorithms have some defects such as local minimum and over learning, which need a large amount of data for support, but the data collection cost in coal production areas is high, leading to small sample size, causing neural network training working bad. Support Vector Machine (SVM) is a machine learning theory for small sample case, which overcomes some inherent weaknesses of neural networks, improving the generalization ability of the model.

Consequently, this paper, according to the nonlinear relationship between the resource investment and evaluation level of ESER and small sample volume, establishes GA-SVR mechanism model, and the idea of cross validation is introduced to improve the optimization method for avoiding over fitting and less learning. The final empirical analysis proves that this model has a stronger effectiveness and generalization ability, which can provide theoretical support and decision-making basis for the optimal allocation of coal mine energy saving and emission reduction.

2 Input Index System Construction

Energy consumption in coal mine production includes raw coal, gasoline, diesel and electric power, in which raw coal and electric power respectively used by boiler and production equipment account for more than 90 % of total energy consumption [6].

Table 1 The coal mine energy saving and emission reduction input index system

First grade indexes	Second index	Third grade indexes	Explanation
The coal mine energy saving and emission reduction input index system	Energy saving index	Power equipment X_1 Coal equipment X_2	Use energy saving technology to transform the production equipment and heating equipment, energy real-time monitoring to avoid waste
	Emission reduction index	Harmful dust control X_3 Solid waste management X_4 Mine water treatment X_5	Strengthen the construction of environmental protection facilities, improving the efficiency of the "three wastes" treatment

Accordingly, in this paper, the energy saving investment focus on the transformation and maintenance of power consumption equipment and coal combustion equipment; As for the selection of reducing emissions indexes, we select the variables which are the main part of the waste discharge statistics in coal production as the main resource input object. In summary, the Coal mine energy saving and emission reduction input index system is showed in Table 1.

3 Mechanism Model Based on Improved GA-SVR

3.1 Support Vector Machines Regression (SVR)

When support vector machine is used for regression estimation, it is called support vector machine (SVR) and there is the basic idea of SVR: For training data set (x_i, y_i) $(i = 1, 2, 3, \ldots, l;\ x_i \in R^m,\ y_i \in R,$ where x_i are the input vectors, y_i the output), we can convey the input vectors x_i into a higher dimensional feature space F by a mapping function φ and then solving a linear regression in F. After non-linear mapping, the following estimation functions are used in the feature space for linear regression:

$$f(x) = [w \cdot \varphi(x)] + b \tag{1}$$

$$\varphi\colon R^m \to F, W \in F \tag{2}$$

According to the statistics theory, support vector machine obtains the regression function by making the following objective function minimization:

$$\min\left\{\frac{1}{2}\|w\|^2 + C\cdot\frac{1}{l}\sum_{i=1}^{l}(\xi_i + \xi_i^*)\right\}$$

$$St:\begin{cases} y_i - w\cdot x_i - b \le \varepsilon + \xi_i \\ w\cdot x_i + b - y_i \le \varepsilon + \xi_i^* \\ \xi_i, \xi_i^* \ge 0, \quad i = 1, \ldots, l \end{cases} \tag{3}$$

where C indicates the degree of penalty for a sample that is out of the error, $C > 0$; ξ_i are the slack variables and ε is insensitive loss function. Lagrange multiplier method is used to solve the problem:

$$f(x) = \sum_{i=1}^{l}(\alpha_i - \alpha_i^*)K(x_i, x_j) + b \tag{4}$$

where α_i and α_i^* are support vectors' indicators; x_i is training sample input data vector, x_j is analysis sample input data vector; $K(x_i, x_j)$ is kernel function. According to the definition of Mercer, we use the RBF kernel function:

$$K(x_i, x_j) = \exp(-\mathrm{g}\|x_i - x_j\|^2) \tag{5}$$

where g is the kernel function parameter, $g = \frac{1}{\sigma^2}$; σ is the width parameter for kernel function. According to the SVR theory, the selection of parameter C and g plays an important role in the regression model.

3.2 GA-SVR Based on Improved Method

Genetic algorithm is an artificial intelligence optimization algorithm for global optimization search, which has highly nonlinear mapping, self-adaption and self-organization function [7, 8], and applying genetic algorithm to SVR parameter optimization (GA-SVR) can improve the speed and accuracy of optimization. At the same time, the cross validation is introduced to improve the GA-SVR optimization process in order to avoid the occurrence of the model excessive learning and less learning.

Cross validation (CV) is a statistical method to eliminate the training errors caused by the random sampling [9, 10]. Considering the sample size and computational efficiency, we introduce tenfold cross-validation to evaluate the training performance of the model, to divide the original data into 10 disjoint sets, each subset as a validation set, respectively, and the remaining 9 sets of subsets as the training set. Using mean square error (MSE) as the evaluation index, the expression is as follows:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[f(x_i) - y_i\right]^2 \tag{6}$$

where $f(x_i)$ is predictive value and y_i is actual value. The smaller the MSE, the higher the accuracy of the model. After GA optimization, the 10 sets will obtain 10 groups of parameter (c, g), from which we choose one group having the smallest MSE as the optimal parameter group.

3.3 Mechanism Model Construction

Combined with the above theoretical analysis and the strong nonlinear characteristics of the resource investment and evaluation level of ESER in coal mine, we need to use SVR to map the input variable (x_1, x_2 … x_5) to a high dimensional feature space F, and according to statistical theory and Lagrange multiplier method, we will substitute Eq. (5) into Eq. (4) nonlinear function as follows:

$$f(x) = \sum_{i=1}^{l}(\alpha_i - \alpha_i^*)\exp(-\mathrm{g}\left\|x_i - x_j\right\|^2) + b \tag{7}$$

4 Experimental Study

4.1 Data Collection and Processing

We selected the 25 coal mines in Henan Province as the research object, the average annual output of 200–300 million tons, the average annual output value of about 5–6 million. We obtained 25 training datasets from historical data, including enterprises' annual investment in the ESER indicators, energy consumption and pollutant control, and had a non dimensional treatment of the data. We treated 5 ESER indexes as the input of the SVR model, the corresponding ESER levels as the output. We divided the evaluation of ESER level into two parts, namely, the energy-saving level and the pollution-control level. Specific calculation methods are as follows:

$$\text{Energy-saving level: } A = \frac{a - b}{a} \times 100\,\% \tag{8}$$

$$\text{Pollution-control level: } B = \frac{1}{3}\sum_{i=1}^{3}\frac{c_i - d_i}{c_i} \times 100\,\% \tag{9}$$

$$ESER\text{ level: } C = \frac{1}{2}(A + B) \quad (10)$$

The following is an explanation of the symbols: A is energy saving level; B is pollutants control level; C is ESER level, a and b respectively represent the energy consumption of enterprise per 10,000 Yuan of industrial output value in the year and the last year (converted into standard coal quantity). c_i and b_i respectively indicates that the amount of pollutants generated or discharged by the enterprises within one year of the class i (i = 1, 2, 3, represents harmful gas dust, solid waste and mine water, respectively). Based on this, the annual ESER level of 25 enterprises are selected as the SVR output, then randomly selected 20 groups as training samples and the other 5 groups as testing samples to verify the validity of the model.

4.2 *Model Parameter Selection*

We use the PSO algorithm and the improved GA-SVR to optimize the parameters (c, g) and get the performance parameters, mean square error (MSE) and squared correlation coefficient (R^2), see Table 2. At the same time, we can get the comparison chart of the original data and regression data, as shown in Figs. 1 and 2.

From Figs. 1 and 2 we can clearly see that the training data and regression data of the fitting model based on improved GA-SVR is closer, and its MSE is smaller.

Table 2 Comparison of parameters optimization method

	c	g	MSE	R^2
PSO-SVR	100	0.01	0.4192	0.9461
Improved GA-SVR	99.8966	0.1955	0.0229	0.9972

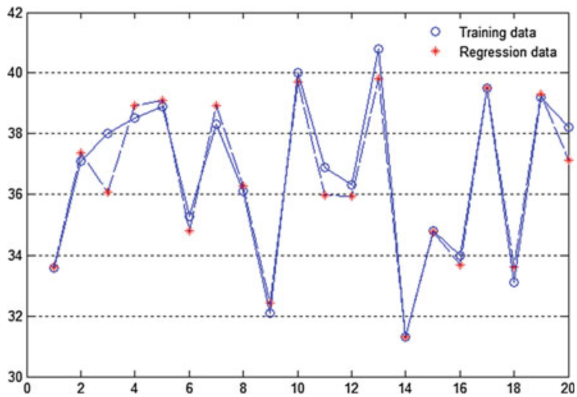
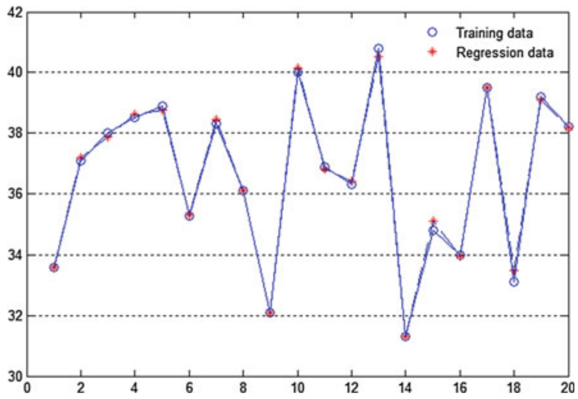


Fig. 1 Training samples based on PSO-SVR

Fig. 2 Training samples based on improved GA-SVR



So the optimal parameters obtained by the improved method are more effective than the PSO method. We obtain the coefficients $\alpha_i - \alpha_i^*$ of the 20 support vectors in the decision function by training, see Table 3.

At the same time, we get the b value is 36.8968, taking $\alpha_i - \alpha_i^*$ and b into (7), then we have established a mechanism model of resource investment and evaluation level of ESER in coal mine.

For further comparison of the two methods forecasting results, respectively taking 5 sets of test samples into the 2 models, we can see their forecast effect in Table 4.

By comparing with the real value of ESER level, we find that the MES of improved GA-SVR is smaller, and its forecast value was more close to the real value. It shows that the improved GA-SVR algorithm has more advantages than the PSO in the parameter optimization, and better reflecting the relationship between the resource investment and evaluation level of ESER in coal mine, having a stronger effectiveness and generalization ability.

Table 3 Model parameter $\alpha_i - \alpha_i^*$

Number	$\alpha_i - \alpha_i^*$	Number	$\alpha_i - \alpha_i^*$
1	59.6361	11	−99.8966
2	99.8966	12	−99.8966
3	99.8966	13	−56.6286
4	−99.8966	14	16.0401
5	14.3024	15	−99.8966
6	99.8966	16	−99.8966
7	99.8966	17	−18.7586
8	−99.8966	18	99.8966
9	−13.9778	19	−99.8966
10	99.8966	20	99.2830

Table 4 Model prediction results

Enterprise	Real value	PSO-SVR	Improved GA-SVR
21	39.0	38.9528	39.0543
22	35.3	36.4116	35.5386
23	35.5	36.4535	35.8801
24	34.1	34.0842	34.0789
25	38.2	36.7667	38.6391
MSE	–	0.8403	0.0795
R^2	–	0.7629	0.9916

5 Conclusion

In order to analyze the nonlinear interaction between the resource investment and evaluation level of ESER in coal mine, this paper proposed a mechanism model based SVR, and use the PSO algorithm and the improved GA-SVR to optimize the parameters, then establish the best training model. The final empirical study proves that the model based on the improved GA-SVR has a stronger effectiveness and generalization ability, which can provide theoretical support and decision-making basis for the optimal allocation of coal mine energy saving and emission reduction.

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The Research to the Influential Factors of Credit Risk in the P2P Network Loan Under the Background of Internet Financial

Feng-ge Yao and Xin Sui

Abstract This article is based on the borrowers' information data from P2P network loan platform on PPDAI during February to July, 2015, the research analyzes the relevance between the borrower's user age, gender, credit rating, successful number of times, flow mark, loan amount, interest rate, term, monthly payments, loan credit, borrow credit 11 indexes and whether the borrower default behavior happen. The research shows that there is a significant positive correlation between the borrower loan interest rates and the borrower default behavior, there is a significant positive correlation between the age of the borrower and the borrower default behavior. In this paper, the results of the research, can not only provides the new ideas to the credit risk of loan in P2P network platform, but also provides empirical evidence to our P2P network industry government.

Keywords Internet financial · P2P network loan · Credit risk

1 Introduction

As the one of the greatest scientific and technological inventions in the 20th century, the Internet is gradually changing the old mode of the financial system and the market structure. Xie etc. [1] pointed out that Internet financial model is different from the indirect financing of commercial bank, it is also different from the third financial financing model in direct financing capital market. Li [2] and Huo [3] pointed out that can be roughly interpreted as "Internet financial", under the condition of new technology, all kinds of traditional financial institutions, financial

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institutions and emerging electric business enterprise depends on its vast amounts of data accumulation and powerful data processing ability, through the Internet channel and technology provided by the credit, financing, financing, payment and a series of financial intermediary services.

P2P network loan is the abbreviation of English Peer-to-Peer, peer-to-peer lending, refers to the individual or entity though an independent third party network platform, lending to each other by P2P network platform as the intermediary, loan borrowers funding in the platform, investors bid for lend to borrowers. Since 2005, the world's first P2P network platform loan established in the UK, P2P network model have been thriving on a global scale. Now, the world's largest P2P network platform is founded in 2006 in the United States named Prosper website, has more than 2.1 million registered members and a $1 billion loan amount. In the past two years, the domestic network platform loan quantity rapid growth, has reached more than 2000. Since 2012, the entire network lending industry volume up to 20 billion yuan. Just six years, the P2P lending has development of the booming. Li [2] pointed out, peer-to-peer (P2P) network loan is regarded as a new type of financial intermediary to provide more simple, rapid and convenient than traditional financial institutions of the lending service to the users, to a certain extent, solve the problem of the shortage of funds bottom earners, partly meet the demand of the public finance at the same time, it is one of the highlights of pratt and whitney financial development.

Due to the P2P lending industry has "no threshold, no industry standards, and no regulators" and some other reasons, make P2P industry face great risks. With the social development speeding up, P2P lending platform must deal with a lot of the complex risks that have great influence on the operation and development. Credit risk as the main risk faced by network lending, also known as default risk, refer to the borrower for various reasons, unwilling or unable to perform the contract conditions, constitute a default, the possibility to cause investors to suffer losses. Credit risk mainly includes three aspects of content: one is the borrower default is subjective intention, the moral risk; The other is a borrower objectively the lack of the ability of reimbursement, namely the borrower's solvency; Finally also includes the borrower's credit status and the change of credit rating, this is the possibility of potential losses. At the same time, lending risk management level determines its own survival and development, having a big impact on the stability and development of the financial system. Credit risk as the main risk faced by network borrowing, is due to the debtor default loans and bonds and other assets caused by the loss of solvency risk. Credit risk management is to through effective means of methods of credit risk analysis and prevention and control, make risk loan security, to ensure that the principal and interest.

PPDAI is the first lending to P2P network loan platform in our country. At present, it is also the largest domestic P2P network platform, the most active users of lending platform. So we choose the PPDAI website users' information as the research object of P2P credit risk. This article selects the data are from the PPDAI loan users' information on the website, and in this paper, by establishing the crawlers, dig the information of the website. Through the network programming statistical data mining, this paper selected the February to July, 2015, 80053 specific users' information was listed, delete information statistics of loan list, the remaining 75433 loan list. We mainly improve the result of the previous research from the following four aspect enrich the theory about P2P of the factors affecting the credit risk. First of all, this article selects the PPDAI borrow site users' information in age, gender, credit rating, successful number of times, flow mark, loan amount, interest rate, term and monthly payments, bids, loan credit, borrow credit 11 indicators to measure whether the borrower default behavior happen. Secondly, this paper use the Logit regression model, more intuitive shows the relationship between the 11 variables and whether the default behavior happens. Third, this paper using the method of information mining, through the establishment of crawlers, dig the information of the website, and required the data. Fourth, this paper adopted the ROC curve to show the accuracy of the model.

2 The Literature Review and Hypothesis Developmemt

A large number of studies have shown that, with the high-speed development of the Internet financial, the credit risk of P2P platform as the main risk is becoming more and more attention by scholars. P2P as the trading platform, need to provide personal information of borrowers as the basis of risk assessment. Mr Stiglitz and Weiss [4] proposed that long ago that even though the borrower's credit history information (such as credit rating, history performance) is open to all investors, but the network anonymity could exacerbate the typical information asymmetry problem of borrowing. Early study of P2P lending platform pointed that borrowers in the individual character has little difference, but credit risk is significant. Ahlin and Townsend [5], Mr Stiglitz and Weiss [4] argue that lending to P2P network can result in adverse selection and moral hazard problems, because of information asymmetry of the lending market crisis, such as the United States several times of financial crisis. Sufi [6] and Klafft [7], as well as in the financial markets generally, network lending market also exists information asymmetry, in addition, due to the lack of experience, investors under the network environment the credit risk of loan is higher. Wang [8] by researching the domestic major network platform, put forward in recent years due to network lending platform qualification the good and bad are intermingled, development mode is not standard, bring a lot of credit risk. Niu [9] argues that the current P2P lending risks include four aspects: one is the lack of capital security, two it is the real intention of funds can't verify, three is a personal information may be leaked, four is the lack of effective regulation of P2P lending platform.

Ou [10], selected the data of RRDAI for empirical analysis, results show that there is s positive relationship between the credit rating and default behavior. Iyer et al. research from the credit scores, credit history etc. aspect. The study found that credit score and credit history have relevant impact on credit risk. Therefore, this article puts forward assumptions [11].

Hypothesis 1: there is a significantly positive relationship between the borrower's credit rating of the P2P network platform loan and default behavior.

Yu used the method of Logistic regression model to measure the credit default risk of the Prosper company, the results show that the credit rating, loan term and loan interest rates based indicators such as default risk measures, and have passed the test of significance. Therefore, this article puts forward assumptions [12].

Hypothesis 2: there is a significantly positive correlation between the P2P network platform user lending rates and loan default behavior.

3 Sample Selection and Descriptive Statistics

3.1 Sample Selection

In this paper, based on the data of borrowers' age, gender, credit rating, successful number of times, flow mark, loan amount, interest rate, term, monthly payments, loan credit, borrow credit 11 indexes form the PPDAI network platform, research data based on the PPDAI user information on the website, this paper selected the February to July, 2015, 80053 specific user information. In order to make the data more reliability and integrity, delete the user information data that is incomplete, eventually 75433 users' information in this sample. In this paper, by establishing the crawlers dig the information of the website. In this paper, the data are from PPDAI loan users' information website.

3.2 Variables to Build

In this paper, the research is aimed at PPDAI user information in the website information. In Table 1 we can see the variables.

Be explained variable: In order to accurately measure the credit risk of the P2P network loan platform, this article selects the user whether the default behavior happen to measure credit risk in P2P network. And adopt Yu [12] research methods, using Logistic regression model of binary choice model analysis the credit risk of the P2P network platform of loan more intuitive. When the borrower has the default behavior, represented by 1, the borrower does not have default behavior, represented by 0.

The variable: This paper selected the PPDAI borrowers' information such as age, gender, credit, success, flow mark, loan amount, interest rate, the limit of time, monthly payments, loan credit, borrow credit 11 indexes as the explanatory variables. At PPDAI loan borrowers age is divided into 20–25, 26–31, 32–38, and more than 39 years old, in the empirical process, put them separately in 1, 2, 3, 4 instead. In this paper, there are two samples in both men and women, in order to study the convenient, "1", the male assignment women assigned "0".

Table 1 The definition of main variables

Variable	Variable description
Be explained variable	
Risk	Credit risk borrowers default behavior
Explanatory variables	
Credit	Borrower credit rating
Success	Borrowers bidding success
Fail	Borrowers bidding fail
Total	The total amount of borrowing
Rate	The interest rate
Time	The limit of time
Monthly	Monthly payments
b-credit	Borrowing in the credit
l-credit	Lending in the credit
Gender	Gender
Age	Age

3.3 The Main Variables of Descriptive Statistics and Correlation Analysis

Table 2 reported in this paper, the description of the main variable statistics, including PPDAI website in February to July, 2015, the users' information data. The statistics of variable description in Table 2 shows, as explained variable, the mean value of the credit risk is 0.08. The maximum is 1, the minimum is 0. In the explain variables, the credit of the mean value is 5.13, the success of the mean value is 2.98, the average rate is 13.00, the average time is 8.19, the total average is 3931.20.

Table 2 The description of the main variable statistics

Variable	Mean	Std. Dev.	Min	Max
Risk	0.0732268	0.2605127	0	1
Credit	5.129832	2.546342	1	8
Success	2.977449	16.88191	0	372
Fail	1.139876	1.289896	0	33
Total	3931.197	9111.474	100	500,000
Rate	12.99627	3.268426	7	24
Time	8.189449	3.051242	1	24
Monthly	682.6987	1717.362	27	69,415
b-credit	22.50812	13.14844	0	240
l-credit	1226.758	11015.6	0	309,926
Gender	0.1542874	0.3612299	0	1
Age	1.994977	0.2605127	1	4

4 P2P Network Platform: An Empirical Study of Credit Risk Factors

In order to inspect the influence factors of the credit risk in P2P network platform loan systematic, this section focuses on the PPDAI borrower loan information users in age, gender, credit rating, successful number of times, flow mark, loan amount, interest rate, term and monthly payments, bids, loan credit, borrow credit affect whether the borrower default behavior happen. This section used the econometric model as shown below:

$$\begin{aligned} \text{risk} = {} & \partial_0 + \partial_1 credit + \partial_2 success + \partial_3 fail + \partial_4 total \\ & + \partial_5 rate + \partial_6 time + \partial_7 monthly + \partial_8 b - credit \\ & + \partial_9 l - credit + \partial_{10} gender + \partial_{11} age + \varepsilon \end{aligned} \tag{1}$$

The credit risk is the explained variable, α is the coefficient. The credit, success, fail, total, rate, time, or, bids, b-credit, l-credit, gender, and age as the explained variable. ϵ is the random perturbation terms. The empirical results are as follows:

ROC (Receiver Operating Characteristic) curves can through the way of graphics intuitive to show the accurate level of model, the curve line can judge model fitting though line with 45 degrees of deviation degree. At the same time, there is an indicator of judgment AUC (Area Under the ROC Curve), express the area at the bottom of the ROC curve. Through the model of the ROC = 0.9887 can quickly determine the extent of the ROC curve deviates from the 45° line, illustrates the model fitting effect is very good, the ROC curve as shown in the Fig. 1.

Can be seen from Table 3, the borrowers' information form PPDAI network platform loan, there is a significant negative correlation between the borrower's credit rating and the borrower default behavior, may be due to the P2P network platform loan low rating of the borrower, the credit level is low, the behavior is more likely to default when borrowing, leading to a significant negative correlation

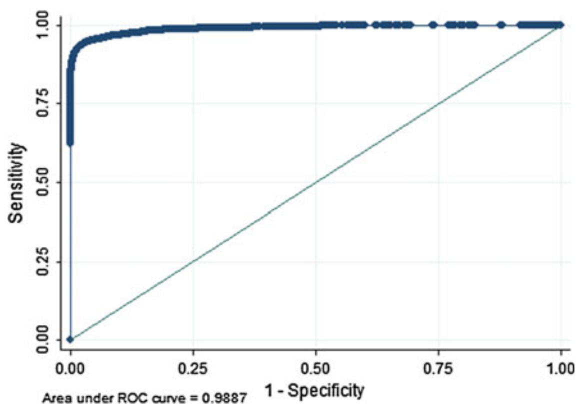

Fig. 1 Sample data of ROC curve

Table 3 The analysis result of the PPDAI network platform loan credit risk factors affecting

Variable	coefficient	Z value	*P* value
Credit	−0.4334512***	−9.48	0.000
Success	0.6225831***	17.48	0.000
Fail	0.1421392***	4.73	0.000
Total	1.04e−06	0.08	0.934
Rate	0.1225034***	5.10	0.000
Time	−0.0047524	−0.25	0.802
Monthly	0.0000342	0.45	0.654
b-credit	−0.2439233***	−20.77	0.000
l-credit	0.4477229***	32.64	0.738
Gender	0.0492476	0.33	0.000
Age	0.3213288***	5.16	0.000

Note * represents significant under 10 % level
** represents significant under 5 % level
*** represents significant under 1 % level

relationship. There is a significant positive correlation between the bid success number and the borrower default behavior. There is a significant positive correlation between the bidding failure number and the borrower default behavior. There is a significant positive correlation between the borrowers' loan interest rate and the borrower default behavior, the borrower repayment pressure may be due to increasing of the high interest rate, cause the borrowers cannot pay as scheduled, resulting in a significant positive correlation. There is a significant negative correlation between the borrowing in the credit and the borrowers default behavior, there is a significant positive correlation between the borrower's loan credit and the borrowers default behavior. There is significant positive correlation between the age of the borrowers and the borrowers default behavior, may be due to the borrower's age increases, the increase of credit default risk to bear ability, lack of repaying self-control, leading to the present a significant positive correlation. There is no relationship between the borrower loan amount, loan term, amount of every month of reimbursement, gender and the borrower default behavior.

5 Conclusion

This article is based on the borrowers' information data form P2P network platform loan on PPDAI during February to July, 2015, the research analyzes the relevance between the borrower's user age, gender, credit rating, successful number of times, flow mark, loan amount, interest rate, term, monthly payments, loan credit, borrow credit 11 indexes and whether the borrower default behavior happen. To develop and reform the P2P network loan industry in the future, provide strongly empirical analysis of P2P network loan industry to prevent credit risk at the same time.

In this paper, from 2015 February to July PPDAI borrowers' information on the website, the conclusion is that, there is significant negative correlation between the borrower's credit rating and the borrower default behavior. There is significant positive correlation between the bid success number and the borrower default behavior. There is a significant positive correlation between the bidding failure number and the borrower default behavior. There is a significant positive correlation between the borrower loan interest rates and the borrower default behavior. There is a significant negative correlation between the Borrowing credit and the borrower default behavior. There is a significant positive correlation between the age of the borrowers and the borrower default behavior. There is no relationship between the borrowers' loan amount, loan term, amount of every month of reimbursement, gender and the borrower default behavior. Results show that the hypothesis 1, hypothesis 2 is not established. Features in the research, first of all, this article selects the PPDAI borrow site users' information in age, gender, credit rating, successful number of times, flow mark, loan amount, interest rate, term and monthly payments, bids, loan credit, borrow credit 11 indicators to measure whether the borrower default behavior happen. Secondly, this paper use the Logit regression model, more intuitive shows the relationship between the selected 11 variables and whether the default behavior happens. Third, this paper use the method of information mining, through the establishment of crawlers, dig the information of the website, and required the data. Fourth, this paper adopted the ROC curve to show the accuracy of the model. The research shows that we can guard against P2P network loan credit risk though strengthen the regulatory measures, establish a unified, standardized credit rating system, strengthening the user credit checks, and strengthening the protection of users' information.

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Predicament and Way of Lean Production in Manufacturing Practice in China

Yi-min Huang, Qiu-xiang Li and Er-shi Qi

Abstract Over the last 30 years, Lean production (LP) is a kind of production mode which could improve the production efficiency of enterprises proved by theory and practice, and caused strong repercussions in the industry and academia. However, there are very few successful cases by importing the lean production from enterprise practice around the world. In China, many enterprises implement the lean production often failed to succeed. Learning and effective promotion of lean production enterprises are put forward by means of the analyzing of many problems that exist in the process of implementing lean production in this paper.

Keywords Lean production · Industry engineering · Predicament and way

1 Introduction

LP is an intellectual approach consisting of a system of measures and methods which when taken all together have the potential to bring about a lean and therefore particularly competitive state in a company [1]. The term of LP was first coined by Krafcik in his Master's degree thesis at the MIT Sloan School of Management [2]. Subsequently used the term "lean production" in the Machine book to contrast it with the Western mass production System [3]. When in 1990 a book appeared by the title, The Machine that Changed the World, often referred to as the "MIT study", no-one anticipated the repercussions which the ensuing debate would have [4]. LP has become one of the most widely cited references in operations management over the past twenty years [5]. Then industry and academia has achieved rich results through a lot of practice and research of the lean production mainly in

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the United States, Europe and China, etc. Scholars made a thorough research on lean production at home and abroad: Lean concept [6–9]; lean Methodologies such as total quality management (TQM) [14]; The principles of lean production. [10, 11]; The implementation process such as the results of implementation, the impact of lean production on the value chain, extending lean principles to the value chain [12]; Impact of the geographical context on lean production [13, 14]; The application of lean production [15–19].

Learning and effective promotion of lean production enterprises are put forward by means of the analyzing of many problems exist in the process of implementing lean production in this paper. The work extends the lean production theory and in order to have promotion and will be applied on the lean production theory and practice of Chinese enterprises to provide reference.

2 Management Characteristics of LP

2.1 Basic Accumulation

Accumulation is the continuous accumulation. That is to say there have a really good return when a process of cumulative production value reached a certain degree. To that extent, between the management of investment and benefit is the relationship of exponential distribution. Study on the regularity of the thing itself is one of the necessary conditions of being successful, when we do something. Many manufacturers are using industrial engineering to guide and improve the production practice in China, such as lean production, six sigma management, ERP (Enterprise Resource Planning), MES (manufacturing execution system), etc. But the effect is poorer and they couldn't be consistent with the principle and method of IE in the practice of these enterprises in the application. They have not been formed the endogenous dynamic of ascension to improve the capacity and ability. This is a continuous improvement process which needs to constantly accumulate. For example, in the process of the application of it must be form ERP-1, ERP-2, ERP-3…, which is continuous improvement through management innovation. This is the process of basic accumulation and it needs a lot of research and practice. However it is basic accumulation that is lacking in China's manufacturing industry. To complete this accumulation a series of work needs to be done: work study, human factors engineering, lean design, management innovation, integrated innovation and so on. The accumulation is weak in China's manufacturing industry for the following reasons. Compared with the developed countries and regions, Chinese industrial engineering accumulation is insufficient significantly in time dimension. America created the industrial engineering in the late 19th century early 20th century, Japan began study and application of it in the 1940s, South Korea in the 1950s, Taiwan China in the 1960s, China in the 1990s, the accumulation of IE lags far behind the United States, Japan, Korea and Taiwan China. Another more important reason is that the management of the basic technology research and application have been ignored in the enterprise for a long time. Cause of this phenomenon is the special history of China. In China the context of learning and supplicating of IE is in the age with the development of commodity economy greatly lagging behind the western industrialized countries and science and technology development are far more than the level of the western countries. China's manufacturing industry develops rapidly over the past 30 years under the strong push of market economy since the reform and opening up.

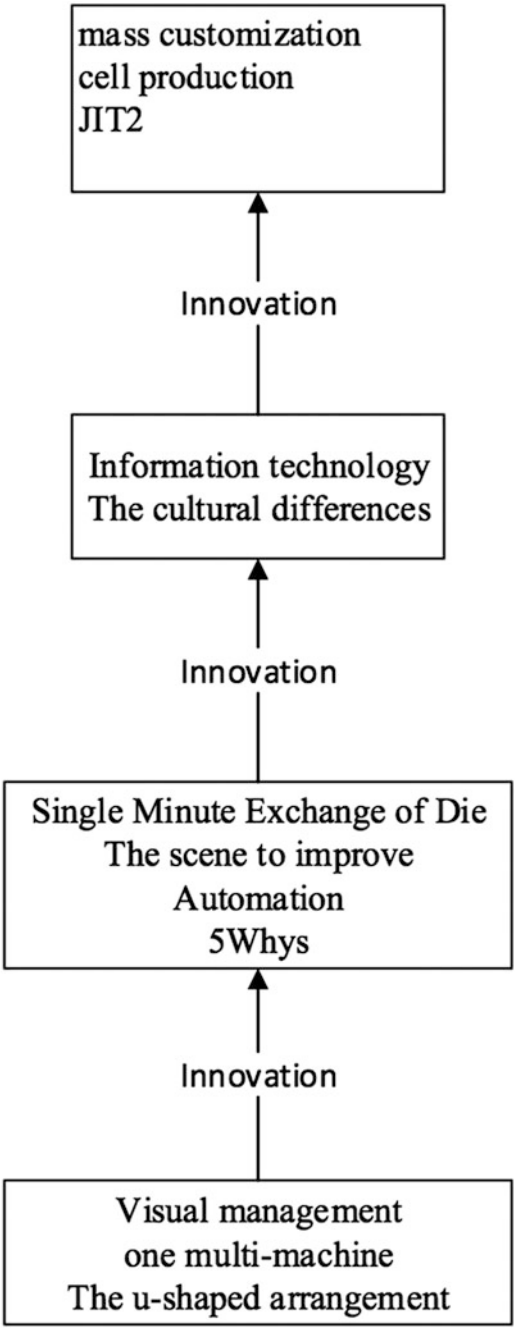
2.2 Innovation

From the development of LP and the process of LP is shown in Fig. 1. So, it has characteristics of innovative management. This is also one of the important reasons led to other enterprises in the introduction of lean production mode of failure or poor effect. As all known is that the essence of LP are five basic principles which come from IE: (1) Specify value; (2) Identify the value stream; (3) Avoid interruptions in value flow; (4) Let customers pull value; (5) Start pursuing perfection again. Integrated with actual conditions of Toyota, IE is the birth of LP. Therefore IE is the seed, enterprise practice is the soil, the system integration is the nutrient, all of these together form the lean production which has been affecting the world now and in the future, as shown in Fig. 2. Each enterprise soils are different, so the nutrient is different, we need integrate different methods to get the desired effect. In this sense, LP cannot be copied.

2.3 The Satisfied Principle

At the Cowles Commission, Simon's main goal was to link economic theory to mathematics and statistics. His main contributions were to the fields of general equilibrium and econometrics. He was greatly influenced by the marginalist debate that began in the 1930s. The popular work of the time argued that it was not apparent empirically that entrepreneurs needed to follow the marginalist principles of profit-maximization/cost-minimization in running organizations. The argument went on to note that profit-maximization was not accomplished, in partly, because of the lack of complete information. In decision-making, Simon believed that agents face uncertainty about the future and costs in acquiring information in the present. Behind LP is the pursuit small and continuous improvement, to the satisfaction of principle, through continuous accumulation. With zero inventories leans improvement as an example to illustrate the satisfied principle of lean production (Fig. 3). As long as the stock B is less than A is a small step to improve the success, and continuously improve as C&D, until the stock tends to zero.

Fig. 1 Innovation in the development and process of LP



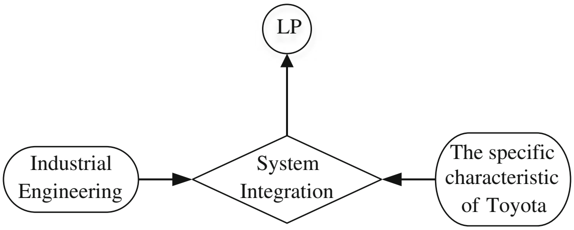


Fig. 2 The basis of lean production and its forming process

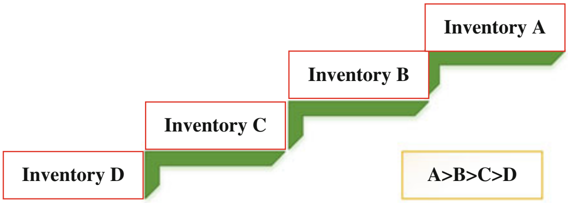


Fig. 3 Lean satisfaction principle to improve inventory

3 Predicament and Way of Lean Production from China

3.1 *Ignore the Origin of LP*

LP is a good way of production proved by practice. Known as "the machine that changed the world" is the mass production after human modern mode of production of the third milepost. So far, however, it has not heard of any companies for the introduction of lean production mode and gained a great success. The reasons leading to this phenomenon are these enterprises ignore the origin of LP in the learning and imitation. The origin of LP is industrial engineering. Many of the core technology and method of LP such as single minute exchange of dies, Kaizen, Jidoka, five questions, supplier team reorganization and partnership, pull production, are based on time study and action research of industrial engineering, as shown in Fig. 4.

3.2 *Violate the Basic Principles of LP*

Kingdom of Heaven on Earth, Aptitude for Exercise, Subordinated the interests of the individual to the group, An ability to assemble, Respect for the technology, 5 major factors have considered the power of cycle rise about Britain, America, Japan which presented in the book, The Puritan Gift: Triumph, Collapse and Revival of an American Dream, by Kenneth Hopper and William Hopper. These basic principles as follows are shown in Fig. 5.

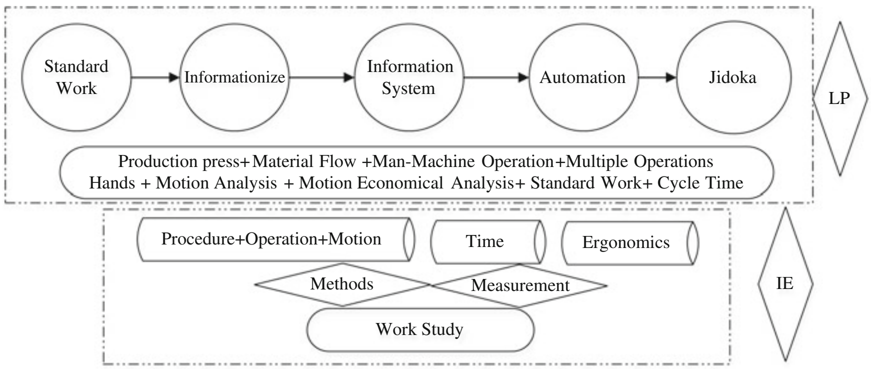


Fig. 4 Lean satisfaction principle to improve inventory

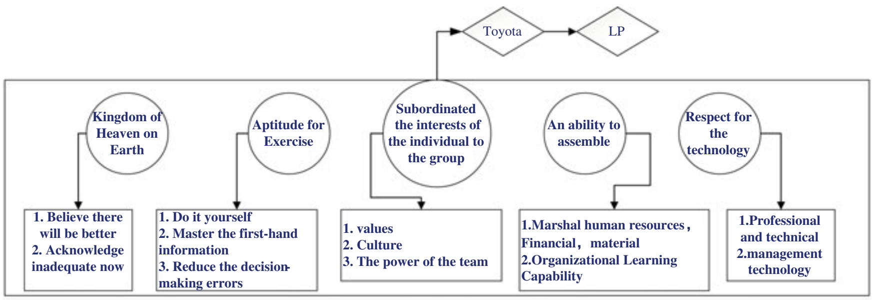


Fig. 5 The basic principles of LP and its internal logical relationship

3.3 Organization and Security System

Some enterprises in the application of LP could not set up to the mechanism that ensure such as Kanban management, eliminate waste, improve, JIT, single minute exchange of dies give full play to the role of it. Introduction of LP is a team thing, not an individual affair, we must establish the necessary organizational LP Promotion Center.

Companies must have an incentive mechanism in which there has a professional upward path for people with the ability of technology innovation and management innovation in the process of lean production application. This is a security mechanism in the enterprise application of lean production. It is important to have the system and incentive to ensure the full and effective participation and make full use of collective wisdom. In the early introduction of lean production mode, cooperate with professional consulting team is necessary. We design the Organization and security system LP in Fig. 6. In this system, a few key points as following: (1) The promoting of lean production will stop when met with resistance without the

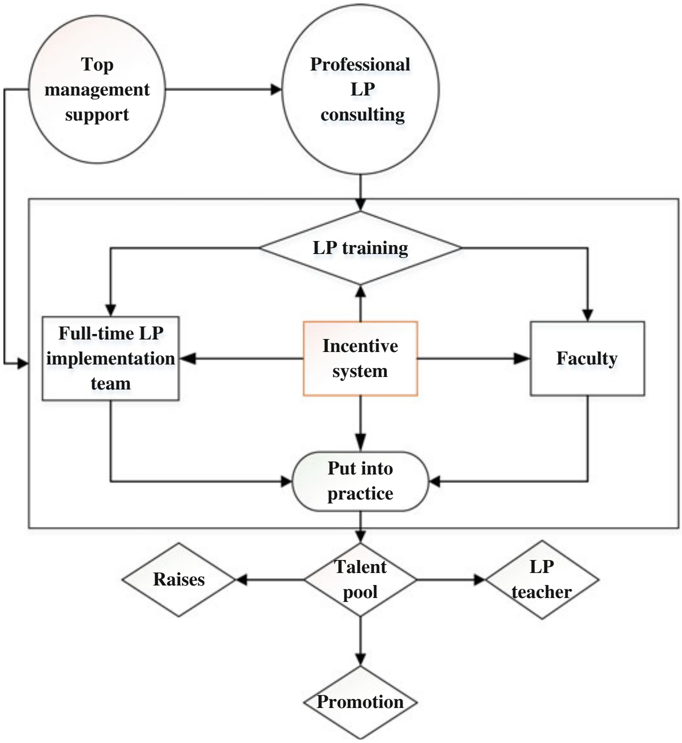


Fig. 6 Organization and security system

support of senior executives. So, the support of executives is the first priority. (2) When companies do not have basic ideas and methods of the lean production, it is necessary to form and train a full-time lean team hiring from outside professionals with the support of senior executives. (3) Relevant personnel participate in training and practice, during which process companies should build an incentive mechanism to ensure the competent person to join the talent pool of the enterprise. (4) Professionals must be full-time staff, otherwise, energy will be less and less in promoting lean production pressure which will eventually lead to failure of the implementation of lean production.

3.4 No Good Corporate Culture of Lean

LP is often considered such as Kanban management, eliminate waste, improve, JIT, fast changing technology system, learning and reference tools and methods, ignoring the core elements about "educating people", "custom", "corporate culture", "organization reengineering" when China's enterprises in the application of

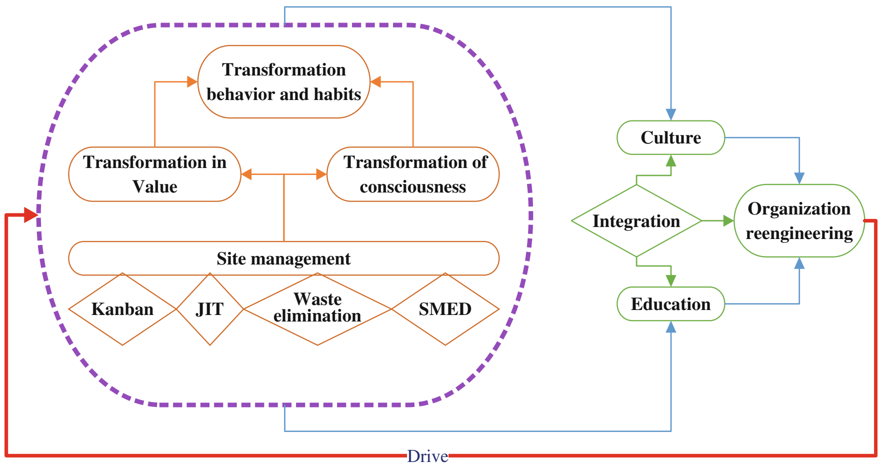


Fig. 7 Corporate culture of lean

lean production. These techniques have not developed, but in the course of practice they have repeated improved summarized and sublimated. The above-mentioned technology will play its due effect only combined with the following three aspects: cultivation of talent, cultivation of enterprise lean culture, guarantee organization of the application of lean production. Lean figure the relationship between technology and lean methods between the core elements. This is an iterative process, as shown in Fig. 7. Lean techniques constantly change employees' values and perception of issues when solving specific problems of enterprises, which will develop a behavior and practice further. This practice continually accumulates into part of enterprise culture to change the organization's current situation. All of these will form a closed loop benign circulation system which core is the cultivation of lean culture.

4 Summary

Based on the analysis of typical characteristics of the lean production, the present situation and existing problems of lean production are obtained. We put forward the way of China enterprise practice from four aspects, and the four aspects include the origin of LP, the basic principles of LP, the application of security system of LP, the corporate culture of LP. The work extends the lean production theory and will be applied on the lean production theory and practice of Chinese enterprises to provide reference.

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IoT Enabled Production-Logistic Synchronization in Make-to-Order Industry

Hao Luo, Jian Chen and George. Q. Huang

Abstract This paper investigates the synchronized production-logistics decision and execution problem under a specific industry format: make-to-order (MTO) production with cross-docking (CD) warehouse. The MTO strategy only manufactures the end product once the customer places the order. Normally, MTO firms need a space for temporal storing finished product and consolidating different finished products within the same customer order. The cross-docking policy is widely adopted to operate the t warehouse. In this environment, the production and logistics have multiple interactions in decision making and execution. This special problem is defined as MTO-CD synchronization. To achieve a successful MTO-CD synchronization, an IoT (Internet of Things) enabled information infrastructure is proposed. This infrastructure creates a closed decision-execution loop of by linking the frontline real time data, user feedback and optimized computation together. A real life case study in a chemical firm has been conducted to illustrate the usage as well as the effectiveness of proposed total solution.

Keywords Production-logistic synchronization · IOT (internet of things) · Make-to-order · Cross docking

1 Introduction

Logistics is one of the most crucial driving force of the global economic development and internationalization. It has become a key function at strategic business levels as it has proven to achieve significant competitive advantage by catering the

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growing demands in speed and flexibility [1]. However, comparing with other industry segment, logistics industry is a laggard rather than a leader in adopting new technologies. Global logistics sustainability is facing Grand Challenges in terms of economic, environmental and social. Symptoms of today's logistics include waste space and energy, delay deliveries, endanger workers, increase road congestion, and pump out vast quantities of carbon dioxide [2].

This paper addresses a real life industrial project in chemical industry. Although the main content of this case study is manufacturing management, the synchronization of production and internal logistics already illustrates some core concepts of Physical Internet.

The major problem in this case is a synchronized decision of production scheduling and warehouse operation in "make-to-order" (MTO) industry. The MTO strategy only manufactures the end product once the customer places the order. Be part of very competitive supply chains, manufacturing companies cater to an increasing variety of products with client specific features, special packaging etc. to increase or maintain the market share. In addition, retailers and wholesalers expect small batch deliveries within short and dependable time window. This means that customers prefer a MTO policy with short response time.

High degree of customization and no excessive inventory are widely accepted as two significant features of MTO. In many literatures, it is believed that no finished goods inventory is maintained in MTO environments [3–6].

In practice, however, many firms with MTO production fashion cannot achieve absolute zero finished product inventory. Notably this situation is not referring to the firms apply the combination of MTO and MTS (make-to-stock). In some pure MTO firm, the products cannot be loaded to vehicle and delivery immediately after the production process. Specifically in food industry and chemical industry, the product variety is huge and one customer order normally contains a large number of product types which produced in different plants and cannot be completed at the same time.

Once the first product in a customer order is released from production line, a certain storage space should be reserved to the whole order. The space will be occupied for a while until all products in the same order are ready to deliver. This temporary storage function is very similar to the cross-docking in the distribution centre. The basic idea of cross-docking is to transfer incoming shipments directly to outgoing vehicles without storing them in between [7]. However, in the MTO manufacturing, the cross-docking warehouse has two additional functions: (1) temporal storage for finished product, (2) consolidating finished products within the same customer order.

In this make-to-order and cross-docking environment, the operations in manufacturing plant and warehouse have multiple interactions. The production scheduling in shop floor affect the storage space planning in the warehouse, and vice versa. For instance, if items in the same customer order cannot arrive warehouse synchronously due to the deficient production scheduling, the space occupation time in warehouse has to be extended. It even leads to delay of truck loading and delivery. Likewise, the space of cross-docking warehouse in MTO industry is usually very limited. An improper space planning may lead to product blocking in the pick hour. The finished products wait outside the warehouse, even if there is still some room inside. Because the space is reserved by a customer order with long waiting time, it cannot be released until all products finish the loading.

We defined this production environment as Make-to-order production and cross-docking warehouse (MTO-CD) synchronization. To achieve a successful MTO-CD synchronization, there are two crucial issues need to consider. In the decision level, a coordinated decision mechanism between production scheduling and warehouse operation should be established to balance the pressure between two departments. In the execution level, a real time information infrastructure should be developed to instruct the front line operations in shop floor and warehouse. Meanwhile, the real time status of production, internal transportation, storage space assignment and truck loading should be posted back to the decision level to create a close information loop.

Although there are some research work related to make-to-order and real time manufacturing informatics in literature, following research gaps still can be identified.

The need for real-time data in production shop floors and warehouse has been long recognized in industry. Recent developments in wireless sensors, communication and information network technologies (e.g. radio frequency identification—RFID or Auto-ID, Bluetooth, Wi-Fi, GSM and infrared) have created a new era of the internet of things (IoT) [8]. The successful application of IoT and the urgent need of real-time data support in the manufacturing execution system have nurtured the extension of the IoT to the manufacturing field. However, the most of IoT applications isolated in single manufacturing segment. The IoT enabled data sharing and coordinated operation between production and logistics are still overlooked by both academia and industry. The real-time visibility and interoperability, which are core characteristics of IoT, created opportunity to achieve synchronized production-logistics decision and execution.

The aim of this paper is to identify the characteristics of MTO-CD synchronization problem from a real life industry case and propose a general solution framework with MIOT technology to solve the problem.

The structure of this paper is organized as follow. Section 2 will give a literature review of related research work. Section 3 will introduce the motivation case company. Some general requirement of MTO-CD synchronization will be abstracted from this case. Section 4 will propose a general solution framework for MTO-CD synchronization problem. Section 5 will give the detailed discussion about the implementation of IoT enabled execution system, respectively. The final section will summarize the key findings and contribution of this paper.

2 Motivation Case of the MTO-CD Synchronization Problem

This study is motivated by a real life MTO based firm in chemical industry. This collaborating company is the leading paint manufacturer in China. They produce 6 major categories (timber coatings, decorative paints, floor paints, industrial paints, waterproof paints, printing ink) and more than 6000 types of products from 7 plants. Due to the huge number of product variety and the erratic consumer behavior, it is thus impractical for manufacturers to make to stock on the basis of the forecasts of customer order. The production only takes place after consumers confirm their orders. Orders are received through telephone, fax, and online commerce platform every day. The customers are scattered all over the country. Finished products released from plants are temporal stored in a cross-docking warehouse before shipping. The transportation is taken by a third part logistics company with trucks.

Some characteristics emerged in this MTO-CD case have substantiated the complexity of the problem. The challenges are summarize in following three aspects.

2.1 Challenges in MTO Production

The combination of product types in one customer order is complex. Normally, one customer order may contain more than thirty types of products with various colors, recipes and usages. These products come from different plants with a variety of production rout and processing time but should be shipped at the same time. It is imperative to create schedule that can guarantee simultaneous production.

Due to the feature of the paint industry, the changeover times and machine cleaning cost between product of different coolers and recipes should be considered. However, if the production schedule merely prefers grouping same product types together to reduce changeover time and clearing cost, there exists a fair chance that products in one customer order are split and the simultaneous is sacrificed.

2.2 Challenges in CD Warehouse Operation

A warehouse with cross-docking function is available for temporal storage of finished product. As shown in Fig. 1, the layout and operations in the warehouse is special.

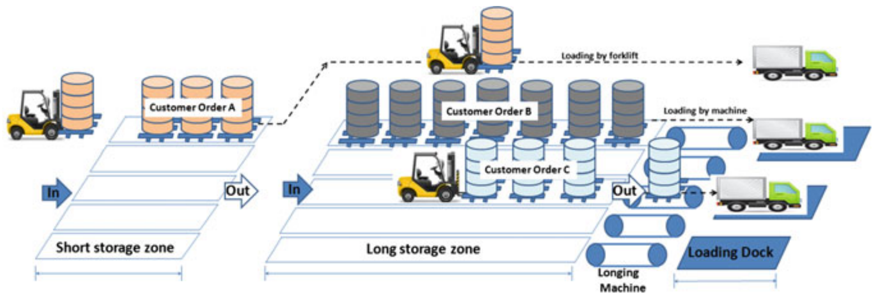

Fig. 1 Cross-docking operation in the collaborating company

(1) There is no shelf in the warehouse. The product pallets are put on the floor and lined up in the strip zones.
(2) Because of limited of space, there is no aisle between each strip zones. The pallet operation must follow the first in first out fashion in one direction. That means the pallet can only be put away into the strip zone from left head side and be picked up from right hand side one by one.
(3) The strip zones have different size and loading speed. For example, in the zone on right hand side is a long zone, which can story 30 pallets. The zone on left hand side can only story 10 pallets. Since the long zone directly connects to the loading dock, the product in this zone can be loaded on the truck by loading machine. Because the number of loading dock is limited, pallets in short zones can only be transported by forklift. The loading speed is much lower than the long zone.
(4) The cross-docking operation is novel due to the production and shipping police. When the first pallet of a customer order is released from a plant, it must be moved into the warehouse and occupies one zone. Once a zone is assigned to an order, pallets in other orders cannot be mixed in such zone, since there is no space to do the order consolidation inside the warehouse. Therefore, the track allocation and loading operation pose many challenges for warehouse management.

3 Overall Solution of MTO-CD Synchronization

The aim this section is to develop an IoT enabled manufacturing information infrastructure for MTO-CD to implement real-time visibility and synchronized decision and execution in production, internal logistics and warehouse section.

The core concept of this architecture is adapted from AUTOM proposed by Huang et al. (2008), which is industry-proven best practice solution to known in real time manufacturing resource management. Some key component has been

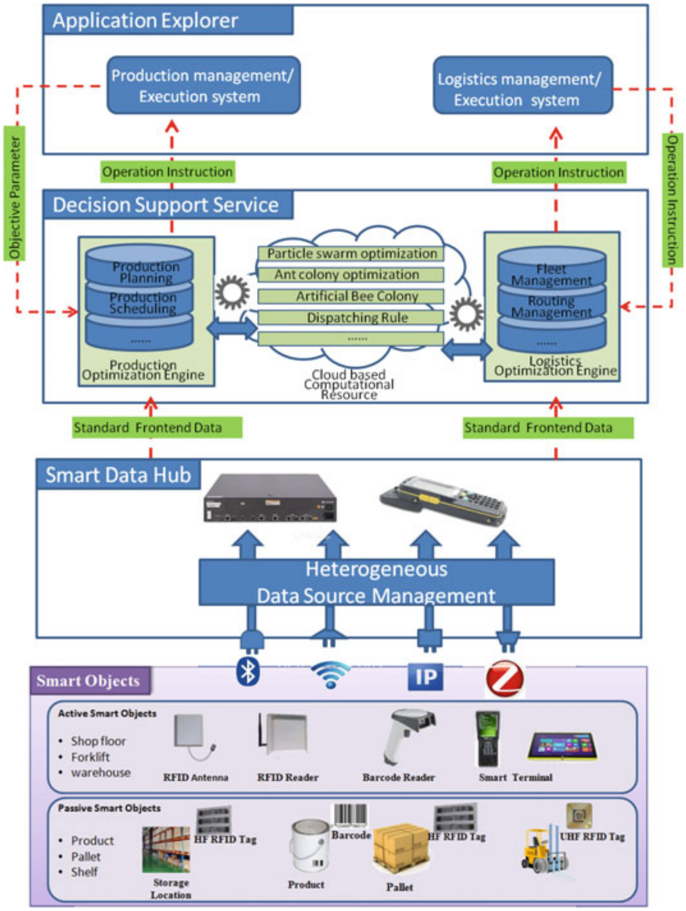

Fig. 2 IoT enabled information infrastructure for MTO-CD synchronization

modified to meet the specific need of MTO-CD environment. Four functional components involved in this infrastructure are described as follows (Fig. 2).

3.1 Smart Objects

Manufacturing information capturing plays a very important role in the proposed infrastructure. Smart objects are responsible for capturing the real-time manufacturing information occurred at production, internal transportation and warehouse. Smart objects are those physical manufacturing objects that are made "smart" by equipping them with IOT devices. Manufacturing objects with smart terminal device, such as RFID readers, PDA, are active smart objects. Those manufacturing objects with identification tags (RFID tag, QR code) are passive smart objects. Smart objects interact with each other through wired and/or wireless connections, creating what is called an intelligent ambience. Therefore, smart objects are able to sense, reason, act/react/interact in the intelligent ambience community.

3.2 Smart Data Hub

Smart data hub acts as a server that hosts and connects all RFID-enabled smart objects in the in the intelligent ambience. This turnkey hardware provides a unified platform to deploy and manage RFID and other Auto-ID devices and associated software systems for collecting and processing real-time field data.

The core smart data hub technology packages all necessary IOT devices such as the desktop, embedded, mobile and portable, into suitable forms so that they are suitable to be deployed in different environments. Smart objects are represented as software agents in the smart data hub operating system within which they are "universal plug and play (UPnP)" and interoperable.

3.3 Decision Support Service

Decision support service is the brain of this infrastructure, which can provide intelligent decision making service. Optimization engines with specific strength features are embedded in this service level. The optimization engine contains multiple optimization algorithms with general defined input and output, such as particle swarm optimization, ant colony optimization, genetic algorithm and other heuristic algorithm. Those optimization algorithms are well organized in several groups that suitable for different application environment, for example, the production planning and scheduling module, routing optimization module, and material handling optimization module. Since many optimization problem in manufacturing is NP hard, which need great computation resources consumption, the expansibility and scalability of the optimization solution should be considered. Therefore, the design of optimization engines follows the SaaS (Software-as-a-service) specification. The computation resources located on cloud side can be used when solving some large size optimization problem.

3.4 Application Explores

The application explores provides multi-view manufacturing interface for target users in plant and warehouse to visualize real-time manufacturing information and decisions so as to facilitate their adaptive execution. According to the requirement of synchronized decision and execution, the application explores can be divided into multilevel. It can provide real-time operational instructions for the operators in plants, forklift and warehouse.

4 Implementation of MTO-CD Synchronization Case

This section illustrates how to implement the proposed total solution into the synchronized production-logistics environment.

4.1 Creation of Smart IoT Environment

The first step of the implementation is to create an IoT based smart environment (see Fig. 3). In order to achieve the dual-way interaction between frontend operators and backend decision support system, following data interaction points, which are facilitated by specific IoT equipment, have been deployed in the environment.

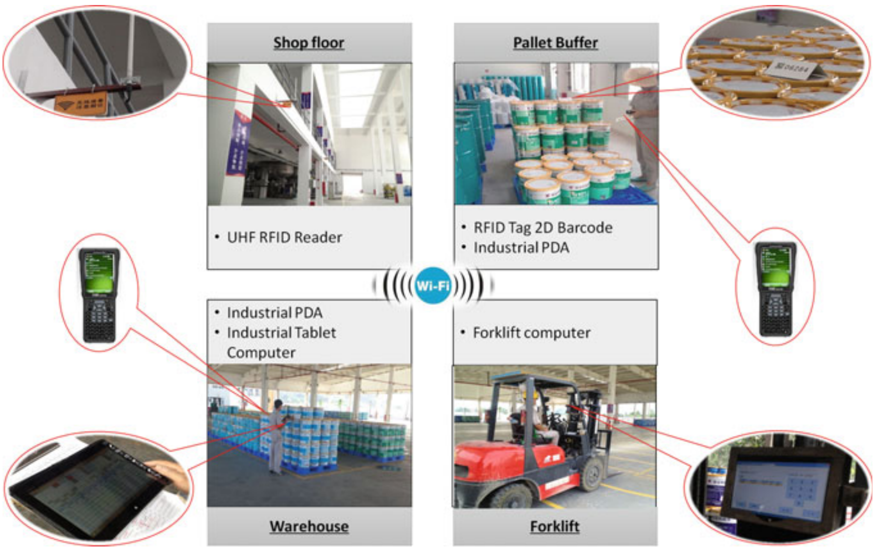

Fig. 3 Creating the smart IoT environment in the MTO-CD synchronization case

4.2 Operations in Production and Logistics

Figure 4 shows the workflow and corresponding system user interfaces of production and logistics in this MTO-CD synchronization case.

(1) The start point is the marketing department. The customer order received by marketing department will be evaluated by the marketing officer. This evaluation should consider the quantity of product, processing time of product as well as current capacity of plants. After this evaluation, the customer orders will be dispatched to the plants. At the same time, the expected delivery data of each order is confirmed.
(2) When the production department received the daily order, the production scheduling will be conducted in each plant. The decision support service will help the planner to determine the production sequence of orders and the assignment of machines.
(3) The operators in shop floor will execute the production under the instruction of production planner. An industrial PDA is equipped to each operator. The order sequence and machine assignment information can be downloaded to the

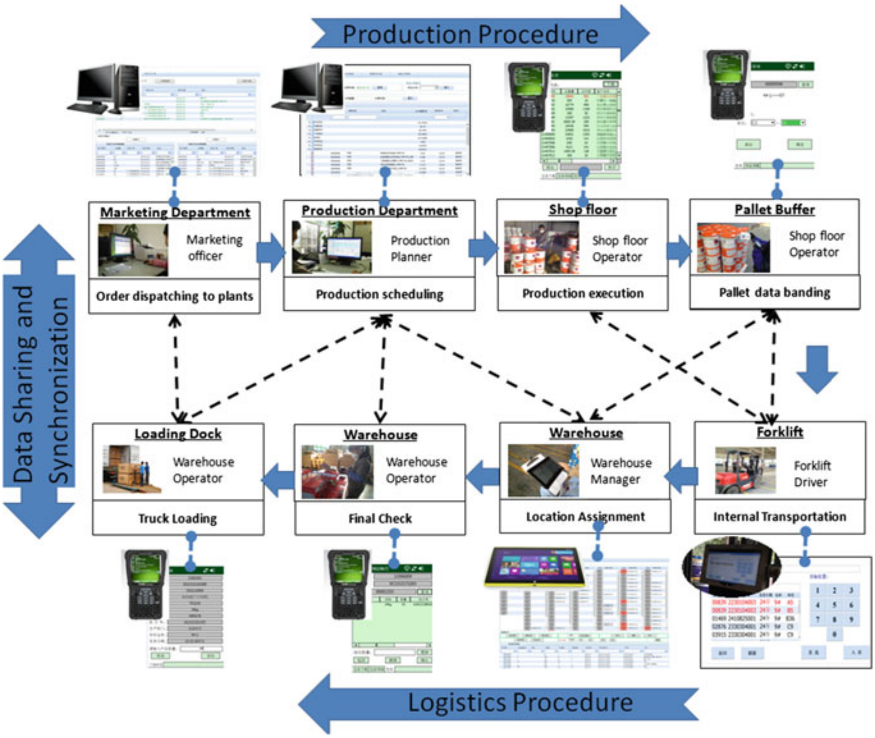

Fig. 4 Work flow and system interfaces in the MTO-CD synchronization case

PDA. The operator also can use the reader function on the PDA to identify the raw material and machine ID.

(4) When the finished products are packed by the bins, the operator will stake the bins on the pallet. And then, the pallet will be moved out from the plant and put into the pallet buffer. In the pallet buffer, the operator will use the PDA to read 2D barcode on the product and band the product information to the RFID Tag on the pallet.

(5) The forklift takes the internal transportation tasks from the pallet buffer of each plant to the finished product warehouse. The forklift is equipped with specialized forklift computer and portable RFID reader. When the forklift takes a pallet in the pallet buffer, the RFID tag on the pallet can be detected. The information of product and destination warehouse will be shown on the screen.

(6) In the warehouse, the task of warehouse manager is to assign the storage location to customer orders. This assignment is conducted by the decision support service. The manger uses a tablet computer to monitor the warehouse space assignment. The major interface of the tablet is the warehouse layout. The occupation status of storage zones are shown on the layout. The manger review the storage zone assignment generated from the decision support service and can make adjustment according to current situation.

(7) In the warehouse, the warehouse operator will use the PDA to check the sorting progress of each customer order. Since the products in one customer order are produced from different plants. The sorting operation may take a long time. When each new pallet is moved in and put into the storage zone, the operator will use the PDA to check the item information and report the arriving to the backend service.

(8) At the loading dock, there is a final check point before the product pallets are loaded onto the truck. The delivery order can be downloaded to the PDA and generates a loading check list. Warehouse operator uses the device to read the pallet tag, the corresponding item and quantity can be automatically matched and ticked. After the operator finished the final check of the whole customer order, the storage zone can be released. This information can real timely updates to the decision support server and trigger a next round storage assignment.

5 Conclusion

This paper investigates the synchronized production-logistics decision and execution problem under a specific industry format: make-to-order production with cross-docking warehouse.

The MTO systems offer a high variety of customer-specific and more expensive products. Many MTO firms adopt the cross-docking policy to manage the finished product warehouse. In this environment, the production and logistics have multiple interactions in decision making and execution. To achieve a successful coordination in these two functional departments, two crucial issues have been identified in this paper: (1) establish a coordinated decision mechanism between production scheduling and warehouse space management and (2) build a real time information infrastructure to support frontend production and logistics operation.

To fulfill these special requirements in the MTO-CD environment, a IoT enabled manufacturing information infrastructure has been developed. In this proposed infrastructure, heterogeneous devices in shop floor and warehouse are wrapped up as smart objects. The real time frontend data generated from smart objects can be captured and standardized by a smart data hub. A decision support service provides a cloud-based computational resource specific optimization problem, such as, production planning and scheduling, warehouse space assignment. The operators in shop floor and warehouse conduct their operation under the instruction of an application service. This infrastructure creates a closed loop of decision and execution by linking the frontline feedback, real time machine status and the optimization results together.

In order to demonstrate the proposed infrastructure, a real life case in a chemical industry has been studied. In this chemical firm, the smart production and logistics environments has been created by installing RFID reads and tags on shop floor, pallets, warehouse entrance as well as forklift. The coordinated decisions between shop floor scheduling and storage space assignment have been facilitated by an optimization engine. The implementation results and user feedback illustrate the usage as well as the effectiveness of proposed total solution. This case study illustrated the key concepts PI in practice and verified that case company can get benefit from PI application.

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New Insights into the Research on the Fiber Optical Monitoring Instruments

Yu-tong Li, Peng-hui Liu and Yu-qing Xia

Abstract Fiber optical monitoring instrument is endowed with many characteristics that traditional materials do not have for its unique size and structure. In order to lead the development of science and technology, many countries increase efforts in research to develop this new material. More and more attention is paid to this fiber optical monitoring instruments all over the world which is reflected in both the development of patent applications and the number of papers. This article give the current performance, definition, classification, distribution and main technologies in China and the leading countries in the field of fiber optical monitoring instruments from the perspective of deep analysis. It turns out that industry of fiber optical monitoring instrument is still in its rapid development stage and that more attention will continue to be paid to this instrument by various countries in the following period of time.

Keywords New insights · Mechanical analysis · Optical fiber monitoring instruments

1 Introduction

Fiber Bragg Grating, as sensor element, is widely used in measurement for its superior characteristics such as resistance to electromagnetic interference, high temperature and moisture. Its advantages are more prominent in engineering when measurement point is under the harsh environment or far from monitoring center. Fiber Bragg Grating (FBG) is a special fiber optic whose constituents have photosensitive materials. It will change with physical properties outside such as

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pressure and temperature and emit mutative reflected central wavelength. Demodulation system made of FBG can accurately work out the wavelength at the high speed and in the real time and demodulate the physical quantities such as strain and temperature. The wavelength of FBG temperature sensors will be directly proportional to the change of temperature and be inversely proportional to the change of pressure. FBG sensors are placed on the ground and connected to demodulation instruments in cables to monitor the change of wavelength and the dynamic of temperature and pressure of each measurement point where the sensors in the wells are located.

2 Development Trend Analysis

2.1 Definition, Classification and Distribution

Heavy oil is a crude oil with high viscosity and high density that is named heavy crude oil in foreign countries. According to the classification standard proposed by the United Nations Training and Research in the Second International Conference on Heavy Oil and Tar Sands, heavy oil can be divided into categories shown in Table 1.

Heavy oil accounts for a large proportion of oil and gas resources in the world with annual production of over 1.27 × 108 t. Canada has the largest reservoir of heavy oil which is about 2680 ~ 4000 × 108 t. Reservoir of heavy oil underground in Venezuela is about 490 ~ 930 × 108 t and reservoir in the USA is about 90 ~ 160 × 108 t. Resources such as heavy oil and bitumen are widely distributed in China with reservoir predicted to be over 300 × 108 t. With the reduction of reservoir of light oil, exploitation of heavy oil will be continuously increased. Each country has strengthened research and development of exploitation technologies of heavy oil [1].

2.2 Main Technologies in the Past

At the present, most conventional oil and gas fields in China have entered the post stage of exploitation. Exploitation of heavy oil becomes more and more important since reservoir of conventional crude oil has increasingly been reduced. Existing technologies in exploitation of heavy oil mainly include cold exploitation

Table 1 Classification standard of UNITAR

Categories	The first index	The second index	
	μ_0/mPa·s	(16 °C) ρ_0/g·cm^{-3}	60 °F (15.6 °C) API degree
Heavy oil	100 ~ 10,000	0.934 ~ 1.000	20 ~ 10
Asphalt	>10,000	>1.000	<10

Table 2 List of main exploitation technology of heavy oil

Main exploitation technologies	Categories
Cold exploitation technology of heavy oil	Exploitation technology based on viscosity reduction by chemical methods
	Exploitation technology based on the injection of gas
	Exploitation technology based on viscosity reduction by magnetic
	Cold exploitation technology based on sand production
	Other technologies
Thermal recovery technology of heavy oil	Exploitation technology based on steam throughput
	Steam-driven exploitation technology
	Exploitation technology based on in-situ combustion method
	Hot-water-driven exploitation technology
	Other technologies
Composite exploitation technologies	Viscosity reducer + exploitation technology based on steam throughput
	Carbon dioxide + exploitation technology based on steam throughput
	Steam + carbon dioxide + exploitation technology based on surfactant
	Steam-assisted gravity drainage in horizontal wells
	Other technologies

technology, thermal recovery technology, and composite mining technology and so on shown in Table 2 [2].

Thermal recovery technology of heavy oil horizontal wells such as steam throughput has greatly enhanced the production of oil. New exploitation technologies of heavy oil such as steam-assisted gravity drainage has promising application prospect [3].

3 The Instruments System

Most reservoir of heavy oil in China has developed into the middle and late stages. The ways of exploitation have changed from steam throughput into steam-driven and steam assisted gravity drainage (SAGD). Since temperature in oil and gas wells is increasingly high and pressure heavy with the increase of mining depth, testing process and technologies of thermal recovery cannot meet the testing needs of thermal recovery of horizontal wells. However, fiber optic sensors are applicable to the long-term measurement of parameters such as pressure, temperature and steam quality in oil and gas wells because they are resistant to high temperature, corrosion and obstruction, safe, small size and easy to operate. Special environment in oil and gas wells with high temperature, high pressure, corrosion and limited space provides advantageous platform for the application of fiber optic sensors. So, they are widely used in “intelligent well”.

3.1 Fiber Optic Sensors

The primary operating principle of fiber optic sensors is to transmit light from the light source to modulator through fiber optic, then change optical properties such as intensity, wavelength, frequency and phase, after the parameters to be measured interacted with the light that has entered the modulation region, which is named modulated signal light. And finally the parameters can be measured after modulated signal light is transmitted to photo-detector through fiber optic and then is demodulated. Fiber optic sensors can be divided into two categories (Table 3): one is functional (sensitivity-transmitted) fiber optic sensors; the other is non-functional (light-transmitted) sensors.

Fiber optic sensors is the new technology in recent years that can be used to measure many physical parameters such as sound field, electric field, pressure, temperature, angular velocity and acceleration. It can also take measurement tasks that are difficult to finish by existing technologies. Fiber optic sensors have unique and strong capacity even in narrow spaces and in environment with strong electromagnetic interference and high pressure [4].

3.2 Fiber Optical Monitoring System

Below are introductions of several monitoring systems that are able to monitor dynamic of temperature and pressure in horizontal wells of heavy oils and dynamic of steam quality in steam horizontal wells.

(1) *FBG monitoring system*

Fiber Bragg Grating (FBG) is a special fiber optic whose constituents have photosensitive materials. It writes into gratings the frequency and wavelength of the

Table 3 Categories, characteristics and application of fiber optic sensors

Categories of fiber optic sensors	Advantages	Disadvantages	Application
Functional type (sensitivity-transmitted)	Compact and high sensitivity	Special fiber optics is needed and it is of high cost	FOG, fiber optic hydrophone et al.
Non-functional type (light-transmitted)	There is no special fiber optic and technologies. It is easy to make and of low cost	Low sensitivity	More practical

designed spectrum by micro-laser technology and then writes gratings into the core of fibers by UV laser technology according to the spacing between monitoring distance and measurement point. Each group of gratings has fixed frequency of spectrum and wavelength shielded by special polymer materials resistant to high temperature of 350 °C.

Fiber Bragg Grating is a new optic-measurement technology that is most promising and influential. Compared with other types of sensors, FBG has lots of advantages [5]: ① it has high reliability and stability; ② it is easy to take distributed measurement by connecting multiple FBG in series in the same fiber using WDM technology; ③ it is resistant to electromagnetic interference and corrosion, has good insulation of electricity and can work in harsh chemical environments; ④ the sensor head has simple structure and small size that is applicable to various situations. At the present, fiber optic sensors are successfully applied in industries such as bridges, water power, coal and electricity power, but has many problems in the application of engineering.

(2) *Fluorescent fiber monitoring system*

Fluorescent fiber dynamic monitoring system makes use of the emission of linear spectra—fluorescence and its afterglow in particular spectrum from some rare earth's fluorescent substances that are activated after being exposed to sunlight. Temperature can be measured by measuring the time of afterglow since the lifespan of fluorescence changes with temperature. At the same time, pressure can be measured because density of rare earth's fluorescent substances will change with pressure outside, leading to changes of spectra and energy they emit.

Fluorescent fiber temperature sensors and their monitoring system are resistant to electromagnetic interference, high pressure and corrosion. It is also insulating and has high accuracy, high sensitivity, small size and long lifespan. It can be used in contact measurement and also in non-contact measurement, which is applicable to temperature measurement in fields such as electricity power, medical treatment, petrochemical, industrial microwave, food safety, science research, military and national defense. It is a long-lifespan product of low cost, high accuracy, good stability and interchangeability in the single-point temperature measurement.

(3) *Steam quality monitoring system*

Injection of high-temperature-and-pressure steam into wells is the primary way to explore heavy oil. The measurement of the steam quality now is achieved by sampling on the site and then testing in laboratories. According to the requirement of technology, the dryness of steam in boiler outlet in oilfield should be strictly controlled in the range of 75 $\sim$ 80 %. Low dryness cannot meet the needs of thermal exploitation in oilfield while high dryness will lead to scale of boilers which will reduce the heating efficiency and even endanger the safety of equipment. Degree of dryness is the important index that will have impact on the result of thermal recovery of heavy oil. It is also the important parameter of safe function of boilers with steam injection. Fiber dryness measurement technology can achieve continuous measurement in the real time in the measurement of parameters of oil wells with injection of steam. This system is stable, reliable, highly accurate and resistant to interference. It can accurately provide the location and changes of the oil layer underground by measuring and analyzing the dryness of steam, which has broad market prospects.

4 The Instruments Analysis

4.1 Foreign Fiber Optic Sensors

Testing technology of fiber optic in wells has become research hotspot in the field of the International oil production and test. Weatherford in the USA, Schlumberger, Virginia Tech University, Sabeus in the USA, BP, Optoplan A S, Cidra et al. are all committed to the research and development of fiber sensors used in oilfield testing. Some of the products have been widely used. There are some works with features shown in Table 4 [6].

At the present, fiber optic sensors have been more widely used in foreign oil-fields including famous oil companies such as BP, Shell, Chevron et al. and oilfield service companies such as Schlumberger, Weatherford, Halliburton and Baker Hughes who take the lead in the application of this advanced technology to oilfield and have gained lots of benefits. Foreign companies only committed to R&D and production of fiber optic sensors are Sensa, CiDRA, Optoplan, Sensor Highway, Pruett, Prime Photonics, LUNA Innovations, Micron optics, Sensornet and so on. And some of these companies have been acquired by oilfield service companies. Introduction bellow is about the products and technologies of several representative companies [7]:

Table 4 Development of the application of oil and gas wells of foreign fiber optic sensors

Company/research institution	Fiber optic sensors
Optoplan A.S. in Norway	Measurement system for fiber optic in wells
Sensor dynamics	Mach-Zehnder (MZ) pressure sensors with fiber optic interferometer of SD2000
Virginia Tech University in the USA	Samples of sensors
Schlumberger sensa	DTS system used in monitoring temperature in wells of high temperature with steam injection
Sabeus in the USA	Monitoring system of temperature in DTS-250 oil and gas wells
Weatherford	A series of monitoring and measuring instruments used in intelligent wells
Oluma	The sensing system used in measurement of pressure and temperature in oil and gas wells

(1) *Sensornet in the Britain*

Sensornet Company has been committed to the development of distributed temperature and pressure sensors and systems for fibers and has developed a series of products. The core expertise and technology of Sensornet Company is the distributed temperature-and-pressure testing system for fiber optics that is on the basis of Stimulated Brillouin Scattering (SBS). Stress monitoring system developed by this company has also been under verification test of well-set-lapsed monitoring.

(2) *Schlumberger in the USA*

Schlumberger Company in the USA makes use of fiber optic sensors produced by Sensa Branch in the UK. This company has developed monitoring and information-collecting system for distributed thermal sensors. Scientific planning of operations such as measures for well testing, well logging, water blocking and well throughput can be achieved.

(3) *Weatherford in the USA*

Weatherford Company has temperature-and-pressure-testing system for fiber optic parametric test systems designed according to Bragg grating principle. This is an all-fiber system and has characteristic of passivity. Weatherford Company has a wealth of experience in DTS ground system evaluation and can provide ancillary equipment and services for DTS wells.

(4) *Micron Optics in the USA*

Micron Optics is a famous optical fiber sensor in the USA and also one of the earliest manufacturers engaged in fiber optic sensing in the world. Its products include temperature sensors for distributed fibers, pressure change sensors, displacement sensors, acceleration sensors and so on. Their advantages and disadvantages are listed in Table 5.

Table 5 The comparison of classification and characteristics of fiber sensors for pressure and temperature measurement under the oil and gas wells

	Fiber optical interferometric sensors	Raman scattering fiber sensors	Side polishing fiber sensors	Fiber Bragg grating sensors
Advantages	Mature technology and high measurement accuracy	Mature technology and distribution measurements	Relative mature technology and high measurement accuracy	Relative new technology and strong multiplexing capability
Disadvantages	High cost and low product consistency	Unable to obtain the pressure value and data processing is slow	Difficult to produce moderate multiplexing capability	Low pressure sensitivity and complex demodulation system

4.2 Fiber Optic Sensors in China

In China, more and more attention is paid to and even more research is conducted on fiber optic sensors. Shi Xiaofeng, et al. from Beijing University of Aeronautics and Astronautics has researched ways to measure well temperature by raman-scattering-distributed optical fiber temperature measurement system [8]. Yu qingxu, et al. from Dalian University of Technology have developed a fiber-temperature-and-pressure sensors system for the measurement of oil wells with high-temperature steam injection [9]. Wang Hongliang, et al. from Xi'an Petroleum University have designed and developed antioxidant dual FBG sensors with temperature compensation that are resistant to high temperature, high pressure and corrosion [10]. Ma Ming, et al. from Petro China Liaohe Oilfield Company have improved manufacturing processes and packaging technology, solving problems about continuous monitoring thermal dynamics of horizontal wells with thermal recovery by steam injection of heavy oil [11]. Wang Fu from Shengli Oilfield developed a sensor for fiber temperature and pressure that can be used to long-term monitoring under oil wells, which is a breakthrough in sensors for fibers under wells in China [12]. Shun Weiming from Harbin Engineering University produced several fluorescent FBG with different structures by connecting fluorescent fibers and FBG or by making FBG in hydrogen-contained fluorescent optical fibers in order to achieve simultaneous measurement of temperature and strain [13]. Shang Xiansi, et al. from Heavy Oil Development Company of Xinjiang Petroleum Administration Bureau solved problem about direct monitoring of steam quality under shallow heavy oil wells by successfully monitoring steam quality in any depth under wells based on the principle of two-phase flow of injected saturated steam [14]. Penghui lv, et al. from Wuhan University analyzed the developing trend on global green renewable energy standard and several standards on the oil instruments [15].

5 Conclusion

With the growing awareness of resources of monitoring instruments for fibers, more and more attention is paid to the technology of monitoring equipment for fibers. The number of patents in this field shows an upward trend as a whole, which signifies that the development of technology of monitoring equipment for fibers is active and in a rapid growth phase. USA has achieved a dominant position in the patent application of technology of monitoring equipment for fibers. This shows that these countries attach more importance to the technology. So, authorized agencies may cooperate with these relevant areas in the future. All researches in China are conducted for specific application from different perspectives. However, the testing technology is still under developing. More importantly, further researches are under urgent need to work out overall schemes and research ideas for series products, since researches now are lack of extensive investigation and in-depth analysis. There are no mature commercial products now. Systematic research and development of thermal dynamics monitoring instruments under wells will have very important social value and economic value to thermal recovery of heavy oil.

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Design and Development of a Physical Internet-Enabled Smart Factory for Discrete Manufacturing

Ray Y. Zhong

Abstract Discrete manufacturing (DM) is characterized by individual or separated unit production and thus applied in many segments due to its quick responsiveness to market and customer requirements. This paper focuses on reporting the design and development of a Physical Internet (PI)-enabled smart factory for discrete manufacturing. PI-enabled manufacturing management system (PIM^{2}S) is designed to collect real-time data from manufacturing factories by using radio frequency identification (RFID) technology, to facilitate the database design, as well as to interact with other systems by a middleware standardized interface. A case study is introduced to describe how PIM^{2}S helps a DM company to improve its shop-floor management.

Keywords Physical internet · Smart factory · Discrete manufacturing · RFID · Shopfloor

1 Introduction

Discrete manufacturing (DM) is characterized by individual or separated unit production and thus applied in many segments due to its quick responsiveness to market and customer requirements [1]. It plays an important role in manufacturing fields like large-scale machinery manufacturing and mold and die manufacturing etc. DM often features dynamic and complicated manufacturing environment [2]. Hence it faces great challenges on the shopfloors, including manufacturing data management, weak ability of responsiveness and poor visualization. These challenges heavily stymie the productivity improvement on DM shop floors.

Physical Internet (PI) refers to an open global logistics system using encapsulation, interfaces and protocols to achieve physical, digital, and operational interconnectivity, aiming to replace current logistical models [3, 4]. The vision of PI

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is to encapsulate goods in smart, ecofriendly and modular containers ranging from large containers to the small boxes [5]. Internet of Things (IoT) is one of the key technologies to enable PI concept, thus, PI-enabled containers or boxes could be world-standard, smart, green, and modularized within the whole supply chain management (SCM) [6]. Based on the PI concept, smart factory in manufacturing field could be realized by making full of advanced technologies such as IoT, wireless communication, and interfaces.

This paper focuses on reporting the design and development of a PI-enabled smart factory for discrete manufacturing. Due to the limited space, software perspectives such as system architecture and key services are specifically concentrated. PI-enabled manufacturing management system (PIM^{2}S) is designed to collect the real-time data from manufacturing factories by using radio frequency identification (RFID) technology to facilitate the database design, as well as to interact with other systems by a middleware standardized interface.

This paper is organized as follows. Section 2 reports the overview of PIM^{2}S in terms of framework and key components. Section 3 discusses an interface middleware that enables PIM^{2}S real-time intercommunication with other information systems. A case study is introduced in Sect. 4 to describe how PIM^{2}S helps a DM company to improve its shop-floor management. Opportunities and challenges for further study are highlighted in Sect. 5 to conclude the paper.

2 Overview of PIM^{2}S

2.1 System Framework

PIM^{2}S is divided into four layers: Shopfloor Layer, MES Layer, Interface Layer and Decision-making layer (Fig. 1). Shopfloor Layer includes various hardware devices (e.g. readers, tags, communication devices etc.). Detailed information about this layer such as RFID devices deployment, network deployment and the hardware platform working mechanism could be found in [7]. MES Layer contains three core services: communication service, planning and scheduling service and visualization service. Interface Layer is an interface service that is based on middleware philosophy aiming at real-time intercommunicating with other systems. Decision-making Layer encompasses some information systems such as ERP (Enterprise Resources Planning), PDM (Product Data Management), and CAPP (Computer-aided Process Planning), which are primary for making decisions such as planning and scheduling.

The framework forms a closed-loop by enabling information flow from down level to the top level. It uses RFID devices to collect real-time manufacturing data firstly. Secondly, the collected data are sent to the system to process, such as converting the data into information, utilizing the converted information for supporting shop-floor scheduling and then visualizing information for shop-floor

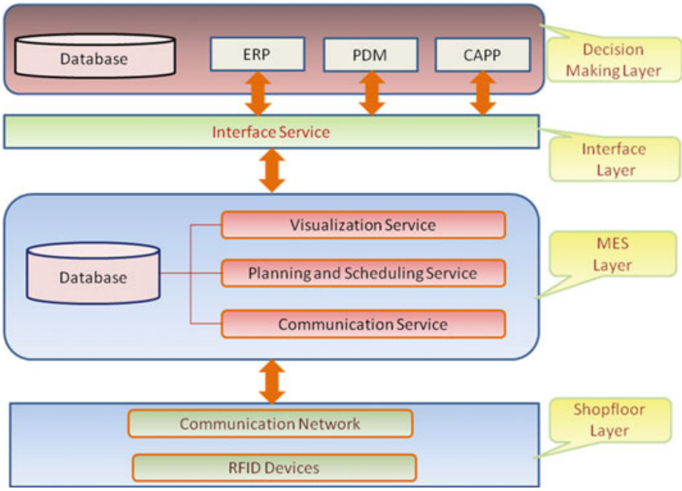

Fig. 1 System framework

management. Thirdly, the interface service sends real-time critical information into decision-making systems for further or high level strategy evaluation and selection.

2.2 *Key Services*

PIM^{2}S includes four vital services which play critical role in shopfloor management. They are Communication Service, Planning and Scheduling Service, Visualization Service and Interface Service. Communication Service manages all data transferring and the data communication between hardware devices such as RFID readers and workstations. The principle was detailed illustrated in [8].

Planning and Scheduling Service mainly executes real-time shop-floor planning and scheduling. The aims of this service are to create a real-time manufacturing environment on shop floors, including auto-assigning tasks, real-time monitoring Work-In-Progress (WIP) items and real-time tracing and tracking logistics within manufacturing processes. This service is based on a critical concept which is real-time job pool. The real-time job pool is detailed illustrated in [9].

Visualization Service provides results view of various information such as machine working status, material delivery, and WIP tracking and tracing information as well as real-time workstation material requirements. This service enables shop-floor managers to real-time monitoring the material delivery due to the up-to-date consumption of material captured by RFID devices. As a result, they can make quick responsiveness on which materials have to be delivered to which workstation at what time. Meanwhile, logistics workers get the logistics tasks when they pat their staff card. Thus, the logistics information can be transferred and visualized on time basis.

Interface Service is a bridge between PIM^{2}S and other systems. Its main function is real-time data intercommunication among heterogeneous enterprise information systems (EISs), aiming at enhancing information sharing. This service enables real-time information reporting from shop-floor to the high-level entities on one hand, the corresponding feedback from high-level decision-making units to low-level execution cells will be delivered timely on the other hand. In this manner, closed-loop is formed in terms of information flow which strengthens the whole managerial level within a company, especially shop-floor management.

3 Interface Middleware

This paper takes a seamless integration of SAP ERP for example to illustrate how to establish an interface to bridge these two systems so as to realize two categories of data intercommunication. One is real-time. Another is timed. Therefore, we utilize the methodology which is waken by middleware to design an interface so-named interface middleware [10].

Interface middleware is a middleware that runs in the Server, aiming at transferring data from SAP ERP to PIM^{2}S. The data transfer includes two aspects. In one side, the critical data such as material consumption, order status etc. are sent to SAP for further planning and decision-making. This follows real-time data transferring mechanism. In the other hand, the production orders, job instructions etc. are provided by SAP to PIM^{2}S periodically. This follows timed data transferring strategy. However in some cases, real-time transferring can be executed by manual operation when facing urgent production orders.

The working mechanism of interface middleware is based on SAP R3 architecture which contains three servers: central DB (Database), application server and customer server combining with the advantage of RFC and BAPI [11]. Figure 2 describes the working mechanism of interface middleware. Two queues play the critical role. First is real-time queue, which controls the real-time data that will be processed. The components of interface middleware use DLLs to process the data that mainly come from PIM^{2}S services. The DLLs are designed by SOCKET technology. Another queue is timing queue, which manages the timed data processing. Both side of PIM^{2}S and SAP have to follow some agreed data protocols. Therefore, we design several SAP connectivity modules to control and process the received data from PIM^{2}S. These modules are intended to uniform the heterogeneous data such as data format, storage etc. within these two systems. They are based on the concept of “mutual design” which meets the data standardization among different systems.

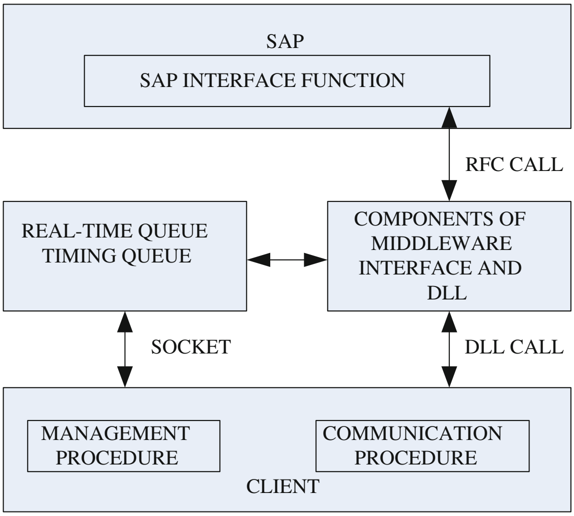

Fig. 2 Working principle

4 Case Study

The case company is Guangdong Keda Electrical and Mechanical Co., Ltd., (Keda for short). Keda was founded in 1992, which is located in the private economic prosperity Guangdong province. The company is a typical discrete manufacturing enterprise and specially to manufacture the ceramic, stone, wall material, energy saving and environmental protection, and other large-scale integration of mechanical equipment. It currently employs more than 2000 workers. Keda is at the forefront of adopting EISs to facilitate its operations and management. Since from 2000, it has been equipped with SAP ERP, CAPP, PDM, CAD and OA.

Despite all the efforts, there are still some problems and complex situations on the shop floors that the above EISs are hardly to cope with. In the first place, machine utilization and personnel measurement are ambiguous since it lacks of shop-floor management system to monitor the manufacturing sites. Moreover, data on shopfloors are managed by manual operations and paper-based system. Therefore, Keda is forced to spend lots of time and efforts to address large number of paper-based documents and sheets. Furthermore, logistics and WIP (Work-In-Progress) items are difficult to control due to the usage of paper-based identification cards on shop floors. The cards are always missing and damaged. Finally, frequent engineering changes and customer variability disturb shop-floor productions. The shop-floor management system cannot handle the disturbances. As a result, the potential of shop-floor production in Keda is confined.

In order to tackle these problems in Keda's shopfloor management, a PIM^{2}S is proposed. PIM^{2}S facilitates and improve the company's shop-floor management in several aspects. Firstly, the planning and scheduling service in PIM^{2}S upgrades the

Table 1 Improvement

Items	Improvement (%)
Reduction of manufacturing cycle	5–12
Elimination of data entry	30
Reduction of WIP	9–18
Reduction of paper work	32–57
Improvement of product quality	6–12
Information delivery on time	96

production level into real-time manufacturing. The working mechanism of this service is illustrated in the following steps.

(1) Production orders from SAP, job instructions from CAPP and material delivery orders from PDM are delivered to planning and scheduling service.
(2) Planning and scheduling uses job pools to deal with the job distribution on the shop floors. Job distribution follows hybrid flow-shop scheduling system which contains several stages. Each stage is equipped by machines with similar function.
(3) Each machine is equipped by RFID readers which can display job instructions. Workers operated the machine reader their staff cards to get production orders from the job pool.
(4) Workers can also input data through readers such as machine status, order fulfillment etc. These data are real-time feedback to SAP and other EISs.

Secondly, the development cycle of PIM^{2}S is greatly reduced by using advanced software development methodology. Generally, it takes more than half a year to fulfill the project since the scope of this project. However, it mainly takes 3 months to accomplish design and programming of PIM^{2}S software, only three technicians involved.

Thirdly, interface service utilizes middleware philosophy to communicate with other EISs. The service enhances the information sharing level and data transmission between heterogeneous systems.

Shop-floor management is improved in terms of real-time data collecting, etc. Table 1 describes how Keda improved in these aspects compared before and after.

The improvement comes from not only macro aspect such as operations and managements, but also from micro aspects. Table 1 gives several statistics of improvements in this company after a year of execution of PIM^{2}S.

5 Conclusion

This paper discusses PI-enabled manufacturing management system (PIM^{2}S) for DM company in the perspective of software design and implementation. The PIM^{2}S framework is proposed firstly. Secondly, an interface service based on middleware concept is elaborated to real-time intercommunication with other EISs.

Finally, a case study from a DM company is illustrated to report how PIM^{2}S improve the shop-floor management.

From the real-life case study, lessons are obtained from the RFID-enabled solution design and implementation. PIM^{2}S can improve the DM shop-floor management in terms of real-time data collection and intercommunication, real-time planning and scheduling as well as efficient tracing and tracking of WIP items. During the PIM^{2}S design and development, middleware service could share the data with other systems with collaborative decision-making.

Further research and improvement are also necessary if this PIM^{2}S is of great merits to promote. Firstly, real-time hybrid scheduling model will be investigated since most of the off-shelf models cannot deal with the RFID-enabled real-time data in shop-floor scheduling aspects. Secondly, emerging technology such as Data Mining (DM) explore the historic RFID data for more precise scheduling through providing corresponding parameters such as set-up time, processing time and logistics information.

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On Pricing and Coordination of Dual Channel Supply Chain with Fairness-Concerned Manufacturer as the Stackelberg Leader

Dao-gang Qu

Abstract We incorporate the concept of fairness in a conventional dyadic dual-channel supply chain to investigate how fairness may affect channel coordination. Three different situations are considered: the centralized supply chain model, the decentralized supply chain model and the decentralized supply chain model with fairness concerned manufacturer. We show that when manufacturer is concerned about fairness, the manufacturer cannot use a simple wholesale price to coordinate this channel in terms of achieving the maximum channel profit. We also find that manufacturer's fairness concern have small effects to the retailer's profits, but may be beneficial to himself. Finally, we present a simulation example to illustrate the magnitude of supply chain and supply chain members' profits under different scenarios.

Keywords Dual channel supply chain · Pricing · Fairness · Supply chain coordination

1 Introduction

Internet has become an important retail channel. Recognizing the great potential of the Internet to reach customers, many brand name manufacturers, including Hewlett-Packard, IBM, Eastman Kodak, Nike, and Apple, have added direct channel operations. More companies are weighing the option to sell directly to consumers.

To traditional retailers and manufacturers, however, the implications for their operational decisions are not all that clear. How should they make the pricing and what will be the outcome in equilibrium?

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As the manufacturer is both the supplier of and competitor with a retailer, traditional supply chain models are not sufficient for developing insights into the equilibrium performance of such supply chains. In this paper, we develop a model to answer the above questions.

Meanwhile, Even profit-maximizing firms will have an incentive to act in a manner that is perceived as fair if the individuals with whom they deal are willing to resist unfair transactions and punish unfair firms at some cost to themselves willingness to enforce fairness is common [1]. So, our objective in this paper is to examine how manufacturer's concerns about fairness affect the nature of optimal pricing in a dual channel supply chain.

There are two streams of related papers related to our research. The first one is past theoretical models that have devoted considerable attention to dual channel supply chain issues. Aussadavut et al. [2] investigated the optimal pricing problem in dual channel supply chain, and showed that the different costs between direct and traditional channel affect the structure of the channel. Hua et al. [3] examined how the lead time decisions influence the pricing decisions in the dual channel supply chain. Chen and Bell [4] analyzed full-refund and no-refund customer returns policies in dual channel supply chain, and showed the optimal pricing strategy. Lu and Liu [5] compared two distribution structures, namely, single and dual channel, their findings indicate that for these kinds of channel structures, the dual-distribution channel maybe unprofitable to the manufacturer, and that the physical retailer may benefit from e-commerce channel entry.

Behavioral operations management has emerged as a stream of research that explores human decision making in various operational contexts. Schweitzer and Cachon [6] described two experiments that investigate newsvendor decisions across different profit conditions. Results from these studies demonstrated that choices systematically deviate from those that maximize expected profit. Subjects order too few of high-profit products and too many of low-profit products. Bolton and Katok [7] investigated learning by doing in the newsvendor inventory problem. Their results implied that the institutional organization of experience and feedback may have a significant influence on whether inventory is stocked optimally. Katok and Wu [8] examined the performance of three commonly studied supply chain contracting mechanisms: the wholesale price contract, the buyback contract, and the revenue-sharing contract, compared the three mechanisms in a laboratory setting. Results indicated that although the buyback and revenue-sharing contracts improve supply chain efficiency relative to the wholesale price contract, the improvement is smaller than the theory predicts.

Liu et al. [9] identify four dimensions of fairness (or justice) relevant in supplier–buyer relationships: distributional, procedural, interpersonal, and informational. Our study focuses on the distributional aspect of fairness. Fairness has been long recognized as one of the most important factors guiding human interactions in everyday life [1, 10–13] incorporated the concept of fairness in a conventional dyadic channel to investigate how fairness may affect channel coordination. Results showed that when channel members are concerned about fairness, the manufacturer can use a simple wholesale price above her marginal cost to coordinate this channel both in terms of achieving the maximum channel profit and in terms of attaining the maximum channel utility. Ho and Su [14] analyzed two independent ultimatum games played sequentially by a leader and two followers. With peer-induced fairness, the second follower was averse to receiving less than the first follower. Using laboratory experimental data, they estimated that peer-induced fairness between followers is 2 times stronger than distributional fairness between leader and follower.

Neither of the two streams of the literature we mentioned above, however, directly investigates the fairness problem in dual supply chain. Our main hypothesis is fairness (also referred to as inequality aversion) are the main preferences for the manufacturer. We attempt to contribute to this growing body of literature by examining the implications of a fairness-minded manufacturer in a dual channel supply chain context, especially for the issue of pricing and coordination.

The rest of paper is organized as follows: in Sect. 2, we present the key aspects of the basic model. In Sect. 3, we analyze the optimal price and the optimal profits for supply chain and supply chain members. We present our simulation result in Sect. 4 and conclude the paper in Sect. 5.

2 Model and Hypotheses

We consider a simple dual channel supply chain made up of one manufacturer and one retailer (see Fig. 1.). Customers can purchase items either from the retail channel (also called traditional channel) or through the manufacturer's direct channel. We assume that both the manufacturer and the retailer choose their own decision variables to maximize their respective profits (or utility). We also assume that the manufacturer is the Stackelberg leader and the retailer is the Stackelberg follower.

In the Stackelberg game, the manufacturer will act as the leader by announcing its decision first. The retailer then announces its own decision, knowing the manufacturer's already declared strategy. For our model, we assume that the manufacturer moves first, and charges the price in direct channel p_d. Then, taking the price in direct channel was given, the retailer sets his price p_r. $p_d > w > c$, $p_r > w > c$.

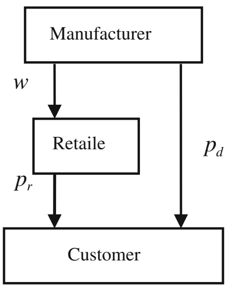

Fig. 1 Dual channel supply chain

Without loss of generality, for simplicity, we assume that the wholesale price is determined before this Stackelberg game [2, 15, 16].

We assume that the demand functions are linear in self and cross-price effects, but with different parameters for each channel. Specifically, the demand function is assumed to be [17]

$$D_r = (1 - s)a - bp_r + ep_d$$
$$D_d = sa - bp_d + ep_r$$

where D_r is the retailer's demand, D_d is the manufacturer's direct channel demand and a is the primary demand (i.e., potential demand if free of charge), s is the percentage share of the demand going to the manufacturer's direct channel when p_d and p_r are zero, and $(1 - s)$ goes to the retailer when p_d and p_r are zero. s reflects the customer's preference for the direct channel (the higher h is, the more customers prefer to use the direct channel). p_d is the price of the manufacturer's direct channel, p_r is the retailer's price, b is the slope of D_d and D_r. Cross-price sensitivity e reflects the degree to which the products of the two channels are substitutes. We assume that $b > e$, so that own price effects are greater than or equal to cross-price effects. All parameters are positive.

In order to capture the effect on pricing decision and its impact on profit, we have three different scenarios: the centralized dual channel supply chain, the decentralized dual channel supply chain and the decentralized dual channel supply chain with a fair-mined manufacturer.

3 Optimal Pricing

3.1 Centralized Dual Channel Supply Chain

We consider the dual channel supply chain as a centralized system in which all decisions are centralized in order to maximize the performance of the entire supply chain and whereby the manufacturer is vertically integrated with the retailer in the retail channel. The manufacturer controls both decisions: the retail's price p_r and the direct channel price p_d. The supply chain performs the best when the manufacturer and retailer are centralized controlled (scenario C). The profit of the entire supply chain is

$$\Pi_I = (p_d - c)D_d + (p_r - c)D_r.$$

Then, we obtain **Proposition** 1.

Proposition 1 *In centralized dual channel supply chain the optimal prices are*:

$$\begin{cases} p_d^I = \frac{ae+b^2c-ce^2+abs-aes}{2(b^2-e^2)} \\ p_r^I = \frac{ab+b^2c-ce^2-abs+aes}{2(b^2-e^2)} \end{cases}$$

The differences between direct channel and retailer's channel are

$$p_d^I - p_r^I = \frac{a(2s-1)}{2(b+e)}.$$

In the centralized scenario, the differences between prices in two channels depend on the parameter s. The optimal direct channel price p_d^I is higher than the optimal retailer's price p_r^I, i.e. $p_d^I > p_r^I$ if $s > 1/2$; $p_d^I < p_r^I$, if $s < 1/2$; $p_d^I = p_r^I$ if $s = 1/2$.

3.2 Decentralized Dual Channel Supply Chain

In the decentralized dual channel supply chain, the manufacturer and the retailer are rational units. The objective of both the retailer and the manufacturer is to maximize expected profits. The manufacturer acts as the leader by announcing its decision first. The retailer then announces its own decision, knowing the leader firm's already declared strategy.

The manufacturer's profit function is

$$\begin{aligned} \pi_m^{DS} &= (p_d^{DS} - c)D_d + (w-c)D_r \\ &= (p_d^{DS} - c)[sa - bp_d^{DS} + ep_r^{DS}] \\ &\quad + (w-c)[(1-s)a - bp_r^{DS} + ep_d^{DS}] \end{aligned}$$

And the retailer's profit function is

$$\begin{aligned} \pi_r^{DS} &= (p_r^{DS} - w)D_r \\ &= (p_r^{DS} - w)[(1-s)a - bp_r^{DS} + ep_d^{DS}] \end{aligned}$$

Thus, the optimal price in direct channel p_d^{DS} and retailer's price p_r^{DS} are shown in **Proposition 2**.

Proposition 2 *The optimal prices of two channels are*:

$$\begin{cases} p_d^{DS} = \frac{c}{2} + \frac{e(a-bc-as+2bw)+2abs}{4b^2-2e^2} \\ p_r^{DS} = \frac{\frac{ab}{2}-\frac{b^2c}{2}+b^2w-\frac{abs}{2}+\frac{aes}{2}}{2b^2-e^2} + \frac{a+bc+ce-as}{4b} \end{cases}$$

3.3 Decentralized Dual Channel Supply Chain with Fair-Minded Manufacturer

In the decentralized dual channel supply chain with fairness manufacturer scenario, the manufacturer and the retailer are rational units. The manufacturer decides the direct channel price first, then the retailer decides the retailer's price. Different form the decentralized scenario, manufacturer is fair-minded. When the manufacturer cares about fairness, besides his profitability, he will maximize a utility function that accounts for the manufacturer's monetary payoff as well as his concern about fairness when setting his price. The disutility due to inequity (denote as f_m) enter the manufacturer's utility function in an additive form [18]. The manufacturer is willing to give up some monetary payoff to move in the direction of more equitable outcomes. We assume that the equitable outcome for the manufacturer in the traditional channel is $r(0<r<1)$ times the payoff in the traditional channel. In other words, the manufacturer's equitable payoff is the payoff it deems deserving relative to the payoff in the traditional channel. Thus, if the manufacturer's monetary payoff in the traditional channel is lower than the equitable payoff, a disadvantageous inequality occurs, which will result in a disutility for the manufacturer in the amount of α per-unit difference in the two payoffs. The disadvantageous disutility is denoted as $-\alpha\max\{r\pi_T - \pi_{mT}, 0\}$. If his monetary payoff is higher than the equitable payoff, an advantageous inequality occurs in the amount of β per-unit difference in the payoffs. The advantageous disutility is denoted as $-\beta\max\{\pi_{mT} - r\pi_T, 0\}$. Algebraically, we have $f_m = -\alpha\max\{r\pi_T - \pi_{mT}, 0\} - \beta\max\{\pi_{mT} - r\pi_T, 0\}$. Accordingly, we further assume $\alpha > \beta$ and $0<\beta<1$ [13].

So, the function of manufacturer's profit is given below

$$\begin{aligned} \pi_m^f &= \pi_m + f_m \\ &= (p_d^f - c)D_d + (w - c)D_r \\ &\quad - \alpha\max\{r\pi_T - \pi_{mT}, 0\} - \beta\max\{\pi_{mT} - r\pi_T, 0\} \end{aligned}$$

And the function of retailer's profit is given below

$$\begin{aligned}\pi_r^f &= (p_r^f - w)D_r \\ &= (p_r^f - w)[(1-s)a - bp_r^f + ep_d^f]\end{aligned}$$

There exists a balance point, the manufacturer's monetary payoff in traditional channel equals to the equitable payoff $\pi_{mT} = r\pi_T$. So we have: $(w-c)D_r = r(p_r^f - c)D_r$, if $(w-c)D_r > r(p_r^f - c)D_r$, an advantageous inequality occurs. We have

$$\begin{aligned}\pi_m^{AD} &= \pi_m + f_m \\ &= (p_d^{AD} - c)D_d + (w-c)D_r - \beta\max\{\pi_{mT} - r\pi_T, 0\} \\ &= (p_d^{AD} - c)D_d + (w-c)D_r - \beta[(w-c) - r(p_r^{AD} - c)]D_r\end{aligned}$$

Thus, the optimal price in direct channel p_d^{AD} and retailer's channel p_r^{AD} are shown in Proposition 3.1.

Proposition 3.1 *When the manufacturer has advantageous inequity. The optimal prices in two channels are*

$$\begin{cases} p_d^{AD} = -\dfrac{ae + 2b^2c - ce^2 - bce + 2abs - aes + 2bew}{2e^2 - 4b^2 + e^2\beta r} \\ \qquad - \dfrac{ae\beta r - be\beta w + bce\beta - bce\beta r - ae\beta rs}{2e^2 - 4b^2 + e^2\beta r} \\ p_r^{AD} = \dfrac{ae^2 - 4ab^2 + ce^3 - 4b^3w + bce^2 - 2b^2ce + 4ab^2s}{2b(2e^2 - 4b^2 + e^2\beta r)} \\ \qquad + \dfrac{be^2\beta w(1+r) - ae^2s - bce^2\beta - 2abes + bce^2\beta r}{2b(2e^2 - 4b^2 + e^2\beta r)} \end{cases}$$

So we can conclude that the supply chain is not coordinated with fair-minded manufacturer.

Accordingly, the wholesale price in the balance point is w_1.

Similarly, if $(w-c)D_r < r(p_r^f - c)D_r$, the disadvantageous inequality occurs. We have

$$\begin{aligned}\pi_m^{DIS} &= \pi_m + f_m \\ &= (p_d^{DIS} - c)D_d + (w-c)D_r - \alpha\max\{r\pi_T - \pi_{mT}, 0\} \\ &= (p_d^{DIS} - c)D_d + (w-c)D_r - \alpha[r(p_r^{DIS} - c) - (w-c)]D_r\end{aligned}$$

Thus, the optimal price in direct channel p_d^{DIS} and retailer's channel p_r^{DIS} are shown in Proposition 3.2.

Proposition 3.2 *When the manufacturer has disadvantageous inequity. The optimal prices of two channels are*

$$\begin{cases} p_d^{DIS} = \frac{ae + 2b^2c - ce^2 - bce + 2abs - aes + 2bew}{4b^2 - 2e^2 + e^2\alpha r} \\ \quad + \frac{-ae\alpha r + be\alpha w - bce\alpha + bce\alpha r + ae\alpha rs}{4b^2 - 2e^2 + e^2\alpha r} \\ p_r^{DIS} = \frac{4ab^2 - ae^2(1-s) - ce^2(b+e) + + 2b^2ce + be^2\alpha rw}{2b(4b^2 - 2e^2 + e^2\alpha r)} \\ \quad + \frac{4b^3w - bce^2\alpha + be^2\alpha(w + cr) + 2abes - 4ab^2s}{2b(4b^2 - 2e^2 + e^2\alpha r)} \end{cases}$$

We can also conclude that the supply chain is not coordinated with fair-minded manufacturer.

Accordingly, the wholesale price in the balance point is w_2.

4 Numerical Examples

To illustrate the main findings, we take a numerical example. Without loss of generality, the values of parameters are as below:

$$a = 100,\ b = 2,\ e = 0.8,\ c = 8,\ \alpha = 1,\ \beta = 0.2,\ s = 0.4,\ r = 0.4$$

Figure 2 illustrates that supply chain cannot be coordinated in DS (decentralized supply chain) or in decentralized supply chain with fairness concerned manufacturer. The profits of AD scenario can be better off than the DS scenario when w is larger than w_3.

Figure 3 shows that if we set the profits of manufacturer in DS scenario as the benchmark, then a fair-minded manufacturer is worse off when w is smaller than w_3, and better off when w is bigger than w_3.

Figure 4 means that if we set the profits of retailer in DS scenario as the benchmark, differently from the manufacturer, the fair-minded manufacturer makes the retailer's profits worse off only when w is smaller than w_1.

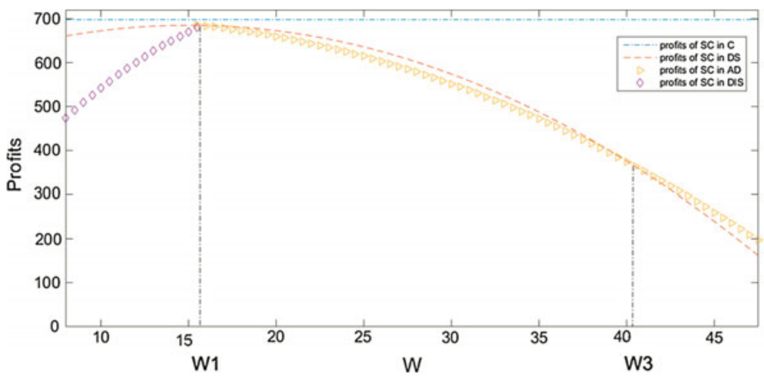

Fig. 2 Supply chain profits of different scenarios with various w

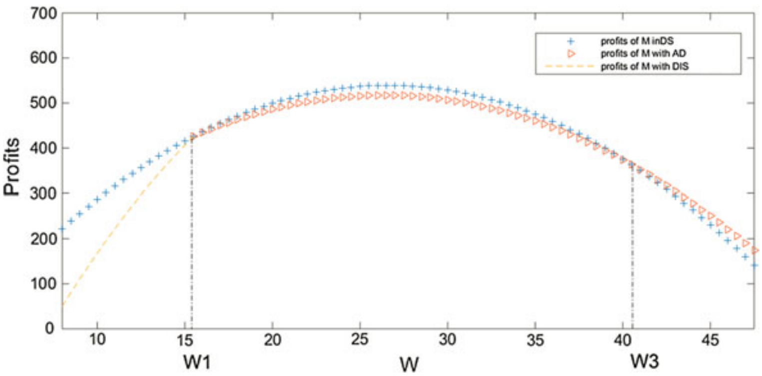

Fig. 3 Profits of manufacturer with various *w*

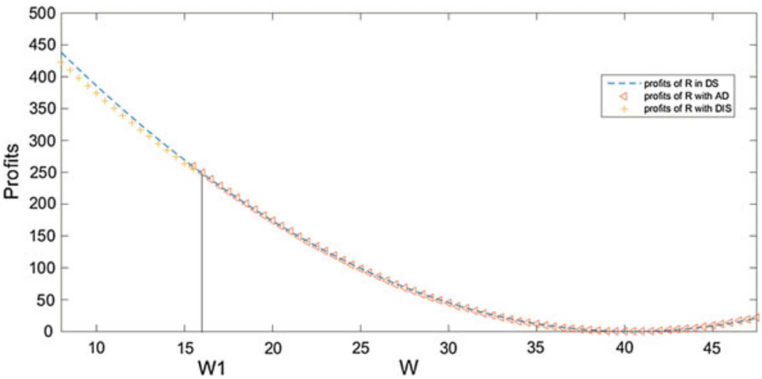

Fig. 4 Profits of retailer with various *w*

Based on the numerical examples, we can conclude that, when the wholesale price is larger than w_3, the manufacturer can be better off; but when the wholesale price is less than w_1, both members of the supply chain are worse off.

5 Conclusion

In this research, we develop a single manufacturer single retailer two-echelon supply chain model which has dual distribution channels. The problem of pricing between different channels is considered when the manufacturer is fairness concerned. Supply chain coordination is also considered.

To investigate the pricing and coordination issue within a supply chain with direct channel and fair-mined manufacturer, we consider three different situations:

the centralized supply chain model, the decentralized supply chain model and the decentralized supply chain model with fairness concerned manufacturer.

The optimal price of direct channel and retailer's channel are obtained in Stackelberg game model, the profits of supply chain and channel members are also given. We also illustrate our analytical results with numerical examples, and we find out the manufacturer's fairness concerning is beneficial for himself in some cases. But on the retailer's perspective, a fair-mined manufacturer is not always good for her profits.

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Optimization of Plug-in Production Line Based on Process Priority Principle

Yun-rui Wang, Juan Li and Xian-gang Cao

Abstract An electronic product company had a very good market, but A5 production line did not finish the task frequently, which influenced on-time delivery and caused a considerable impact to the enterprise. In view of the problems of the A5 plug-in operation line often could not achieve the status of the production tasks and the smooth index was higher, analyzed the characteristics of each working procedure using time study, 5W1H, ECRS, that found the bottleneck process, its operation process was rearranged and divided based on the principle of priority and formed a new operation process. At the same time applied reasonable quality assurance measures to ensure the realization of the expected effect. By improving, productivity of the production line increased by 11.97 %, it played a significant role in ameliorate the current state. In theory, the production line could produce benefits for enterprise more than 1.078 million yuan a year.

Keywords Bottleneck · Smooth index · Process priority principle · Yield

1 Introduction

An electronic product company headquarters in suzhou has become China's leading high-tech manufacturing plant, an annual turnover more than 15 billion yuan, mainly to provide component for electronic manufacturer, product and technology cover LCD monitor, LCD integrated computer, projector and other fields. The company has A5, A7, B1 and others plug-in line and orders very full, but most of the production line plan output is not completed by counting and analyzing the yield of A5 production line in 2014, that due to the production line equipment aging, staff's bad operation habit and so on, also has other old problems that not

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been found, which affect the production capacity [1, 2]. Buy new equipment and expand production line requires a significant capital investment, and the gap between actual yield and order is not very large now, so think through optimizing the production line to augment production capacity.

2 Production Line Status

The main task of A5 production line is to improve the integrated circuit of PCB board, namely the plug-in action, the products are placed inside the MASK that consist of four small board to forming quadruple plate, and then operation of plug-in on the quadruple plate, arrangement of the production station is shown in Fig. 1, each station is a process that includes the content of the operation as shown in Table 1.

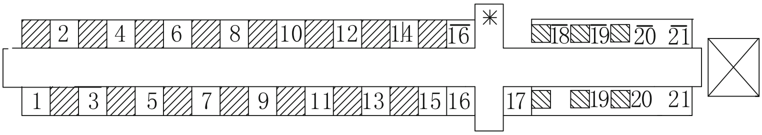


Fig. 1 Production station arrangement

Table 1 Operation content of each station before optimization

Station	Content
1	Place PCB board
2	Insert four carbon film resistors and two thermistors
3	Insert 4 IC and 4 ground plates
4	Insert 4 integrated circuit blocks and 4 ceramic capacitors
5	Insert 8 ceramic capacitors
6	Insert 6 diodes (with polarity, with heat sink)
7	Insert 4 diodes(LED) and 2 diodes (with polarity, with heat sink)
8	Insert 4 integrated circuit blocks and 2 thermistors
9	Insert 4 blocks
10	Insert 8 electrolytic capacitors
11	Insert 4 transformers
12	Insert 4 heat sink
13	Insert 4 electrolytic capacitors (with glue)
14	Insert 4 flower lines, 2 USB sockets
15	Insert 4 insurance tubes, 2 USB sockets
16	Insert 4 bridge piles

2.1 Bottleneck Determination

In order to ensure the accuracy and the scientific of sampling observation, use a stopwatch time study. Stopwatch time study is a common method in work measurement technology, also known as "direct time study—intensive sampling" [3, 4]. The process is as been the research object, determine operating time of the operators continuously according to a predetermined number using a stopwatch when a process of production is being, and then compute the job standard time based on the test result, this is a common method in line optimization. Operation cycle of the 16 stations is about 3 min after preliminary testing and to determine the number of observation is 17 times, for the 16 stations in entire production line of plug-in conduct 17 observation records to calculate the average time for each station as T_i [5], the largest operation time in the cycle is bottleneck process.

Bottleneck existing in the process not only limits the output speed of the production line, and affects production capacity of other areas, the bottleneck is current production beat and its time been as beat time T_m. Relative to the beat time, other processes time are smaller which would lead to free time, free time means working hour without effective homework task, that can refer to equipment or people is idle. Process load rate is the ratio of operation time and the beat time of assembly line, calculating the load rate is to guarantee the balance of assembly line, the calculation results are shown in Table 2 [6, 7].

$$\text{Idle time} = T_m - T_i \tag{1}$$

Table 2 Each station average operating time, idle time and process load rate before optimization

Station	Average operating time	Idle time	Process load rate (%)
1	7.22	6.98	49.55
2	12.58	1.62	86.34
3	10.57	3.63	72.55
4	10.16	4.04	69.73
5	11.05	2.70	75.84
6	13.68	0.52	93.89
7	14.57	0	100
8	14.07	0.13	96.57
9	9.35	4.85	64.17
10	12.04	2.16	86.24
11	9.72	4.48	66.71
12	11.61	2.6	79.68
13	9.31	4.89	63.90
14	14.13	0.07	86.98
15	13.01	0.19	89.39
16	9.56	4.64	65.61

$$\text{Process load rate} = \frac{T_i}{\mathrm{T_m}} \times 100\ \% \tag{2}$$

It can be seen by statistical analyzing, the bottleneck of this line is station 7 where operation time is 14.57 s, namely the beat time $T_m = 14.57\,\mathrm{s}$. It also can been found from Table 2, operating time of each station is not equal, uneven process load rate, there are other processes waiting [8, 9].

2.2 Parameters of the Production Line Calculation Before Optimization

The total number of station of production line N = 16

$$\begin{aligned}\text{Smooth index} &= \frac{1}{N}\sqrt{\sum_{i=1}^{N}(T_m - T_i)^2} \\ &= \frac{1}{16} \times \sqrt{228.19} = 0.94\end{aligned} \tag{3}$$

The effective working time is 21 h a day in the company, then daily output can been calculated,

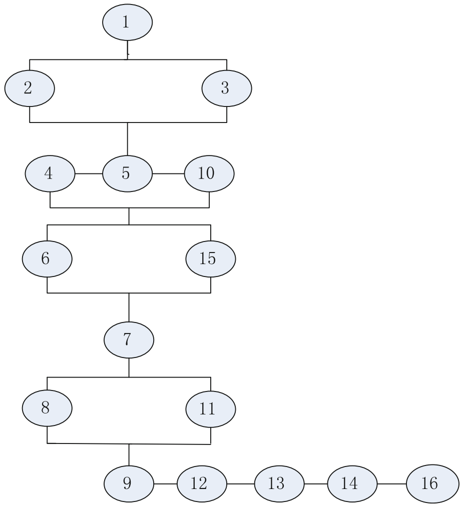
$$\text{Daily output} = \frac{3600 \times 21}{T_m} = \frac{3600 \times 21}{14.57} = 5189 \tag{4}$$

Smooth index is far greater than 0.5, so the production line exists some problems such as WIP accumulation, staff waiting for, which serious impact in efficiency of the line, and the daily output of 5189 pieces before optimization is lower [10].

3 Production Line Optimization Based on Process Priority Principle

Every leading and rear job should be paid attention to when optimize the production process, that is operation priority, leading work must be finished while rear job begin, the same priority of two assignments can be repositioned. After the time research work to further understand the relationship among the 16 processes, plug-in operation follow the principle that from small to big, from low to high, first light after heavy, Fig. 2 shows the process priority (constraints). On the basis of process priority principle, use of ECRS and 5W1H technology in the operation of each process for further decomposition, analysis and optimization, to find some processes which can be merged or rearranged so that the work time of each process in production line into balance [11–13].

Fig. 2 A5 plug-in production line process priority



3.1 Optimization Process

(1) The bottleneck of the original production line is the 7th station that work time of 14.57 s, namely insert 4 diodes (LED) and 2 diodes (with polarity and heat sink). While the process priority figure shows the next process of the 8th and 11th process could be exchanged, and the 11th process in 9.72 s, so the 11th replace the 8th and a diode (LED) of the 7th put up to the 11th station, therefore the 7th station time reduced to 12.02 s and the operation time of 11th enhanced 12.27 s, at the same time the bottleneck of the production line becomes the 14th station which has 14.13 s work time.

(2) The work content of the 14th process is insert 4 flower lines and 2 USB sockets, that need 14.13 s operation time while the 13th only spend 9.31 s, it can be executed that the worker of the 13th share a USB socket, consequently the 13th process take 11.82 s and the 14th cut back 11.62 s, the bottleneck process transforms to the 8th station as 14.07 s.

(3) The 8th station (14.07 s) requires the operator insert 4 circuit blocks and 2 thermistors, and the 8th is priority jobs for the 9th (9.35 s), allowing the 9th share a thermistor, then step 8 is reduced to the time 11.7 s, process time of step 9 is increased to 11.72 s, at this time bottleneck process changes step 6 and the operating time gets 13.68 s.

(4) Because the process of the 6th and the 15th is interchangeable, allowing the 16th (9.56) share the work time of the 6th, the process time of the 6th is cut down 11.31 s while time consume of the 16th expand to 11.93 s.

(5) In order to improve balance of each station time, making worker of the process 1 share a thermistor, the time changes to 9.59 s and the 2nd process time reduced to 10.21 s.

The work content of each station rearranged is shown in Table 3.

Table 3 Operation content of each station after optimization

Station	Content
1	Place PCB board, insert 1 thermistor
2	Insert 4 carbon film resistors and 1 thermistor
3	Insert 4 IC and 4 ground plates
4	Insert 4 integrated circuit blocks and 4 ceramic capacitors
5	Insert 8 ceramic capacitors
6	Insert 5 diodes (with polarity, with heat sink)
7	Insert 4 diodes(LED) and 1 diode (with polarity, with heat sink)
8	Insert 4 integrated circuit blocks and 1 thermistor
9	Insert 4 blocks and 1 thermistor
10	Insert 8 electrolytic capacitors
11	Insert 4 transformers and 1 diode
12	Insert 4 heat sinks
13	Insert 4 electrolytic capacitors and 1 USB socket
14	Insert 4 flower lines, 1 USB socket
15	Insert 4 insurance tubes, 2 USB sockets
16	Insert 4 bridge piles and 1 diode

3.2 Production Line Balance Analysis After Optimization

Based on the principle of priority to optimize production line, the station 6 and 15, 8 and 11 has carried on the exchange, according to the new job content for each station, testing the average operation time and calculate idle time, process load rate as shown in Table 4, the average operating time of each station towards balance significantly [14], as shown in Fig. 3.

Improved bottleneck process time is 13.01 s, namely production beat decreased to 13.01 s, using this set of new data computation again:

$$\begin{aligned}\text{Smooth index} &= \frac{1}{N}\sqrt{\sum_{i=1}^{N}(T_m - T_i)^2} \\ &= \frac{1}{16}\times\sqrt{52.67} = 0.45\end{aligned} \tag{5}$$

The effective working time is 21 h a day in the company, then daily output can been calculated again,

$$\text{Daily output} = \frac{3600\times 21}{T_m} = \frac{3600\times 21}{13.01} = 5810 \tag{6}$$

Table 4 Each station average operating time, idle time and process load rate after optimization

Station	Average operating time	Idle time	Process load rate
1	9.59	3.42	73.71
2	10.21	2.8	78.48
3	10.57	2.44	81.25
4	10.16	2.85	78.09
5	11.05	1.96	84.93
6	11.31	1.70	86.93
7	12.02	0.99	92.39
8	11.70	1.31	89.93
9	11.72	1.29	90.08
10	12.04	0.97	92.54
11	12.27	0.74	94.31
12	11.61	1.40	89.24
13	11.82	1.19	90.85
14	11.62	1.39	89.32
15	13.01	0	100.0
16	11.93	1.08	91.7

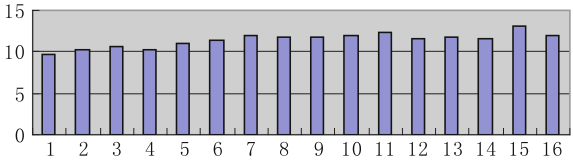


Fig. 3 Average operating time of each station after optimization

It is clearly, the operation time of each station is approximately average, smooth index lower 0.5 and daily output is augmented to 5810 pieces.

3.3 *Analysis of Optimization Result*

The process load rate of each station tends to be more balanced through optimization, as shown in Fig. 4a, b, the productivity is also improved and create considerable profit for the enterprise.

$$\text{Increase in productivity} = \frac{5810 - 5189}{5189} = 11.97\,\% \tag{7}$$

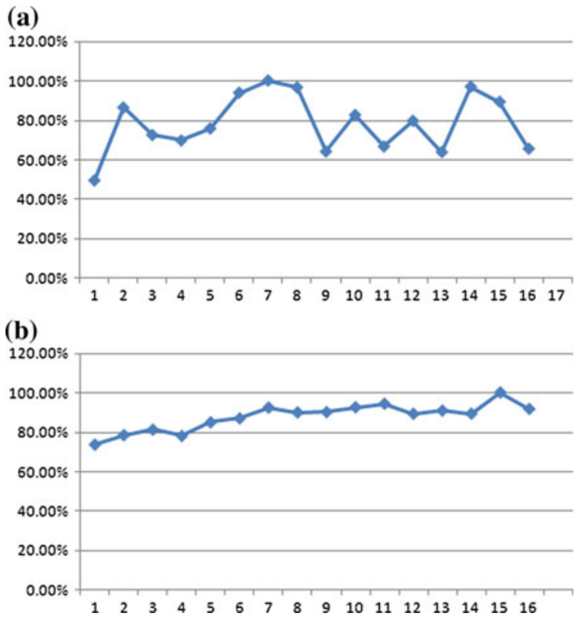


Fig. 4 **a** Process load ratio before optimization. **b** Process load ratio after optimization

By research, profit of a piece of board is 1.2 yuan, work 12 months in one year, 30 days a month, there are 4 small boards in each MASK, so the improvement can increase profit one year for the enterprise,

$$\begin{aligned} Q &= (5810 - 5189) \times 30 \times 12 \times 1.2 \times 4 \\ &\approx 1.078 \text{ million yuan} \end{aligned} \tag{8}$$

4 Quality Guarantee Ways

The optimization of the production line form a reasonable operating norm, further adopt scientific quality assurance way to ensure the whole production line efficiency substantially improve, the assignment of plug-in take measures mainly from the following aspects:

(1) Sure an authority header of quality assurance in the enterprise, the authority, on the one hand, duly authorized by the enterprise leadership, on the other hand on his personal leadership and personal charm, at the same time, the header should understand the relevant state laws, regulations, and procedure rules of product certification, as well as the safety certification standard in enterprise product application [15]. In this way, the header can organize personnel to learn safety standard, and independently and impartially perform CCC safety standard, execute effective supervision.

(2) Strengthen process control in production. The product is simple and has relatively mature technology, it is needed to identify the main production process, know the crucial safety testing and quality control point. At the same time, to clear operation requirement on the key point, and according to the state or industry standard write working instruction, if necessary can acquire skill assessment criteria on related station, such as circuit board plug-in, a circuit board can be placed in the post and identified place to be jack, this facility staff to operation.
(3) Pre-service training should be strengthened for staff, focus on the actual operating skill. Most employees in the enterprise have lower education and little knowledge for the product, therefore the training is very important. Top management of the enterprise, mainly quality assurance header shall specify the difference of the knowledge and skill required in positions, especially in test and experiment position, develop a comprehensive training plan for employees and implement.

5 Conclusion

The optimization of production line for business to find new profits in an increasingly competitive situation is very important. The A5 plug-in operation line often can not achieve the production tasks, to measure the work time of each station for the all production line that includes 16 stations using a stopwatch time study method, finds work time of each station is not balance obviously, the smooth index is bigger, and then adjusts work content based on the process priority principle applying the ECRS, 5W1H technology so that the difference of operation time between 16 stations is improved. At the same time apply reasonable quality assurance ways to ensure the realization of the expected effect. As a result, the yield is increased from 5189 to 5810 and creating a good efficiency for enterprise. It is clear, optimizing a disequilibrium operation line is more necessary without significant investment.

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The Relationship Between Non-resident Patent Applications and Intellectual Property Rights

Xin-yue Hu, Yuan-yuan Li, Claudio Petti, Yong-li Tang and Lu Chen

Abstract International technology transfer is an effective way to narrow the technology gap of developing countries. As the world biggest emerging economy, the inbound and outbound technology transfer of China has attracted much academic attention. The flow of non-resident patents, i.e. patents applied by foreign institutions or individuals, represents one of the most important channels of international technology transfer. The paper analyzes the bilateral non-resident patent application flows between China and core Europe Union countries in order to investigate the relationship between non-resident patent applications and intellectual property rights. The results reveal that the non-resident patent flows between China and EU are quite un-balanced, with much higher inbound flow from EU to China and lower outbound flow from China to EU. Moreover, the non-resident patent applications are positively related to both the IPR level of the destination and the source. Some policy recommendations are drawn from these findings.

Keywords International technology transfer · Intellectual property rights · Non-resident patent application

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1 Introduction

Technology has become a very important factor in economic growth. However, a big technology gap exists between the economically developed countries and developing and emerging countries. Developed countries and regions dominate the technology resources, meanwhile the other countries struggle with low initial technical level and weak innovation ability. To solve this dilemma, countries should introduce advanced technology from abroad, and internalize it. As an important means to solve the problem, international technology transfer is not only improving the technical level in developing and emerging countries, but also promote their technology innovation ability through various channels and mechanisms. International technology transfer (ITT from now on) is a flow process of technologies from one country to another country. The technologies can be tangible, also intangible, and the transfer mechanisms are varied including import, export, international technology cooperation, patent applications and licenses, and so on.

As the biggest emerging economy, China has large demands for obtaining technology and knowledge from the outside world. In recent literatures, China's technology development has become one of the hottest research topics. Large-scale ITT to China started relatively late, more precisely when the intellectual property law was officially issued in 1985. As a matter of facts, technology transfer requires the transfer of intellectual property rights to protect value appropriation, which need the intellectual property rights laws as foundation. Thus, the study of China's technology transfer begins with the establishment of the Chinese intellectual property laws [1]. In the early days of China's reform and opening up, the national government focused on improving the innovation abilities of companies, attempting to get early gain in GDP. As a result, if there are no significant effects on improving the Total Factor Productivity, capital, nature resources and human resources will not be deployed to innovation activities. During the same period, the two main blocks for technology transfer markets were institutional barriers and a lack of incentives. The booming period of China's technology transfer market was from 1999 to 2005. In this period, the number of technology license contracts had increased by 2.8 times to 842 licenses in 2005, with $21.8 million in licensing revenue [2]. Using patent filing as an example, the quantity of technology transfer to China is impressive. The same cannot be said about the quality. Actually, whereas China has caught up with the USA on the amount of patent applications, the quality of these patents remains a concern. Gross discussed the dynamics of the growth of technology transfer markets in China and USA, and estimated the leading role of the industry in the next decade [3]. According to the author, the best guess is that in terms of the current rate of technology transfer, the USA will still dominate the market in terms of both license numbers and license income. On the other side of the Atlantic Ocean European countries too have both technological and economical advantages against China. However, Europe is not always located in the forefront of the world, and technical developments are varied among the European countries and big gaps exit. For example, scholars pointed out that Spain, which had adopted weak patent system, belonged to lagged technologically countries in Europe [4]. Though, Europe is one of China privileged technology partners. Nonetheless Previous studies devoted little attention to technology transfer between China and European countries. To fill this gap, the paper intends to compare the bilateral flows of international technology transfer between China and European countries. In this way, the first research question of this study will be tackled: what is the current status of the international technology flow between China and European Countries?

In order to do so we will rely on non-resident patents application data. As a matter of facts, non-resident application data are one of the main channels of ITT. In this regard there exist many studies concerning this issue by using the non-resident application data [5–8]. Referring to the report published by World Intellectual Property Organization (WIPO from now on) [9], non-resident patent applications are defined as patent applications made from applicants outside the relevant State or region. A patent is a document, issued by an authorized governmental agency, granting the right to exclude anyone else from the production or use of a specific new device, apparatus, or process for a stated number of years. Besides information on the names of inventors, their addresses and the name of the organization to which the patent right may have been assigned, it also lists one or more patent classes that have been assigned by the examiners, citations of a number of previous patents and sometimes also scientific articles from which this particular invention may have drawn ideas. Therefore, there is much more information derived from the patent documents than just simply their aggregated number in a particular year or for a particular organization. In addition, Marzal and Tortajada-Esparza [10] point out to the several advantages of using patent statistics. First, a patent is associated with the development of a new technology; second, patent databases give easy access to information and enable comparison between countries; third, patent analysis also allows for the understanding of knowledge flows, through citations analysis. Furthermore, to a great extent, patent application represents the inventive activities and innovation output and WIPO has pointed out that applicants decide whether or not to file a patent application in foreign countries depending on commercial considerations. Therefore, patent filling by non-residents reflects the internationalization of technology and markets and it is thus a good proxy to measure international technology transfer.

Nonetheless, some problems emerge when patent application data want to be used for such a purpose. Some recognized problems exist: Not all inventions are patentable, and not all inventions are patented [11]. First, applying for a patent is a strategic decision of the firm. Moreover, as long as a large part of knowledge is tacit, patent statistics will necessarily miss that part, because codification is necessary for patenting to occur [12]. As for how to deal with the problems, the two problems can be taken care of by industry dummy variables, or by limiting the analysis to a particular sector or industry [11].

On the other hand, the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) requires a number of countries to strengthen their patent and other intellectual property rights (IPR from now on) systems, while the policymakers of different countries have differing views on the impacts of IPR on economics. Does the strengthening of IPR may have positive impact on the ITT? This is this work's second research questions.

It's a problem discussed for a long time. Lerner analyzed the impact of all significant patent reforms over the last 150 years in a sample of 60 countries, and his findings confirmed that these reforms had few positive effects on patent applications by entities based in the country undertaking the policy change [13, 14]. Park and Lippoldt [6] investigated the influence of the strength of intellectual property rights on technology transfer by using integrated method to measure ITT and IPRs, and they found that stronger patent rights in developing countries appeared to have the potential not only to stimulate international technology transfer but also to provide incentives for foreigners to transfer new technologies.

Most of the authors emphasized on the causal relationship between IPR and ITT, however the conclusions on the topic are complicated and inconsistent on account of different research setting. To fill the gap, we try to adopt another accessible method in order to explore the relationship between IPR and ITT. We hope that our findings and conclusions may provide some implications for the future studies.

The remainder of this paper is organized as follows. Section 2 introduces research methods, including the variable measurements and data source in this study. Section 3 reports results the results of estimation, while Sect. 4 summarizes the results and offers some discussion. Conclusions and implications of findings are presented in the closing section.

2 Methodology

For the reasons explained previously, we adopted the non-resident patent application as a measure of international technology transfer. After collecting and summarizing the available data, we will show descriptive analysis in order to provide a brief account of the technology flows between China and the European countries. Then, we perform the correlation analysis between patent and IPR data.

As for the measurement of Intellectual property rights, scholars present an index of patent rights for 110 countries for the period 1960–1990 [15]. The index differs greatly from previous measures in a number of ways for three reasons. First, it provides information about national patent rights for more countries and periods than do the surveys, which otherwise offer many insights. Secondly, broader categories of the patent system are considered, particularly the treatment of foreigners. Thirdly, the measures obtained in the dummy variable approaches exhibit little variability across countries. Park [16] has updated the index of patent rights to the year 2005 and included more countries (such as China and the East European countries, which were originally excluded because laws protecting industrial property were either non-existent or based on a different system, such as inventor certificates). Based on Ginarte-Park method, some scholars put forward a modified method to evaluate the intellectual property protection (IPP) level of China, quantitative analysis shows that the modified IPP level is much below than the Ginarte-Park level [17]. Although the Ginart-Park method may have underlying defects, it's still recognized by many scholars internationally.

In the process of sampling, considering the tricky and difficult process of data manipulation, after careful consideration and repeated screening, we selected 15 core countries in European Union as representative of European countries. The 15 countries are France, Germany, Italy, Netherlands, Belgium, Luxembourg, Denmark, Ireland, United Kingdom, Greece, Spain, Portugal, Austria, Finland and Sweden. In consideration of the data availability, we choose these countries as research sample.

As for the data source, the non-resident patent application number has been downloaded from the website of World Intellectual Property Organization (WIPO). We choose the data type counting by applicant's origin and filing office. The full range of these patent applications covers the period 1980–2013.

The data for IPR has been collected from previous literatures [15, 16] and Park's homepage. At first, Ginarte and Park calculated an index of patent rights for 110 countries (including 15 countries in EU and China) for the period 1960–1990, which was cited by later articles over 700 times. The index was constructed of five categories of the patent laws: (1) extent of coverage, (2) membership in international patent agreements, (3) provisions for loss of protection, (4) enforcement mechanisms, and (5) duration of protection. Each of these categories (per country, per time period) was scored a value ranging from 0 to 1. The unweighted sum of these five values constitutes the overall value of the patent rights index. The index, therefore, ranges in value from zero to five. Higher values of the index indicate stronger levels of protection. As supplement, Park updated the index to 2005 and extended to 122 countries at 2008. And the newest data available was published on Park's homepage which was updated to 2010. The intellectual property law was not set up until 1985 in China, so we choose the period 1985–2013 as our time series. Thus, the final sample of the paper contains 16 countries with the foreign patent application number and strength of IPR from 1985 to 2013.

3 Results

3.1 Descriptive Statistics of Non-resident Patent

We treat the EU 15 countries as a whole. The total number of non-resident patent applications between EU 15 countries and China is calculated bilaterally from 1985 to 2013.

Figure 1 shows that the flow of non-resident patents from EU to China started in 1986 just after the IP law of China was officially issued. And the flow of non-resident patents from China to EU started in 1991, 5 years later than the starting of inbound flow from EU to China.

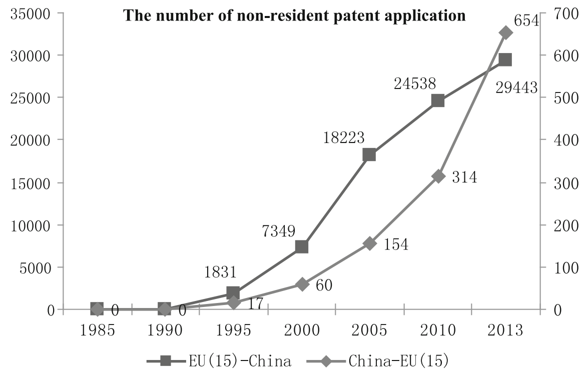

Fig. 1 Non-resident patent application number from 1985 to 2013

Table 1 Descriptive statistics of non-resident patent application

	From EU to China	From China to EU
Average	10,181.66	129.72
Standard deviation	10,373.97	165.47
Coefficient of variation	1.02	1.28
Median	9073	54
Kurtosis	−1.22	2.10
Skewness	0.54	1.49
Minimum	0	0
Maximum	29,443	654
Summation	295,268	3762

As shown in Table 1, the number of yearly non-resident patent applications from EU to China is averagely 78.5 times the number from China to EU over the period of 28 years.

More in detail, the standard deviation and coefficient of variation (CV) are indicators of dispersion degree, however the CV value can eliminate the influence of measurement scale and dimension.

As it can be noticed, a huge gap exists in the average number of the two columns (i.e. 10181.66 and 129.72). Under these circumstances, the CV value is more suitable for analyzing the discreteness of dataset. In general, the higher CV value is, the greater the discrete degree is. The value of the kurtosis and skewness represent of the center aggregation degree and symmetry of the dataset.

The value of the kurtosis and skewness represent of the center aggregation degree and symmetry of the dataset. In the field of Statistics, the boundaries of the two indicators are 3 and 0 separately according to the normal distribution. The two value of the kurtosis are −1.22 and 2.1 separately, which are both less than 3, indicating that the observations are not concentrated as normal distribution with a longer tail. The kurtosis value of outbound flow from China to EU (i.e. 2.1) is bigger than the inbound flow value (i.e. −1.22), declaring that there are more extreme values in the non-resident patent application numbers from China to EU during the observe period.

As a supplement, the value of skewness illustrates the direction of the tail. The two values of the skewness are 0.54 and 1.49 respectively, which are both bigger than 0, indicating that the longer tail is located in the right side of the average value. In the distribution of right-skewed, most of the data are located in the left side of the average value, and the outlier data exist on the right of the average, which makes a long tail on the right side of the curve. The skewness value of outbound flow from China to EU (i.e. 1.49) is bigger than the inbound flow (i.e. 0.54), demonstrating the fact that outliers level of outbound flow from China to EU is much higher.

In general, there are considerable differences in magnitude of the inbound flow from EU to China and outbound flow from China to EU. The developed countries in EU play the role of "exporter" in the international patent activities or international technology transfer, meanwhile China imports more external technology or knowledge. The imbalance between the inbound and outbound flow may result from the difference of accumulated knowledge and owned technology between China and countries in EU.

3.2 Correlation Analysis

The strength of IPR in European is the average value of the IPR of 15 countries each year. To avoid the influence of magnitude, we adopt the Z-core method to standardizing dataset.

The IPR of China and European countries are described as Fig. 2. Both curves show a growing trend with slowing down speed, and the curve representing European countries is always higher than the curve of China. The maximum IPR number of European countries is 1.4 times than the minimum, however the gap between numerical values in China is 3.17 times.

The Pearson correlation coefficients of the patent application number and IPR are listed in Table 2. The results are calculated in SPSS with 0.01 significant level.

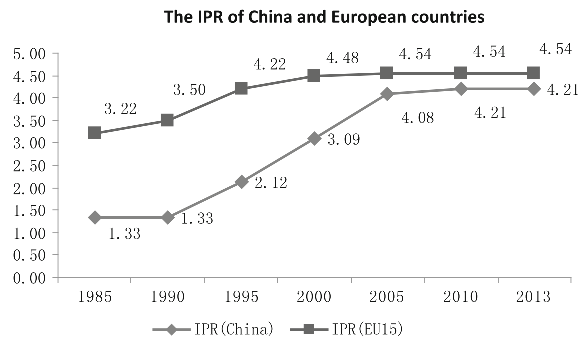

Fig. 2 Intellectual property rights of China and European countries from 1985 to 2013

Table 2 The correlation coefficient between IPR and non-resident patent

	China-EU(15)	EU(15)-China	IPR(China)	IPR(EU15)
China-EU(15)	1.00			
EU(15)-China	0.93** (0.000)	1.00		
IPR(China)	0.86** (0.000)	0.95** (0.000)	1.00	
IPR(EU15)	0.66** (0.000)	0.80** (0.000)	0.90** (0.000)	1.00

**represents coefficient has significant correlation at 0.01 level

First, the coefficient of the two patent application numbers is 0.93. The bilateral flow of patent application has strong positive correlation with each other. Second, the IPR of China and European countries have obvious positive relationship with the bilateral patent flows. Compared with IPR of European countries, the IPR strength of China shows a stronger correlation. The strongest coefficient is 0.95, the relationship between IPR of China and the non-resident patent application number from Europe to China. And the weakest coefficient is 0.66 representing the relationship between IPR of European Countries and the non-resident patent application number from China to Europe.

With a summary of the results, the correlation relationship between IPR and international patent activity or international technology transfer is supported. Even though we cannot judge the dependent and independent variables, we observe the trend between IPR and ITT. Moreover, when knowledge or technology is transferred from EU countries to China, the correlation is much higher than the opposite case. It may provide some implications for policy makers in developing or emerging countries.

4 Discussion

The results of the descriptive analysis and correlation analysis reveal some interesting facts between China and European countries. First, the number of non-resident patent applications manifest a huge difference of international technology transfer between China and EU. Although China exports knowledge and technology to Europe, China plays a role of technology importer primarily. In the international patent activities, the roles of developed countries and developing and emerging countries are distinct. The developed countries have the advantage of accumulated knowledge and technology, and they diffuse the technology included in international patent applications and disclosures to the other countries. The receiving countries can not only profit from the disclosed patent information to accelerate secondary innovation, on the other hand the firms in receiving countries should pay for the royalties of the foreign patents. As a result, developed countries appropriate revenues from these non-resident patent applications protected by the IP law in the destination countries, and in the meantime the destination countries accumulate their technology and knowledge capabilities through absorption and exploitation of the disclosed foreign patent information.

Second, the strength of IPR reveals the policy support for the technology transfer in developed and developing countries. The intellectual property law was not implemented until 1985, and the intellectual property rights in China are gradually approaching to the same level of the developed countries (i.e. EU average) after years of development. From the two figures provide above, the converging trend of the non-residents patent applications and IPR curves has shown this consistency. The IPR strength of China started to improve apparently on 1995, and the non-resident patent application number from Europe to China increased simultaneously.

Third, the correlation coefficients of the patent application number and IPR have shown the relationship between the macro-environment and international technology transfer. When the destination is a developing or emerging country, the strength of the intellectual property shows a stronger positive relationship with the inbound patent application flow, no matter for the IPR of origin or destination country. This is a relevant evidence that stronger intellectual property level can reduce the patentee’s concerns that the patent may be copied without any payment, especially in developing and emerging countries lacking the awareness of intellectual property rights protection. The foreign patentees will increase the filing number in SIPO if they feel safe about the macroenvironment. As a consequence, strong intellectual property rights improves the level and quality of patent applications filing in SIPO, in return, the local firms adopt the patents to accumulate knowledge and improve the innovation performance.

5 Conclusion

We discuss the international technology transfer measured by non-resident patent applications, and the relationship with the intellectual property rights. Although the topic of international technology transfer has drawn much attention from scholars for a long period, little has been done about the bilateral ITT flows between the China and Europe. It is the research gap that the paper attempts to fill.

We also put forward some policy recommendations, expecting that provide some help to the development of innovation capability in China and other developing countries. First, governments should pay more attention on the revising of intellectual property laws in order to guarantee the interests of intellectual property holders. The complete intellectual property protection laws are the foundations of the technology transfer and innovation development. In addition, enforcement of the laws is important to effective patent protection.

Although we have some conclusions from descriptive analysis and correlation analysis, there are still some limitations. First, we prove the correlation relationship between international technology transfer and intellectual property protection, but the causal relationship between them has not been confirmed. Second, the non-resident patent application number is an effective measurement of international technology transfer, but the bias may exist when we only adopt the measurement. In the future study, we mainly make up for the two limitations.

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A Multi-dimensional Analysis of the Knowledge Search Strategies of High-tech Manufacturing Firms in Scientific Fields: Evidence from Guangdong

Yong-li Tang, Hai-wen Zhang, Claudio Petti and Xin-yue Hu

Abstract Even though much studies has explored the firm's knowledge search strategies on various knowledge sources in the external environment, little has been done on firm's knowledge search strategies in the scientific fields. To fill this gap, we analyze firm's search strategies based on the data of scientist mobility from a university-industry interaction program—the Guangdong's Technical Expert Secondment Program for the years 2008–2012. The results reveal that most of the firms search knowledge in a limited number of scientific disciplines, but search deeply. Though, firms' search breadth and search depth both increase along with the search duration. In addition, firms from different industries also show great difference in their search distances in the geographical space. Drawing from the above findings, we propose some policy and managerial implications.

Keywords Knowledge search · Search strategies · Scientific disciplines · High-tech manufacturing firms

1 Introduction

Since Chesbrough [1] firstly introduced the new innovation paradigm—"Open Innovation", academic researchers have increasingly embraced the idea that both internal resources and external resources are critical for firm's innovation. To achieve higher technology innovation performance, a firm has to identify, connect to and leverage external resources like knowledge and combine it with

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internal ideas in its innovation process [2]. Following this argument, searching for knowledge from external environment is one of the vital activities for firm's innovation. In organization learning literature, knowledge search of organizations mainly involves scanning the wide-ranging external environment and then conducting focused search in a narrow segment of the external and internal environment [3]. Actually, this definition of knowledge search had implied that search might be depicted from two distinct dimensions. From the perspective of product innovation, Katila and Ahuja [4] defined innovation search as an organization's problem-solving activities that involve the creation and recombination of technological ideas. They used two distinct terms to describe firm's search strategies, namely search scope and search depth, respectively. Based on the work of Katila and Ahuja [4], Laursen and Salter [5] redefined knowledge search strategies in the open innovation environment, namely external search breadth and external search depth. Their outstanding work investigated firms' search strategies in sixteen external knowledge sources and their impact on the novelty of innovation in UK manufacturing industry. Search breadth is defined as the number of external sources or search channels that firms rely upon in their innovative activities, while search depth is the extent to which firms draw deeply from the different external sources or search channels [5]. Subsequent researchers widely adopted search breadth and search depth as two fundamental dimensions of firm's knowledge search strategies [6–11].

However, to our best knowledge, very little has been done concerning firm's knowledge search strategies in a "fine-grained" level, even though some pioneers, e.g. Rosenkopf and Nerkar [12], Katila and Ahuja [4] had probed firms' technological search activities by using the patent data. More in detail, Laursen and Salter [5] had pointed out that their research didn't analyze the importance of search breadth and search depth with each individual knowledge source or channel to the novelty of innovation. Further, firms that choose "open" search strategies are more likely to draw from universities in their innovative activities [13]. As a matter of facts, past research on University-Industry interaction has provided many clues about firm's knowledge search in scientific fields. Academic researchers from different scientific disciplines may engage differently in the various interaction patterns with firms [14]. Most importantly, academic researchers constituted a key channel for firms engaging into knowledge interactions with universities and research organizations [15]. Theoretically, firms' knowledge search from universities can be captured in terms of search breath and search depth. Nonetheless, in the existing literatures, there are little studies to investigate firm's knowledge search strategies in scientific fields.

Therefore, in order to enrich the understanding of firm's knowledge search strategies within individual knowledge source or channel and at the same time to shed light of these strategies in the scientific channel we aim to provide evidence on knowledge search strategies of high-tech manufacturing firm in scientific fields based on University-Industry interaction. We will do this in Guangdong Province, the world biggest emerging economy's fastest developing region. As a matter of facts, China's high-tech manufacturing industries have gained blooming development. According to the bulletin of National Bureau of Statistics of China, the total aggregated R&D expenditure of Chinese high-tech manufacturing firms whose annual revenue exceed 20 million RMB yuan had reached 203.43 billion RMB yuan in 2013, which increased by 178.2 % since 2008 [16]. Such vast R&D investment paid off. In 2013, the high-tech manufacturing firms in China applied 74 thousand invention patents and their sales revenue of new products reached 3.1 trillion RMB yuan [16]. Moreover, in order to maintain and broaden the technology strengths, Chinese firms in high-tech manufacturing industries resort to the open innovation approach extensively, including engaging in university-industry interactions with local universities and R&D institutes [17]. The university-industry interactions create the opportunity for high-tech manufacturing firm to search scientific knowledge. Moreover, we select Guangdong province as the observed region in China because of it accounted for the highest proportion of high-tech firms in China in 2013. Beyond one fifth (21.57 %) of high-tech firms in China located in Guangdong in 2013 [18]. At the meantime, there were 138 universities and 1103 R&D institutions located in Guangdong in 2013 [18]. Therefore, we believe that the Guangdong province in China is particularly appropriate as the research context to uncover the knowledge search strategies of high-tech manufacturing firm in scientific channel.

In addition, besides the two classical dimensions of search strategies in literatures, search depth and search breadth, we also include the geographic (spatial) and time-related dimensions into our research. Geographic search of firm has gained much attention. For example, Sidhu et al. [19] argued that search may be spatial, emphasizing firms search opportunities, knowledge etc. in different geographic regions. In science and technology intensive Industries in US, Hohberger [20] found that the age of the knowledge increases with geographic distance in firm's search patterns. For the time dimension of search, we use the duration of search to describe whether firms adopt continuous or occasional search strategies.

The remainder of this article is structured as follows: in the Sect. 2, we will introduce the methods to collect the data and construct the sample. Especially, we will present the approach to measure the firm's knowledge search strategies in different scientific disciplines. In Sect. 3, we will present the results based on multi-dimensional analysis. We put forward our discussion as well as policy and managerial implications in Sect. 4. Finally, Sect. 5 summarizes our findings.

2 Methods

2.1 Data Collection

To provide the empirical evidence on firm's knowledge search strategies in scientific disciplines, we performed our research base on a unique dataset of University-Industry interaction based on Guangdong's Technical Expert Secondment Program (TESP). TESP is an initiative supported by Guangdong

Science and Technology Department (GSTD) since 2008. The aim is to encourage researchers and professors from nationwide universities and research institutes (Hereafter, we refer to both universities and research institutes as universities for simplicity, unless specified differently.) to work as technological experts in Guangdong industrial firms on secondment, in order to tighten university-industry links and promote knowledge interactions between universities and firms. Therefore, we propose that firm's knowledge search is embedded in the knowledge interaction originating from firms receiving TESP technical experts. Our original data of TESP from 2008 to 2012 were sourced from GSTD official program records. The records in the original data of TESP include the name of the technical expert, the university from which technical expert came from, the firm where the technical expert was assigned, the city where the firm located, and others not of relevance for this study.

Inspired by the contribution of D'Este and Patel [14], we decide to distinguish scientific knowledge in terms of scientific disciplines. Before measuring firm's knowledge search strategies, we followed two steps to collect related information and ascertain the scientific discipline of each technical expert:

Step 1: For each technical expert that participated in TESP during 2008 to 2012, we used Internet search engines (e.g. Google, Baidu) to search the official websites of the university he or she comes from. We also used technical expert's name and university to search academic publications in the largest Chinese academic journal database, China National Knowledge Internet database. By these two means, we collected the research fields and disciplines of each technical expert from his or her biography.

Step 2: According to the information about the research fields of each technical expert, we referred to the standard of Subject Classification and Code of PRC (GBT 13745-2009), and allocated a 3-digit code to each technical expert. This national standard of subject classification provided the detailed description of 62 first-class disciplines in 3-digit code, 676 second-class disciplines in 5-digit code.

2.2 Sample

Follow with previous studies [9, 10, 20] did and the blooming development of high-tech manufacturing in China in recent years, we choose the firms in high-tech manufacturing industry as the frame population. More specifically, our sample is made of 134 high-tech manufacturing firms that involved in TESP in 2012. Since the TESP was initiated in 2008 and it went through the stage of growing in subsequent years, we set a 5-year observation period which provided us enough time to investigate firms' search strategies. In addition, there were 141 firms participated in TESP in 2008, 625 firms in 2012, respectively. Hence, we selected those 625 firms in 2012 so as to obtain adequate observations in our study. The 134 firms in the sample were selected from the our TESP 2008-2012 dataset by referring to the Classification of high-tech manufacturing issued by National Bureau of Statistics

Table 1 The industrial distribution of the 134 firms in the sample

SIC code (2 digits)	Industry	Number of firms
26	Information chemical manufacturing	3
27	Medical manufacturing	30
35	Medical instruments and equipment manufacturing	14
37	Aviation, spacecraft and equipment manufacturing	2
38	Lithium ion battery manufacturing	4
39	Computer, communications and other electronic equipment manufacturing	66
40	Instrument and apparatus manufacturing	15
	Total	134

of China in 2011 and the main business activity of the firms. As firms might participate in TESP in different year during the 2008 to 2012, we also trace back these 134 firms in previous 4 years (2008–2011), so as to capture these firms' knowledge search activities during the 5-year period (2008–2012). Finally, our sample includes 134 firms, connected to 87 universities and research institutes and involving 466 person times of technical experts exchanges during 2008 to 2012. It's important to note that some of these technical experts were frequently sent to a given firms during the 5-year period. In other words, a given firm may receive the same technical expert in different years. Altogether, 134 firms come from seven high-tech manufacturing industries (see Table 1). Nearly 70 % (96) of these firms are in medical manufacturing and computer, communications and other electronic equipment manufacturing. Besides, the 466 person times of technical experts come from 27 scientific disciplines.

2.3 Measures

(1) *Firm's knowledge search breadth and search depth.*
We use the following equations to measure the knowledge search strategies of firm i:

$$Searchbreadth_i = \sum_{k=1}^{27} a_{ik} \tag{1}$$

a_{ik} = 1 if firm i received any technical expert from scientific discipline, k otherwise a_{ik} = 0.

$$Searchdepth_i = \frac{b_i}{Searchbreadth_i} \tag{2}$$

b_i represents the person times of technical experts received by firm i during 2008 to 2012.

(2) *Firm's search duration*

In the present paper, we use the years of continuous search to describe whether a firm implement continuous search strategy or occasional search strategy. In more detail, we classified 134 sample firms by the years of continuous search during 2008 to 2012. The years of continuous search of firms range from 2 to 5 years. Besides, we identified the firms which search occasionally, only search for 1 year or search discretely during 2008 to 2012, excluding the firms which search continuously at least 2 years during the same period.

(3) *Firm's search distance*

We adopt a simplified method to represent the geographic distance between the firm and the university from which the firm search scientific knowledge. For the focal firm *i* and university *j,* from which the technical expert comes from, if the firm *i* and the university *j* locate at the same city within Guangdong province, then the "geographic distance" between them is 1. If the focal and the university locate at the two different cities but within Guangdong province, the "geographic distance" is 2; if the focal firm and the university locate at the two different cities, and one of them locates outside Guangdong province, the "geographic distance" is 3. Hence, the value of "geographic distance" only reflects the relative magnitude. For a focal firm *i*, it may search scientific knowledge from various universities during 2008 to 2012. So as to describe firm's search distance generally, we then calculate the "geographic distance" of focal firm *i* and university *j* for each person times of technical expert received.

3 Results

3.1 Firm's Knowledge Search Breadth and Depth in Scientific Disciplines

In general, the average search breadth for the 134 firms in our sample is 1.59, while the average search depth is 2.11. The difference of search breadth and search depth between industries is shown in Fig. 1.

Figure 1 reveals that the average search breadth of seven industries range from 1 to 2, which means firms in different industries generally search knowledge from a limited number of scientific disciplines. Regarding to the average search depth, there are differences among industries. Averagely, firms in these four industries, namely information chemical manufacturing, medical manufacturing, medical instruments and equipment manufacturing, and aviation, spacecraft and equipment manufacturing, search more "superficially" than firms in lithium ion battery manufacturing, computer, communications and other electronic equipment manufacturing, instrument and apparatus manufacturing industries.

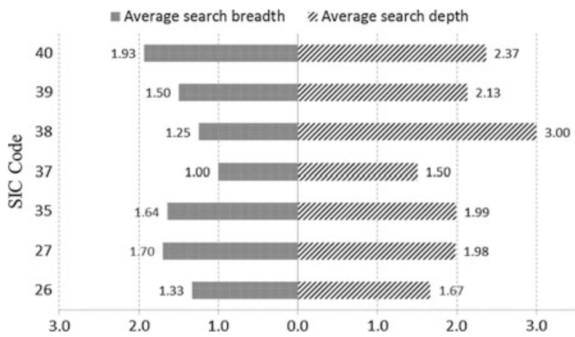

Fig. 1 Comparation on search breadth and search depth among industries

3.2 Continuous or Occasional Search: Difference on Search Breadth and Search Depth

Since firms may search continuously or occasionally, the search breadth and search depth of firms could be different to some extent. We use the search duration as the observation window, and compare the search breadth and the search depth among firms. As shown in Table 2, there are 51 firms in our sample only searched for 1 year or for 2 year discontinuously. Most of firms both searched in 2011 and 2012, which means these firms at least searched for two years. Nearly 30 firms at least searched for 3 or 4 years continuously. However, in our sample only 1 firm searched for 5 years continuously.

As we anticipated, the search depth increases along with the increasing continuous search duration. Surprisingly, in terms of search breadth, the firms that conducted longer, continuous searches have broader search breadth.

3.3 The Search Distance of Firms in Different Industries

Firms may search locally within a given region or search across regions. To better understand the difference of search distance of firms among industries, we illustrate

Table 2 Firm's search duration and search strategies

Years of continuous search	Number of firms	Percentage (%)	Search breadth	Search depth
Only 1 year	42	31.34	1.14	1.06
>1 (occasional)	9	6.72	1.63	2.23
2	53	39.55	1.55	2.20
3	16	11.94	2.06	3.21
4	13	9.70	2.46	3.83
5	1	0.75	3	2

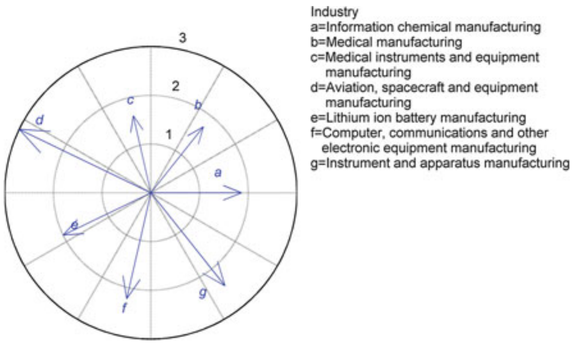

Fig. 2 The search distance of firms in different industries

the average search distance by industries by seven vectors in Fig. 2. The length of each vector represents the average search distance of firms within the same industry. Figure 2 shows that firms—in different industries search differently on geographic scope. Four vectors (a, b, c and e) distribute within a radius of two, while another three vectors (d, f, and g) lie outside of a radius of two. Most of firms have searched across cities within Guangdong province, even some of them search across Provinces in China.

4 Discussion

Even though we only include the high-tech manufacturing firms into our sample as previous studies did, we find some interesting results of firm's knowledge search strategies in science fields in the context of Guangdong, China. Differing from the previous studies on firms search various external knowledge sources, the results of search breadth and search depth in our study show that firms in different industries search rather narrowly in a limited number of scientific disciplines under the framework of TESP. These results imply that firms in different industries have their own technology background, and search the specific scientific knowledge they need. As firms operate the continuous search strategies, both the search breadth and search depth increase by time. However, greater search breadth and search depth also require firms made more investment in absorbing the external knowledge, which may raise a series of managerial problems for firms [5]. Thus, managers should balance the search breadth as well as the search depth.

As shown by the result, more firms are inclined to search non-locally for scientific knowledge. On one hand, government policies like TESP encouraged the nationwide universities and research institutes participate in university-industry interaction with firms. On the other, firms may search knowledge from specific universities and research institutes which may be located far from the firms but are capable to provide valuable scientific knowledge. In firms' search process, managers should broaden their view to nationwide even worldwide scope, so as to identify the valuable knowledge in the external environment.

5 Conclusion

With the aim to investigate the firm's knowledge search strategies in science fields, the present paper presents a preliminary multi-dimensional analysis based on a sample of high-tech manufacturing firms from Technical Expert Secondment Program undertaken in Guangdong, China during 2008 to 2012. These firms concentrate narrowly on some limited scientific disciplines rather than searching broadly. Firms that adopt continuous search strategies, show greater search breadth and search depth. Our results also highlight that firms are likely to search non-locally, in pursuit of scientific knowledge across geographic boundaries.

The limitations in our study open the avenues for further studies. Since our study only investigate firm's knowledge search by focusing on one specified channel in University-Industry interaction and firms may search scientific knowledge from other external channels, further studies could extend and explore our research topic in different channels. For instance, firms may search scientific knowledge by attending academic conferences, reading academic publications as well as searching information from patent databases. We hope our research could shed some light on the understanding of firm's knowledge search strategies beyond the scientific channel.

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Research on the Early Warning Model of Quality Crisis in Product Requirements Identification Process

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Abstract This paper aims to prevent quality crisis event in product requirements identification process effectively. Quality crisis monitoring elements are identified on the basis of four processes of product requirements identification process. 8 quality crisis monitoring elements and 13 quality crisis warning indexes have been confirmed, and early-warning level threshold value of quality crisis early-warning indexes has been explored. The quality crisis early-warning model has been established by using the improved extension theory model. Taking the product requirements identification process of a heavy vehicle as an example, the research of indexes and processes early warning level assessment in product requirements identification process has also been conducted.

Keywords Early warning indexes · Improved extension theory model · Monitor elements · Product requirements identification process · Quality crisis

1 Introduction

The quality crisis warning of product requirements identification process aims to eliminate or reduce the harm caused by quality crisis and narrow the range of influence by monitoring the early warning indexes of product requirements identification process, assessing the warning information and issuing alert timely.

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TQM, ISO9000 standard, Six Sigma quality improvement model, and excellent performance evaluation criteria, etc. have explained macro approaches to warn the product requirements identification process quality crisis from perspectives of customer, laws and regulations, additional requirements of the organization. At the same time, relevant scholars have explored crisis early warning model from different angles, including integration of support vector machine and logistic regression [1], group decision making [2], artificial neural networks [3], Grey Markov forecasting model [4], multivariate classification evaluation model [5], variable precision rough set theory [6], etc. But most of the above mentioned models failed to focus on the quality crisis, and no one focus on the product requirements identification process. And the product requirements identification process as the primary stage of product quality formation process which has a significant influence on product quality. Based on this, in order to monitor and reduce the quality crisis of product requirements identification process effectively, this paper firstly, attempts to identify the monitoring elements; secondly, extracts warning indexes from the perspective of monitoring elements; finally, establishes the warning model.

2 Identification of Monitor Elements

On the basis of systems theory and method such as ISO9000 [7], crisis management theory, quality management theory, product requires identification process has been divided into planning process, identification process, review process, communication and feedback process.

Integrated ISO9001 standards, modern quality management theory and product requirements identification process quality factors research, the questionnaire of correlation between factors and quality crisis has formed. We have invited experts from quality crisis-prone industry to complete the questionnaire. Based on the analysis of the questionnaire's reliability and validity, the completeness of the planning process has been identified as the monitoring elements of planning process; Resources satisfaction in product requirements identification process, planning execute results of product requirements identification process, timeliness of product change information update has been identified as the quality crisis monitoring elements of identification process; Resources satisfaction in assessment process, planning execute results of assessment process, product requirements satisfaction has been identified as the quality crisis monitoring elements of assessment process; Stakeholders feedback information processing timeliness has been identified as the quality crisis monitoring elements of communication and feedback process.

3 Construction of Early Warning Model

3.1 Determining of Early Warning Indexes and Warning Level

(1) *Determining of early warning indexes*: Combining with the monitoring elements and objective analysis method, we have drafted the relationship diagram of warning elements and indexes as shown in Fig. 1.

(2) *The formula for calculating the indexes value*

(1) *Closing of unqualified items* C_{i1}

$$C_{i1} = 1 - \sum_{h=1}^{3} a_{ilh}\eta_h / \sum_{h=1}^{3} n_{ilh}\eta_h \times 100\,\% \tag{1}$$

$i = 1, 2, 3, 4$; $h = 1, 2, 3$; $a_{ilh} = 0, 1, 2\ldots n_{ilh}$; a_{ilh} refers to the number of unclosed nonconformity in i process; h indicates the severity level of nonconformity, $h = 1–3$ respectively indicates the item to be seen, slight nonconformity and common nonconformity (because the alarm has been triggered after severe nonconformity, it will not included in the scope of statistics); η_h refers to the weight of h severity level nonconformity, By inviting the aforementioned experts to analyze, we have determined that $\eta_1 = 1/6$, $\eta_2 = 1/3$, $\eta_3 = 1/2$; n_{ilh} refers to the total number of nonconformity in i process with h level.

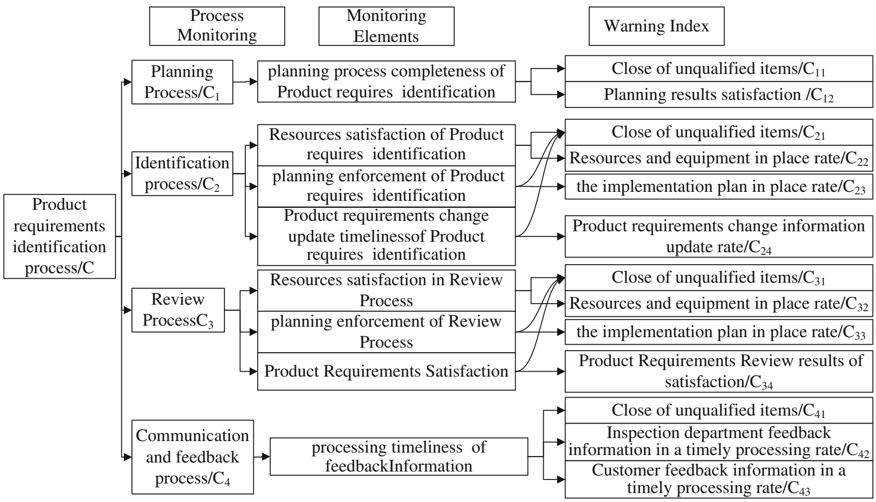

Fig. 1 The relationship between quality crisis monitoring elements and early warning indexes

(2) *Planning results satisfaction* C_{12}

$$C_{12} = \mathrm{v}/\mathrm{V} \times 100\ \% \tag{2}$$

v is the number of planning in place in the divided product requirements identifications, its control point, reviews, verification and validation activities, authorities and interfaces relations; V is the total number of activities required planning.

(3) *Resources in place rate* C_{i2}

$$C_{i2} = 1 - \sum_{l=1}^{4} r_{il}\beta_{il} / \sum_{l=1}^{4} R_{il}\beta_{il} \times 100\ \% \tag{3}$$

$i = 2, 3$; $l = 1, 2, 3, 4$; $r_{il} = 0, 1, 2 \ldots R_{il}$; r_{il} refers to the true number of resources l in place, R_{il} refers to the total number of resources l needed in place, β_{il} refers to the relative importance of resources l, $\beta_{21} = \beta_{31} = 5/14$, $\beta_{22} = \beta_{32} = 1/14$, $\beta_{23} = \beta_{33} = 5/14$, $\beta_{24} = \beta_{34} = 3/14$

(4) *In place rate of planning implementation* C_{i3}

$$C_{i3} = u_i / U_i \times 100\ \% \tag{4}$$

u_i is the actual number of the planning implementation, $i = 2, 3$; U_i refers to the number of activities need to be implement.

(5) *Product requirements change information update rate* C_{24}

$$C_{24} = b/B \times 100\ \% \tag{5}$$

B refers to the total number of related party requirements changes; b refers to the number of changes reflected by final product

(6) *Product requirements review results satisfaction* C_{34}

$$C_{34} = d/D \times 100\ \% \tag{6}$$

D refers to the total number of related party requirements; d refers to the number of the organization that have the ability to meet the requirement.

(7) *Inspection department feedback information timely treatment rate* C_{42}

$$C_{42} = e_1/E_1 \times 100\ \% \tag{7}$$

e_1 refers to the timely processed number of feedback information from the inspection department; E_1 refers to the total number of feedback information from the inspection department.

(8) *Customer feedback information timely treatment rate* C_{43}

$$C_{43} = e_2/E_2 \times 100\ \% \tag{8}$$

e_2 refers to the timely processed number of customer feedback information; E_2 refers to the total number of customer feedback information.

Table 1 The level of quality crisis early warning indexes in product requirements identification process

Quality crisis early warning indexes	C_{ij}
No warning I	[100 %, 99.73 %)
Low warning II	[99.73 %, 98.63 %)
Moderate alert III	[98.63 %, 94.11 %)
Major alert IV	[94.11 %, 75.62 %)
Giant alert V	[75.62 %, 0]

(3) *Determining of early warning level*: Based on most crisis early warning indexes classification standards [8], we have divided the level of quality crisis early warning indexes into five levels as no warning (I), low warning (II), moderate alert (III), major alert (IV), giant alert (V), and setting 5, 0.27, 3.4×10^{-4} % as three initial threshold according to the common error probability, three Sigma economic magnitude of process capability, six Sigma management requirements. Combining with expert judgment and maximum membership degree principle, 0.27 % was as the initial threshold of warning indexes. On the basis of initial threshold we have identified the threshold of low warning, moderate alert, major alert, giant alert with geometric sequence as shown in Table 1.

3.2 Construction of Early Warning Model

(1) *Determination of the classical field and segment field*: According to the principle of extension theory model, the quality crisis indexes early warning level interregional of product requirements identification process in Table 1 was the classical field of early warning indexes.

(1) *Determining of warning indexes and processes standardization classical fields*: facilitating the building of the early warning model and data processing, we have standardized the classical field, and the result are shown as follows.

$$R_1 = (I, C_{1j}, V_{1j1}) = \begin{bmatrix} C_{11} & [0, 0.0027) \\ C_{12} & [0, 0.0027) \end{bmatrix} \quad R_2 = \left(\prod, C_{1j}, V_{1j2}\right) = \begin{bmatrix} C_{11} & [0.0027, 0.0137) \\ C_{12} & [0.0027, 0.0137) \end{bmatrix} \quad R_3 = (III, C_{1j}, V_{1j3}) = \begin{bmatrix} C_{11} & [0.0137, 0.0589) \\ C_{12} & [0.0137, 0.0589) \end{bmatrix}$$

$$R_4 = (\mathrm{IV}, C_{1j}, V_{1j4}) = \begin{bmatrix} C_{11} & [0.0589, 0.2438) \\ C_{12} & [0.0589, 0.2438) \end{bmatrix} \quad R_5 = (\mathrm{V}, C_{1j}, V_{1j5}) = \begin{bmatrix} C_{11} & [0.2438, 1) \\ C_{12} & [0.2438, 1) \end{bmatrix}$$

Due to space limitations, we only show the standardization classical field of C_1, and the standardization classical field of C_2, C_3, C_4 can be obtained in the same way.

(2) *Determining of the whole product requirements identification process standardization classical field*: Combining the standardization classical

field of C_1–C_4 we can get the standardization classical field of the whole product requirements identification process.

(3) *Determining of segment field*: Combining the classical field we get the segment field of C_1–C_4, respectively represent by R_{p1}, R_{p2}, R_{p3}, R_{p4}. Combining R_{p1}, R_{p2}, R_{p3}, R_{p4} we can get R_p as the alert level segment field of the whole product requires identification process.

$$R_{p1} = \left(P, C_{1j}, V_{1jp}\right) = \begin{bmatrix} I:V & C_{11} & [1,0] \\ & C_{12} & [1,0] \end{bmatrix}$$

$$R_{p2} = \left(P, C_{2j}, V_{2jp}\right) = \begin{bmatrix} I:V & C_{21} & [1,0] \\ & C_{22} & [1,0] \\ & C_{23} & [1,0] \\ & C_{24} & [1,0] \end{bmatrix}$$

$$R_{p3} = \left(P, C_{3j}, V_{3jp}\right) = \begin{bmatrix} I:V & C_{31} & [1,0] \\ & C_{32} & [1,0] \\ & C_{33} & [1,0] \\ & C_{34} & [1,0] \end{bmatrix}$$

$$R_{p4} = \left(P, C_{4j}, V_{4jp}\right) = \begin{bmatrix} I:V & C_{41} & [1,0] \\ & C_{42} & [1,0] \\ & C_{43} & [1,0] \end{bmatrix}$$

$$R_{p} = \left(P, C_{ij}, V_{ijp}\right) = \begin{bmatrix} I:V & C_{11} & [1,0] \\ & C_{12} & [1,0] \\ & \cdots & \cdots \\ & C_{43} & [1,0] \end{bmatrix}$$

(2) *Weight of warning indexes*: To avoid using subjective weight over-reliance on personal preferences, objective weight over-reliance on sample data, we combine subjective with objective method to calculate the weights of warning indexes [9].

(1) *Subjective weight w_{ij}*: Using AHP [10] method to determine the warning indexes subjective weight as shown in Table 2.

(2) *Objective weights w_{ij}*: To highlight the effect of monitoring data on the level of quality crisis, superscalar weighting method is used to determine the objective weight of warning indexes [11], as shown in Eq. (9):

$$w'_{ij} = C'_{ij} / \sum_{j=1}^{J} C'_{ij},\ C'_{ij} = \frac{\lambda}{C_{ij}} \tag{9}$$

Table 2 The subjective weight of warning indexes

Warning indexes	Process weight	Overall weight	Warning indexes	Process weight	Overall weight
C_{11}	0.33	0.05	C_{32}	0.07	0.01
C_{12}	0.67	0.11	C_{33}	0.47	0.05
C_{21}	0.15	0.07	C_{34}	0.23	0.02
C_{22}	0.45	0.22	C_{41}	0.2	0.05
C_{23}	0.30	0.16	C_{42}	0.4	0.1
C_{24}	0.10	0.04	C_{43}	0.4	0.1
C_{31}	0.23	0.02			

C_{ij} is the actual value of corresponding indexes, j = 1–J; when i = 1, J = 2; when i = 2, J = 4; when i = 3, J = 4; when i = 4, J = 3; λ is the average value of early warning indexes standard threshold.

(3) *Comprehensive Weight* W_{ij}: Using the objective weight and subjective weight comprehensive method, with Eq. (10) to determine the comprehensive weight of the quality crisis early warning indexes:

$$Wij = \mu w_{ij} + (1 - \mu) w'_{ij} \tag{10}$$

μ is the policymakers preference degree to subjective and objective weight, $0 < \mu < 1$.

(3) *Construction of correlation function*: Scholars have proved that there are some drawbacks of correlation degree formula in classic extension theory model [12, 13]. To overcome these shortcomings, a new function is constructed based on the definition of correlation degree, as shown in formula (11).

$$k_{ijt}\left(v'_{ij}\right) = \begin{cases} \frac{v'_{ij} - a'_{ijt}}{S_{ijt} - a'_{ijt}}, v'_{ij} \in [a'_{ijt}, b'_{ijt}] \cap v'_{ij} \le s_{ijt} \\ \frac{b'_{ijt} - v'_{ij}}{b'_{ijt} - S_{ijt}}, v'_{ij} \in [a'_{ijt}, b'_{ijt}] \cap v'_{ij} > s_{ijt} \\ \frac{v'_{ij} - a'_{ijt}}{b'_{ijt} - v'_{ij}}, v'_{ij} \notin [a'_{ijt}, b'_{ijt}] \cap v'_{ij} < s_{ijt} \\ \frac{b'_{ijt} - v'_{ij}}{v'_{ij} - a'_{ijt}}, v'_{ij} \notin [a'_{ijt}, b'_{ijt}] \cap v'_{ij} > s_{ijt} \end{cases} \quad S_{ijt} = \begin{cases} \frac{a'_{ijt} + b'_{ijt}}{2}, t < 5 \\ 2a'_{ijt} - S_{ijt-1}, t = 5 \end{cases} \tag{11}$$

where $k_{ijt}(v'_{ij})$ refers to correlation degree; i = 1–4; j = 1–2 when i = 1; j = 1–4 when i = 2; j = 1–4 when i = 3; j = 1–3 when i = 4; t = 1–5 respectively represent no warning, low warning, moderate alert, major alert, giant alert. S_{ijt} refers to the gray interval threshold value of warning level t of the indexes j in process i; a_{ijt}, b_{ijt} refers to the left and right endpoints of the standardization classic field of the indexes j in process i, which in warning level t.

(4) *Construction of early warning model*: On the basis of calculated correlation degree with Formula (11), the results were normalized. Finally combined with the calculated data and the formula (12), the alert level can be calculated as follows.

$$j_i^* = \sum_{t=1}^{5} k_{it} t \tag{12}$$

where:

$$k_{it} = \sum_{i=1}^{J} \overline{k_{ijt}(v'_{ij})}' W_{ij}; \overline{k_{ijt}(v'_{ij})}' = \overline{k_{ijt}(v'_{ij})} / \sum_{t=1}^{5} \overline{k_{ijt}(v'_{ij})}$$

$$\overline{k_{ijt}(v'_{ij})} = \frac{k_{ijt}(v'_{ij}) - \min k_{ijt}(v'_{ij})}{\max k_{ijt}(v'_{ij}) - \min k_{ijt}(v'_{ij})}$$

$\overline{k_{ijt}(v'_{ij})}$ refers to normalized correlation degree; $\overline{k_{ijt}(v'_{ij})}'$ refers to standardization of the normalized correlation degree; ji^* refers to the warning level.

Based on the analysis of related literature and the early warning model, we have proposed the rules to determine the warning level. And the finally result are shown in Table 4:

4 Application of the Model

The product requirements identification process of a heavy-duty automotive product as an example, with the data collected and the formulas to calculate the indexes value and the alert level.

(1) *Product requirements identification planning process quality crisis early warning*

(1) *Indexes Warning*: With the raw data of C_{11}–C_{12} and the Eqs. (1), (2), the value of C_{11}–C_{12} can be calculated. C_{11} = 100 %, C_{12} = 99.3 %, two indexes did not reach the alarm level.

(2) *Process Warning*: Based on subjective weight of C_{11}, C_{12} in Table 2, the value of C_{11}, C_{12}, Eqs. (9), (10), the comprehensive weight of C_{11}, C_{12} can be calculated, and the result are shown in Table 4. Combining with the data calculated and Eqs. (11), (12), the alert level can be calculated. As for $2 < j_1^* = 2.2186 < 2.5$, according to the rules in Table 3, so the warning level is between the low warning and moderate alert but incline to the low warning.

(2) *Product requirements identification process quality crisis early warning*

(1) *Indexes Warning*: With the raw data of C_{21}–C_{24} and Eqs. (1), (3), (4), (5), value of C_{21}–C_{24} can be calculated. Since C_{21} = 1, C_{22} = 0.9464, C_{23} = 1,

Table 3 The quality crisis early warning level determine in product requirements identification process

j_i^*	Early warning level
$j_i^* < 1$	No warning
$1 \le j_i^* < 1.5$	No warning to low warning but incline to no warning
$1.5 \le j_i^* < 2$	No warning to low warning but incline to low warning
$2 \le j_i^* < 2.5$	Low warning to moderate alert but incline to low warning
$2.5 \le j_i^* < 3$	Low warning to moderate alert but incline to moderate alert
$3 \le j_i^* < 3.5$	Moderate alert to major alert but incline to moderate alert
$3.5 \le j_i^* < 4$	Moderate alert to major alert but incline to major alert
$4 \le j_i^* < 4.5$	Major alert to giant alert but incline to major alert
$4.5 \le j_i^* \le 5$	Major alert to giant alert but incline to giant alert

Table 4 The comprehensive weight of warning indexes

Warning indexes	Process weight	Overall weight	Warning indexes	Process weight	Overall weight
C_{11}	0.4158	0.0896	C_{32}	0.1612	0.0350
C_{12}	0.5842	0.1174	C_{33}	0.3590	0.0544
C_{21}	0.1991	0.0681	C_{34}	0.2413	0.0427
C_{22}	0.3573	0.1443	C_{41}	0.2563	0.0637
C_{23}	0.2749	0.1053	C_{42}	0.3562	0.0882
C_{24}	0.1687	0.0532	C_{43}	0.3875	0.0961
C_{31}	0.2385	0.0420			

$C_{24} = 1$, C_{22} has reached the alarm level, it is necessary to deal with C_{22} until the warning level returned to low warning or no warning.

(2) *Process Warning*: Based on subjective weight of C_{21}–C_{24} in Table 2, the value of C_{21}–C_{24}, Eqs. (9), (10), the comprehensive weight of C_{21}–C_{24} can be calculated, and the result are shown in Table 4. Combining with the data calculated and Eqs. (11), (12) the results of alert level can be calculated. As for $2 < j2^* = 2.1555 < 2.5$, according to the rules in Table 3, so the warning level is between the low warning and moderate alert but incline to the low warning.

(3) *Quality crisis early warning of product requirements identification assessment process*

(1) *Indexes Warning*: With the raw data of C_{31}–C_{34} and Eqs. (1), (3), (4), (6), the value of C_{31}–C_{34} can be calculated. Since $C_{31} = 1$, $C_{32} = 0.9679$, $C_{33} = 0.9667$, $C_{34} = 0.9778$, C_{32}, C_{33}, C_{34} has reached the alarm level, it is necessary to deal with C_{32}, C_{33}, C_{34} until the warning level returned to low warning or no warning.

(2) *Process Warning*: Based on the subjective weight of C_{31}–C_{34} in Table 2, the value of C_{31}–C_{34}, Eqs. (9), (10), the comprehensive weight of C_{31}–C_{34} can be calculated, and the result as shown in Table 4. Combining with the data calculated and Eqs. (11), (12), the results of alert level can be calculated. As for $2.5 < j_3^* = 2.9858 < 3$, according to the rules in Table 3, so the warning level is between the low warning and moderate alert but incline to moderate alert. It is necessary to take some measures until the warning level returned to low warning or no warning.

(4) *Quality crisis early warning of communication and feedback process*

(1) *Indexes warning*: With the raw data of C_{41}–C_{43} and the Eqs. (1), (7), (8), the value of C_{41}–C_{43} can be calculated. Since $C_{41} = 1$, $C_{42} = 1$, $C_{43} = 0.8333$, C_{43} has reached the alarm level, it is necessary to deal with C_{43} until the warning level returned to low warning or no warning.

(2) *Process warning*: Based on the subjective weight of C_{41}–C_{43} in Table 2, the value of C_{41}–C_{43}, Eqs. (9), (10), the comprehensive weight of C_{41}–C_{43} can be calculated, and the result are shown in Table 4. Combining with the data calculated and Eqs. (11), (12), the results of alert level can be calculated. As for $2 < j_4^* = 2.3801 < 2.5$, according to the rules in Table 3, so the warning level is between the low warning and moderate alert but incline to low warning.

5 Conclusion

Based on the analysis of quality management theory and questionnaires, 8 quality crisis monitoring elements have been recognized, which overcome the lack of systematic exist in the previous research on product quality crisis monitoring elements. Moreover the quality crisis has been divided into 5 levels, and the alert level threshold of warning indexes has been determined, which overcome the difficulty of quantifying the level of quality crisis early warning indexes. Finally, with the improvement of classic extension theory model, the established warning model has been applied with the data from a heavy-duty automotive products requirements identification process, which overcome the problem that the quality crisis early warning mainly depends on the expertise judgment and lack of quantitative research, and the drawbacks of calculate the alert level based on the correlation degree in classic extension theory model.

If follow-up studies using this model for quality crisis early warning in product requirement identification process, the warning indexes and evaluation rules should be changed with the industry.

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An Assessment Approach for Process Capability in Simple Linear Profile

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Abstract Process capability assessment is important to statistical quality control. The existing univariate or multivariate process capability indices cannot be directly applied to assess the process for the quality characterized by a simple linear profile. There has been little attempt to study the process capability assessment in simple linear profile. This paper proposes a method to assess process capability for simple linear profile. Since two-dimensional predictions of the slope and the intercept of simple linear profile can represent the prediction profile, the process capability analysis can be treated as a two-dimensional correlated variables problem. Then, a multivariate process capability index based on a vector of three components is applied to assess the process capability in simple linear profile. The proposed method was proved by a simulation study.

Keywords Process capability index (PCI) · Simple linear profile · Nonconforming percentage · Multivariate capability

1 Introduction

Process capability analysis is very important for quality improvement. It should be studied performance before quality control. Process capability indices (PCIs) have been widely used in industries to quantify process for engineering convenience in recent years, and the role of PCIs is becoming more and more important [1].

The process capability assessment for univariate or multivariate quality characteristic has been studied and applied in depth. Univariate PCIs, such as C_P, C_{PK}, C_{PM} and C_{PMK}, have been extensively explored in the literature. See, Kane [2], Kotz and Johnson [3], Pearn and Kotz [4]. The four PCIs C_P, C_{PK}, C_{PM} and C_{PMK},

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only used in univariate process. In recent years, there are more and more studies on multivariate PCIs. Chan et al. [5] proposed a multivariate version of C_{PM} based on measuring how far away from the target vector and the process mean is in the Mahalanobis distance. Pearn et al. [6] extended C_P and C_{PM} to a multivariate version. Hubele et al. [7] provided a PCI vector for bivariate normal process. Then Shahriari et al. [8] extended the bivariate PCI vector to the multivariate case. Taam et al. [9] proposed a multivariate version of C_P as the ratio of two areas, which are the area of a modified engineering tolerance region and the area of the elliptical process region that covers 99.73 % of the multivariate normal process. Shinde and Khadse [10] applied principal component analysis to assess multivariate process capability.

In some manufacturing process, the quality of the product is characterized by a simple linear functional relationship between a response variable and an independent variable. Kang and Albin [11] presented examples of calibration applications for simple linear profiles. Woodall [12] reviewed the literature of profile monitoring. However, there has been little research on assessment of process capability in simple linear profile. The main purpose of the paper is to propose an approach for assessing the process capability in simple linear profile. The method, based on predicted values of the slope and the intercept of simple linear profile, transforms the profile problem into multivariate analysis. To prove the effectiveness of the proposed method, a simulation study is conducted.

The remainder of this paper is organized as follows. In Sect. 2, a brief review of univariate and multivariate process capability indices is introduced. Section 3 presents the simple linear profile model. Section 4 gives the method based on two-dimensional indices to assess process capability in simple linear profile. In Sect. 5 a simulation study is conducted to prove the effective of the proposed method. The last section contains the conclusions of this research.

2 Process Capability Indices

Process capability indices (PCIs) quantify the relationship between the actual process performance and the specification limits of the products. Four univariate PCIs, commonly used to assess the process performance, are C_P, C_{PK}, C_{PM} and C_{PMK}. C_P, recommended by Kane [2], quantifies the process capability by scaling the quality characteristic tolerance to the process standard deviation.

$$C_P = \frac{USL - LSL}{6\sigma} \tag{1}$$

where σ is the standard deviation of the process. $(USL - LSL)$ is the difference between the upper and lower specification limits of the quality characteristic. C_P is lack of consideration about the process mean.

C_{PK}, C_{PM} and C_{PMK}, based on Kotz and Johnson [3], are respectively defined as:

$$C_{PK} = \mathrm{Min}\left\{\frac{USL-\mu}{3\sigma}, \frac{\mu-LSL}{3\sigma}\right\} \tag{2}$$

$$C_{PM} = \frac{USL-LSL}{6\sqrt{\sigma^2+(\mu-T)^2}} \tag{3}$$

$$C_{PMK} = \mathrm{Min}\left\{\frac{USL-\mu}{3\sqrt{\sigma^2+(\mu-T)^2}}, \frac{\mu-LSL}{3\sqrt{\sigma^2+(\mu-T)^2}}\right\} \tag{4}$$

where μ is the process mean, T is the target value and $\sqrt{\sigma^2+(\mu-T)^2}$ scales the average product deviation from T. C_{PK}, C_{PM} and C_{PMK} considers the mean and the standard deviation of the process simultaneously.

For multivariate PCIs,

$$MC_{PM} = \left[\frac{\text{vol.of engineering tolerance region}}{\text{vol.of modified process region}}\right]^{\frac{1}{v}} \tag{5}$$

where the numerator is the area or volume defined by the engineering tolerance region, the denominator is the area or volume of a modified process region. Define X as a $v \times q$ sample matrix which v represents the number of quality characteristics and q is the number of the parts, and Σ as the variance-covariance matrix. Then MC_{PM} can be calculated from:

$$MC_{PM} = \left[\frac{\prod_{j=1}^{v}\left(USL_j - LSL_j\right)}{\prod_{j=1}^{v}\left(UPL_j - LPL_j\right)}\right]^{\frac{1}{v}} \tag{6}$$

where $j = 1, 2, \ldots, v$. The limits UPL and LPL are the projection of the probability ellipse onto the respective axes [13],

$$\begin{aligned} UPL_j &= \mu_j + \sqrt{\frac{\chi^2_{(v,a)} \det\left(\Sigma_j^{-1}\right)}{\det\left(\Sigma^{-1}\right)}}, \\ LPL_j &= \mu_j - \sqrt{\frac{\chi^2_{(v,a)} \det\left(\Sigma_j^{-1}\right)}{\det\left(\Sigma^{-1}\right)}} \end{aligned} \tag{7}$$

where $\chi^2_{(v,a)}$ is the upper 100(α) % of a χ^2 distribution with v degrees of freedom, Σ_j^{-1} is a matrix calculated from Σ^{-1} by deleting the jth row and column, and $\det\left(\Sigma_j^{-1}\right)$ is the determinant of Σ_j^{-1}.

In multivariate process capability analysis, there exists correlation among measured quality characteristics. While in simple linear profile, the measured values of each point are independent. In this paper, we consider situations where the quality characteristic is a profile, and we assume that the measurement points are fixed.

3 Simple Linear Profile Model

A simple linear profile is usually represented by a simple linear regression model, where the response variable Z is described by a single explanatory variable [14], that is

$$Z = \alpha + \beta X + \varepsilon \tag{8}$$

where ε is random variable distributed with mean zero and variance σ_ε^2. For the simple linear profile case, the model is in the form [15]

$$Z_i = \alpha + \beta x_i + \varepsilon_{it}, \quad i = 1, 2, \ldots, n,\ t = 1, 2, \ldots, k \tag{9}$$

For simplicity, we assume that the values of explanatory variable x_i are fixed for all profiles. The intercept α and the slope β of the line are profile coefficients [16]. The least squares estimators $\hat{\alpha}$ and $\hat{\beta}$ could be obtained from:

$$\begin{cases} \hat{\alpha} = \bar{z} - \beta\bar{x} \\ \hat{\beta} = S_{xz}/S_{xx} \end{cases} \tag{10}$$

where $\bar{z} = \sum_{i=1}^{n} z_i/n, \bar{x} = \sum_{i=1}^{n} x_i/n, S_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2, S_{xz} = \sum_{i=1}^{n} (x_i - \bar{x})z_i, i = 1, \ldots, n.$

$$\begin{cases} \sigma^2_{\hat{\alpha}} = \sigma^2_\varepsilon\left(\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}}\right) \\ \sigma^2_{\hat{\beta}} = \sigma^2_\varepsilon\left(\frac{1}{S_{xx}}\right) \end{cases} \tag{11}$$

The predictions $\hat{\alpha}$ and $\hat{\beta}$ are correlated and the covariance between them is calculated as:

$$\mathrm{cov}\left(\hat{\alpha}, \hat{\beta}\right) = -\sigma_\varepsilon^2 \frac{\bar{x}}{S_{xx}} \tag{12}$$

4 Proposed

Two predicted values of the intercept α and the slope β are adequate to represent the linear prediction profile. To observe simple linear profile, a statistic consists of sample intercept α and the slope β as parameters of the simple linear profile. The statistic is showed as follows:

$$M_p = \left(\hat{\alpha}_p, \hat{\beta}_p\right)^T \tag{13}$$

Because the $\hat{\alpha}$ and $\hat{\beta}$ are correlated, similar to the quality characteristics in multivariate analysis, vector M_p follows multivariate normal distribution with mean vector and covariance matrix as follows:

$$\mu_M = (\alpha, \beta)^T \tag{14}$$

$$\Sigma_M = \begin{bmatrix} \operatorname{var}(\alpha) & \operatorname{cov}(\alpha, \beta) \\ \operatorname{cov}(\beta, \alpha) & \operatorname{var}(\beta) \end{bmatrix} \tag{15}$$

Using (11) and (12), Σ_M can be obtained as follows:

$$\Sigma_M = \begin{bmatrix} \sigma_\varepsilon^2\left(\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}}\right) & -\sigma_\varepsilon^2 \frac{\bar{x}}{S_{xx}} \\ -\sigma_\varepsilon^2 \frac{\bar{x}}{S_{xx}} & \sigma_\varepsilon^2\left(\frac{1}{S_{xx}}\right) \end{bmatrix} \tag{16}$$

The specification limits for each level in simple linear profile are given as LSL_i and USL_i $(i = 1, \ldots, n)$. Assuming that the tolerances TOL_i s are same, the predicted specification limits for the intercept α can be calculated as:

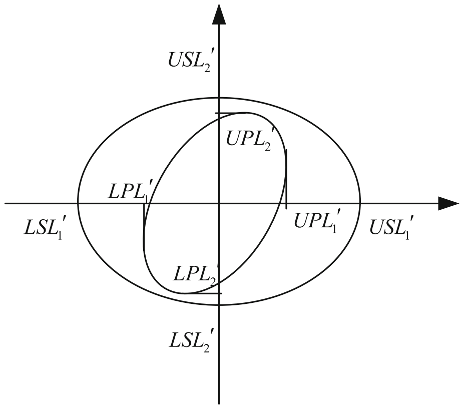
$$\begin{cases} LSL'_1 = LSL' - L'_2\bar{x} \\ USL'_1 = USL' - L'_2\bar{x} \end{cases} \tag{17}$$

where $LSL' = \sum_{i=1}^{n} LSL_i/n$, $USL' = \sum_{i=1}^{n} USL_i/n$, $L'_2 = S'_{xy}/S_{xx}$, $S'_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})LSL_i$ (Fig. 1).

The predicted specification limits for the slope β can be calculated as:

$$\begin{cases} LSL'_2 = \frac{LSL_n - USL'_1}{x_n} \\ USL'_2 = \frac{USL_n - LSL'_1}{x_n} \end{cases} \tag{18}$$

Fig. 1 Predicted specification limits and projection limits



Then the process capability index MC_2 in simple linear profile can be calculated from

$$MC_2 = \sqrt{\frac{\left(USL_1' - LSL_1'\right)\left(USL_2' - LSL_2'\right)}{\left(UPL_1' - LPL_1'\right)\left(UPL_2' - LPL_2'\right)}} \tag{19}$$

where the projection of the probability ellipse limits UPL_1' and LPL_1' are,

$$\begin{aligned} UPL_j &= \mu_j + \sqrt{\frac{\chi^2_{(2,a)} \det\left(\Sigma_j^{-1}\right)}{\det\left(\Sigma_M^{-1}\right)}}, \\ LPL_j &= \mu_j - \sqrt{\frac{\chi^2_{(2,a)} \det\left(\Sigma_j^{-1}\right)}{\det\left(\Sigma_M^{-1}\right)}} \end{aligned} \tag{20}$$

where $\chi^2_{(2,a)}$ is the upper 100(α) % of a χ^2 distribution with two degrees of freedom, Σ_j^{-1} is a matrix calculated from Σ_M^{-1} by deleting the jth row and column, and $\det\left(\Sigma_j^{-1}\right)$ is the determinant of Σ_j^{-1}, $\mu_1 = \alpha$, $\mu_2 = \beta$, $j = 1, 2$.

5 Simulation Study

In this section, the performance of the proposed method is evaluated through simulation studies. In this example, the quality characteristic of a product or a process is a simple linear profile. MATLAB software is applied to generate 10,000 runs for simple linear profile, and sample size is 20. The relation of the simple linear profile is $z_i = 3 + 2x_i + \varepsilon_{it}$, where the fixed values of x_i are equal to 2, 4, 6, and 8, ε_i

Table 1 Specification limits and tolerance for each level

	L1	L2	L3	L4
LSL	2.50	6.85	11.25	16.25
USL	10.00	14.35	18.75	23.75
TOL	0.50	0.50	0.50	0.50

follow normal distribution with mean 0 and variance 1. The specification limits for each level of independent variable in simple linear profile are given in Table 1.

We can compute $LSL_1' = -2.20$, $USL_1' = 5.30$, $LSL_2' = 1.41$, $USL_2' = 3.24$ through using (17) and (18). According to (16), we can compute the sample covariance matrix Σ_M. Then we can obtain the simple linear profile process capability index MC_2. The estimated overall percentage of nonconformities obtained from MC_2 is 0.13 %, which is near to the actual overall percentage of nonconformities 0.12 %. In the simulation, the proposed approach applied to evaluate process capability for simple linear profile is been proved to be effective.

6 Conclusion

Process capability analysis is important to measure the manufacturing process ability. Lots of exiting studies on process capability assessment are about univariate quality characteristic or multivariate quality characteristics, while there are few studies about the product or process quality characterized as simple linear profile. This paper proposes a method to evaluate process capability in simple linear profile. The approach is proved to be effective by a simulation study. Further study will include considering the nonlinear profile process capability analysis.

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The System Dynamics Model and Simulation Analysis of Iron and Steel Supply Chain Carbon Emissions

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Abstract This paper built the iron and steel supply chain system dynamics model of carbon emissions with an in-depth analysis on the iron and steel supply chain system causality, and simulated the effects of three parameters on the iron and steel supply chain total carbon emissions, which are tons of steel production of carbon emissions, units purchasing carbon emissions and procurement cycle. The study shows that: with the increase of tons of steel production of carbon emissions and units purchasing carbon emissions, supply chain total carbon emissions increase correspondingly, and the effect is very obvious. While procurement cycle has certain influence on supply chain total carbon emissions, but the effect is not obvious; Finally, the paper put forward carbon emission control suggestions from three aspects: the introduction of relevant technologies and equipment to reduce tons of steel production of carbon emissions, optimizing logistics processes to reduce units purchasing carbon emissions, and arranging reasonable procurement cycle to optimize inventory levels.

Keywords Iron and steel supply chain · Carbon emissions · Control · System dynamics

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1 Introduction

Since the Industrial Revolution, the emission of greenhouse gases, such as carbon dioxide, has been increasing annually. With the greenhouse effect, there has aroused a series severe problem such as climate change. It is that carbon emissions that have became the international consensus. As one of countries with the most carbon emissions, the Chinese government had made a solemn promise, in the World Climate Conference, held in Copenhagen in 2009, that, the carbon emission per GDP in 2020 should be decreased by 40–45 % compared with the amount in 2005. The State Department had published “the 12st 5-year plan on energy conservation and pollution reduction”, which had analyzed the context and circumstance in energy conservation and pollution reduction, making sure the energy conservation and pollution reduction targets, main tasks and key projects. Currently, the national iron and steel industrial production has still been an extensive style, thus, economic development should depend on high level depletion, which can contribute to environmental pollution [1]. However, the iron and steel industry is still the one of the mainstay industries in our country, also the one of the main sources of carbon dioxide emissions. Therefore, how to decrease the carbon emission in iron and steel supply chain, has been important for the carbon emission reduction task for our country.

For the issue of carbon emission in supply chain, much researchers home and abroad had done much relevant researches in different methods. Krikkle [2], taking printer as an example, had analyzed the carbon footprint influence in different closed loop supply chains. Sundarakani [3] had constructed a quantified model to decrease carbon emissions in supply chains by the use of Lagrange algorithm and Euler transportation model. Bojarski [4] had built a supply chain model with the consideration of environmental cost by the means of LCA life circle estimation. Yang [5] had built a supply mode which had stimulated the carbon emission impact in two carbon policies, enforced carbon emission and carbon tax respectively. Long [6] had used the systematic dynamistic in order to analyze the Chinese Industrial iron and steel enterprises carbon emission reduction results under different policy, and had made a prediction. He [7], based on VAR model, had researched on the relationship between carbon emission and economic development, energy consumption and foreign trade. Pang [8], had build a circular green supply chain model in the iron and steel manufacturer. Hong [9], focused on Baosteel, had estimated and valued the innovation in low-carbon supply chain. Xie [10] had researched on the issue that how to decide the emission reduction based on supply chain upstream and down stream companies, by the method of new classical economic and game theory in the big-scale national manufacturers. Lan [11] had created a storage cost model considered with carbon emissions, with the consideration of trading and storage, and researched the impact of carbon emissions quota and trade mechanism on input strategy. That is to say, at present, the researches on the carbon emissions in logistic in iron and steel supply chain have stayed little, and scholars have scarcely made systematic and comprehensive research on every single factors in iron and steel supply chain to analyze the carbon emissions. For this reason, this paper, based on systematic dynamic VENSIM software, has established a iron and steel supply chain basic model, and made a link with carbon and supply chain management. Making a detailed researches on the purchase, production, sale, and logistic, the four processes in the carbon emission system, this paper had aimed to find a method and measures to decrease the total amount of carbon emissions in supply chain.

2 Iron and Steel Supply Chain Carbon Emissions System Analysis

2.1 Model Assumption

The model designed by this paper was only composed of one supplier, one manufacturer and one retailer. Supplier was obliged to supplying raw materials, and manufacturer was responsible for manufacturing products and retailer was bound to do sales. Manufacturer was provided by supplier with raw materials every a period. The purchasing process created carbon emissions. For the purpose of production continuity, manufacturer usually stored the raw materials, however, the storage process can emit carbon emissions as well. Moreover, the manufacture process was the main process for carbon emissions, meanwhile, as for the uncertainty for the products need, it is sure that there was products storages, and this process will also create some amount of carbon emissions. As well retail purchased products from manufacture every a period, the purchase process must create carbon emissions. For the purpose of market circulation, retail will store some products, the storage process will create carbon emissions as well. Therefore, the model assumed the four assumptions. First of all, the carbon emissions in purchasing process only considered the amount in the day which give the purchase order, and every cycle only created one time, which the carbon emissions amount scaled up with the purchase amount. Second, carbon emission in storage consisted of conveyance in manufacture industry of raw materials and products, assembly, the process on load and unload, and the warehouse routine energy consumption. The relationship between the amount of carbon emissions and the storage and storage time showed a linear relationship. Thirdly, the need of every member in supply chain kept stable, and amount of purchase of every member was equal and stable, on no account of the shortage of supply in supply chain. Finally, the amount of carbon emissions in supply chain was equal to the amount in every process, such as production, purchase and sale.

2.2 Analysis of Cause and Effect

The each processes in iron and steel supply, which is purchase, production, sale and logistic, all created carbon emissions. That is to say, it is plausible to decrease amount in every processes in order to optimize the whole carbon emissions in the whole system. Thus, there consisted of 3 subsystems in the designed model, and the main feedback as Fig. 1 showed:

(1) storage optimized subsystem: the amount of carbon emission in supply chain → competitive strength in supply chain → the ability to make profit → technology innovation and management → the level of skills and management → storage amount → production/purchase/sale/logistic carbon emissions → the whole carbon emissions in supply chain
(2) carbon emission per ton optimized subsystem: the amount of carbon emission in supply chain → competitive strength in supply chain → the ability to make profit → technology innovation and management → the amount in carbon emissions per ton → the amount in production process → the whole carbon emissions in supply chain
(3) purchase process optimized subsystem: the amount of carbon emission in supply chain → competitive strength in supply chain → the ability to make profit → technology innovation and management → the level of skills and management → the carbon emissions in purchase → the whole carbon emissions in supply chain

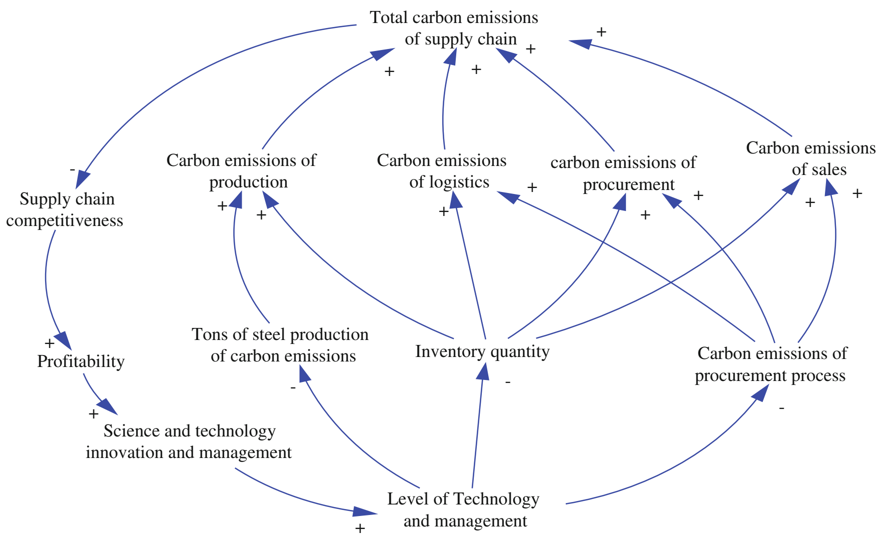

Fig. 1 The cause and effect of iron and steel supply chain in carbon emissions

The three subsystems all created positive feedbacks, which made for the communication between every member in supply chain, storage optimized and decreasing the carbon emissions in storage process. Only can we continue optimizing production process, the carbon emissions in production can be reduced. And it is also helpful to choose the suitable conveyance, to optimize conveyance routine, for the purpose to subside the carbon emissions in logistic process.

3 Dynamic System Model

3.1 *Iron and Steel Supply Chain Carbon Emissions Optimized System Flow Diagram*

According to the cause and effect diagram, we used the VENSIM software in order to set up the iron and steel supply chain carbon emissions optimized system flow diagram, as Fig. 2 show. In the model, we mostly considered the each carbon emissions in supplier, manufacture and retailer respectively in purchase, production, sale and logistic processes.

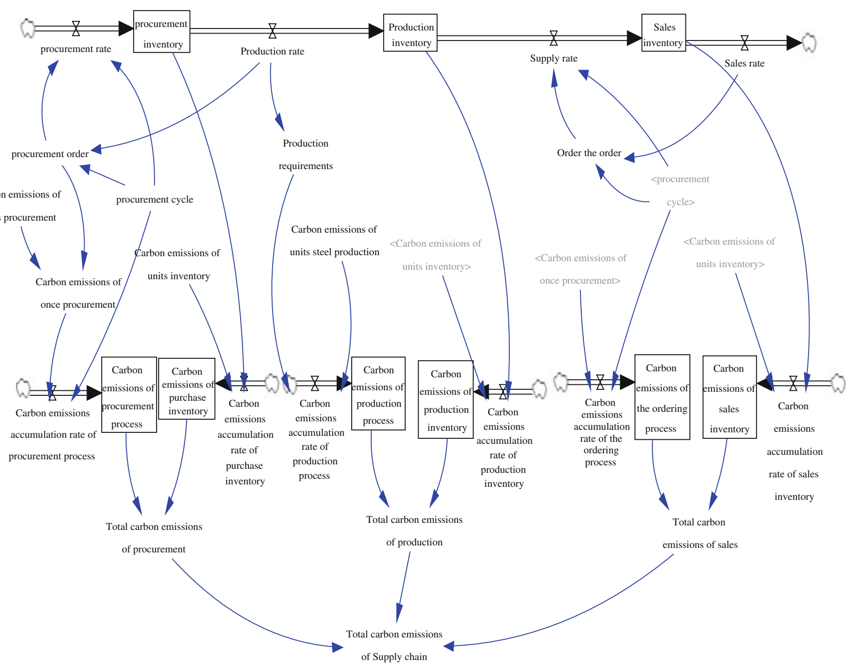

Fig. 2 Iron and steel supply chain carbon emissions optimized system flow diagram

3.2 Equations in Model

(1) supply velocity = order note × PULSE TRAIN (0, 1, purchase circle, 120);
(2) the whole amount of carbon emissions = amount in production process + amount in purchase process + amount in sales;
(3) reserve in manufacture = INTEG (production velocity-supply velocity, 2000)
(4) carbon emission in reserve = INTEG (accumulated velocity in production reserve, 0)
(5) accumulated velocity in production reserve = carbon emissions per reserve in storage × production reserve
(6) carbon emissions in production = amount in production reserve + amount in production process
(7) carbon emissions in production process = INTEG (carbon emissions accumulated velocity in production process, 0)
(8) carbon emissions accumulated velocity in production process = amount per ton × production demand;
(9) production demand-production velocity
(10) order in purchase = purchase circle × sale speed
(11) carbon emissions in require and purchase = INTEG (carbon emissions velocity in purchase process, 0)
(12) carbon emissions velocity = INTERGER [amount in purchase every times × PULSE TRAIN (0, 1, purchase circle, 120)];
(13) purchase storage = INTEG (purchase speed-production speed, 500)
(14) carbon emissions in purchase storage = INTEG (carbon emissions accumulated velocity in purchase reserve, 0)
(15) carbon emissions accumulated velocity in purchase reserve = carbon emissions per storage × purchase storage
(16) carbon emissions in purchase = amount in purchase storage + amount in purchase process
(17) purchase demand = purchase circle × production speed
(18) carbon emissions in purchase process = INTEG (carbon emissions velocity in purchase process, 0)
(19) carbon emissions velocity in purchase process = INTEGER [amount in purchase every single times × PULSE TRAIN (0, 1, purchase circle, 120)]
(20) purchase speed = order demand × PULSE TRAIN (0, 1, circle, 120)
(21) sale storage = INTEG (supply speed-sale speed, 500)
(22) carbon emissions in sale storage = INTEG (amount in sale storage velocity, 0)
(23) carbon emissions velocity in sale storage = amount per storage × sale storage
(24) carbon emissions in sale = amount in demand + amount in sale storage
(25) carbon emissions in purchase every single time = amount per purchase × demand

3.3 Parameters in Model

See Table 1

3.4 Model Check

The check method of systematic dynamic model was mainly composed of stability test, effectiveness test and sensitivity test. As Fig. 3 show, after simulated model, the system had a great ability in keep stable. Then, in the production process, the carbon emissions scaled up to accumulate in a linear tread, which is corresponded with the reality. Furthermore, different number in purchase circle must cause apparent change in production reserve, which signified the sensitivity test passed. To conclude, the model check passed mostly and thoroughly.

Table 1 Relevant parameters in model

Name	Number	Quantity
Initial time	0	Day
Time step	1	Day
Sale speed	100	Ton/day
Carbon emissions per ton	Simulated	Ton
Carbon emission per purchase	Simulated	Ton
Final time	120	Day
Carbon emissions per storage	0.001	Ton
Production speed	100	Ton/day
Purchase circle	Simulated	Day

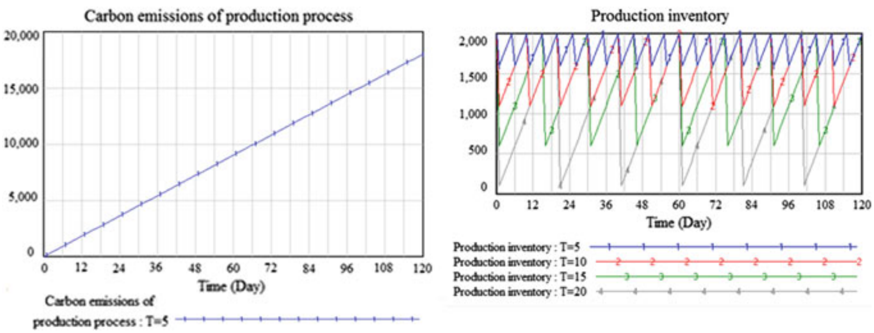

Fig. 3 Carbon emission in production process and production storage simulation

4 Analysis and Simulation on Carbon Emissions in Iron and Steel Supply Chain

In this model, a season was treated as a simulated circle, a day as a step. By the help of VENSIM software, we can compute and simulate the carbon emissions in different circumstances. We adjusted 3 parameters, such purchase circle, carbon emissions per ton and carbon emissions per purchase, according to relevant parameters in systematic dynamic model. Through it, we simulated different results under different accounts, in order to optimize the supply chain.

4.1 Model Simulation

1. Simulation in different purchase circle

Storage had a direct relationship between purchase circle, which is mainly decided by circle. Manufacturers demanded raw materials from suppliers in a certain circle, and sales required iron and steel from manufacturers in a certain circle as well. Assumed the demand in supply chain was stable, without consideration of shortage of raw materials and productions. Thus, take the purchase circle as 5, 10, 15 and 20, these four number, and simulate under different circles, how the amount come about. And the results as Table 2 showed:

(1) Assumed T = 5, in a season, the whole amount both in purchase and in sale was 1284 ton, but when T = 10, 15, 20, the amount got larger. But in the four different circumstance, differences in carbon emission did not change more. The optimum is T = 5.
(2) Carbon emissions in production consisted of amount in production process and in production reserve, for the reason of production per day was firm, thus, the carbon emissions showed linear tread increase, as Fig. 3 show, without impact of circle T. Whereas, the carbon emissions in production reserve was affected by circle T. So as to guarantee no shortage, the largest circle in original reserve in this paper was T = 20. As T got larger, the amount in purchase once got larger, but the storage in a circle got little, and then, the carbon emissions became little.

Table 2 Different carbon emissions in different purchase circle

	Carbon emissions (ton)			
	T = 5	T = 10	T = 15	T = 20
Amount in purchase	1284	1314	1344	1374
Amount in manufacture	24,216	24,186	24,156	24,126
Amount in sale	1284	1314	1344	1374
Whole amount in supply chain	26,784	26,814	26,844	26,874

(3) As for the three aspects, the model built in this paper, when T = 5, amount in supply chain kept lowest, 26,784 tons.

2. simulation in different carbon emission per ton in production

Steel industries occupied the major share in carbon emissions. The amount per ton in productions meant quite importance in supply chain. Took amount per ton as 2.0, 1.9, 1.8, 1.7, 1.6 and 1.5 ton, to make simulation, and results as Fig. 4 and Table 3 show: when the amount decreased from 2.0 to 1.5 ton, the amount in supply chain cut down as well. Even, in a circle reduced 6000 ton.

3. simulation in different carbon emission in purchase

In the model built in this paper, carbon emission in purchase process came about in raw materials purchase and sale processes, so in this paper, we chose carbon emission per purchase were 0.2, 0.18, 0.16, 0.14, 0.12, 0.1 ton in order to simulate the influence in whole carbon emission. Because carbon emission was only created in the day purchasing, so the process is of period characteristic, and amount showed ladder-trend increase. When the quantity reduced from 0.2 to 0.1 ton, the whole carbon emission reduced correspondingly, in a circle, the maximum reduction can be 2400 ton.

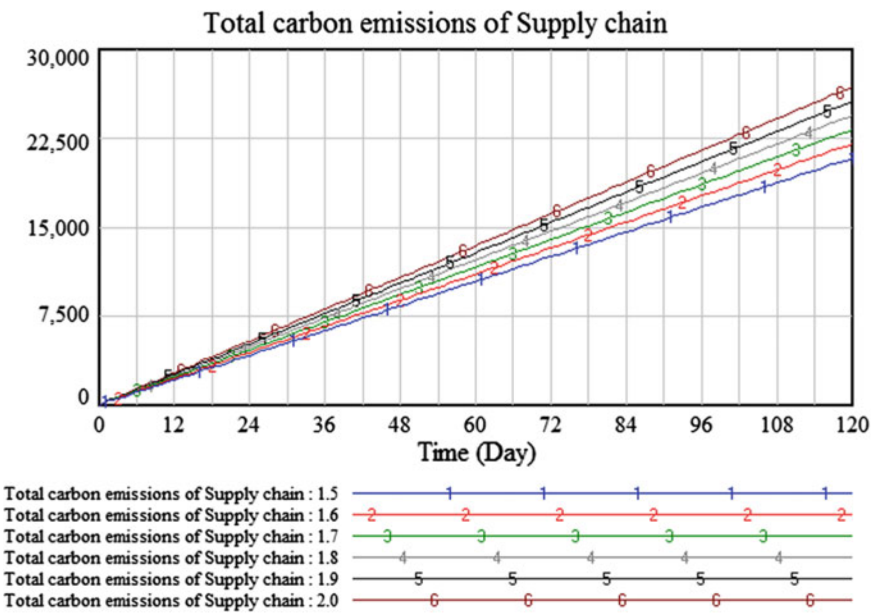

Fig. 4 Different carbon emission in different amount per ton in production

Table 3 Different carbon emission in different amount per ton in production

Carbon emission per ton (ton)	Whole carbon emission in supply chain
2.0	26,784
1.9	25,584
1.8	24,384
1.7	23,184
1.6	21,984
1.5	20,784

4.2 Emulation Analysis and Optimization Method

By the help of simulation, purchase circle, carbon emission per ton, carbon emission per purchase can control the whole amount in supply chain effectively. And the relevant parameters had a great significance for carbon emission reduction.

(1) Purchase circle had some influence on the carbon emission, but the effect may not be evident and apparent. It mostly affected the reserve in every member in the chain, in order to impact the whole amount. However, the storage is the source of evil. Every manufacturer hoped to decrease the storage, which can low cost in finance and space. Conversely, in order to guarantee the consequence of production and supply and consider the uncertainty in demand, it was necessary to spare more storage. Notwithstanding the storage did not cost expense, it can directly or indirectly increase the carbon emission, because the carbon emissions in storage had a positive correlation with storage time. As a consequence, according to the sub-member demand and storage, members in the supply chain made a reasonable circle to optimize storage, in order to accomplish the low-carbon assembly technology. And Built a nice friendship between other cooperatives, so as to communicate effectively, share messages, co-work plan and handle together. When decreased the uncertainty in supply and demand, with the reserve reduced, the whole amount can be decreased.

(2) Carbon emission per ton in production exerted significantly impact on the whole amount reduction. And the effective method were corresponding skills innovated and facilities improved. Recently, nevertheless, the amount per ton in production decreased largely, the whole steel production increased drastically, the whole amount in steel industry kept improving certainly. So it is a longtime and hard task to reduce the amount per ton. Manufacturers can do these 3 aspects below: ① Skill innovation. The innovation was the propulsion to develop, so manufacturers ought to introduce hi-tech, such as new smelt technique, low-carbon manufacture, green energy, and recycle and reuse carbon dioxide and so on. ② Industrial structure optimization. In the strategic management level, manufacture managers should eliminate backward facilities and technique, give the original model, and improve the information management, so as to focus on the quality, efficiency, and friendly-environmental

style. Try to finish to low-energy, low-carbon and low-pollution target. ③ Manufacturers integration. Currently, in the majority micro steal manufacture industries, the level of skills and technologies was low and deficient, and the scale was small, with dispersed market. It was necessary to strengthen the force on integration, for the purpose to construct a big-scaled industry, so as to improve the competitive strength.

(3) On the account of reasonable circle, optimal reserve, and minimum space to improve, the carbon emission in purchase process played a greatly indispensable role in low-carbon plan. The role was logistic, which was composed of supplier, method of conveyance, routine, instruments and so on. There was five methods to arrange logistic. ① Adopt the principle to purchase in neighborhood to decrease the distances in transportation. ② Take prior to choose transportation in water and in railway. And use green energy, in order to decrease the fossil consumption. ③ In line with different amount to purchase, we can choose reasonable transportation, to guarantee the utility. ④ Make a suitable conveyance routine. ⑤ Use the efficient method to load and unload.

Recently, for the aim to decrease the carbon emission per ton in production, great technology, large amount of money and long time should be expended. As a comparison, there was larger space to optimize in purchase process.

5 Conclusion

In this paper, we constructed a systematic dynamic carbon emission model in supply chain. We simulated the influences of different parameters, such as purchase circle, carbon emission per ton in production and carbon emission in purchase process, on the whole carbon emissions. Through the simulation, we could discovery three key points below: ① Reasonable purchase circle was able to decrease the carbon emission in supply chain, but not conspicuously. ② Carbon emission per ton in production played a significant role in control the whole amount, which can be optimized by improving technology, adjusting industrial structure, and integrating manufacturers. ③ There was large space to improve, so it was necessary to arrange the logistic process reasonably and suitably. The decrease of whole carbon emission in supply chain depended on effects of every members in the chain, to use low-carbon method to purchase, low-carbon skill to manufacture, low-carbon way to sale and low-carbon style to do logistic. It was meaningful to decrease the whole carbon emission amount, to improve the competitive strength, to develop sustainably.

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Study on Seed-Metering Device Belt Mixed Flow Assembly Line of Flexsim

Hui Zhang, Cheng-song Li, Yu-lin Li, Hai-cao Song and Xi-yang Li

Abstract Nowadays, as the product is updated quickly, the demands of the individual and the customized products as well as the mixed flow assembly line get more and more attention. This study, based on object of R company seedmeter belt assemble, via station division on A, B, C three kinds of models belts mixed-model assemblies, by studying on assembly line type planning and mixed flow sort and using Flexsim simulation software to verify simulation analysis on assembly line, get a seedmeter belt mixed flow assembly line planning scheme.

Keywords Mixed flow assembly line · Station division · Assembly line type · Mixed flow scheduling · Flexsim

1 Introduction

Belt as the main component infecting the performance of seed-metering device, has the characteristics of typical multi species and small batch production. And the current situations of the assembly of seedmeter belt assemble are: single and single products assembly form, the long order response period, the long assembly time, etc. Assembly line as an effective way of production has been widely used in automobile, home appliances, electronic products and other industries. Mixed model assembly line can be in the same production line for the production of different types of products that meets the collinear production of multiple varieties of flexible assembly system. The layout of seedmeter belt mixed flow assembly line plays an important role in improving the efficiency of seedmeter belt assembly [1].

Mixed flow assembly line is of great importance in the production of enterprises. In the research of mixed flow assembly line, Li and Dong [2] proposed a genetic

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algorithm with simulated annealing factor, and studied the problem of assembly line balancing in automobile industry; Yan and Xiong [3] in order to make the mixed flow assembly line efficient operation, studied a class of mixed flow assembly line scheduling optimization problem based on the jumping assistant operation strategy. In order to study the relationship between the process and the operation sequence, Wang and Fan [4] takes the total production time of each job in the mixed flow production line as the research objective, designed the matrix operation method to judge the relationship between the process of the mixed flow production line, and judges the existence of the conflict; Xia et al. [5] discussed the factors that affect the layout of the mixed flow production workshop, the change of operation time and the emergence of new processes; Song and Pang [6] used the cyclic sorting method to sort the different kinds of relays. In analysis of balanced software on the mixed flow assembly line, Peng [7] carried on the balanced design of the mixed flow packaging production line, and used the simulation software Flexsim to carry on the simulation.

This paper, based on the characteristics of assembly process analysis on seed-meter, divided mixed flow assembly line station and selected the type of assembly line. Considering the influence of first batch, production sequence and batch on mixed flow assembly line sequencing, combined with the analysis of the simulation of Flexsim software, this paper finally obtained the planning scheme of the seed-meter belt mixed flow assembly line.

2 The Design of Mixed Flow Assembly Line Balance

(1) Determine the assembly process.
(2) Calculate the assembly line beat (CT), the formula is as follows

$$CT = \frac{T}{\sum_{i=1}^{n} S_i} \tag{1}$$

CT assembly line beat
T assembly line daily production time;
S_i Assembly number of i product group within the plan period;
n The sum of product groups

The actual production time of daily assembly line (T) calculation formula:

$$T = \frac{\sum_{i=1}^{n} S_i T_i}{N} \tag{2}$$

N number of workstations;
T_i the time to assemble an i product

Get the beat of mixed flow assembly line from the above formula:

$$CT = \frac{\sum_{i=1}^{n} S_i T_i}{N \sum_{i=1}^{n} S_i} \tag{3}$$

(3) Divide the assembly line operating element; consider the job balance between stations; assembly line balancing rate (E) is used as the evaluation index. Calculation formula for equilibrium rate of mixed flow assembly line:

$$E = \frac{\sum_{i=1}^{n} S_i T_i}{N \sum_{i=1}^{n} S_i M_i} \times 100\,\% \tag{4}$$

M_i bottleneck working hours for i products

(4) Select the appropriate type of assembly line.
Reasonably lay out station, working area and finished products, etc.
(5) Study on the problem of assembly line mixed flow.

3 Problem Description

R Company is a small and micro agricultural machinery enterprise in the production of mechanical seedmeter, the main machinery seedmeter models are A, B, C three models. The belt seedmeter is the key part, the assembly quality and the efficiency of the device directly affect the assembly of the arrangement. At present, the assembly of the belt mainly uses single product assembly model, the assembly efficiency is low and the reliability and stability of the assembly quality is high. The number of protocol production A, B and C seedmeter was 8000, 6000 and 6000 respectively.

3.1 Assembly Processes and Standard Work Hours

Belt assembly process is as shown in Fig. 1, mainly including inoculation box installation inoculation box installation, inlet mouth installation, the retaining plate installation, installation for extraction components belt, fixing screw installation, forked tail installation, spring installation and inspection. Using MOD method to find out operation standard time of different types of the operation seedmeter each process, which is shown in Table 1.

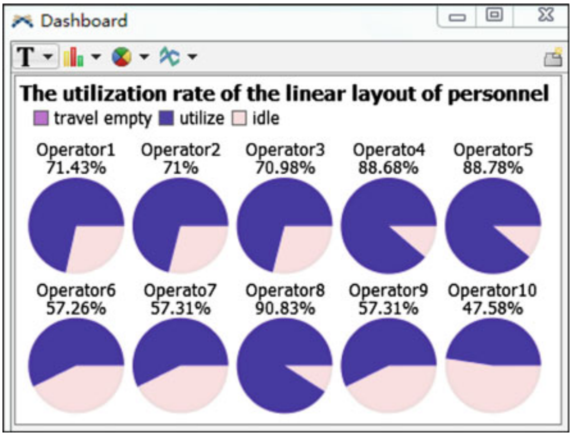

Fig. 1 The utilization rate of the linear layout of personnel

Table 1 The standard work time of each process of seedmeter

No.	Operation element	A (s)	B (s)	C (s)
1	Installation of the inoculation box (3 stations)	395	452	508
2	Installation of the inoculation box (3 stations)	331	378	420
3	Install retaining plate to extraction components belt	243	243	243
4	Extraction components belt and belt installation	78	78	78
5	Fixed screw installation	106	106	133
6	Forked tail installation	107	122	137
7	Installation and inspection of spring	67	77	87
8	Inspection	21	25	27
Total		1348	1481	1633

3.2 Determination of the Beat

If the number of workstations is 7, the number of A, B and C seedmeters is 8000, 6000 and 6000 respectively. According to the formula got the beat:

$$CT = \frac{\sum_{i-1}^{n} S_i T_i}{N \sum_{i-1}^{n} S_i} = \frac{8000 \times 1348 + 6000 \times 1481 + 6000 \times 1633}{7 \times (8000 + 6000 + 6000)} = 211\ (\mathrm{s/piece})$$

3.3 Division of Work Station

Seedmeter belt assembly adopted a fixed beat, the production beat is 211S, which cannot continue to be subdivided and there is a fixed assembly process sequence. The specific work station is shown in Table 2. To ensure the smooth progress of the

Table 2 Assembly work stations division

Workstation	Work element	Number of worker	Type A (s)	Type B (s)	Type C (s)
Workstation1	1	3	132	151	169
Workstation2	2	2	166	189	210
Workstation3	3	2	122	122	122
Workstation4	4, 5	1	184	184	211
Workstation5	6	1	107	122	137
Workstation6	7, 8	1	88	102	114
Total			799	870	963

assembly and avoid the loss of working hours and the bottleneck phenomenon, should increase workers in the station according to the appropriate time. Workstation 1 requires 2 workers in the assembly of A, B, C takes 3 workers; increase 1 worker at 2 and 3 workstations respectively. After dividing, A, B, C three kinds of seedmeter belt assembly bottleneck time is 184, 189, 211 s respectively.

3.4 *Calculate the Assembly Line Balancing Rate*

$$E = \frac{\sum_{i-1}^{n} S_i T_i}{N \sum_{i-1}^{n} S_i M_i} \times 100\,\%$$
$$= \frac{8000 \times 799 + 6000 \times 870 + 6000 \times 963}{6 \times (8000 \times 184 + 6000 \times 189 + 6000 \times 211)} \times 100\,\% \approx 75\,\%$$

By the calculation results, we know that the production line can reach the high efficiency, meeting the requirements of production.

4 Analysis of Assembly Line Simulation

4.1 *Basic Data for Modeling*

Process the actual site data of R Company, use Flexsim simulation software for modeling and simulation. It is able to use Source object in the software representing the raw material library (Source) to supply components to assembly line, As in Table 3. The simulation station can be expressed by the Combiner object in the software, and it is very vivid to assemble several parts to the product to be assembled transported by the upstream station. After the assembly is finished, the product is transported to the downstream station by the conveyor belt (Conveyer object), which

Table 3 Flexsim simulation model corresponds entity description

	Corresponding entity name	Corresponding buffer cache	Corresponding operating personnel
Workstation 1	Workbench 1	Queue 1	Operator1, Operator2, Operator3
Workstation 2	Workbench 2	Queue 2	Operator4, Operator5
Workstation 3	Workbench 3	Queue 3	Operator6, Operator7
Workstation 4	Workbench 4	Queue 4	Operator8
Workstation 5	Workbench 5	Queue 5	Operator9
Workstation 6	Workbench 1	Queue 6	Operator10

means that the assembly work of seedmeter on the belt in this position is completed. Each assembly station has a buffer zone (Queue object in software), which can reduce the impact of accidents on assembly line production [8].

4.2 Assembly Line Type Selection

(1) Linear type assembly line

According to the actual situation, if you choose the linear assembly line and establish model and run, then the utilization rate of personnel, are as shown in Fig. 1.

By graph analysis, station 6, 7, 9, 10 staff utilization rate is just more than 50 %, the overall utilization rate of staff is not high and the difference is obvious, which goes against the long-term development of the company.

(2) U type assembly line

Aiming at the problem of the actual assembly mode of seedmeter belt, the U type assembly line is designed [9]. Operations of workstation 1 and 6 are by the same group of employees; operation of workstation 3 and 5 can also be carried out by the same group of employees. The got employee utilization rate as shown in Fig. 2. The number of employees from 10 to 8 people, and the level of the basic level of the difference between the employee utilization rate is more than 80 % [9].

In addition, the U type assembly line makes the material delivery distance shorten, thereby reducing the handling time of raw material and finished product and the area of the assembly line, to improve the working efficiency of the assembly line. Require that the staff have all the post operation skills, when some of the production process time is slower than that of the whole line or when the fault happens, other stations can give support in time.

Final layout model of seedmeter belt mixed flow assembly line is as shown in Fig. 3.

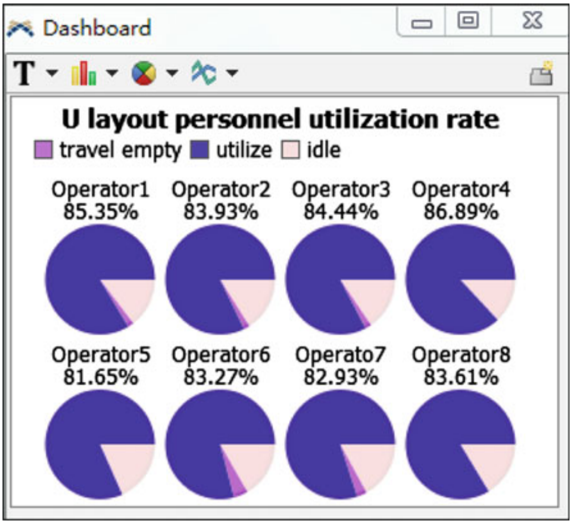

Fig. 2 U layout personnel utilization rate

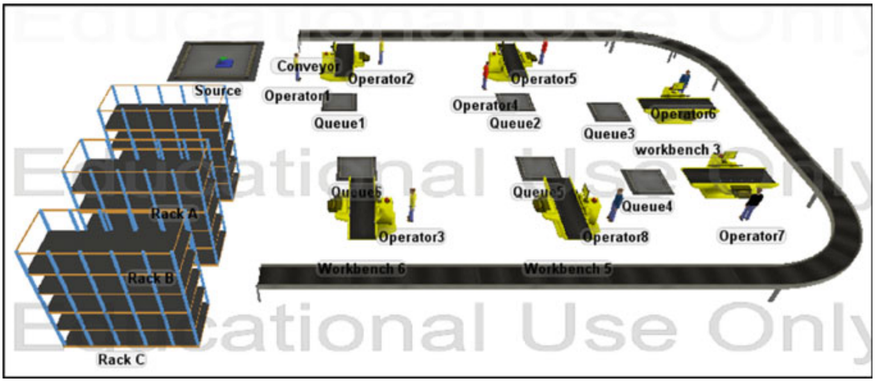

Fig. 3 Seedmeter belt mixed flow assembly line layout

4.3 Mixed Flow Production Scheduling Analysis

In the simulation, we find that the different types of seedmeter belt assemblies at random order are equipped with a belt, and the three types of the belt can save the assembly time. Through simulation, the three key points that affect the total assembly time and scheduling sequence are key points. One is the first batch model, the two is the order of production. The three is the effect of the size of the batch. Specific analysis is as follows [10].

(1) The impact of the first lot size on the total assembly time

Total assembly time of the first batch = The total hours of the non bottleneck station of this model + Bottleneck working hours * N (N is the number of batches), and the first batch increased the assembly time of the non bottleneck station.

(2) Effects of production sequence combinations on the total assembly time

The influence of the previous batch on the later batch caused assembly time change. In order to consider the effect, firstly, should study the minimum composition, then increase the number of combinations and observe the rules. Exclude the impact of the first batch of research. Assuming a batch is 20 sets/batch, using the calculation formula: ***saving time = bottleneck hours of latter type of product in combination * 20 − actual assembly time.*** Using Flexsim simulation on the three types of six kinds of combination belts: AB, BA, AC, CA, BC, CB the actual assembly time, get their assembly time and saving time, as shown in Table 4.

Observing the table we found that, without considering the belt type impact of the first batch, within the six groups of combinations, "The bottleneck labor longer and the bottleneck labor shorter" combination saved the max time. For example, the bottleneck man-hour of C is 211S, the bottleneck man-hour of A is 184 s, and the combination of CA and AC saved the most time. Thus, the three combinations should be selected are CA, CB, and BA respectively.

Take a combination of CA, in which the combination should increase a batch to observe the impact. The increased batch belt categories were A, B, C respectively, and the assembly time to save and the ratio of the time to save time are as Table 5. With the change in the type of C batch before the batch, the range ability of final batch A assembly time to save compared with the belt type has been reduced. Analysis of Table 5 shows that the new increased batch belt model still has an impact on A belt saving assembly time. However, the distance is to the A batch

Table 4 Assembly time for each combination

	AB	BA	AC	CA	BC	CB
Actual assembly time (s)	4905	5050	5195	5375	5391	5430
Saving time (s)	1125	1320	975	1695	1171	1670
Save time (%)	29.76	35.8	23.1	46.1	27.7	44.2

Table 5 Effect of different batches of a type belt assembly time

Three batches	ACA	BCA	CCA
Actual assembly time (s)	7018	7369	7724
Saving time (s)	1498	1869	2204
Saving time (%)	27.13	33.9	39.9
Four batches	**ACCA**	**BCCA**	**CCCA**
Actual assembly time (s)	9594	10236	10517
Saving time (s)	2234	2876	3157
Saving time (%)	30.35	39.07	42.8

Table 6 Effect of batch size on CB assembly time

Batch (one/batch)	5	10	15	20
Assembly time (s) of CB combination	3502	5570	7643	9715

farther, the smaller the impact on it. The key factor in determining the assembly time of the A type belt is the type of belt in the front of its phase.

(3) Effects of batch size on assembly time

Research when different kinds of belt type mixed production, effect of batch size on assembly time. Take two types of belt combination as an example, six kinds of combination forms after simulation, the relationship between the total assembly time and batch size should be the same. Still select the CA combination, using Flxeism successively to simulate batches are 5, 10, 15, …, as shown in Table 6. Through the analysis, with the batch of equal difference growth, assembly time of CB combination is in equal difference growth trend.

(4) Simulation results

Taking into account the impact of the three factors on the total assembly time can help us quickly seek a better and put into operation. A belt as the first to be better than B type belt, CA combination put in a position can save more than CA type belt as the first two batches to save the time, and the assembly of A type belt is also the largest, so the selection of A type belt led batch assembly is better. And then according to the two combinations, CB, CA, BA three kinds of combinations save the most assembly time, and should be given priority. And then consider the production rate of the three types of belts: 4:3:3, The assembly time of the combination of CA is more than that of CB, so should give priority to the combination of CA, which can be the production of the B type of batch after the A type. And from the actual situation of the factory, the volume set to 20 sets. Using a combination of Flexsim can quickly find the shortest time is ABABBACCCA, the total assembly time is 4,536,152 s

5 Conclusion

Seedmeter belt mixed production is conducive to the promotion of crop sowing technology and equipment. "Multi species mixed flow production" model is very suitable for agricultural equipment manufacturing enterprises. This paper, using Flexsim software to simulate the production problem, proposed a planning scheme of the belt assembly line of a mixed type of arrangement. The simulation data shows that the scheme can improve the utilization ratio and working efficiency. It is advantageous to enlarge the scale of production, reduce the manufacturing cost, guarantee the assembly quality, and provide some reference value for other similar mixed flow production line planning.

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Seeder Rack Welding Robot Workstation Design Based on DELMIA

Xi-yang Li, Bin Cheng, Cheng-song Li, Hui Zhang and Yu-lin Li

Abstract The seeder rack of 2 MBJ series requests comparatively higher demand for welding quality, thus, this paper proposed a welding workstation design to replace labors with robots. This paper, by applying the virtual welding function of DELMIA digital simulation software, conducts digital visual study on the robots working process of welding seeder rack. According to production requirements of seeder rack, the paper established three-dimensional physical model of workstation, planned facility layout, robot welding assignment, its process and so on, then on the basis of digital simulation of workstation, analyzed the robot reachability, welding path, interference and ergonomic, utilized the Gantt chart to ensure the tact time, output the robot offline procedures, finally achieved the process welding requirements of seeder rack, welding robot workstation design plan which is in accordance to the production reality. Therefore, welding quality and production efficiency of the seeder rack are improved.

Keywords DELMIA · Seeder rack · Virtual welding · Process analysis

1 Preface

Welding seeder rack, an important part in the seeder production process, acts as a force support of seeder, requests higher welding intensity, and the welding process of welding seeder rack directly determines the productive output of the seeder [1]. Currently, seeder racks are mainly welded by manual work, but the manual work cannot satisfy the requirement of standardized welding, and has these disadvantages of low consistency, high volatility of welding quality. Besides, because there is an obvious difference in seeder production demands between the slack season and peek season, in the peak season, crashing quality is not stable, and in the slack

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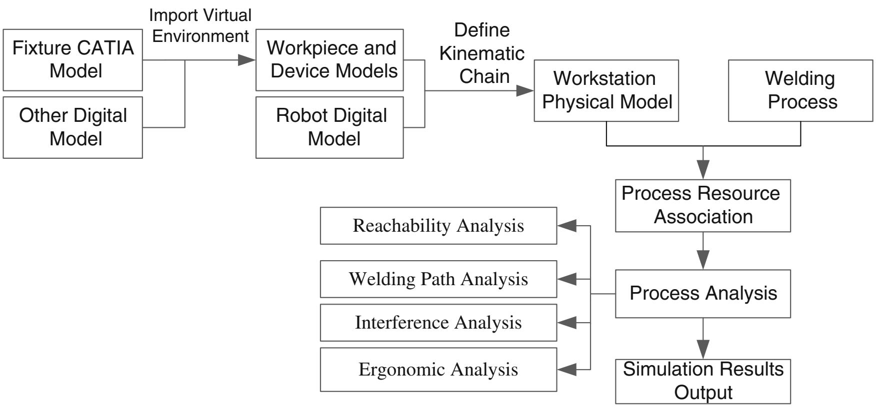


Fig. 1 DELMIA robotic welding simulation process

season, human resources are wasted. Robot welding quality is stable and welding efficiency is higher. This paper put forward the seeder rack welding robot workstation design of 2 MBJ series, conducted the digital simulation study on the working procedure of the seeder rack welding robot by applying the virtual welding function of the DELMIA digital simulation software.

In the welding workstation design, many digital factory simulation software like DELMIA, eM-Power, Witness can conduct efficiently modeling simulation of producing, and DELMIA can conduct modeling simulation under the visual environment from process design to the entire processes of product, then find problems exist in the design [2–6]. The application of DELMIA digital simulation software to welding field is mainly shown in early process planning of welding workstation to process verification [7]. According to the features of visual welding and the key technology of visual welding system, this paper considers welding simulation, reachability analysis and others as the important part [8–11]. On the basis of DELMIA's welding simulation process as shown in Fig. 1, in the visual environment, it simulates the process of completing workstation layout, constructs robots' task, regulates workers' job, planning welding path, analyzes robots' reachability, collision interference test, and ergonomic test, then analyzes the welding ability of workstation, finally outputs the seeder rack welding robot workstation design of 2 MBJ series which is accord with the actual production.

2 The Modeling and Simulation of Workstations

2.1 Tact Calculation

The workstation design needs to meet the need of multi-models of 2 MBJ series seeder frame mixed flow welding, thus, the left and the right beam of the welding seeder rack must first be completed, and then the rack can be welded as a whole. Production rhythm calculation is as follows:

$$C = \frac{T}{n} \tag{1}$$

$$T = p \times (I - t_1 - t_2) \tag{2}$$

$$C = \frac{p \times (I - t_1 - t_2)}{n} \tag{3}$$

C = production takt;
T = effective production time;
n = scheduled production;
P = production period;
I = operation mode;
t_1 = scheduled downtime;
t_2 = unscheduled downtime.

The Seeder rack production period P = 6 months, operation pattern I = 8 h/day, scheduled downtime t_1 = 1.0 h, unscheduled downtime t_2 = 0.2 h, welding production of the seeder rack must be complete n = 6000 sets of seeder, production takt plan is 734 s.

2.2 Workstations Simulation Model

In the 3D modeling software, workers, products, and jigs and other 3D resources which are needed for workstation are imported into DELMIA's DPM digital simulation model. The workstation employs dual-robot welding to conduct welding of seeder racks on left and right side beams assembly, pre and post beams and retaining film bars, and the robots are chosen from Fanuc company's M-20iA type six-axis welding robots. Clamping of workpieces applies hand-operated jig, for example, vertical hinge—leveraged clamping apparatus, push-pull type horizontal clamping apparatus. Positioner and guild rail both adopt the AC Servo motor control and coordinate control with robots. In device building part of DELMIA, the kinematic chain of robots, guild rails and positioners need to be defined, including the information like maximum rotating speed, rotation and acceleration.

3 Process Design

3.1 Workstation Layout

Due to the space limitation of the plant, CAD two-dimensional layout are made out on the basis of the product data of welding workstation, process requirements and facility information as shown in Fig. 2. The plant layout part in DELMIA needs to be transferred into a 3D layout, and according to process plan, the workstation's 3D model needs to be placed in the corresponding place of the layout. Finally, the logical movement relationship between facilities and facilities' task should be established in the module of Device Task Definition.

3.2 Create Robots Task

Seeder frame of the weld is linear discontinuous welds, each section of the weld continuous motion into multiple welds. Arc Welding module in the rack model planter switch to Design Mode, through the Create Arc Tags on curves command to Create the Arc Welding robot tasks. In the Device Task Definition module, the welding tasks Add Tag command assigned to the appropriate robot welding torch set the speed, adjust the rotation angle positioner and the relative position of the robot and positioner, the robot welding all welds get the best angle into the gun welding. Through Teach device dialog programming the robot's motion path, and

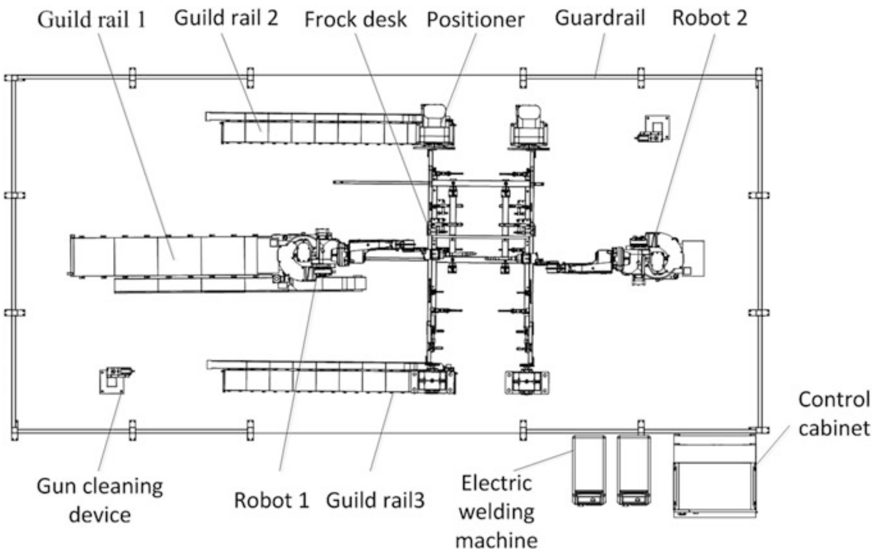


Fig. 2 Workstation layout

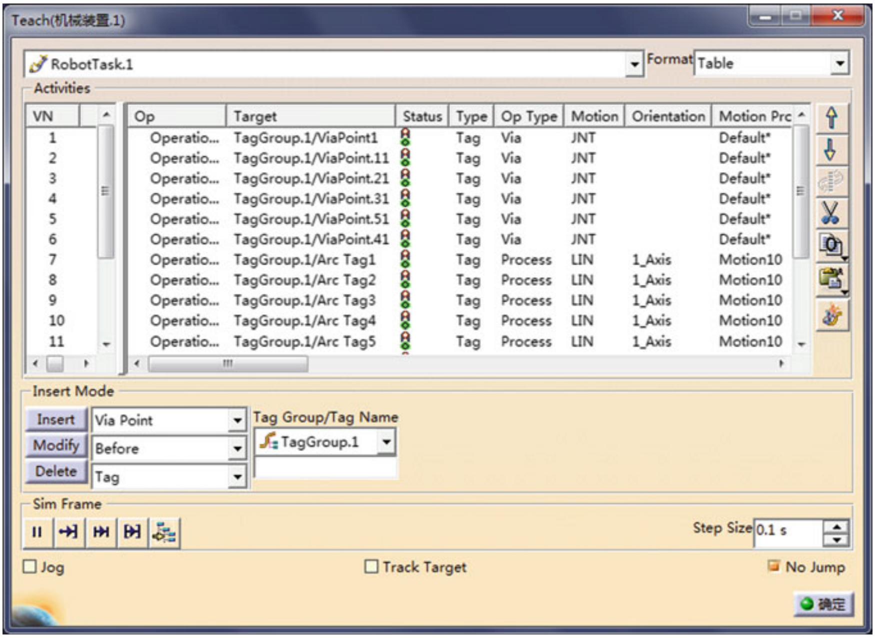


Fig. 3 Robots' task

by Jog adjusted for position and orientation of each operating point of the robot, to coordinate robot to complete the welding operation, as shown in Fig. 3. Ultimately achieves the digital simulation workstation each resource real process.

3.3 Workstation Process Design

After the completing settings of all kinds of facilities in seeder rack welding robot workstation, personnel and other process tasks, use PERT diagram to arrange the order of each process's sequence. The process is shown in Fig. 4: from the workstation to work, connect worker jig, the robot action, positioners' flips and other process in turn until the next welding task of workstation by arrows. PERT

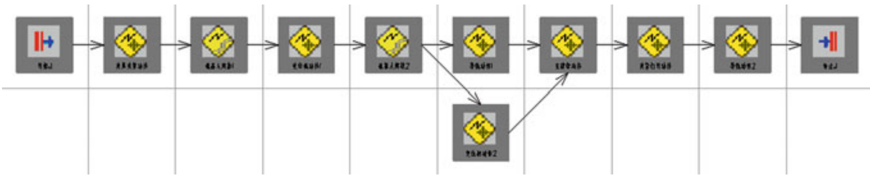


Fig. 4 PERT chart

chart completed the entire production processes arrangement of seeder rack welding robot workstation by clear form.

When the production processes of seeder rack welding robot workstation are made, in DELMIA environment, it is convenient to do simulation like robots' welding, clamping action, and personnel actions, and then further analyze the workstation process, which brings convenience to workstation's planning, installation and commissioning.

4 Workstation Process Analysis

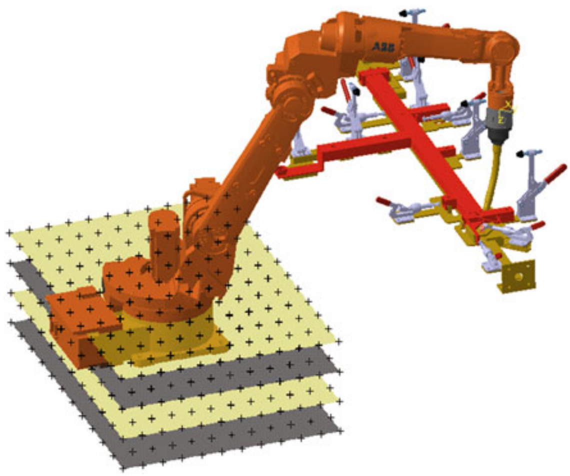
The task of process analysis for seeder rack welding robot workstation is based on the results of workstation's 3D simulation to analyze the rationality of facilities' layout, robots' reachability, welding path, interference, ergonomics and others.

4.1 Robots' Reachability Analysis

In the arc welding robot workstation space layout, by using the Auto Place command of Device Task Definition module, automatically search for the robot reachable position in the designated space for robots place and highlighted the reachable space in different colors, complete the space layout of welding robots to ensure each of the pads is within the working area of the robot, and then determine if the robot installation position is appropriate or not, as shown in Fig. 5.

As it is shown in Fig. 6, when the position of robots is selected, in Arc Welding module, we can use Robot Positioner Program command to do the secondary

Fig. 5 Robots reachable region



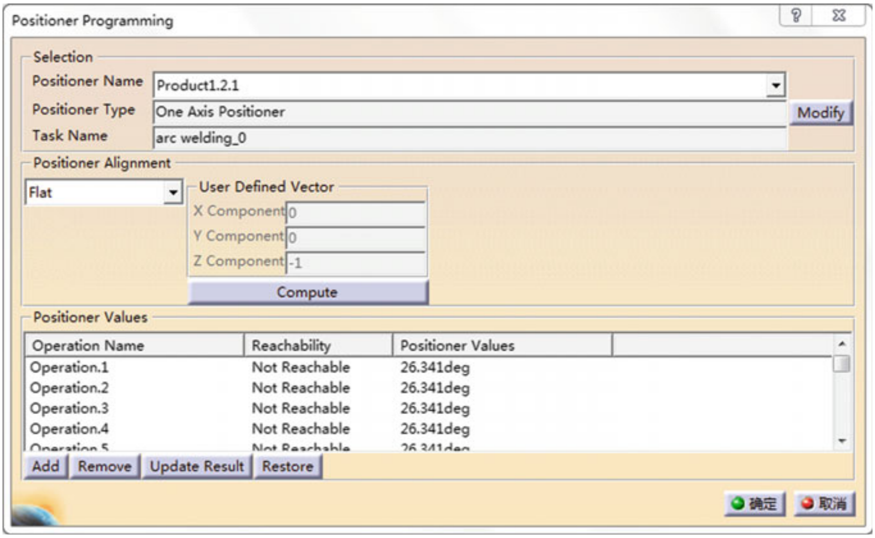


Fig. 6 The secondary verification of robots reachability

verification of robots reachability to find out the specific welding spots and positions where robots cannot reach, then according to the results of the validation, further adjust the position of robots and rotation of positioners, finally ensure the best spatial position of robots.

4.2 Optimize the Robots Welding Path

In DELMIA 3D environment, robots welding path simulation teaching can greatly reduce the workload of the manual on-site robots teaching, it can reduce production cost and improves the accuracy of robots welding position. Using the Set Turn Numbers command in Task Definition Device module, the robot welding trajectory should be automatically taught to eliminate the robot arm's odd actions, as shown in Fig. 7.

Further, if there are still some problems existed after automatic teaching correction, by Teach panel adjust the motion path and welding position of robots, and the angle from which the welding gun gets, edit the increase or decrease of welding spots again, coordinate the movement of robots, guide rails, positioners and other mechanism, avoid interference from various components in the welding process, and ultimately optimize the welding path.

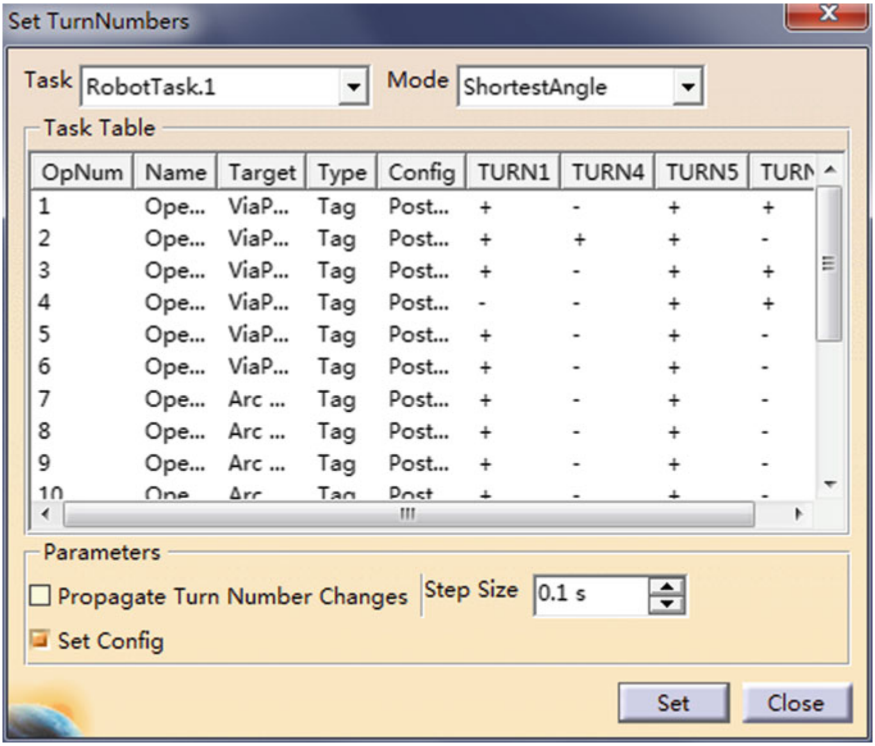


Fig. 7 Robots teaching demonstration

4.3 Interference Analysis

When the seeder frame welding workstation 3D simulation model is established, analysis on the interference between robots in workstation and workpieces, between robots and clamps, between clamps and workpieces and others should be conducted. In the simulation process of workstation, open the interference analysis function, as shown in Fig. 8, when interference problems come out, red warning interference spots will appear in the system and through this function, and then the interference spots could be quickly located to adjust the welding robots' pose, the angle from where the welding gun gets, the positioners' rotation and other methods to rectify the existing problems in welding. The interference analysis data can generate XML (Extensible Markup Language) report which brings convenience for relevant personnel to make inquiries. Thought tests, that there is no collision in the simulation of welding robots workstation in the paper can be corrected.

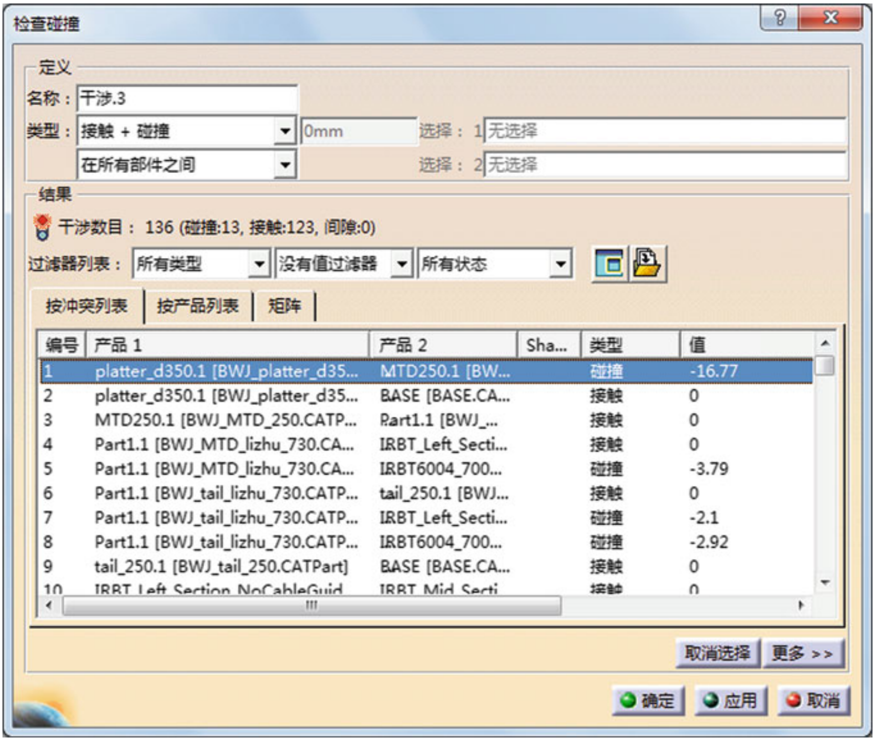


Fig. 8 Interference analysis

4.4 Ergonomic Analysis

By Ergonomics Design and Analysis module, the work of grabbing in the well-defined 3D workers model and placing the workpieces, and simulating walking speed and route, workpieces clamping posture and etc. can verify the operation space rationality, comfort of working height, and then to decide the best walking route. Through the visibility analysis, we can capture the real-time workers vision, find the blind area from the first person perspective, so as to optimize the corresponding workstation design, solve the inconveniences of workers operating in practical operation, and eliminate the potential dangers. Eventually it can standardized workers actions, make workers' job detailed and specific, and provide quota reference for workers.

5 Result Output

After perfecting and determining the process of seeder racks welding robot workstation, we can use the Gantt chart to compare simulation production takt and ensure whether it meets the design requirements or not, and finally outputs robots' off-line program.

5.1 Determine Production Takt

Through the Gantt chart, the time of each process's starting time, the sequential order and the time of a production cycle can be obtained. According to the planning scheme, the Gantt chart shows that production takt of the seeder rack welding robots workstation is 592 s which is less than the theoretical 734 s, but meets the design requirements, as shown in Fig. 9.

5.2 Export Offline Program

Enter the Robot Offline Programming module, click the Create Robot Program commands, and then encode off-line program on two robots respectively. This paper chooses arc welding robots from Fanuc Ltd., at the bottom of the window you can switch the robot language of Fanuc Ltd. in "Change Downloader" column, the program can be imported into the robot controller to run, replace on-site synchronous teaching program, optimize welding process and improve work efficiency. It is shown in Fig. 10.

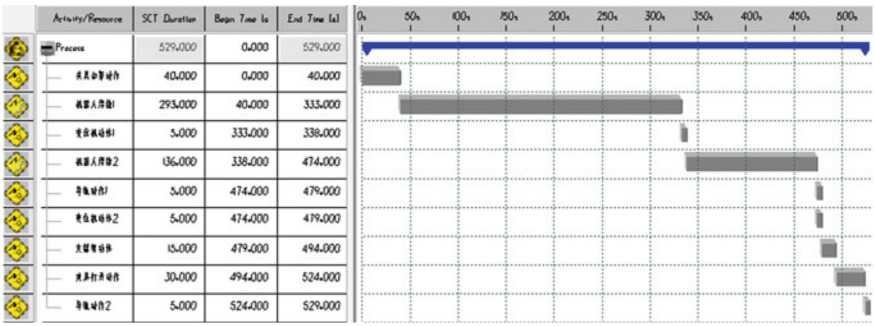


Fig. 9 The Gantt chart of workstation production

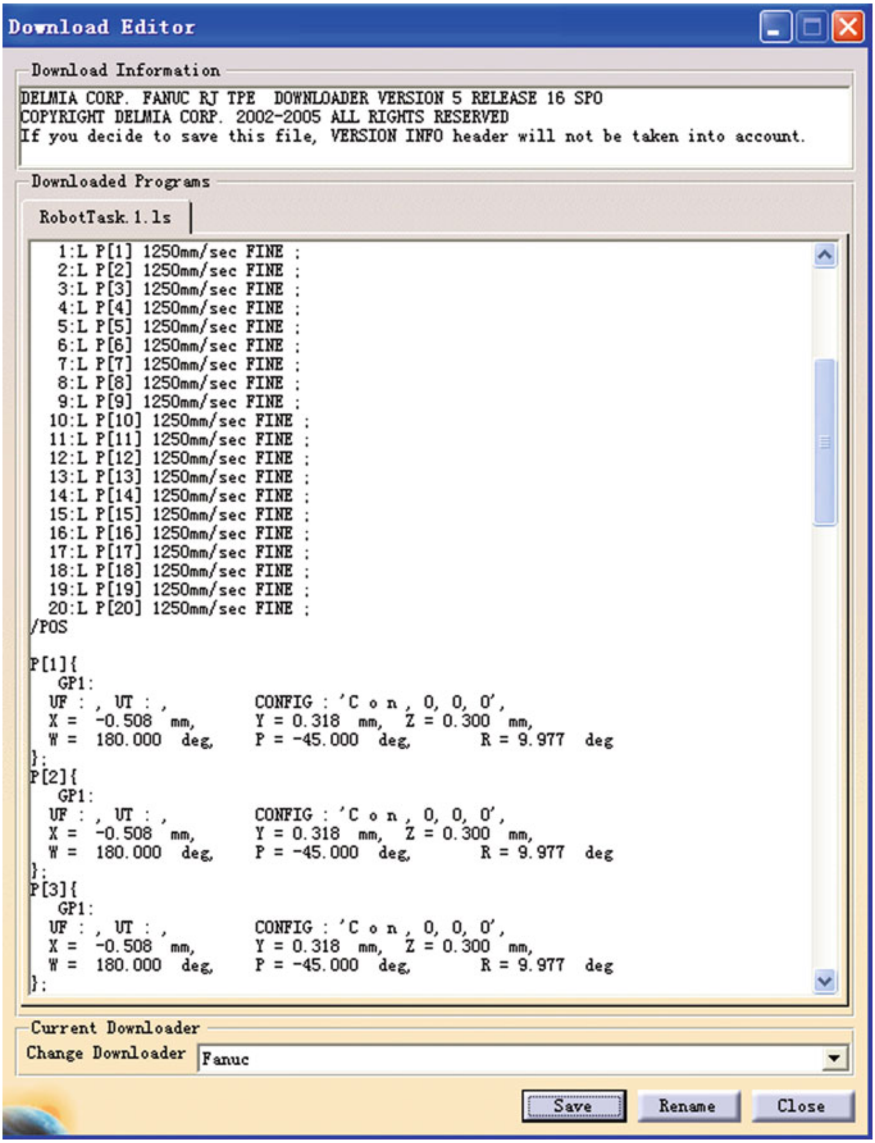


Fig. 10 Robot offline program

6 Conclusion

This paper presented a welding robot workstation design of 2MBJ series seeder rack, made a simulation analysis on workstation by applying the DELMIA digital simulation software, optimized the welding process, gained the best install location of robots, eliminated interference region, regulated the workers' job, and then made a more feasible workstation welding process, guaranteed the welding quality of seeder rack, improved the workstation design efficiency, reduced the developmental costs and gave important instructions to the actual production of enterprises.

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Application Research of Improved SB Method in Multi-echelon Inventory System

Jie Wan, Rui-xue Shan and Rui-ceng Meng

Abstract This research proposes a solution framework based on discrete-event simulation, sequential bifurcation (SB) to address a multi-response screening problem inherent in a multi-echelon inventory system. The objective is to eliminate unimportant factors so that the remaining important factors can be more thoroughly studied in later experiments. In the proposed framework, we first extended the SB to the multiple responses, called multi-response SB (MSB) which is more effective and efficient. To obtain enough replications for correctly classifying a group effect as being important or unimportant, we present a method for determining the final number of replicates by the initial number of replicates. We then apply the MSB to identify the important factors that influence multi-echelon inventory system responses. The performance of the new method is proven and compared with the original SB procedure, the results are very promising.

Keywords Factor screening · Multi-echelon inventory system · Sequential bifurcation · Simulation

1 Introduction

Screening experiments are designed to search for the really important factors in a simulation experiment aimed at eliminating the unimportant ones; this is based on the sparsity-of-effects principle or so-called "curse of dimensionality", see Kleijnen et al. [1]. Namely: the majority, they can only lead to the little effect; the minority, they cause the major impact. It is also the reason for screening factors.

Review a number of screening methods, most of the strategies are concerned with physical experiments, including central composite, fractional factorial and

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Plackett-Burman designs [2]. Campolongo et al. [3] introduces the one-factor-at-a-time designs, which is based on frequency domain analysis [4], those methods do not take advantage of the sequential property of simulation experiments and the experimental cost and the test time are relatively high.

The group screening methods was proposed to overcome these limitations of physical experiments. There are several group screening methods, such as the Trocine screening procedure [5], supersaturated designs, aggregated designs, classic two-level designs and frequency domain experimentation, detailed by Kleijnen [6]. Those methods have a much more flexible experimental process which then determines the important factors efficiently in the sense of needing a relatively small number of simulation runs.

In this paper, we focus on the sequential bifurcation (SB) screening method, because it is the most efficient and effective method specifically developed for simulation experiments [7]. SB is a sequence of steps in which groups and factors are tested. If the group effect is considered unimportant, then all factors in the group will be considered unimportant. If the group effect is considered important, the factors in the group will be split into two subfactors for further testing. Every factor will eventually be classified as important or unimportant.

The earliest publication on SB is Bettonvil and Kleijnen [8], they assume that the simulation is deterministic and contains negligible random error. Then, Cheng [9] extended SB to handle simulation where the response is stochastic and subject to significant error. Wan et al. [10] propose controlled sequential bifurcation (CSB) for stochastic simulations, to control the type-I and type-II error probabilities, Shen and Wan [11] propose a different approach to controlled screening, namely controlled sequential factorial design (CSFD), this method is suitable for systems with a moderate number of factors and large variances. Next Wan et al. [12] improve the efficiency of CSB. For the CSB and the CSFD, which method is more efficient are complementary, so, the two-stage controlled fractional factorial screening was proposed, it can test interaction effects and do not require the directions of the effects to be known, see Wan and Ankenman [13]. CSB is also used to software reliability study [14] with non normal distribution. Shi et al. [15] applied SB and response surface methodology (RSM) to an auto parts supply chain. They identified the important factors that significantly contribute to cycle time (CT) and number of throughput (NT). MSB is a new group screening method specifically designed for multi-response simulation experiments. MSB will be have few simulated input combinations and replicates, and higher probability of finding important factors, detailed by Shi et al. [16].

The rest of this paper is organized as follows. Section 2 describes MSB method and its performance in detail, we focus MSB on only two output types. We also present a method for determining the final number of replicates by the initial number of replicates. Section 3, we introduce the multi-echelon inventory system. MSB and SB are implemented in simulation model, and compare the results of factor-screening, MSB turns out to require fewer simulation observations than SB. Conclusion and future research are discussed in Sect. 4.

2 Methodology

2.1 Model Description

Suppose there are in total of k factors. A general metamodel including all main-effects and interactions is given as follows:

$$y^{(l)} = \beta_0^{(l)} + \sum_{j=1}^{k} \beta_j^{(l)} x_j + \sum_{j'=1}^{k} \sum_{j \neq j'}^{k} \beta_{j';j}^{(l)} x_j x_{j'} + \sum_{j=1}^{k} \beta_{j;j}^{(l)} x_j^2 + \varepsilon^{(l)} \tag{1}$$

here $y^{(1)}$ denotes the simulation response for output l; x_j is the standardized value of input j, which code is −1 or +1; $\beta = \left[\beta_0^{(l)}, \beta_j^{(l)}, \beta_{j';j}^{(l)}, \beta_{j;j}^{(l)}\right]$ are the coefficients of main interaction and quadratic effect respective; the error term, $\varepsilon^{(l)}$, is a residual in metamodel for output l with zero mean. When estimate the factor's main effect in (1), it is efficient to select only two values per input.

In this paper, we focus on MSB in the simple and practical case of only two output types, namely output l and l', we let $\beta_{j';j}^{(l)}$ be the sum of main effects of factors j' through j, and

$$\beta_{j'-j}^{(l)} = \sum_{i=j'}^{j} \beta_i^{(l)} \tag{2}$$

let $w_j^{(l)}$ be the simulation response when inputs 1 through j are at their high level and inputs $(j+1)$ to k are at low level, similarly, $w_{-j}^{(l)}$ denotes when inputs 1 through j are low, while inputs $(j+1)$ to k are high.

In the following research, all factors are divided into positive and negative groups and within each group factors are sorted. Because there are two outputs in our methods, when changing the input j from low level to high level, it can makes output l increase while the output l' increase or decrease, namely the unbiased group estimators of the group main effects for output l and l' may have the same signs or the opposite signs, so the unbiased group estimators of the group main effects for output l and l' are:

(i) if inputs j' through j are in the same group and they have the same signs for outputs l and l':

$$\beta_{j'-j}^{(l)} = \frac{\left[w_j^{(l)} - w_{-j}^{(l)}\right] - \left[w_{j'-1}^{(l)} - w_{-(j'-1)}^{(l)}\right]}{4} \tag{3}$$

$$\beta^{(l')}_{j'-j} = \frac{\left[w^{(l-l')}_{j} - w^{(l-l')}_{-j}\right] - \left[w^{(l-l')}_{j'-1} - w^{(l-l')}_{-(j'-1)}\right]}{4} \tag{4}$$

where $j' \leq j$, and when $j' = j$, for the single input case.

(ii) if inputs j' through j are in the same group and they have the opposite signs for outputs l and l':

$$\beta^{(l)}_{j'-j} = \frac{\left[w^{(l)}_{j} - w^{(l)}_{-j}\right] - \left[w^{(l)}_{j'-1} - w^{(l)}_{-(j'-1)}\right]}{4} \tag{5}$$

$$\beta^{(l')}_{j'-j} = -\frac{\left[w^{(l-l')}_{j} - w^{(l-l')}_{-j}\right] - \left[w^{(l-l')}_{j'-1} - w^{(l-l')}_{-(j'-1)}\right]}{4} \tag{6}$$

where $j' \leq j$, and when $j' = j$, for the single input case.

It is worth noting that, in MSB, if a group is declared to be significant, then this group is split into two subgroups for further evaluation. Yet, if a group is declared no-significant, then all factors in the group are classified as unimportant and discarded in the next steps. In a group, if at least one of the (multiple) outputs shows significant changes, we declare the group is important.

2.2 The Final Number of Replicates

Signal to Noise Ratio (SNR) = noise/signal, if the SNR is too large, it will affect the accuracy of the experimental results, at this time, we need to adjust the number of replicates to improve the accuracy of the experiment results. The final number of replicates $m_{0:j}$ will affect the accuracy of the experiment results. Experimental results show that the changed replicates will be more conducive to improve the accuracy of the simulation experiments, reduce the number of replicates of the simulation experiments. We let n_0 denotes the initial number of replicates in the first stage, and the initial number of replicates in the next stage as 50 % of the final number of replicates in the immediately preceding stage, but not smaller than n_0.

The specific method is: we first let n_0 = 10, running the simulation program and the simulation result is $w^{(l)}_{n_0=10}$ and $w^{(l')}_{n_0=10}$. Due to less number of replicates will affect the accuracy of simulation experiment, so set the number of replicates is at least 5 times. Then let n_0 = 5, similarly, the simulation result is $w^{(l)}_{n_0=5}$ and $w^{(l')}_{n_0=5}$, if $\left|w^{(l)}_{n_0=10} - w^{(l)}_{n_0=5}\right| < \theta^{(l)}$ and $\left|w^{(l')}_{n_0=10} - w^{(l')}_{n_0=5}\right| < \theta^{(l')}$ (here $\theta^{(l)}$ and $\theta^{(l')}$ are the set of error values for output l and l', in practice, the users of the underlying simulation model should provide these values), then the final number of replicates $m_{0:j}$ equal to 5. Otherwise, we let n_0 = 6, repeat the above steps to determine the final number of replicates. The value of $m_{0:j}$ is set to 5, 6, 7, 8, 9, 11, 12, 13…, repeat the above steps until you find the appropriate value of $m_{0:j}$.

After the first stage of the final number of replicates is determined, the initial number of replicates in the next stage as 50 % of the final number of replicates in the immediately preceding stage, but not smaller than 10 times, the value of the final number of replicates of this stage is determined by the above method.

3 Case Study

3.1 Multi-echelon Inventory System Description

Jie and Cong [17] implemented Arena to study a simplified multi-echelon inventory to minimize the total inventory cost while satisfying end-customer service-level requirements. In this section, we use SB and MSB to study the case again. The results from SB and MSB are compared.

The detailed description of the multi-echelon inventory system will not be repeated here. In summary, there are supplier stores, manufacturing stores, warehouse stores and retailer stores in the supply chain, the system operates according to the continuous review policy. The simulation of the system including four sub-models: the retailer sales decision process, the distribution center (DC) order process, the factory process and the manufacturing process, which the DC order process is the most complicated process, Fig. 1 shows the operational flow chart of DC.

First, the retailer orders arrive at DC and DC to judge whether the retailer needs to order, if DC need to order, then separate the retailer orders and send the production orders to manufacturers, after the completion of product manufacturing,

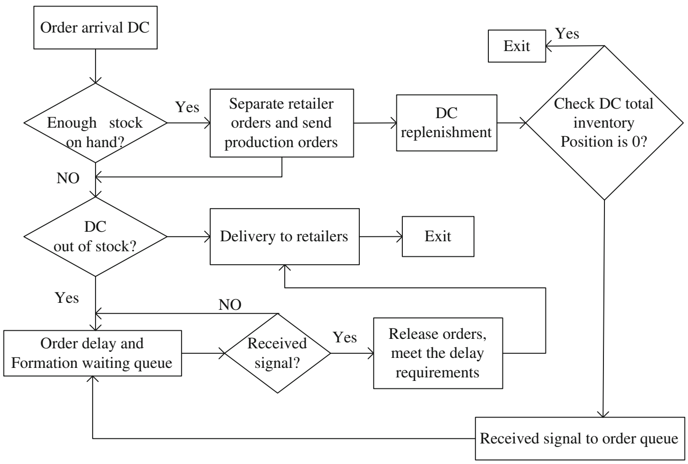

Fig. 1 The operational flow chart of DC

DC complete replenishment. At this time, we need to check the DC's total volume of less is zero or not, if not to zero, complete the retailer orders, exit the system; otherwise, we need to send a signal to the order queue, formation the order delay and waiting queue.

If DC does not need to order, it is to check whether DC is owe goods, if not, delivery directly to the retailer, complete the order, exit the system; Otherwise, the waiting queue is formed by the order delay until the signal is received, after receiving the signal, then release the order to meet the delay requirements, and then deliver to the retailer, complete the order and exit the system.

In this paper, our objective is to identify the important factors for the multi-echelon inventory system so as to minimize the total inventory cost (TC) while satisfying end-customer service-level requirements (FR). When important factors are identified, we can more accurately analyze these factors to accomplish our goals. The simulation model has 21 factors that may contribute to the variation of TC and FR, and 10 of them the main effects are nonnegative, the remaining 11 of them the main effects are negative. These inputs together with their low and high values are detailed in Table 1. So we form two groups: namely, group 1 with inputs 1 though 10 and group 2 with inputs 11 though 21.

Table 1 Influence of factors on the system

ID	Factors value				
	Factors	Low level	High level	TC	FR
1	Unit retail ordering cost	14	16	↑	↑
2	Unit retail holding cost	8	12	↑	↑
3	Unit DC ordering cost	8	12	↑	↑
4	Unit DC holding cost	1	3	↑	↑
5	Unit backorder cost	2	4	↑	↑
6	Retail 2 inventory	10	27	↑	↑
7	Retail 3 inventory	9	33	↑	↑
8	Retail 1 reorder point	10	24	↑	↑
9	Retail 2 reorder point	8	20	↑	↑
10	Retail 3 reorder point	5	30	↑	↑
11	Retail 1 order size	4	20	↑	↓
12	Retail 2 order size	4	20	↑	↓
13	Retail 3 order size	4	20	↑	↓
14	Retail 1 inventory	15	27	↑	↓
15	DC inventory	70	92	↑	↓
16	Production lotsize	20	25	↑	↓
17	DC order size	40	60	↑	↓
18	DC reorder point	20	30	↑	↓
19	Retail 1 on order	0	20	↑	↓
20	Retail 2 on order	0	20	↑	↓
21	Retail 3 on order	0	20	↑	↓

3.2 Applying SB to TC and FR

The simulation programming of the multi-echelon inventory system was done in Arena software, the simulation were run for 10 replications, for each replication, 100 days of operation were simulated with a 8 h warm-up period. We select $\Delta_0^{(TC)} = 0$ and $\Delta_0^{(FR)} = 0$ as the minimum acceptable TC and FR values. We select $\Delta_1^{(TC)} = 30,000$ and $\Delta_1^{(FR)} = 0.1$ as the performance improvement that we do not want to miss.

Since there are two responses in our study, we use SB to search for the critical factors for TC and FR, respectively. Figure 2 shows that SB stops after 22 screening, requires 220 replicates for TC. The four most important factors and their corresponding estimated main effects are shown in Fig. 2, they are factors 8, 10, 11 and 19, corresponding to retail-reorder-point 1, retail-reorder-point 3, retail-order-size 1 and retail-on-order, which are defined in Table 1.

Similarly, for FR, the SB requires 160 replicates to identify the three important factors labeled 8, 11 and 19, see Fig. 3.

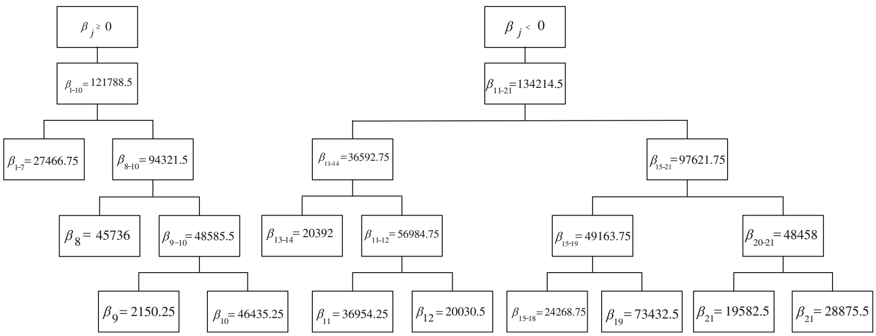

Fig. 2 SB procedure for TC

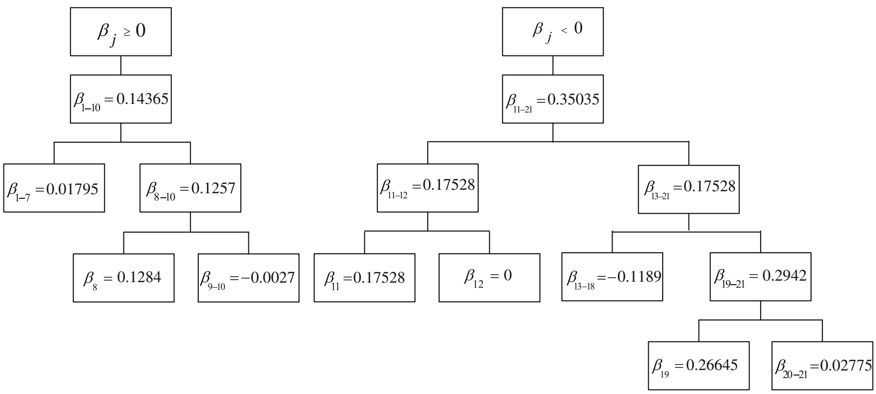

Fig. 3 SB procedure for FR

3.3 Applying MSB to TC and FR

In MSB, we select $\theta^{(TC)} = 5000$ and $\theta^{(FR)} = 0.04$ as the error values for TC and FR. Inspired by the final number of replicates, we select the initial number of replicates in the first stage n_0 equal to 10, the initial number of replicates in the next stage as 50 % of the final number of replicates in the immediately preceding stage, but not smaller than 10. Such as, for w_0, we first get the simulation result $w_{n_0=10}^{(TC)} = 292,894$ and $w_{n_0=10}^{(\mathrm{FR})} = 0.7011$, when the number of replicates $m_{0:j}$ is set to 5, the simulation result is $w_{n_0=5}^{(TC)} = 291,079$ and $w_{n_0=5}^{(\mathrm{FR})} = 0.7370$, because $\left|w_{n_0=10}^{(ITC)} - w_{n_0=5}^{(TC)}\right| = 1815 < 5000$, $\left|w_{n_0=10}^{(FR)} - w_{n_0=5}^{(FR)}\right| = 0.0359 < 0.04$, so the final number of replicates for w_0 equal to 5, and in the next stage w_{10}, the initial number is 10 (5 * 50 % but not smaller than 10). The final number of replicates for w_{10} is determined by the above method. Table 2 shows that the initial and final number of replicates per stage.

Figure 4 shows the results of identify the important factors, MSB identify factors 8, 10, 11 and 19 as important, the factors 8 and 10 are in group 1 and the factors 11 and 19 are in group 2, that is the same as SB. Table 2 shows that the initial number of replicates is 220 and the final number of replicates is 148. That is, the less number of replicates can also get the equally accurate results of the screening. This improvement of effectiveness in prescreening makes it possible for the MSB to take full advantage of the strength of SB procedures to obtain the best efficiency.

Table 2 The number of replicates

$\beta_j \geq 0$			$\beta_j < 0$		
w_j	$n_{0:j}$	$m_{0:j}$	w_j	$n_{0:j}$	$m_{0:j}$
w_0	10	5	w_0	10	5
w_{10}	10	7	w_{21}	10	5
w_7	10	13	w_{12}	10	5
w_{-7}	10	5	w_{-12}	10	5
w_8	10	13	w_{18}	10	7
w_{-8}	10	13	w_{-18}	10	5
w_9	10	9	w_{19}	10	5
w_{-9}	10	7	w_{-19}	10	5
			w_{20}	10	5
			w_{-20}	10	5
			w_{14}	10	9
			w_{-14}	10	5
			w_{11}	10	5
			w_{-11}	10	5
Total	80	72		140	76

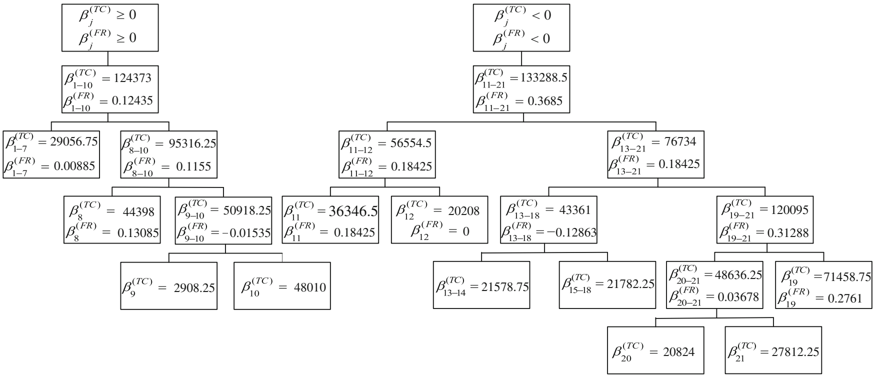

Fig. 4 MSB procedure for TC and FR

Altogether, the SB requires 220 and 160 replicates for TC and FR respectively, so SB requires 380 replicates totally, whereas MSB requires only 148 replicates, the results are satisfactory. SB and MSB identify the same factors as being important, but MSB is more effective and efficient than SB.

4 Conclusion

In this paper we presented two methods for factor screening which we called SB and MSB. With the option of using SB, MSB can handle multi-response screening problem efficiently, and it also requires few assumptions on the model. MSB is inherited from SB, but MSB uses groups of factors such there is no cancellation of main effects for any output type, moreover, MSB identify a group to be important if at least one of the (multiple) outputs shows significant changes, it can improve the screening efficiency of MSB.

More specifically, in MSB, we derived a more efficient rule for determining the final number of replicates by the initial number of replicates, the rule is based on SNR and uses the changed initial number of replicates, so the MSB requires fewer replicates than SB and they can obtain the same accuracy of screening. Thus, MSB prvides all of the benefits of SB with more generality and without a loss of efficiency, namely, MSB is more effective and efficient. In the future we are interested in exploring MSB to other simulation models with more than two outputs.

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The Effect of Color on Implicit Cognition and Cognitive Control

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Abstract The presentation of information on the human computer interface has an effect on the user's cognitive behavior. In this paper, choose the colour as the basic elements to explore the implicit cognition and cognitive control of the individual. Through the experiments, the colour and the type of word were combined with the basic principle of Stroop task and Flanker paradigm. The research discovered red colour could induce positive emotions, whereas blue colour conduced to produce negative ones. And red was more powerful than blue to moderate cognitive conflicts. This article also discussed the influence of cognitive control on the spatial and colour based inhibition of return. The results showed that attention had selection process, and the choice of position was superior to colour. According to the results of the above experiments, put forward the optimization criteria for human machine interface design, which can help improve the user's cognitive efficiency.

Keywords Colour · Cognitive control · Human-computer interface · Implicit cognition

1 Introduction

The information is mainly presented in the human-computer interface by different elements, which makes the interaction between human and computer. The interface emphasizes the principle of "people oriented", which highlights the intuitive nature of the information to enhance the user's cognitive effect. The presentation modes of elements include shape, size, location, layout, colour and other factors.

Colour is a basic attribute of the things appearance. The colour has an impact on not only human's visual perception but also the psychology features. According to the Parallel perceptual cue model proposed by Baldwin, when colour activates the perception reaction also activates the people's cognition and behavior. And the

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activation mechanism belongs to the category of the unconscious implicit association [1]. A series of experiments have been carried out on the theory of implicit cognition and cognitive control. Soldat thought warm colour had a happy implicit association, whereas cool colour tended to form the sad implicit cognition [2]. Bellizzi found that the colour of the product on the packaging had a psychological impact on customers' behavior, warm tone would let customers feel relaxed, so as to increase the purchase motivation [3]. Hill through the study of clothing colour obtained red was more likely to induce people's aggression, caused people's mood swings, and promoted the sense of anxiety [4]. Mehta found blue was associated with approach motivation, induced positive perception reaction, conducive to promote the task completion, and whereas red was associated with avoidance motivation [5]. The category of colour cognition is related to human's physiology and psychology, and the mechanism is not only controlled by the nervous system, but also related to regional and cultural environment [6].

The study of colour in cognitive control research originated from the Law's experiment [7], he used a simple test to explore the colour based inhibition of return effect under the given space position. When the target stimulus was same as the previous ones, the reaction was slower. However, Ming Zhang believed that the repetition disadvantage effect was not determined by the spatial location, the task demands were the key factor of the phenomenon [8]. Li-yan Jiao changed the type of stimulus to the letters and colours, proved that the cognitive memory of spatial location was less than colour cognition [9]. Jian-bao Zhao further explored the effect of the task demands on the colour based inhibition of return, and found that the task processing level of the stimulation target determined whether the effect occurs [10].

This paper explored the effect of colour on human implicit cognition and cognition control under the specific environment. Increased influence factors on the basis of previous research, and analyzed the different mode of colour rendering effect. Experiments were carried out from the following aspects: (1) Explored the basic psychological effects of colour on cognitive, verified that the warm colour and cool colour had different effect on subject's emotion. (2) Analyzed the effect of colour to solve the cognitive conflict. Red was conducive to reduce conflict, eased the conflict effect; blue caused conflict effect amplification. (3) Further explored the cognitive control, analyzed the spatial and colour based inhibition of return. The effect was related to the task demands, and it needed more attention than position.

2 Methodology

2.1 Experimental Design

There were four experiments conducted to study. The first and the second experiments explored the influence of colour on implicit cognition. Based on the principle of the Stroop task [11], experiment 1 explored the influence of red or blue colour for the judgment of emotional vocabulary, and proved whether the colour had an effect on people's positive or negative emotions. Experiment 2 was based on the principle of Flanker paradigm, used the different type of words as the conflict information, and explored the solution of the cognitive conflict under different backgrounds (red and blue). At the same time, the time interval was introduced to judge whether the effect of time on the cognitive conflict exists.

The third and the forth experiments were based on the repetition disadvantage effect. Experiment 3 was a simple task based inhibition of return, to perform the type of word judgment task. Experiment 4 was the colour judgment task based inhibition of return, and compared the two experiments, analyzed whether the nature of the task has an effect on such phenomenon.

2.2 Subjects

56 subjects participated in the experiments. All of them were college students at the age between 20 and 25 years. Among the participants there were 42 males and 14 females. No any intelligence problems, with good vision and visual acuity, and did not participate in such test before.

2.3 Environment

The experiments were carried out on one laptop computer with the external keyboard, and the processor was Athlon II (TM) X2 Processor 245 AMD (2 CPUs), 2.9 GHz. The resolution was set to 1440 × 900 pixels at its 17″ screen. The Windows XP Professional operating system was installed along with E-Prime program, which is the universal psychological experiment generation system software, and can be employed to record the user activity such as keystrokes performed during the tests.

2.4 Materials

There were 10 positive words and 10 negative words selected in the experiments. Positive words include: happiness, optimism, joy, pride, delight, gladness, excitement, satisfaction, cheerfulness, pleasure. Negative words include: sadness, weariness, anger, anxiety, boringness, fear, pain, hatred, worry, depression.

Experiment 1 was presented in white background with 10 positive words and 10 negative words, half of them were in red colour and others in blue.

Experiment 2 had 8 groups of words in white, they were: happy-optimistic, joy-pride, sad-weariness, angry-anxious, delight-boring, exciting-hatred, satisfied-worry, glad-depress. Four groups were in blue background, others in red.

Experiment 3 had three parts of materials, the first part was blue or red rectangle showing at the side of the screen; the second part was the gray rectangle in the middle; the third part was the red or blue rectangle with emotional vocabulary. The experiment selected 4 positive words: happiness, optimism, delight, joy, and 4 negative words: sadness, boringness, anger, anxiety.

Experiment 4 was basically same with experiment 3 except the third part rectangle didn't contain the emotional vocabulary.

2.5 Procedure

(a) *Experiment 1: Colour-mood test*

The independent variables were colour (red, blue) and type of word (positive, negative), and the dependent variables were correct rate and the reaction time of the subjects. The whole experiment contained 24 groups test, included 4 groups of practice, and 20 groups formal test. At the beginning of the experiment, the red "+" presented in the screen during 800 ms, to remind the test began. The subjects needed to judge the part of the speech, if it was the positive word pressed "F" key on the keyboard. The negative word pressed "J". In the practice part, it would present the results feedback, which was replaced by white screen in the formal test. The flow chart of the experiment is shown in Fig. 1.

(b) *Experiment 2: Cognitive Conflict test*

The independent variables were background colour (blue, red), time interval (250, 2000 ms) and type of word (same, different). The dependent variables were correct rate and reaction time. The content was to make a judgment on the consistency of the two words, pressed the "F" key if the type of words were same, otherwise pressed "J". The flow chart is shown in Fig. 2.

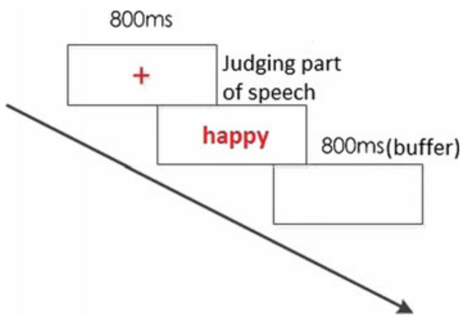
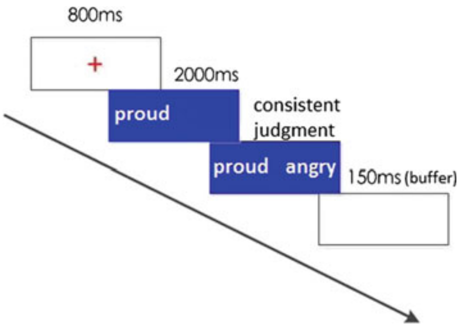


Fig. 1 Experiment 1 process

Fig. 2 Experiment 2 process



(c) *Experiment 3: Simple task based inhibition of return test*

The independent variables were colour, position and type of word. The dependent variables were same with the above experiments. At first, a blue or red rectangle would present at the side of screen. After 2000 ms delay, a gray rectangle showed in the middle. And then there would present a rectangle containing emotional vocabulary. The subject made a judgment on the type of word, if it was the positive word pressed "F", and if negative pressed "J". The experimental flow chart is Fig. 3.

(d) *Experiment 4: Colour judgment based inhibition of return test*

The independent variables were colour and position. It was similar with experiment 3. The subjects needed to judge the colour of the third rectangle, for red colour pressed "F", blue pressed "J". The experimental flow chart is Fig. 4.

Fig. 3 Experiment 3 process

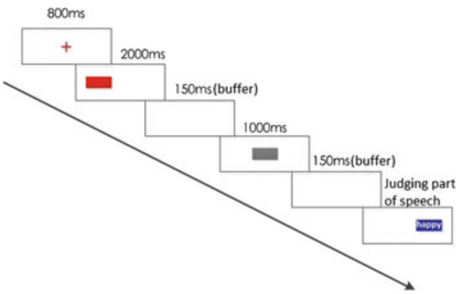
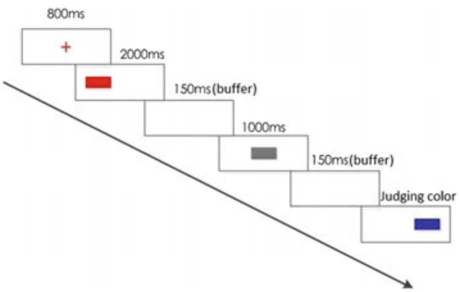


Fig. 4 Experiment 4 process



3 Results

3.1 Experiment 1: Colour-Mood Test

(a) *Descriptive statistics*

The basic descriptive statistics for all examined are summarized in Table 1, which was analyzed by SPSS software.

The results showed that the correct rate of positive words in red background was the highest, and the reaction time was the shortest. It followed by the negative words in blue background.

(b) *Significance testing*

In order to further test whether the red and blue colour had a significant impact on the reaction time and the correct rate, used the method of paired-samples T test to explore. The results are shown in Table 2.

The correct rate of positive words and negative words: $p = 0 < 0.05$, the reaction time: $p = 0.003 < 0.05$, meant the difference was significant. Combined with the average value of the statistics, when the word was red, the positive words were significantly better than the negative words for both the reaction time and the correct rate. That is, red had significant effect on vocabulary (Table 3).

When the colour was blue, for the correct rate: $p = 0.514 > 0.05$, and for reaction time: $p = 0.985 > 0.05$, there was no significant difference between positive word and negative word. Synthesized the basic statistical data, when the vocabulary was blue, the judgment of negative word was better than positive word, but the difference wasn't significant.

(c) *Results*

From the experiment, red colour had positive drive in mood and the effect was obvious, but there was no obvious difference in blue colour. The results conformed to Yan Cheng's hypothesis, that blue had melancholy meaning in western countries, usually considered to be associated with negative emotions. But it had no fixed intention in Chinese culture [12]. Alan had a psychological survey of the Chinese

Table 1 Descriptive statistics: reaction time and accuracy

	Min	Max	Mean	SD
Red P ACC	1.00	1.00	1.000	0.000
Red N ACC	0.00	1.00	0.942	0.232
Blue P ACC	0.00	1.00	0.935	0.245
Blue N ACC	0.00	1.00	0.946	0.225
Red P RT	288.00	1570.00	580.110	179.917
Red N RT	269.00	3078.00	618.896	244.600
Blue P RT	264.00	1868.00	614.460	195.483
Blue N RT	292.00	2532.00	614.200	245.988

Table 2 Positive and negative words in red background

Red passive ACC	Red negative ACC	Mean difference	t	P
1.000 ± 0.000	0.943 ± 0.232	0.057	4.112	0.000
Red passive RT	Red negative RT	Mean difference	t	P
580.111 ± 179.918	618.896 ± 244.601	−38.785	−3.007	0.003

Table 3 Positive and negative words in blue background

Blue passive ACC	Blue negative ACC	Mean difference	t	P
0.936 ± 0.246	0.946 ± 0.226	−0.010	−0.654	0.514
Blue passive RT	Blue negative RT	Mean difference	t	P
614.461 ± 195.484	614.200 ± 245.988	0.261	0.019	0.985

people's perception of colour, and found that the Chinese people's psychological suggestion to the colour was different with the Americans [13]. The results also showed that the colour of the implicit cognition was related with the culture and environment.

3.2 *Experiment 2: Cognitive Conflict Test*

Take the method of paired-samples T test to examine the background colour, time interval and type of word.

(a) *Background colour*

On the correct rate, there was no significant difference both in red and blue background, and on the reaction time, the significance levels of the red background were 0.309 and 0.499 respectively in 2000 and 250 ms interval. And for blue background, $p = 0.008$ and 0.031, the difference was significant. Figures 5 and 6 reflect this effect more clearly.

From the two graphs, there was less difference of the reaction time in red background. The amount of cognitive conflict was small. On the contrary, the amount of cognitive conflict was greater in blue background than that of red (Table 4).

(b) *Interval*

The results showed: $p = 0.464 > 0.05$, shortening the time interval could increase the correct rate, but the effect was not significant. For the reaction time: $p = 0.008 < 0.05$, the growth of the time interval could be obviously reduce the reaction time (Table 5).

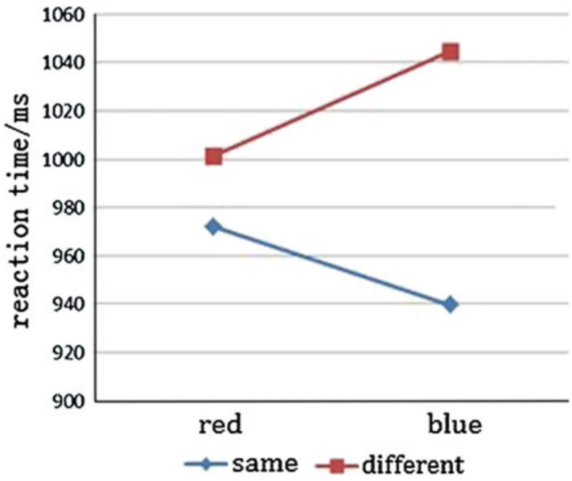


Fig. 5 Reaction time under the *red* and *blue* background in 2000 ms

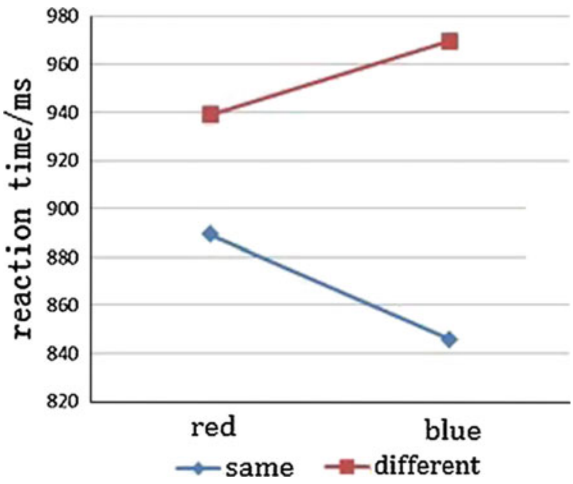


Fig. 6 Reaction time under the *red* and *blue* background in 250 ms

Table 4 Paired sample statistics: time interval

2000.ACC	250.ACC	Mean difference	t	P
0.882 ± 0.323	0.897 ± 0.304	−0.015	−0.733	0.464
2000.RT	250.RT	Mean difference	t	P
910.924 ± 481.748	989.239 ± 491.963	−78.315	−2.646	0.008

Table 5 Paired sample statistics: type of word

Same.ACC	Different.ACC	Mean difference	t	P
0.866 ± 0.341	0.913 ± 0.282	−0.047	−2.316	0.021
Same.RT	Different.RT	Mean difference	t	P
911.621 ± 457.614	988.630 ± 513.427	−77.009	−3.156	0.002

(c) *Type of word*

The correct rate of the type of words consistency was: $p = 0.021 < 0.05$, reaction time: $p = 0.002 < 0.05$. Combined with the basic statistics, the different type of words could improve the accuracy of the judgment, but would significantly increase the response time.

(d) *Results*

Red colour to solve the cognitive conflict was better than blue and it was conducive to reducing the amount of conflict, improving the cognitive ability. As an environmental variable, it could be proved that the colour would induce the emotional response by the corresponding mechanism [14]. In addition to this factor, the growth of the stimulus presentation time interval would reduce the reaction time. Besides, the effect of type of word was remarkable, when there was no interference conflict, the reaction time would be shortened.

3.3 Experiment 3: Simple Task Based Inhibition of Return Test

(a) *Descriptive statistics*

From the descriptive statistics, when the colour and position changed, the correct rate increased and the reaction time reduced. Especially when the position was different, the effect was significant. But the influence of colour wasn't obvious (Table 6).

(b) *Significance testing*

By the method of significant mean differences in the group t test, explore the two kinds of condition when the position was different and when the colour changed.

(1) Spatial based inhibition of return

When position wasn't consistent, for the reaction time: $p = 0.049 < 0.05$, the effect of the position was obviously influenced the reaction time, which was shortened when the position changed.

Table 6 Descriptive statistics: reaction time and accuracy

	Min	Max	Mean	SD
Original.ACC	0.00	1.00	0.964	0.185
Position.ACC	0.00	1.00	0.964	0.185
Colour.ACC	0.00	1.00	0.982	0.132
P&C.ACC	0.00	1.00	0.973	0.161
Original.RT	398.00	3874.00	764.763	315.391
Position.RT	359.00	2195.00	760.857	217.225
Colour.RT	388.00	2268.00	732.419	202.325
P&C.RT	443.00	2749.00	763.392	284.997

(2) Colour based repetition disadvantage effect

There was no significant effect whether the colour was consistent. The correct rate: $p = 1 > 0.05$, the reaction time: $p = 0.849 > 0.05$.

(c) *Results*

The mechanism of inhibition of return is that when a certain clue appears, it will inhibit the same stimulus. That is, when the cue comes again, it will cause a delay in response [15]. In this experiment, when we needed to perform a simple task, there wasn't any phenomenon on colour based repetition disadvantage effect, but there was a position based inhibition of return. According to the theory of resource allocation [16], the position needed less attention than colour.

3.4 Experiment 4: Colour Judgment Based Inhibition of Return Test

(a) *Descriptive statistics*

From the Table 7, the reaction and the correct rate were obviously improved when the colour or location wasn't consistent. And the time was the shortest when both the colour and position changed.

(b) *Significance testing*

(1) Spatial based inhibition of return

There was no significant difference between the correct rate, and for the reaction time: $p = 0.027 < 0.05$, it was obvious that the position had an influence on the reaction time.

(2) Colour based repetition disadvantage effect

When colour was different, the correct rate: $p = 0.809$, reaction time: $p = 0.054$, compared with the experimental 3, it could be considered that the colour's change would improve the correct rate and reduced the response time.

Table 7 Descriptive statistics: reaction time and accuracy

	Min	Max	Mean	SD
Original.ACC	0.00	1.00	0.933	0.250
Position.ACC	0.00	1.00	0.950	0.216
Colour.ACC	0.00	1.00	0.937	0.242
P&C.ACC	0.00	1.00	0.955	0.206
Original.RT	317.00	1869.00	669.330	226.784
Position.RT	272.00	1963.00	634.700	234.351
Colour.RT	318.00	1519.00	641.071	211.880
P&C.RT	252.00	2325.00	624.745	283.342

(3) Spatial and colour based inhibition of return

When both the colour and position were not consistent, the reaction time: $p = 0.018 < 0.05$, the difference was significant, noted that the reduction in response time was obvious.

(c) *Results*

Because the task demands changed, there was a more obvious phenomenon on position based inhibition of return in experiment 4. At the same time, the subjects focused more attention on colour, thereby improving the colour observation, there was a colour based repetition disadvantage effect came out. In the visual processing stage, the colour required to be judged from the hue, brightness and saturation [17]. Therefore, it was considered that the colour would be ignored in the simple task, but could be concerned in the colour judgment.

4 Discussion and Conclusion

Through a series of experiments, the analysis revealed: (1) red could produce positive mood, blue tended to induce negative emotion. With the cultural background of our country, red is a symbol of the positive psychological hint, for the subjects had the tendency to be motivated. The blue has no obvious intention, so the negative effect was not obvious. It can be concluded that the effect of colour on the psychological suggestion was closely related to the region and culture. (2) Red had a significant role in easing the cognitive conflict and improving the ability to resolve conflicts. In contrast, the effect of blue was weak. At the same time, the growth of the time interval was conducive to the improvement of the resolution. (3) In the selection of information, the judgment of the position was automatic. It didn't need to consume too much attention. Therefore, according to the Russell's hypothesis "There may be the position of the automatic processing in attention". Position needed less attention than colour. (4) The cognitive control was an essential condition for the production of colour based repetition disadvantage effect. The way that general knowledge to guide the perception of information processing is called "top-down processing", the high level of general knowledge affects the lower levels of consciousness units, the cognition of colour accorded with this mechanism. So the top-down cognitive control was a key factor in the colour based inhibition of return when the spatial position was uncertain.

These studies have indicated the non-independence of the cognitive control process and the systematic nature of the human mental process. As an intermediary variable, colour would have an effect on a series of cognitive operations (emotions or motives). It also showed that there was a close relationship between the two kinds of behavior of human beings—the consciousness system and the unconscious system. Bargh further proposed the automatic activation model of perception, and the study showed that when colour induced the psychological effects, it would produce the startup phenomenon which was similar to the subliminal [18].

5 Application

Human machine interface design is to optimize the arrangement of the elements and the mode of the communication, achieve the user's needs as well as improve the cognitive efficiency [19]. According to the results of the experiments, the influence of colour on human cognition and cognitive control can be applied to the interface display design. Combined with the control interface of the vehicle equipment, put forward the following optimization criteria.

The key of vehicle equipment control interface design is to improve the safety and reliability of the operation. For cognitive conflict solution, the warm colour is better than cold colour, so it could choose warm colour as the background in the interface of conflict information presentation. It is conducive to help the operator to determine and respond to the inconsistent information, improve the operation efficiency and reduce the error rate. Because the spatial based inhibition of return is better than colour, so the position could be choosed as the primary layout, meanwhile add colour logo. In addition, the colour can also be applied to the functional classification and environment adaptability design. Eventually make the interface more in line with the operator's cognitive characteristics.

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Research on the Relief Scheduling Model Considering Victims' Satisfaction for Emergency Response in Large-Scale Disasters

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Abstract On the basis of analyzing reviews on relief scheduling model, this paper conducted a basic research on emergency response process and victims' satisfaction. Then, a multi objective relief model considering victims' satisfaction for emergency response from the perspective of time and quantity attributes was proposed. And then genetic algorithm with decimal coding was designed to solve this problem discussed here by combining with the characteristics of relief scheduling. Finally, example from Wenchuan earthquake was presented to the demonstrate feasibility and effectiveness of the proposed model and algorithm.

Keywords Emergency response · Genetic algorithm · Relief scheduling · Victims' satisfaction

1 Introduction

In the past few decades, it resulted in a worse negative effect on society and economy with the frequency of large-scale disasters increasing. For example, fatal earthquakes in China (Sichuan 2008), Chile (Iquique 2014) and Nepal (2015), Tsunami in Japan in 2011, Hurricane Katrina in United States of America in 2005, Southern Big Snowstorm in China in 2008 resulted in a large number of casualties, property losses and environmental disruption. Particularly, Tangshan earthquake in China killed 240,000 persons and destroyed over 10 billion RMB worth of heavy property losses [1].

Emergency response without relief has no the original significant meaning. There is a short or limited time for decision-makers after large-scale disasters

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happen. Leaders have to make a feasible and reasonable scheduling strategy immediately. Otherwise the chance to govern may not be in right time. And the aftermath of large-scale disasters may be worse and worse. Moreover, that may induce victims to show extreme behaviors, resulting in society being out of order. To reduce or mitigate such various losses, relief scheduling is the key of emergency response process. The major question is how to design relatively reasonable relief scheduling scheme to improve efficiency of emergency response with the limited relief as soon as possible, which is the challenge faced by society being solved immediately.

2 Literature Review

Considering models focused on the relief scheduling, common objectives used in the models include minimizing the time to distribute reliefs [2–4], the minimization of the expected number of fatalities [5, 6], minimizing the cost of transporting the reliefs in question [7–9], and the minimization of victims' dissatisfaction or the maximization of victims' satisfaction [10–15]. However, the models referred in the literature [2–9] considered mainly time factor instead of quantity factor for relief scheduling scheme. And several models gave no explicit consideration to victims' satisfaction with time and quantity attribute of relief scheme. Despite the importance of relief distribution considering victims' satisfaction, the literature in this field is limited. Models may be proposed for the key rescue period without focusing on the lifecycle of emergency response and pay no attention to the impact of victims' satisfaction on emergency management. Victims in different affected areas have different sensitivities to the arrival time of relief. And these papers viewed victims in emergency response as the whole without classification. It may be unreasonable [5]. The essence of relief scheduling model with single or multi objectives can be attributed to agents' satisfaction problem. Relief scheduling models in the literatures aren't fitted with the actual emergency management being out of quick response to disasters well during the process of emergency response.

3 Relief Distribution Model Considering Victims' Satisfaction

3.1 The Breakdown of Emergency Response Process

Based on the relevant literatures, initial rescue period of the large-scale disasters can be defined as key rescue or golden rescue time [5, 6, 9]. By summarizing above analyses, the first stage in emergency response is called 'Golden rescue stage' in this paper. In general, the duration of this stage is 3 days or 72 h. Usually the maximal time of surviving lies between 4 and 7 days [5]. With the evolution of emergency response process in large-scale disasters, the demands on time and quantity attribute of relief scheduling scheme for victims are change. That is to say, the satisfaction of demand agent is taken into account. This paper divides the periods left into two parts based on the differences between psychological perception state and degree of demand, namely buffer rescue stage and the recovery stage. Large-scale disasters with different types and levels have different standards and methods of measuring cycle for the second and third stage [15]. The cycle of emergency response process and the length of each stage can be defined according to the number of fatalities and demand change on relief.

3.2 The Relationship Between Victims' Satisfaction and Psychological Behavior

Victims are always assumed to be rationality under emergency state. However, demand agent is usually bounded rationality during the process of actual relief scheduling. And this bounded rationality is defined as psychological behavior of agent. Psychological behaviors of demand agent will be treated as their expectation of two attributes of relief scheduling scheme on the condition that relief scheduling scheme can be described by time and quantity attribute [16]. Victims' practical experience produced by comparing the expectations of attributes with actual value is called or defined as victims' satisfaction [4, 10]. Different victims for the attributes of relief scheduling scheme maybe have different psychological behaviors. And it includes two points. The first one is that victims may have the particular expected requirement on certain an attribute during the given time. The second one is that victims have different expected requirements on attributes at different periods. That is to say, the change of victims' satisfaction results from that of psychological behavior with time.

3.3 Measurement of Victims' Time and Demand Amount Satisfaction

Time satisfaction of the trapped victims or rescued victims with serious injury: the measured methods of these victims' satisfaction can reference probability of surviving function in earthquake [5]. This assumption shows that victims' time satisfaction is similar to survival probability function of the trapped victims. Then time satisfaction function for these victims can be denoted by as follows:

$$g_1(\pi) = \prod_{hos=1}^{n_{HOS}} \xi_{hos}(t) \quad (1)$$

In the formula (1): $\xi_{hos}(t)$ is the comprehensive time satisfaction of various reliefs arriving at hospitals or on-the-spot scene areas. *hos* denotes hospital or on-the-spot scene area with n_{HOS} representing the total number.

Time satisfaction of the victims with no injury or minor injury: time satisfaction measured by the gradient function for these victims can be denoted by:

$$g_2(\pi) = \prod_{tes=1}^{n_{TES}} \xi_{tes}(t) \quad (2)$$

In the formula (2): $\xi_{tes}(t)$ is the comprehensive time satisfaction of various reliefs arriving at temporary settlement areas. *tes* denotes the temporary settlement area with n_{TES} representing the total number.

Time satisfaction of the victims around the lifelines rehabilitation area: time satisfaction for the lifeline rehabilitation areas is mainly influenced by expectations reflecting victims' psychological behaviors and actual perception of the victims. Combined with expectation difference theory, the time urgency function can be introduced into measuring time satisfaction of the victims around the lifeline rehabilitation areas [17]. Then expression can be noted as follows:

$$g_3(\pi) = \prod_{lr=1}^{n_{LR}} \xi_{lr}(t) \quad (3)$$

In the formula (3), $\xi_{lr}(t)$ is the comprehensive time satisfaction of various reliefs arriving at lifeline rehabilitation areas. *lr* denotes the lifeline rehabilitation area with n_{LR} representing the total number.

Demand quantity satisfaction of victims: during the process of relief scheduling in large-scale disasters, victims focused on arrival time as well as distributed quantity of relief. Demand quantity satisfaction of victims can be measured by the relative proportion demand function. The victims' demand quantity satisfaction of each demand point may be determined by the weight of demand point and the relative satisfaction.

$$g_4(\pi) = \frac{1}{n}\sum_{j=1}^{n} \xi_j(x) \quad (4)$$

In the formula (4): $\xi_j(x)$ is the demand quantity satisfaction of victims on relief *i* arriving at demand point *j*. *n* is the number of demand point.

3.4 Objective Function of Relief Scheduling Model Considering Victims' Satisfaction

Simon indicated that the expectations of bounded rationality treated agents' satisfaction as criterion. Relief scheduling considering victims' satisfaction can be attributed to agents' satisfaction problem. The first objective function taken by decision-makers into consideration is the maximization of minimum victims' satisfaction for demand point. It can be denoted by:

$$\begin{aligned} &Objective\,1: \\ &\max\ \min\{f(DS_j^{(s)})\}, \quad \forall s \in S \end{aligned} \tag{5}$$

In the formula (5), s denotes any stage during the process of emergency response. j represents any demand point. $f(DS_j^{(s)})$ is the victims' satisfaction on the demand point j at stage s.

The second objective function taken by decision-makers into consideration is the minimization of the biggest difference of the victims' satisfaction for demand point. Then, it can be denoted by:

$$\begin{aligned} &Objective\,2:\ \min \quad Sa \\ &Sa \geq \left|f(DS_j^{(s)}) - f(DS_{j'}^{(s)})\right|, \quad \forall s \in S, \ \ \forall j, \ \ j' \in J, \ \ j \neq j' \end{aligned} \tag{6}$$

In the formula (6), Sa is the minimum of maximized absolute obtained by difference of victims' satisfaction for any two demand points. j' denotes any demand point. And the meaning of other parameters is the same to that of formula (5).

The third objective function taken by decision-makers into account is the minimization of the biggest difference of the victims' satisfaction for any stage. Therefore, it can be denoted by:

$$\begin{aligned} &Objective\,3:\ \min Sa' \\ &Sa' \geq \left|h^{(s)}(\pi) - h^{(s')}(\pi)\right|, \quad \forall s, \ \ s' \in S, \ \ s \neq s' \end{aligned} \tag{7}$$

In the formula (7), Sa' is the minimum of maximized absolute obtained by difference of victims' satisfaction for any two demand points. s' denotes any stage. $h(\pi)$ is the victims' satisfaction of demand point at each stage. And relief scheduling scheme is denoted by π.

This paper needs to calculate the victims' satisfaction from the perspective of fine-grained for the first and second objective function. They are denoted by:

$$f(DS_j^{(s)}) = f^{Aa}(DS_j^{(s)}) \times f^{Ta}(DS_j^{(s)}), \quad \forall j \in J \tag{8}$$

$$f^{Ta}(DS_j^{(s)}) = \frac{1}{n_{HOS_j} + n_{TES_j} + n_{LR_j}} \times \left(\sum_{hos_j=1}^{n_{HOS_j}} \xi_{hos_j}^{(s)}(t) + \sum_{tes_j=1}^{n_{TES_j}} \xi_{tes_j}^{(s)}(t) + \sum_{lr_j=1}^{n_{LR_j}} \xi_{lr_j}^{(s)}(t) \right), \quad \forall j \in J \tag{9}$$

$$f^{Aa}(DS_j^{(s)}) = \xi_j^{(s)}(x), \quad \forall j \in J \tag{10}$$

In formula (8)–(10), $f^{Aa}(DS_j^{(s)})$ is the demand quantity satisfaction of the victims on the demand point j at stage s. $f^{Ta}(DS_j^{(s)})$ is the time satisfaction of the victims on the demand point j at stage s. For the third objective function, the overall goal can be divided into two parts, including victims' satisfaction for time attribute and demand quantity attribute of the relief scheduling scheme. Then victims' satisfaction for golden rescued stage, buffer rescued stage, and the recovery stage is denoted by:

$$h^{(s)}(\pi) = \left[p_1^{(s)} \times \frac{1}{\alpha^{(s)}} \times k_1^{(s)}(\pi) \right] \times \left[p_2^{(s)} \times \frac{1}{\beta^{(s)}} \times k_2^{(s)}(\pi) \right] \tag{11}$$

$$k_1^{(s)}(\pi) = 1/3 \times \{ g_1^{(s)}(\pi) + g_2^{(s)}(\pi) + g_3^{(s)}(\pi) \}, \quad k_2^{(s)}(\pi) = g_4^{(s)}(\pi) \tag{12}$$

In formula (11)–(12), $k_1^{(s)}(\pi)$ and $k_2^{(s)}(\pi)$ represent relief arrival time satisfaction and demand quantity satisfaction respectively. $g_1^{(s)}(\pi), g_2^{(s)}(\pi)$, and $g_3^{(s)}(\pi)$ denote time satisfaction of the trapped victims or rescued victims with serious injury, that of the victims with no injury or minor injury, and that of the victims around the lifeline rehabilitation area at stage s respectively. Relief demand quantity satisfaction of the victims at stage s is denoted by $g_4^{(s)}(\pi)$. Meanwhile, $\alpha^{(s)}$ and $\beta^{(s)}$ are introduced to eliminate dimension of indexes. $p_1^{(s)}$ and $p_2^{(s)}$ are the victims' preference to time and quantity attribute of relief scheduling scheme. And the value of them is varied from time. It should meet constraints as follows:

$$P_1^{(s)} + P_2^{(s)} = 1, \quad \forall P_1^{(s)} \in [0.1, 0.9], \; P_2^{(s)} \in [0.1, 0.9] \tag{13}$$

3.5 Multi Stage Model Considering Victims' Satisfaction

The importance of golden rescued stage, buffer rescued stage, and the recovery stage is treated as the same by decision-makers. Moreover, the victims' satisfaction of three stages has some relationship. Then the ultimate satisfaction function of victims is denoted by:

$$H(\pi) = \prod_{s=1}^{3} h^{(s)}(\pi) \tag{14}$$

Therefore, relief scheduling model considering victims' satisfaction for emergency response in large-scale disasters discussed here can be formulated as multi objective programming model. It is denoted by as follows:

$$\begin{aligned}
&\mathit{Objective}\,1: \quad \max\ \min\{f(DS_j^{(s)})\} \\
&\mathit{Objective}\,2: \quad \min\ Sa/Sa \geqslant \left| f(DS_j^{(s)}) - f(DS_{j'}^{(s)}) \right| \\
&\mathit{Objective}\,3: \quad \min\ Sa'/Sa' \geqslant \left| h^{(s)}(\pi) - h^{(s')}(\pi) \right| \\
&S.T.\ \ \sum_{i=1}^{m} x_{i\to j}^{(s)} \leqslant e_j^{(s)}, \quad \forall j \in J,\ \ s \in S(C1) \\
&\sum_{s=1}^{3}\sum_{j=1}^{n}\sum_{i=1}^{m} x_{i\to j}^{(s)} < \sum_{s=1}^{3}\sum_{j=1}^{n} e_j^{(s)} (C2) \\
&Q_i^{(s)} = \sum_{j=1}^{n} x_{i\to j}^{(s)}, \quad \forall i \in I,\ \ s \in S(C3) \\
&\sum_{s=1}^{3}\sum_{i=1}^{m} Q_i^{(s)} = \sum_{s=1}^{3}\sum_{i=1}^{m}\sum_{j=1}^{n} x_{i\to j}^{(s)} (C4) \\
&\sum_{i=1}^{m} x_{i\to j}^{(s)} \geqslant E_{lower\,j}^{(s)}, \quad \forall j \in J,\ \ s \in S(C5) \\
&P_1^{(s)} + P_2^{(s)} = 1, \quad \forall s \in S(C6) \\
&Y_{i\to j\,or\,jde}^{(s)} = \{0,1\}, \quad \forall i \in I,\ j \in J,\ jde \in JDE,\ \ s \in S(C7) \\
&Z_{i\to j\,or\,jde}^{(s)} = \{0,1\}, \quad \forall i \in I,\ j \in J,\ jde \in JDE,\ \ s \in S(C8) \\
&x_{i\to j\,or\,jde}^{(s)} \geqslant 0, \quad \forall i \in I,\ j \in J,\ jde \in JDE,\ \ s \in S(C9) \\
&t_{i\to j\,or\,jde}^{(s)} \geqslant 0, \quad \forall i \in I,\ j \in J,\ jde \in JDE,\ \ s \in S(C10) \\
&P_1^{(s)}, P_2^{(s)} \in [0.1, 0.9], \quad \forall s \in S(C11) \\
&x_{i\to j\,or\,jde}^{(s)} = Y_{i\to j\,or\,jde}^{(s)} = 0, \quad Z_{i\to j\,or\,jde}^{(s)} = 1;\ \ if\ t_{i\to j\,or\,jde}^{(s)} > T_{upper\,i\to j\,or\,jde}^{(s)} (C12a) \\
&x_{i\to j\,or\,jde}^{(s)} > 0, \quad Z_{i\to j\,or\,jde}^{(s)} = Y_{i\to j\,or\,jde}^{(s)} = 1;\ \ if\ t_{i\to j\,or\,jde}^{(s)} < T_{upper\,i\to j\,or\,jde}^{(s)} (C12b) \\
&\alpha^{(s)} = \max\{\max\{\xi_{hos\in HOS}(t), \max\{\xi_{tes\in TES}(t), \max\{\xi_{lr\in LR}(t)\}\}(C13) \\
&\beta^{(s)} = \max\left\{\xi_1^{(s)}(x), \xi_2^{(s)}(x), \ldots, \xi_j^{(s)}(x), \ldots, \xi_m^{(s)}(x)\right\}(C14)
\end{aligned}$$

In the model, C(1) and C(2) ensure that actual amount of transported relief can't exceed expectation for demand points at each stage. C(3) and C(4) indicate that relief stocks for all categories are equal to the sum of this kind of relief transported to all demand points in terms of relief distribution centers. C(5) shows that actual amount of transported relief for stage s can't be less than the lower bound which can be accepted by the victims in the demand point. C(6) gives a method to measure the victims' preference to time and quantity attribute of relief scheduling scheme at each stage. C(7) and C(8) give the relationship between relief i and demand point j or the detailed area jde at stage s. C(9) and C(10) define respectively the range of decision variable on demand quantity and time. C(11) gives the range of parameters p_1 and p_2. C(12a) and C(12b) represent time constraints during the process of relief scheduling. C(13) and C(14) give the expressions of parameters α and β.

4 Algorithm Solving for Relief Distribution Model and the Simulation

4.1 Genetic Algorithm Design

Genetic algorithm was applied to solve the relief scheduling model considering victims' satisfaction in this paper [18]. Its iterative process is as follows:

Step 1: Relief scheduling scheme is expressed as $8 \times n$ matrix with decimal coding.
Step 2: Initial population, whose size is at the interval [20, 50], can be produced randomly with constraints.
Step 3: Individual fitness function is denoted by $eval(h, l) = f(h, l)$ with the specific rules. In the formula, $f(h, l) = \mu_1 \overline{\lambda} + \mu_2 \times (1/\overline{Sa}) + \mu_3 \times (1/Sa')$.
Step 4: Parent individuals can be selected with the accumulated probability and rules by roulette.
Step 5: Chromosomes are paired match by single-point crossover, then modified.
Step 6: The mutation of chromosomes is conducted by uniform mutation, and then modified.
Step 7: The terminated command including two aspects. The first one is obtaining satisfactory solution for the given times. The second is the value of fitness function converging to a fixed number.

4.2 Parameter Definition of Relief Scheduling Model for Wenchuan Earthquake

In this paper, the affected heavily areas of Wenchuan earthquake are relief-demand points, including Du Jiangyan, Mianzhu and Guangyuan. The weight of

Du Jiangyan is 0.6118, that of Mianzhu is 0.3203, and that of Guangyuan is 0.0679. Chengdu and Mianyang were treated as relief distribution centers. And relief supply points include Zhengzhou, Xian and Wuhan. Based on the trend of accumulated fatalities [19], the interval of golden rescued stage is denoted by [0, 5], that of buffer rescued stage is (5, 11], and that of the recovery stage is (11, 24]. And relief arrival time can be determined by uniform distribution with certain an internal. Space distance from supply point to demand point may refer to literature [20]. Relief stocks in distribution centers at stage s respectively are [18, 27, 15, 35], [24, 18, 21, 10], [9, 15, 18, 20]. Relief quantity of demand points respectively is [50, 50, 20], [30, 30, 40], [40, 30, 23]. What should be mentioned is that the unit of relief quantity is "unit". Compared with the population in the affected areas, the proportion of victims in hospitals or on-the-spot scene areas, temporary settlement areas, and lifeline rehabilitation areas respectively is 0.3, 0.2, and 0.5. The urgency degree on relief of demand points is respectively 1000 (Du Jiangyan), 500 (Mianzhu), 2000 (Guangyuan). The victims' preference to time and quantity attribute at stage s can be denoted respectively by [0.1, 0.9], [0.5, 0.5], [0.9, 0.1].

4.3 Simulation Results and Analysis

The prerequisite in this paper is that relief scheduling initial scheme is obtained by related persons, including decision agent certainly. In Wenchuan earthquake, the quantity and time relation between relief distribution center and demand point as well as detailed rescued area and demand point has been determined. The value of the first objective is 0.0006, that of second is 0.1542, and that of third is 0.0422 for initial relief scheduling scheme with model and algorithm mentioned above.

Simulation is realized by Matlab (2012b) based on the proposed model and designed algorithm. All algorithms run on the computers with a dual core processor labelled by core duo i5-5200. The satisfactory solution which refers to relief scheduling scheme with optimal objective was obtained by genetic algorithm on the basis of meeting constraints. In this paper, crossover probability is 0.1, mutation probability is 0.01, the size of population is 50, and the iterative time is 800. Converged process of fitness function shows that the average value of fitness function begins to converge in the 300th generation. The convergence rate of average at interval [0, 100] is faster than [100, 300]. In the end, the average value of fitness function is converged to 2.8 more or less. Then we find the optimal relief scheduling scheme.

The victims' satisfaction of initial (being in bracket) and satisfactory solution is depicted in Table 1. In terms of the three objectives, the minimum of victims' satisfaction in Du Jiangyan, Mianzhu and Guangyuan has been improved by optimizing. For the first objective, the minimal satisfaction of golden rescued stage rose from 0.0007 to 0.0108, that of buffer rescued stage rose from 0.0008 to 0.1027, and that of the recovery stage rose from 0.0003 to 0.1008. For the second objective, the absolute of maximal difference on victims' satisfaction for golden rescued stage, buffer rescued stage, the recovery stage respectively decreased to 0.1605, 0.0417,

Table 1 Victims' satisfaction of initial and satisfactory solution of relief scheduling scheme

Emergency response	Du Jiangyan	Mianzhu	Guangyuan	Comprehensive satisfaction	Minimum	Absolute of biggest difference for demand points	Absolute of biggest difference for stages
Golden rescued stage	0.0108	0.1713	0.1078	0.1068	0.0108	0.1605	
	[0.0007]	[0.1771]	[0.0172]	[0.0088]	[0.0007]	[0.1764]	
Buffer rescued stage	0.1373	0.1027	0.1325	0.1079	0.1027	0.0345	0.0011
	[0.0008]	[0.0157]	[0.0425]	[0.0479]	[0.0008]	[0.0417]	[0.0422]
The recovery stage	0.2509	0.1008	0.1217	0.1070	0.1008	0.1501	
	[0.2450]	[0.0003]	[0.0273]	[0.0057]	[0.0003]	[0.2447]	

Emergency response	Time satisfaction of hospital response or on-the-spot scene area	Time satisfaction of temporary settlement area	Time satisfaction of lifeline rehabilitation area	Demand quantity satisfaction
Golden rescued stage	0.3427	0.6146	0.0198	0.1348
	[0.2376]	[0.5424]	[0.0021]	[0.1188]
Buffer rescued stage	0.2569	0.7290	0.2658	0.2414
	[0.2129]	[0.9475]	[0.0750]	[0.0312]
The recovery stage	0.4704	0.4324	0.1030	0.1689
	[0.4017]	[0.0000]	[0.0185]	[0.1218]

and 0.0345. In addition, the absolute of maximal difference on victims' satisfaction among the three stages decreased from 0.0422 to 0.0011. Overall, simulated results indicated the three objectives discussed here were achieved. To some extent, it verified the effectiveness and feasibility of proposed model and designed algorithm.

5 Conclusion

5.1 Conclusions

The first conclusion is that the three objectives of relief scheduling scheme are realized. The second one is that relief scheduling scheme considering victims' satisfaction made by decision-makers is good for reducing or mitigating losses, which can be measured by victims' satisfaction indirectly. The third one is that the type of victims has a larger impact on relief-demand category at the same stage. The fourth one is that relief-demand for victims is different because of stages' difference. And the last one is that victims' satisfaction doesn't have the specific change with the evolution of emergency response process.

5.2 Limitations

First of all, a limitation is experimental design. Parameter constraints in model and the operators of genetic algorithm, including coding, crossover, selection, mutation, which is obviously limited to experimental design in this paper. A second limitation is simulated data. Model and algorithm is verified by example from Wenchuan earthquake assuming that the relevant data has been obtained by various technologies [6, 9]. Therefore, the simulated data source has certain limitations. A third limitation is simulated results. Simulation may be conducted by global data instead of only local data in the future. Even the size of sample includes all affected areas.

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Robust Optimization Model for a Food Supply Chain Under Uncertainty

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Abstract Nowadays, the business environment has become an internal playing field in which companies have to work together as a whole to fight for disturbances. Companies have to turn lean and responsive for winning competitive advantage in market. However, lean supply chains would be more vulnerable in the case of disruption. Food supply chains have some special characteristics that make supply chains even more vulnerable, such as shelf life constraints, material seasonality. Food supply chains have to become robust to resist all kinds of disruptions. This paper has developed a stochastic mathematical formulation for achieving a robust optimal food supply chain. The model considers both supply-side uncertainties and demand-side uncertainties. Finally, to illustrate and analyze the model outputs, we apply this model to a numerical experience and test the validity of the model.

Keywords Food supply chain · Robust optimization · Stochastic programming · Uncertainty

1 Introduction

Nowadays, customers have high expectations for fresh, diverse, safe food. However, the food industry would be disrupted by many kinds of uncertainties. If not properly managed, uncertainty in supply chains can result in many forms of disturbances, such as disruption, disaster and deviation (Gaonkar and Viswanadham [1]). Uncertainty is mainly caused by internal factors and external factors (Vlajic et al. [2]). Uncertainty is an inherent characteristic of supply chains (Landeghem and Vanmaele [3]). Uncertainty within a food supply chain can be seen as a characteristic of material, production and information. Materials within food supply chains are perishable and would easily cause food safe problems.

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In recent years, food safe events frequently happened. In 2003, the Big-head baby incident happened in Fuyang, Anhui province. People started to doubt the quality of domestic dairy products. In 2008, Chinese were shocked by melamine incident. Before the scandal broke, San Lu milk powder had been as a popular brand for a long time. Following the San Lu event, Fonterra milk powder scandal broke in 2012. In the wake of the events in China, food safety incidents have attracted extensive attention. However, the whole reason for the scandal lied not in individual firm, but in supply chains. The perishable materials in food safety events always lead to the failure of supply chains. In other word, supply-side uncertainties would easily jeopardize the whole supply chain. In general, supply chains' complexity is caused by the multiple interactions within the network itself (Asbjørnslett and Rausand [4]). Uncertainty and complexity require food supply chains to be robust to improve their competitive position. A robust food supply chain is able to function well in the case of disruption as well as in normal environment.

Mulvey et al. [5] first presented the robust optimization concept. They formulated the robust optimization model for practical applications. Nevertheless, heavy computational burden prevented wider applications. Subsequently, Yu and Li [6] proposed a new solution to simplify the model. The new model included a fewer number of variables and constraints. Their method was more computationally efficient than previous methods. The following literatures mainly made use of the theory to build a model.

van der Vorst [7] introduced a step-by-step approach to generate, model and evaluate supply chain scenarios in food supply chains. Leung et al. [8] builded a robust optimization model to optimize a cross-border logistics problem between mainland and Hong Kong. Subsequently, a multiproduct, multistage robust operating model was proposed to deal with multiple incommensurable goals for a two-layer supply chain with uncertainty by Xu and Huang [9]. The robust optimization model is of very wide application in production planning problems. Leung et al. [10] developed a robust optimization model for a perishable production planning problem under demand-side uncertainties and parameters uncertainties. At the same year, Leung et al. [11] formulated a robust optimization model for a production planning problem under uncertainty. Zhang [12] presented a multiobjective three-layer supply chain production planning under demand-side uncertainties and parameters uncertainties. Similarly, current literature starts to focus on the robust optimization problem in food supply chain network context. Vlajic et al. [13] developed a frame to support the analysis and design of robust food supply chains. Baghalian et al. [14] introduced a three-layer multiproduct stochastic programming approach for rice supply chain network design under uncertainty. Validi et al. [15] developed a multiobjective dairy supply chain model for a real-life case study in Ireland. Gabrel et al. [16] depicted a representative picture of the robust optimization explored in recent years.

The remainder of this paper is organized as follows. Section 2 describes and develops the problem to be studied in this paper. Section 3 applies the model to a numerical experience and solves the model by lingo 11.0. Finally, we analyze the result and summarize the findings from the case in Sect. 4.

2 Problem Description

This paper presents a robust solution approach which focuses on a model for a three-layer dairy supply chain in china. In this paper, we are to find the optimal procurement plan, production plan and distribution plan to achieve robust optimal supply chain performance. The three-layer supply chain includes several suppliers, manufacturers and retailers. We consider demand-side uncertainties and supply-side uncertainties simultaneously. The uncertainties are all considered as discrete sets with certain probabilities and described through various scenarios. The quality of raw material results in the supply-side uncertainty. It is well known that, when some factors change, such as season, stage of lactation and climate, the composition of milk will be changed. We assume that two kinds of raw materials, high-quality and low-quality materials, supply from suppliers. It is a tactical supply chain planning model integrating procurement, production and distribution activities into the food supply chain network. According to demand-side uncertainty, decision makers set safety stock for reducing the market' stockout risk. The manufacturer, with the material warehouse and product warehouse, produces products to fulfill retailers' orders. Suppliers supply manufacturers with materials. The objective function is to maximize the whole profit of supply chain. The whole profit is calculated as the difference between its total cost and the sales revenue. The total cost is the sum of inventory costs, material procurement costs, production and shortage costs. In order to build the mathematical model, the notation described below is used.

2.1 Sets and Index

$m \in M$ set of retailers and set of markets. Both are represented by one set because in each market there is only one retailer.
$g \in G$ set of suppliers.
$s \in S$ set of scenarios.
$s' \in S'$ set of scenarios of demand-side uncertainty.
$s'' \in S''$ set of scenarios of supply-side uncertainty.

2.2 Parameters

Pr_s probability of the occurrence in scenario s
C_s handling cost of a unit of product; it includes unit production cost and unit material procurement cost.
P^m unit material inventory cost
P^p unit product inventory cost
P_s price of unit product in market of scenario s

I^m	inventory of material
I_s^p	inventory of product of scenario s
TC	the total cost of the model
Scp_m	shortage cost of unit of unmet demand for product in market m
St_{ms}	stockout of product of retailer m of scenario s
D_{ms}	demand of product of scenario s in market m
saf_{ms}	safety stock of retailer m in scenario s
I^{pmax}	capacity of the product warehouse
I^{mmax}	capacity of the material warehouse
Cap_g	capacity of supplier g for material
$\delta'_{ms}, \delta_{ms}$	inventory of product in manufacturer

2.3 Decision Variables

y_g	procurement volume of materials from supplier g
x	production of products of the manufacture
z_m	products assigned to retailer m from the manufacturer

2.4 Mathematical Model

The mathematical formulation of addressed problem is described in the following. The objective function is defined as the following:

$$Max\,Tl_s = In_s - Oc_s - Ic_s - Scc_s \tag{1}$$

$$In_s = P_s \times \left(\sum_1^M Z_m - I_s^p \right) \tag{2}$$

$$Oc_s = C_s \times \left(\sum_1^M Z_m - I_s^p \right) \tag{3}$$

$$c_s = [P^m \times I^m + P^p] \times_s^p \tag{4}$$

$$Scc_s = \sum_1^M St_{ms} \times Scp_m \tag{5}$$

In the objective function (1), the first term represents sales revenue; the second term describes the handling cost; the third term exhibits material and product inventory cost; the fourth term represents shortage cost.

Subject to:

$$x \leq \sum_{1}^{G} y_g + I_0^m \tag{6}$$

$$\sum_{1}^{M} z_m = x + I_0^p \tag{7}$$

$$z_m - D_{ms} - saf_{ms} = \delta'_{ms} - \delta_{ms} \tag{8}$$

$$I^m = \sum_{1}^{G} y_g + I_0^m - x \tag{9}$$

$$I_s^p = \sum_{1}^{M} \left(saf_{ms} + \delta'_{ms} - \delta_{ms} \right) \quad \left(saf_{ms} + \delta'_{ms} \geq \delta_{ms} \right) \tag{10}$$

$$I_s^p = 0 \left(saf_{ms} + \delta'_{ms} < \delta_{ms} \right) \tag{11}$$

$$St_{ms} = D_{ms} - z_m \; \left(D_{ms} \geq z_m \right) \tag{12}$$

$$St_{ms} = 0 \left(D_{ms} < z_m \right) \tag{13}$$

$$I^m \leq I^{mmax} \tag{14}$$

$$I_s^p \leq I^{pmax} \tag{15}$$

$$y_g \leq Cap_g \tag{16}$$

Constraint (6) explains the production volume must be less than the sum of procurement volume and initial inventory. Constraint (7) describes products assigned for markets are equal to the sum of production volume and initial product inventory. According to (8), we hope that the shipped product fulfills market demand and safety stock in retailers. Constraints (9)–(11) express the material inventory and product inventory. Constraints (12)–(13) are stockout. Constraints (14)–(15) enforce the capacity constraint of material inventory and product inventory. Constraint (16) indicates the procurement volume from suppliers is less than the capacity of each supplier.

2.5 Robust Model

After realization of markets' demand and supply scenarios, objective functions are all very different. According to robust model introduced by Mulvey and improved by Yu and Li, we formulate a robust mathematical model of the addressed problem. The robust model is described as follows:

$$Max\, Z = \sum_{s \in S} Pr_s \times Tl_s - \lambda \sum_{s \in S} Pr_s[(Tl_s - \sum_{s' \in S} Pr_{s'} \times Tl_s) + 2\theta_s] \\ - \omega \sum_{s \in S} \sum_{1}^{M} (\delta'_{ms} + \delta_{ms})$$

Subject to:

$$Tl_s - \sum_{s' \in S} Pr_{s'} \times Tl_{s'} + \theta_s \geq 0 \quad \forall s \tag{17}$$

$$\theta_s \geq 0 \quad \forall s \tag{18}$$

λ denotes the weight of model robustness. In model robustness, the solution of the model remains "almost" feasible for any occurrence of the scenario. But in solution robustness, the solution of the model always is "close" to the optimum for any occurrence of the scenario. The weight ω can trade off between model robustness and solution robustness. A robust optimization model is formulated for measuring this trade-off. Constraint (17) impose the second term is nonnegative in the objective function. Constraint (18) indicates nonnegative variables. Constraints (2)–(16) should be added to the robust model.

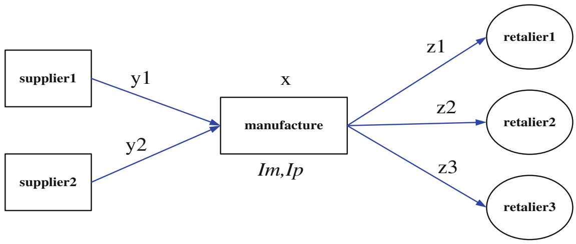
3 Numerical Example

Dairy products play an important role in our daily life. In recent years, our domestic dairy product is not as popular as before. In this paper, the case is a dairy supply chain, which consists of two suppliers, one manufacturer and three kinds of retailers. A manufacturer company takes charge of production and inventory. Three types' retailers locate in three different markets. They are the key retailer, main retailer and ordinary retailer. Figure 1 depicts the structure of the supply chain.

For simplicity, without considering other market behaviors, each market demand is considered as three discrete scenarios (s′) with probabilities of 0.5, 0.4 and 0.1.

Correspondingly, we assume suppliers can provide the high-quality material with the probabilities of α and β, respectively. The four scenarios (s″) are defined as follows. The first scenario that high-quality materials supply from two suppliers. The probability of the occurrence of this scenario is α * β. The second scenario that

Fig. 1 The constitute of dairy supply chain network



high-quality materials supply from the first supplier and low-quality materials provide by the second supplier with the probability of α * (1 − β). The third scenario that low-quality materials come from the first supplier and high-quality materials supply by the second supplier. The probability of the occurrence of this scenario is (1 − α) * β. Both suppliers provide low-quality materials for the fourth scenario with the probability of (1 − α) * (1 − β).

Therefore, the uncertainty can be described in 12 scenarios in the supply chain network. The low-quality material needs more complex and expensive processing. Each unit low-quality material would cause more 10 yuan cost in the handling cost than high-quality material. And, if we use each unit low-quality material to make product, the sales price of product will be reduced 10 yuan. Therefore, the procurement volume of low-quality material has an impact on the average handling cost (C_s) and the average market selling price (P_s). As we are all known, safety stock affect the supply chain performance. We try to find the optimal performance by setting different safety stock levels. According to the above content, the values of required parameters show in the following Tables 1, 2 and 3.

After running on the LINGO 11.0, the computational results for the model are listed in Table 4. The time for solving the model was less than 1 s. Besides, $TL = \sum_1^S Pr_s * Tl_s$, $IN = \sum_1^S Pr_s * In_s$, $OC = \sum_1^S Pr_s * Oc_s$, $IC = \sum_1^S Pr_s * Ic_s$, $SCC = \sum_1^S Pr_s * Scc_s$.

Sensitivity analysis. In order to illustrate the solutions' sensitivity in terms of important and changeable parameters of the problem, we try to exhibit how changing some parameters may affect procurement, production and distribution plans of supply chain. At first, by increasing the robustness coefficient λ, the model will prefer to choose more reliable plans, which are more costly. For example, when λ is equal to 2, the whole profit is 969,268 yuan and the objective functions is less

Table 1 Scenarios of demand-side uncertainty and safety stock level

Markets		$D_{ms'}$			$saf_{ms'}$	
	s′ = 1	s′ = 2	s′ = 3	s′ = 1	s′ = 2	s′ = 3
m = 1	2190	3490	4790	1000	1000	1000
m = 2	1160	2360	3560	500	500	500
m = 3	680	1230	1780	300	300	300

Table 2 Scenarios of supply-side uncertainty

Parameters	$s'' = 1$	$s'' = 2$	$s'' = 3$	$s'' = 4$
$P_{s''}$	300	$300 - \frac{y2}{y1+y2} * 10$	$300 - \frac{y1}{y1+y2} * 10$	290
$C_{s''}$	120	$120 + \frac{y2}{y1+y2} * 10$	$120 + \frac{y1}{y1+y2} * 10$	130

Table 3 Other given parameters

The given parameters	
$\boldsymbol{I_0^m} = 0$	$I_0^p = 0$
$\boldsymbol{I^{mmax}} = 5000$	$I^{pmax} = 5000$
$\boldsymbol{P^m} = 3$	$P^p = 4$
$\boldsymbol{Cap} = 6000, 8000$	$Scp_m = 50\ 30\ 20$
$\lambda = 1$	$\omega = 0.5$
$\alpha = 0.9$	$\beta = 0.8$
$\boldsymbol{Pr_s} = 0.36\ 0.09\ 0.04\ 0.01\ 0.288\ 0.072\ 0.032\ 0.008\ 0.072\ 0.018\ 0.008\ 0.002$	

sensitive to change under all scenarios than the results in Table 4. Secondly, we investigate the effect of changes in the probability of supply-side uncertainty of the first supplier. The probability can be different from time to time because it is influenced by the change of season, climate and so on. The probability changes from 0.9 to 0.6. The results are shown up within Table 5. When the probability changes from 0.9 to 0.6, the procurement volume from the first supplier is decreased gradually. Similarly, the whole profit is also declined as probabilities' decline. Then, we change the safety stock level to find an appropriate safety stock. The results demonstrate in Table 6. In Table 6, the research indicates the whole profit incrementally increases and stockout decreases when the safety stock increases, but it doesn't mean the higher the better. In the fourth state, the production is 9030 units, which is over twice as much as the demand, 4030 units, in scenarios 1–4. The higher safety inventory level leads to shorter remaining shelf lives for products on retailer shelves. We consider the importance of freshness of product. Therefore, the level of safety stock (1000, 500, 300) is a better choice than the high level one (1300, 1200, 550).

Table 4 Computational result of the model

Results	Plans	Profit and stockout
	$y_1 = 6000$; $y_2 = 2880$	$TL = 100{,}009$
	$x = 8880$	Stockout = 125
	$z_1 = 4490$; $z_2 = 2860$; $z_3 = 1530$	

Table 5 Computational results of the sensitivity analysis for the probability of supplier1

State	Probability		Stockout	TL	IN	OC	IC	SCC	TC	Safety stock			Distribution plan			Procurement		Production
	g = 1	g = 2								m = 1	m = 2	m = 3	m = 1	m = 2	m = 3	g = 1	g = 2	
1	1	0.8	125	1,008,738	1,717,059	691,641	12,580	4100	708,321	1000	500	300	4490	2860	1530	6000	2880	8880
2	0.9	0.8	125	1,000,709	1,713,044	695,656	12,580	4100	712,336	1000	500	300	4490	2860	1530	6000	2880	8880
3	0.8	0.8	125	992,680	1,709,030	699,670	12,580	4100	716,350	1000	500	300	4490	2860	1530	6000	2880	8880
4	0.7	0.8	125	989,239	1,707,309	701,391	12,580	4100	718,071	1000	500	300	4490	2860	1530	880	8000	8880
5	0.6	0.8	125	985,798	1,705,589	703,111	12,580	4100	719,791	1000	500	300	4490	2860	1530	880	8000	8880

Table 6 Computational results of the sensitivity analysis for the safety stock level

State	Probability		Stockout	TL	IN	OC	IC	SCC	TC	Safety stock			Distribution plan			Procurement		Production
	g = 1	g = 2								m = 1	m = 2	m = 3	m = 1	m = 2	m = 3	g = 1	g = 2	
1	0.9	0.8	305	969,268	1,659,834	673,266	6100	11,200	690,566	0	0	0	3490	2360	1230	6000	1080	7080
2	0.9	0.8	205	986,097	1,689,149	685,952	9700	7400	703,052	500	300	200	3990	2660	1430	6000	2080	8080
3	0.9	0.8	125	1,000,709	1,713,044	695,656	12,580	4100	712,336	1000	500	300	4490	2860	1530	6000	2880	8880
4	0.9	0.8	110	1,001,430	1,717,525	697,475	13,120	5500	716,095	1300	1200	550	3690	3560	1780	6000	3030	9030

4 Conclusions and Future Work

We consider both demand-side uncertainty and supply-side uncertainty to achieve robust optimal procurement, production and distribution plans. We change the robustness coefficient, the probability of first supplier to illustrate the solutions' sensitivity. And we have demonstration that how changeable parameters can affect operation plans. By changing safety stock levels, we find a relative appropriate safety stock.

According to the computational time of this model, this solution can be applied to more variables and more products problem, and to solve larger size stochastic math problems. Another area of possible research is the model for continuous demand instead of discrete demand. In other words, the demand-side uncertainty can be described as a random variable with a known distribution.

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Demand Analysis and Optimal Production Quantities for a Short-Expiration-Date Item at a Retail Store

Hai-xia Sang, S. Takakuwa and R. Zhao

Abstract Retailers that sell short expiration-date items often must carefully manage the risks associated with the uncertain demand for their products. Demand shortages due to out-of-stock items lead to customer dissatisfaction and loss of potential profits. However, products left over after expiration dates must be scrapped at a great loss. Because both scrap loss and opportunity loss can have an impact on the retailer's profit, it is important for retail managers to determine the optimal order/production quantities required to balance the scrap loss and opportunity loss and thus maximize the expected profit. In this paper, Winters' method is adopted to forecast the demand and the demand distribution was developed. Based on the newsvendor problem, a simulation model was constructed and optimal tool called OptQuest was utilized to identify the optimal production quantities. The results suggest that inventory problems for items with short expiration dates can be solved both quickly and efficiently.

Keywords Newsvendor problem · Retail store · Simulation · Winters' method

1 Introduction

The expiration-dated items, such as fried chicken and French fries have become essential commodities in convenience stores of Japan. The opportunity loss that results from an item being out-of-stock leads to customer dissatisfaction and a loss

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of potential profits. However, products left on the shelves past their expiration dates must be scrapped, resulting in potentially large losses. Although many managers realize the importance of forecasting the demand of these items, because forecasts must be performed frequently and many of the forecasting techniques are difficult to implement, most managers rely on their own experience or consult a POS (Point of Sales) system to predict future demand and place purchasing orders [1]. This method does not always produce a good profit.

Exponential smoothing is an efficient technique for estimating the coefficients in a polynomial model. However, there are many time series processes that cannot be adequately described by a polynomial model. Winters' method improved these models and can forecast a time series with seasonal variation [2]. Typically, the only input for a forecasting system is the past history of the demand data of the item. However, in Winters' model, the most recent demand information can be introduced easily and cheaply [3]. By utilizing Winters' method, the result shown in the forecast can almost always reflect the real demand trends and variability. However, a forecast is not always accurate on each day. It is still a problem to determine the optimal order quantity making the retailer's profit maximization under an uncertain demand [4].

The classical newsvendor problem addresses a single-period inventory that generates the maximum expected profit. Based on the newsvendor problem, a simulation model was constructed, and the forecasted demand was used as input data for the model to simulate the change of the scrap loss and the opportunity loss. Because of the existence of a common sales period, the optimal tool called OptQuest is used to specify the optimal quantities for each production.

2 Forecasting Method

Developed in 1960, Winters' method has been a common method used to forecast time series with seasonal variation, such as the demand for air conditioning and electricity [5]. To implement this method, the user must provide the initial value of the permanent component (a_0), the linear tread component (b_0) and the time interval seasonal factor (c_0).

The following procedure is used for periodically revising the estimates of the model parameters and for forecasting. At the end of any period T, the current period's demand (D_t) is observed, and the estimate of the permanent component is revised as follows:

$$a_t = \alpha \frac{D_t}{c_i'} + (1 - \alpha)(a_{t-1} + b_{t-1}) \quad (1)$$

The estimate of the trend component is then revised as follows:

$$b_t = \beta(a_t - a_{t-1}) + (1 - \beta)b_{t-1} \tag{2}$$

and the estimate of the time interval seasonal factor for period T is revised as follows:

$$c_i = \gamma \frac{D_t}{a_t} + (1 - \gamma)c'_i \tag{3}$$

The forecast for current period T is based on the following:

$$\hat{D}_{t+\tau} = (a_t + b_t)c'_i \tag{4}$$

In every period, a forecasting error is observed:

$$E_t = D_t - \hat{D}_t \tag{5}$$

The forecast for any future period T + τ is based on the following:

$$\hat{D}_{t+\tau} = (a_t + b_t\tau)c'_i \tag{6}$$

where smoothing constants are

$0 < \alpha < 1$,
$0 < \beta < 1$,
$0 < \gamma < 1$, and

c'_t is the time interval seasonal factor of the designated day of the week in previous years.

The prediction error is one of the important indicators used to evaluate the forecasting method with high accuracy. However, the predicted value $\hat{D}_t$ may be more than or less than the actual demand D_t; thus, E_t may be a negative or positive value. To avoid the problem of offsetting by the negative and positive quantities, instead of the prediction error, the residual sum of squares for prediction errors is always used to evaluate the forecasting method. Previous research, such as Takakuwa [6], Takakuwa et al. [7], Sang [8] have shown that to improve prediction accuracy, a set of (α, β, γ) minimizing the residual sum of squares for prediction errors must be found.

3 The Classic Newsvendor Problem

An extreme case of the stochastic inventory problem for expiration-dated items is the newsvendor problem [9]. The classical newsvendor problem addresses a single-period inventory, in which newspapers are delivered and scrapped one time each day to generate the maximum expected profit under an uncertain demand. The expression for the newsvendor's profit can be written as follows:

$$u(D,q) = (r-c)*\min(q,D) - (r-c)*\max((D-q),0) - c*\max((q-D),0) \quad (7)$$

where

c cost per unit,
D quantity demanded, a random variable,
q order quantity, a decision variable,
r selling price per unit,

Because c and r have known, the problem is to find the optimal order/production quantity maximize the profit under an uncertain environment. Although many authors have used mathematical methods to maximize the profit, many studies have shown that simulation is an important research methodology and is more suitable when studying complex issues [10]. For example, Zhan and Shen [11] developed an iterative algorithm and a simulation-based algorithm to help newsvendors make pricing and inventory decisions in a stochastic price-sensitive demand environment. Li et al. [12] developed a procedure to maximize profits with two products and verified the result using simulation. Dimitriou et al. [13] used agent-based-simulation as an evaluation tool, to investigate the effect on suppliers and retailers by varying individual preferences with respect to contract efficiency. Shao and Ji [14] considered the multi-product newsvendor problem using fuzzy demand under budget constraints. The numerical models were developed to solve the newsvendor problem in a hierarchical decision system using a hybrid intelligent algorithm based on the genetic algorithm fuzzy simulation. All of these studies have proven that simulation is a useful problem solving approach to solve the newsvendor problem. In this paper, the demand is forecasted by utilizing Winters' method, based on the newsvendor problem, a simulation model was constructed and optimal tool was used to find the optimal manufacturing quantities.

4 Case Study

4.1 Description of the Store and the Item

FamilyMart is Japan's third largest franchise chain of convenience stores. The store studied here is located on the campus of Nagoya University and operates from 7:00 AM to 11:00 PM.

Various types of commodities, from food and drink to items produced daily, are displayed in the store. In Japan, fried chicken is a popular fast food not only in restaurants such as Kentucky Fried Chicken (KFC), but also in the convenience

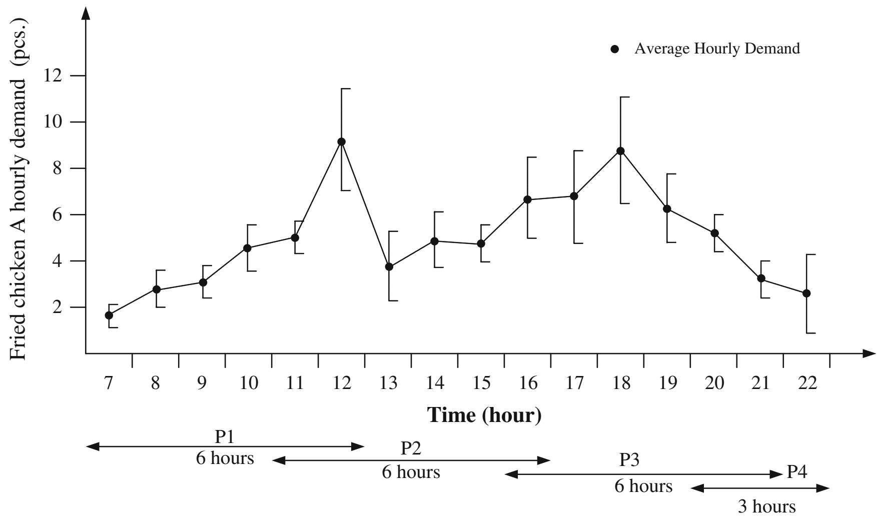


Fig. 1 The 95 % confidence interval for the daily changed in demand for fried chicken A and information regarding the item's cooking time and scrap time

store examined, which has various types of fried chicken available. To satisfy customer demand, these items can be ordered from a delivery center every day except for Wednesday and Sunday. If the manager orders the items from the wholesaler before 10:00 AM, then the merchandise can be shipped by 7:00 PM. To guarantee quality, the items were precooked, frozen and shipped. The store has 3 fryers that can be operated simultaneously.

This study uses fried chicken A, the store's most popular item, as an objective item for the analysis. Figure 1 shows the 95 % confidence interval of the hourly demand change. Fried chicken A has 3 fixed cooking times: 7:00 AM, 11:00 AM and 4:00 PM. The cooking time is 5 min and the permitted selling window is 6 h. Therefore, any amount unsold is scrapped at 12:00 AM, 4:00 PM and 9:00 PM. Because fried chicken A is a popular item, and is supposed to be displayed at all operational hours (from 7:00 AM to 11:00 PM), fried chicken A could be cooked again after 5:00 PM. For example, if it was cooked at 8:00 PM, any leftovers would be scrapped at 11:00 PM after only 3 selling hours. The manager sought to find the quantity of fried chicken A that maximizes profit based on consideration of both opportunity loss and scrap loss.

4.2 Forecasting Method

As Fig. 1 show, P1, P2, P3 and P4, which was produced on time 7, 11, 16 and 20 have a limited selling time interval, and the demand in each time interval is uncertain. Let us denote the four production quantities as Q1, Q2, Q3 and Q4 respectively. Because the optimal production quantities Q1*, Q2*, Q3*, Q4* depend on the demand of each time interval, the essential forecast problem in this paper is to identify the demand during a specific time interval on the designated day of the week.

This paper used 5 years of demand data, from 2010 to 2014, to estimate the year 2015 demand. The study duration period was set at 15 weeks, approximately from every year's April 10th to August 7th, which is Nagoya University's spring semester. As the authors mentioned before, to make the forecasting more accurate, the data were divided into seven data-sets on the days of the week, and this paper used Friday's data-set as the basis for estimates.

In this paper, the classic Winters' method was modified to forecast the hourly demand for the designated day of the week. In each hourly demand forecasting procedure, the optimal set of (α, β, γ) was used to generate forecasts for any future period. The forecasting procedure is shown in Fig. 2. The index of the time interval is used to present the hourly demand within a day. For example, the index 7 is used for the time interval between 7:00 AM and 8:00 AM.

Figure 3 shows the actual demand and the forecast during the time interval from 6:00 PM to 7:00 PM on Friday. Through comparing the actual demand and the forecast, it was found that the forecast can almost reflect the actual demand's trend changes. However, from a certain day standpoint, the forecast result is still uncertain. The constructed simulation model, which is based on the newsvendor problem, can help the authors to solve this problem for the purpose of using the result in the simulation model. The forecasted demand was fit and used as simulation model's input data, as shown in Fig. 4.

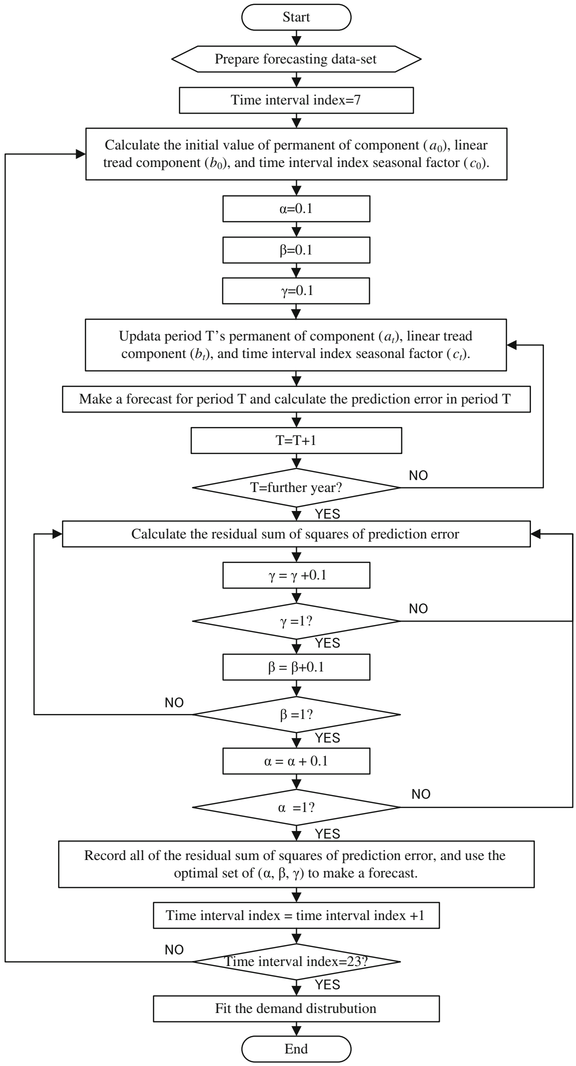
4.3 *The Developed Newsvendor-Problem*

Because of the existence of a common sales period, the classic newsvendor problem cannot be solved in a simple way. A simulation model for the retail store was constructed using the simulation package Arena [15] and the simulation logic is shown in Fig. 5. The simulation model logic was composed of three parts: the delivery logic, the scrap logic and the first-in-first-out logic. The first-in-first-out logic means that, until the old item is sold out, the new item cannot be sold. The performance measure used in this paper is the expected profit, taking the opportunity loss and scrap loss into consideration.

Based on the newsvendor problem, the profit can be written as follows:

$$W(I) = (r - c)\sum_{i=7}^{22} a_i - (r - c)\sum_{i=7}^{22} b_i - c(S_{12} + S_{16} + S_{21} + S_{22}) \tag{8}$$

Fig. 2 Modified Winters' method to forecast hourly demand



where

a_i (pcs.)	the sales during time interval i,
b_i (pcs.)	the opportunity loss during time interval i,
c (JYen)	the average cost per unit,
i (hour)	the index for the time interval,
r (JYen)	the average selling price per unit,
S_{12} (pcs.)	the scrap loss at time interval 12,

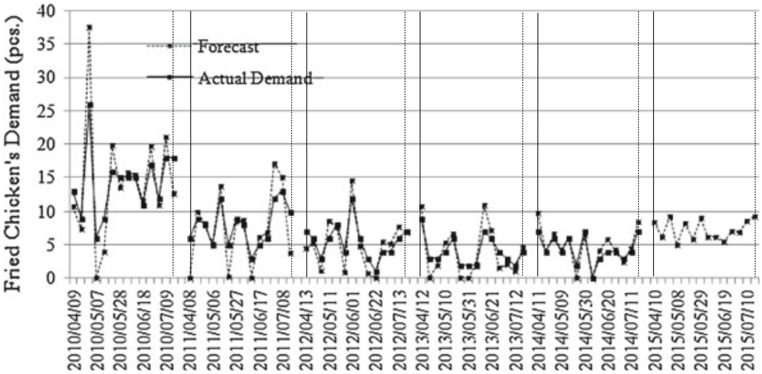


Fig. 3 The comparison between the forecast and the actual demand during the time interval from 6 PM to 7 PM

	Time interval index				
	7	···	12	···	22
1th week	TRIA(-0.5, 0, 2.5)	···	TRIA(4.5, 9, 17.5)	···	TRIA(-0.5, 0, 2.5)
2th week	TRIA(-0.5, 0, 2.5)	···	TRIA(6.5, 7, 16.5)	···	TRIA(-0.5, -0.5, 6.5)
3th week	TRIA(-0.5, 0, 3.5)	···	TRIA(5.5, 11, 29.5)	···	TRIA(-0.5, 0, 5.5)
4th week	TRIA(-0.5, 0, 1.5)	···	TRIA(4.5, 9, 15.5)	···	TRIA(-0.5, -0.5, 2.5)
5th week	TRIA(-0.5, 0.5, 2.5)	···	TRIA(4.5, 13, 26.5)	···	TRIA(-0.5, 0, 4.5)
6th week	TRIA(-0.5, 0, 3.5)	···	TRIA(6.5, 12.5, 18.5)	···	TRIA(-0.5, 0, 3.5)
7th week	TRIA(-0.5, 0, 1.5)	···	TRIA(2.5, 13, 27.5)	···	TRIA(0.5, 1, 4.5)
8th week	TRIA(-0.5, 0, 2.5)	···	TRIA(7.5, 8, 32.5)	···	TRIA(-0.5, 0, 3.5)
9th week	TRIA(-0.5, -0.5, 2.5)	···	TRIA(4.5, 5, 32.5)	···	TRIA(-0.5, 0, 2.5)
10th week	TRIA(-0.5, 0, 3.5)	···	TRIA(11.5, 18, 21.5)	···	TRIA(-0.5, 0, 3.5)
11th week	TRIA(-0.5, 1, 2.5)	···	TRIA(2.5, 10, 25.5)	···	TRIA(-0.5, 0, 1.5)
12th week	TRIA(-0.5, -0.5, 1.5)	···	TRIA(3.5, 4, 24.5)	···	TRIA(-0.5, 0, 5.5)
13th week	TRIA(-0.5, 0.5, 2.5)	···	TRIA(5.5, 6, 30.5)	···	TRIA(-0.5, 0, 7.5)
14th week	TRIA(-0.5, 0, 4.5)	···	TRIA(7.5, 8, 20.5)	···	TRIA(0.5, 1, 4.5)

TRIA: Triangle Distribution (Min, Mode, Max)

Fig. 4 Forecasted demand distribution for fried chicken a during the spring semester of 2015

S_{16} (pcs.) the scrap loss at time interval 16,
S_{21} (pcs.) the scrap loss at time interval 21, and
S_{22} (pcs.) the scrap loss at time interval 22.

The equation was constructed in 3 parts. The first part represents the revenue obtained from the item sales. The second part represents the opportunity loss during the day from time intervals 7 to 22, and the third part represents the scrap loss at time intervals 12, 16, 21 and 22. In this model, the cost and selling price were estimated as 69.42 and 158 JYen, respectively.

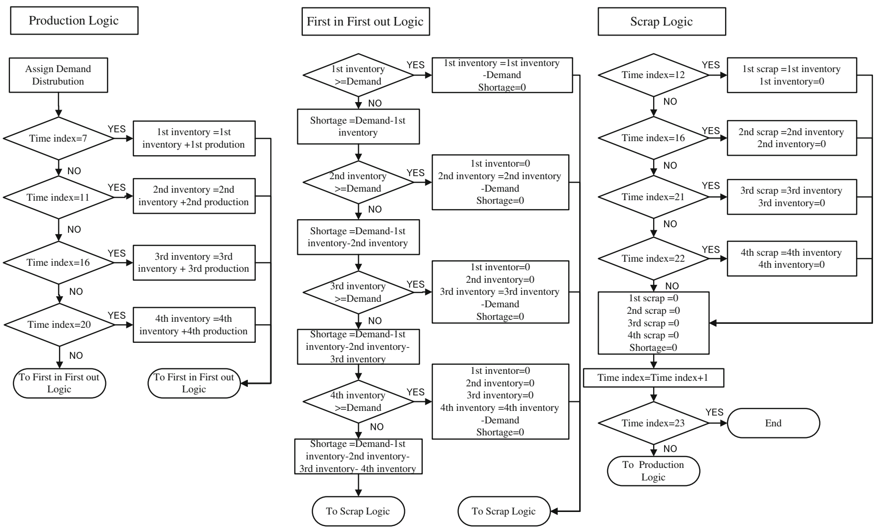


Fig. 5 Simulation flow chart

4.4 *The Optimization Process*

The item's demand, cost and profit were set as functions into the simulation model, and the profit, the scrap loss and the opportunity loss are produced as the outputs of the model. It must be noted that although the simulation can provide estimates of performance measures, it cannot provide the optimal production quantity for Q1*, Q2*, Q3* and Q4* to maximize the expected profit. Therefore, this study adopts the simulation together with the optimization tool to achieve the objective.

Figure 6. Because of the uncertain demand during the evening, to obtain the expected profit, Q4* should be set to 0. Q1*, Q2*, Q3* should be set to 37, 40, and 6, respectively. The observation interval for the expected profit, the average scrap loss and the average opportunity loss is also shown in Fig. 6.

Q1* (pcs.)	Q2*(pcs.)	Q3* (pcs.)	Q4*(pcs.)	Profit (JYen)	Average Scrap loss (pcs.)	Average opportunity loss (pcs.)
37	40	6	0	-1338 4295.52 7086.40 3912.23 4678.81	0 17.86 55 15.22 20.5	0 2.65 42 1.4 3.9

Observation Intervals Min Avg Max 95%CL

Fig. 6 The optimal results

5 Conclusion

Winters' method was applied to forecast the hourly demand for an item with a short expiration date on a designated day of the week. To forecast demand with higher accuracy, the residual sum of squares for prediction errors was used as a measure to identify the optimal set of (α, β, γ). Based on the newsvendor problem, a simulation model was constructed, and optimization tool was used to identify the optimal production quantities. The results showed that the optimal inventory solution can be obtained easily, and the proposed procedure was found to be both practical and powerful in assisting managers in their inventory management efforts.

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Research on Profit Allocation of Campus Express Alliance Based on the Improved Shapley Value Method

Yu-feng Zhuang and Li-li Ma

Abstract Disorder and inefficiency problems have been widely seen in campus express terminal distribution. In order to solve these serious problems, the alliance of distribution services should be established to integrate existing resources and standardize operational processes. Furthermore, reasonable profit allocation mechanism is the key to stable development of such distribution alliance. In this paper, we discuss how to allocate profits after the campus express alliance formed. For this purpose, we propose Shapley value method and its improved model to allocate profits. Moreover, the results before and after utilizing the revised Shapley value are compared by numerical analysis, which prove this methodology rational and practical.

Keywords Campus express alliance · Profit allocation · Shapley value

1 Introduction

E-commerce might be one of the most eye-catching industries in China today with a rapidly increasing rate. Up to June, 2015, the number of on-line shopping customers in China has reached 374 million, with an increase of 12.49 million compared to the end of 2014 [1]. Considering the occupational structure of on-line shoppers, school students cannot be neglected and occupy an important position. The bursting number of package orders generated by students is challenging the campus "last mile" logistics and demanding a higher standard of courier services.

As a result, quite a lot delivery methods have sprung up like mushrooms among campus. However, because of the resource and technical limitations, disorder and inefficiency are common problems, making it difficult to meet students' demands of

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receiving or sending their packages safely and conveniently by one carrier alone. In order to create customer satisfaction, many carriers cooperate with each other and establish campus express alliance so that they are able to achieve resources integration. Specifically, at first, packages are centrally managed and space can be used more reasonably, which would help reduce stock and lower the rental costs of house; Secondly, professional couriers are centralized to help with the distribution so that damage and lost rate of the packages would drop as well as the successful delivery rate would reach a higher level. In this way, express companies win a better reputation from campus students and achieve business expansion. Therefore, campus express alliance can not only bring better quality services to school teachers and students, also bring couriers greater benefits, making it become a trend in campus express distributions.

Reasonable profit allocation mechanism is the key to stable development of such distribution alliance. Many scholars have carried out related research on different allocation methods in different areas. Morasch [2] studied profit sharing in a production joint venture based on the Stackelberg cooperation game model. Wei [3] proposed an ideal framework from resources' contribution ratio in alliance profit distribution. Gavirneni [4] analyzed how to decide the allocation proportion of each partner in n-person cooperative game by applying fuzzy decision theory. Liang [5] introduced the shared remuneration payment model for the league of B2C e-commerce enterprise and convenience store. On the basis of analyzing the Shapley value, Dai Pei-hui, Fan De-cheng etc. discussed fairly distribution methods in supply chain alliance management [6, 7].

However, little effort has been spent on the study of the profit allocation in campus express alliance. In this paper, the Shapley value method is applied to solve the revenue allocation of campus express alliance based on the cooperate game theory. Moreover, considering the three most important factors, i.e., prophase investment, market position and service quality, which affect the allocation results in real life operation, an improved model combined with AHP method is proposed. Finally, the numerical study compares the results before and after revised Shapley value method, which shows this improved model rational and practical.

2 The Shapley Model of Campus Express Alliance

2.1 Shapley Value Method Model

Shapley value method, proposed by Shapley L.S in 1953, is mainly used in solving the problems in n-person cooperative game [8]. Moreover, one condition should be meet in a successful cooperative game model, i.e., the overall profit of the alliance should be larger than the total profit got by each member's individual operation. As for campus express alliance, through the integration of resources, delivery companies can reduce the total cost of both manpower and material resources, improve service quality, enhance competitiveness, and also increase business scale, which would bring out higher benefits for each currier than it works independently. Therefore, Shapley value method can be used in the profit allocation of campus delivery alliance.

We define the campus express alliance's Shapley model as follows.

Assumed that a set of n carriers is $N = \{1, 2, \ldots, n\}$, and S ($S \subseteq N$) is any subset in N, which represents one alliance that the carriers may be formed. $v(S)$ is a characteristic function to represent the maximum payoff that the alliance S achieves. Let $\varphi_i(v)$ be the allocated profit gained by member i in the n-person cooperative game, and $\varphi_i(v)$, the Shapley value, should be expressed as:

$$\varphi_i(v) = \sum_{i \in S} \omega(|S|)[v(S) - v(S\backslash i)] \tag{1}$$

$$\omega(|S|) = \frac{(n - |S|)!(|S| - 1)!}{n!} \tag{2}$$

where $v(S\backslash i)$ is the payoff after removing carrier i from set S, and thus $[v(S) - v(S\backslash i)]$ represents the marginal contribution that carrier i brings to S. $|S|$ is the element number in the subset, $\omega(|S|)$ is weighted factor that can be regarded as the probability of each alliance S happens. That is to say, from a probabilistic viewpoint, the Shapley value is exactly the marginal contribution expectation of the carrier i.

2.2 Limitations of the Basic Model

The reason why Shapley value method can be so widely used is that it ensures the profit that the members gain in the alliance is larger than that by their independent work. It follows the idea that the worth of an individual participant is the mean value of the worth in all possible coalitions he has taken part in. The distribution result is symmetric and fair, and also monotonic and additive [9]. However, the Shapley value theory still has some defects. It makes profit allocation assuming that all the carriers are in equal status. That is to say, individual differences of the alliance members are ignored [10]. For example, given that there are only two players in the alliance, some profits would be achieved when alliance is successfully formed while nonprofit would be gained when separate operation. Then according to the calculation formula of Shapley value, as long as the success formation of the alliance, the profits attained by the two participants are definitely equal, because their marginal contributions to the alliance are identical, no matter how much they have ever put into the alliance. This is obviously contrary to common sense that when an enterprise is formed, the participant with more investments should get more rewards. Moreover, different enterprises have different market positions. Company with more customer resources and stronger business ability often plays a leading role in the league, and thus its bargaining power is higher than the weak side of the alliance [11]. In real life operation, they can always be paid more.

Hence, in the next chapter, we will introduce an improved Shapley value method, which takes those influent factors into account, so as to let the profit distribution more fair and reasonable in the campus express alliance.

3 Improved Shapley Value Method

3.1 Appraisement Index System of Campus Curriers

According to expert advice and market research, the factors that need to be mainly considered in profit distribution of campus express alliance are summarized as follows:

(1) *Prophase Investment*: During the formation of express delivery alliance, all the distributors need to devote money for house lease and manpower for business management and system integration. When making profit distribution, distributors who invest more should be compensated to get more profit in accord with the distribution principle of more pay for more work.
(2) *Market Position:* Considering the differences among various distributors in business scale, market share and customer scale, those who in high position often predominate in the actual profit distribution and have more discourse rights, they should be given higher weight.
(3) *Service Quality*: It includes pickup and delivery speed, customer satisfaction, attendants' attitude, safety level of distribution services, etc. These are all intangible assets for the alliance to retain competitiveness.

Based on the above mentioned, we construct a comprehensive appraisement index system about curriers. As is shown in Fig. 1, the target layer of this system is obtaining the comprehensive evaluation of couriers, while the rule layer includes

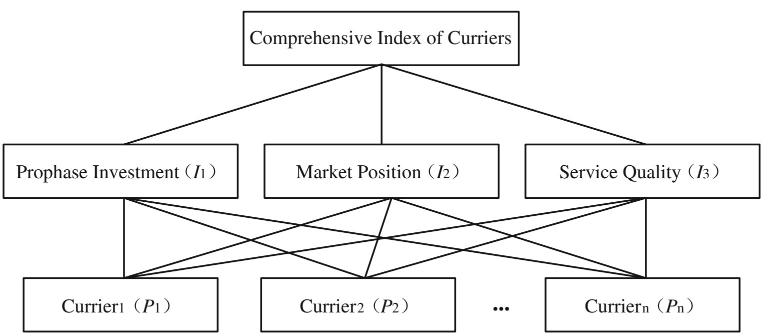

Fig. 1 Comprehensive appraisement index system of campus curriers

the three most important factors that cannot be neglected in the distribution, i.e., prophase investment, market position and service quality. And each specific courier is an alternative scheme which needs to be evaluated in this system.

3.2 Improved Shapley Value Method

After the establishment of the comprehensive evaluation index system of the express company, the Analytic Hierarchy Process (AHP) could be used to evaluate the weight of indicators. AHP is a useful and powerful tool in fuzzy comprehensive evaluation, which makes weight analysis by the judgment matrix layer by layer. Detailed steps on how to use AHP to calculate the weight are introduced in [12–15], and because of the limited space, this paper will not repeat them.

Assumed that the determined evaluation indicator by AHP method is W_i (i = 1, 2, …, n). Obviously, W_i satisfies the condition $\sum W_i = 1$. For currier i, let $\triangle W_i$ be the correction factor of profit allocation in campus express alliance,

$$\triangle W_i = W_i - 1/n \tag{3}$$

where $1/n$ represents the average level in the distribution. When the courier's evaluation index W_i is higher than the average standard, $\triangle W_i > 0$,which means the currier should be compensated in the allocation;Conversely, when W_i is below the mean value, $\triangle W_i < 0$,the currier will get punishment.

Supposed that $V(I)$ is the total revenue in the campus express alliance, then the improved Shapley value $\varphi_i'(v)$ can be expressed as:

$$\varphi_i'(v) = \varphi_i(v) + V(I) \times \triangle W_i \tag{4}$$

Because

$$\begin{aligned}\sum [V(I) \times \triangle W_i] &= V(I) \times \sum (W_i - 1/n) \\ &= V(I) \times \left(\sum W_i - \sum 1/n\right) \\ &= V(I) \times 0 \\ &= 0\end{aligned}$$

Therefore

$$\begin{aligned}\sum \varphi_i'(v) &= \sum [\varphi_i(v) + V(I) \times \triangle W_i] \\ &= \sum \varphi_i(v) + \sum [V(I) \times \triangle W_i] \\ &= V(I) + 0 \\ &= V(I)\end{aligned}$$

That is, the sum of the profits each carrier gets based on the improved model is still equal to the total profits obtained by the big alliance, which proves the revised method is feasible.

4 Case Analysis

4.1 Case Description

Supposed there is a campus express alliance consisting of three curriers A, B and C. A is one of the earliest delivery companies to develop campus express service in e-commerce field, with the largest scale, abundant financial resources but the service quality is poor; B has a high standard management system and enjoys good reputation from teachers and students at school, while the business scale is moderate; As for the carrier C, it is a smaller company who is striving to form the coalition with the other two expresses to enlarge its business scope. Hypothesis that the annual profits that A, B and C can obtain are respectively $v(A) = 240{,}000$ yuan, $v(B) = 220{,}000$ yuan and $v(C) = 170{,}000$ yuan when they operate separately in a school; if carrier A and carrier B set up the alliance, they can obtain profit $v(A, B) = 500{,}000$ yuan, likewise, $v(A, C) = 450{,}000$ yuan, $v(B, C) = 400{,}000$ yuan, and $v(A, B, C) = 800{,}000$ yuan.

According to the conditions mentioned above, curriers could achieve more benefits through the cooperation, which is in accordance with the basic conditions of the cooperative game, so we can calculate the initial profit distribution based on Shapley value method.

4.2 Profit Allocation Based on the Shapley Value

Based on the Shapley value method, the calculation process of the profit distribution of currier A in the alliance is as shown in Table 1.

By summing the last row values in Table 1, we can get the allocation profit of A: $\varphi_A(v) = (80.0 + 46.7 + 46.7 + 133.3) * 1000 = 306{,}700$ yuan.

Similarly, $\varphi_B(v) = 271{,}700$ yuan and $\varphi_C(v) = 221{,}700$ yuan.

Table 1 Currier A obtained profit based on shapley value

s	$\{A\}$	$\{A, B\}$	$\{A, C\}$	$\{A, B, C\}$
$v(S)$	240	500	450	800
$v(S \backslash i)$	0	220	170	400
$v(S) - v(S \backslash i)$	240	280	280	400
$\lvert S \rvert$	1	2	2	3
$\omega(\lvert S \rvert)$	1/3	1/6	1/6	1/3
$\omega(\lvert S \rvert)[v(S) - v(S \backslash i)]$	80.0	46.7	46.7	133.3

Unit Thousand Yuan

When comparing the profit before and after the campus express alliance is formed, the increasing benefits of A, B and C are 66,700 yuan, 51,700 yuan and 51,700 yuan. The result shows that there is no enough differences on the profit allocation among the three carriers, which seems unfair to carrier A with high market position and B with good service, while the weaker carrier C might “get a bargain”. Therefore, the results are not reasonable enough and there is still room for improvement.

4.3 *The Improved Allocation*

After experts’ assessment and evaluation of prophase investment, market position and service quality for the three carriers, the determined evaluation indicator weight vector that is calculated by AHP method is $\overrightarrow{W_i} = (0.372, 0.351, 0.277)$. And thus the correction factors in the distribution are:

$$\begin{aligned} \triangle W_A &= W_A - 1/n = 0.039 \\ \triangle W_B &= W_B - 1/n = 0.018 \\ \triangle W_C &= W_C - 1/n = -0.056 \end{aligned}$$

Based on the improved method mentioned before, the revised profit allocation results are as follows:

$$\begin{aligned} \varphi'_A(v) &= \varphi_A(v) + V(I) \times \triangle W_A = 337{,}600 \text{ yuan} \\ \varphi'_B(v) &= \varphi_B(v) + V(I) \times \triangle W_B = 285{,}800 \text{ yuan} \\ \varphi'_C(v) &= \varphi_C(v) + V(I) \times \triangle W_C = 176{,}600 \text{ yuan} \end{aligned}$$

When compared with the profit that they get in independent operation, the growth benefits are 97,600, 65,800 and 6600 yuan. The payment of carrier A and B in the new distribution method is higher than that in the basic Shapley value method, while the allocation profit of C is down. The result is matched with the three companies’ initial investment, market position and service quality and their contributions to the campus express alliance are fully affirmed. Therefore, the improved Shapley value method with comprehensive revised factor is more scientific and reasonable, and more practical in real life operation.

5 Conclusion

In this paper, we apply the Shapley value method to the profit distribution of campus delivery alliance. According to the characteristics of campus express collation in e-commerce industry, three impact factors, i.e., prophase investment, market position and service quality, are taken into consideration to improve the original model. AHP method is introduced to determine the weight of those indicators. Finally, results of numerical study verify the effectiveness of Shapley value and its improved method in the profit allocation of campus express alliance and prove that the improved model more reasonable and practical.

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Inventory Hedging and Revenue Sharing Under Inventory-Level-Dependent Demand

Ting Zhang, Zong-zhong Wang, Xin Chen and Ting Qu

Abstract A group company with a headquarter-managed centralized distribution center (HQ-CDC) and several subsidiaries is considered in this paper. The HQ-CDC provides inventory spaces and services for its subsidiary companies whose demands are inventory-level-dependent. To deal with uncertainty in inventory management, subsidiaries usually reserve more inventory spaces than their actual demands. This extra inventory space strategy is called "inventory hedging" in this research. As a result, subsidiaries may reserve excessive spaces which are never required for their business operations, leading to inconsistency with the lean warehousing and logistics strategy that the HQ-CDC would like to implement. This paper theoretically examine if the inventory hedging strategy is advantageous to subsidiaries, and if so how best such a strategy should be implemented. A coordination scheme with dynamic pricing is introduced here to coordinate the implementation of the inventory hedging strategy. Two types of prices are introduced. One is the basic price used for block-reserving inventory spaces. The other price is the "hedging price" which is the extra amount to the basic price in addition charged for the space more than the actual demand. The proposed coordination scheme is modeled using a Stackelberg game where the HQ-CDC is the leader and subsidiaries are followers. It is demonstrated that the coordination scheme through dynamic price can successfully reduce inventory hedging amount required by the subsidiaries and can increase the group company's total profit, as compared to the decentralized decision model without considering the hedging price. However, the coordination scheme sacrifices the subsidiaries' profit. Therefore, a revenue sharing contract is negotiated to guarantee both parties' interests.

Keywords Supply-chain coordination · Risk management · Hedging · Dynamic pricing · Game theory · Revenue sharing contract · Inventory management · Inventory-level-dependent demand

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1 Introduction

Inventories play an extremely important role. For many companies, inventory cost could be as much as pretax operating profits [1, 2]. Thus, a small decrease in inventory cost could result in substantial gains in an organization's profitability [3]. Consequently, companies are allocating an increasing proportion of resources to controlling inventory [2]. With the growing focus on supply chain management, companies realize that inventories across the entire supply chain can be more efficiently managed through greater cooperation and better coordination [4].

This paper considers an inventory coordination problem in a group company. The group company is composed of a headquarter-managed centralized distribution center (HQ-CDC) who supplies inventory space and multiple subsidiaries with inventory-level-dependent demands. The subsidiaries are exposed to a portfolio of risks from warehousing and marketing, such as warehouse capacity shortage, customer demand fluctuations, etc. To avoid such risks, a strategy defined as "inventory space hedging" is implemented. Specifically, the subsidiaries require more inventory space than their actual demand so that they can secure customer demands in the amount they need on time. However, the HQ-CDC intends to reduce the stocks holding for the purpose of promoting a lean warehouse.

Several research questions are examined: What scheme should be used to resolve the conflict? What are optimal strategies for the HQ-CDC and the subsidiaries under this scheme? How is the group company's total profit influenced by the scheme?

To be more specific, the scheme discussed in this paper involves a "hedging price" and a revenue sharing contract. The HQ-CDC charges the subsidiaries a fair hedging price to adjust the space hedging required by the subsidiaries. A Stackelberg game is played, which gives the HQ-CDC a leading role. It is demonstrated that the coordination scheme can successfully reduce the space hedging amount required by the subsidiaries and can improve the group company's total profit. However, the subsidiaries' interest is sacrificed. Hence, a profit sharing contract is negotiated to guarantee both parties' profit. A profit-splitting fraction is given by an interval. Each party's actual profit depends on its negotiation abilities. Moreover, the marketing price and the basic price charged by the HQ-CDC are determined but the sensitivity analyses are conducted. The sensitivity analyses show that the space hedging value does not depend on how much the HQ-CDC charges, but is affected by the marketing price. In face of a high marketing price, the HQ-CDC will gain a relatively large profit but the subsidiaries' profit will be reduced.

The remainder of this paper is arranged as follows. Section 2 provides a brief review of related literature. In Sect. 3, the assumptions and notations for the problem are provided. In Sect. 4, a decentralized decision scheme and a centralized decision scheme are presented and optimal strategies for the models are studied. In Sect. 5, a coordination scheme through hedging price and revenue sharing contract is introduced. A Stachelberg game model in which the HQ-CDC plays a leading role is studied. We devote Sect. 6 to compare the three models. The results from the analytical and the numerical studies are reported. The managerial implications are provided. We conclude by identifying directions for further investigation in Sect. 7.

2 Literature Review

Retailers can often affect a product's sale volume by increasing the shelf space allocated to it [5]. Since the increased shelf space often require the retailer to keep a higher inventory level, some operations management researchers have incorporated inventory-level-dependent demand into various inventory control models. [6] first developed an inventory model with a stock-dependent consumption rate, which is a function of the initial stock level. Further, the coordination problem in a decentralized manufacturer-retailer(s) or a supplier-retailer(s) supply chain, where the retailer faces the inventory-level-dependent demand, was studied. Different coordination schemes with the purpose of performance improving were proposed. [7] presented a coordination model through a price plus inventory-subsidy contract. [8] considered a quantity discount coordination schedule and a profit sharing contract. [9] developed a performance-improving model through trade credit policy. [10] proposed a continuum of buyback contracts. These coordination schemes were demonstrated to improve each member's performance as well as the whole channel's performance.

Another stream of previous study is about operational hedging. Hedging, as an effective task to mitigate risk, involves taking counterbalancing actions [11]. Therefore, the risks will be less over the possible states of nature. The definition of operational hedging from the perspective of real option, was first introduced by Eynan and Kropp [12]. The definition, quoted in [13], states that "Operational hedging strategies…can be viewed as real (compound) options that are exercised in response to demand, price and exchange rate contingencies faced by firms in a global supply chain context." These options or counterbalancing actions are derived from the global coordination of sourcing and/or production decisions. It includes various types of processing flexibility. Postponing the logistics decision [13], switching production and sourcing strategies contingent on demand and exchange rate uncertainties, switching among supply chain network structures, holding excess capacity and delaying the final commitment of capacity investments are means of operational hedging.

This paper studies one kind of operational hedging in the warehousing, which is named as "inventory space hedging". It can be seen as a case of the operational hedging problem. Specifically, the plants prefer to require more inventory space than their actual demand so that they can secure customer demands in the amount they need on time. This extra space strategy is defined as "inventory space hedging".

3 Mathematical Model

3.1 Notations and Assumptions

In this paper, a group company with one headquarter-managed centralized distribution center (HQ-CDC) and several subsidiaries, donated as $i = 1, 2, \ldots, n$, is considered. The customer demand in each subsidiary i, denoted as D_i, is given and can be different from each other. In other words, the probability to fulfil the demand, denoted as $P(s_i)$, is assumed to increase as the amount of inventory space increases. More specifically, it is reasonable to assume that $P(s_i)$ is an increasing and concave function to reflect the motivational effect of inventory on demand and the "diminishing returns" (Wang and Gerchak 2001, Hu, Guan et al. 2011). That is,

$$P'(s_i) > 0 \quad \text{and} \quad P''(s_i) \leq 0 \tag{1}$$

To make the calculation more convenient, in this paper, we assume the fulfilment probability follows an exponential distribution. For instance, for each subsidiary i,

$$P(s_i) = 1 - a\mathrm{e}^{-\lambda(\frac{s_i}{D_i} - 1)}, \quad \lambda > 0,\ 0 < a < 1,\ i = 1, 2, \ldots, n \tag{2}$$

It is easy to observe that (2) satisfies the condition described in (1). Under this setting, when $s_i = D_i, P(s_i) = 1 - a$. This implies that when these is no inventory hedging, there is a $1 - a$ probability that the subsidiary can satisfy the customer demand on time. As $s_i \to \infty, P(s_i) \to 1$, the subsidiary guarantees to satisfy the customer demand on time.

In this paper, our focus is on the interface of the HQ-CDC and the subsidiaries. We assume that the unit sale price, denoted as p per unit, and the marketing price for unit space unit time, denoted as c_m, are exogenously given. Since the headquarter in a group company always has the power of control, the HQ-CDC has the full information about each subsidiary's customer demand D_i and its space demand s_i.

As previously described, The HQ-CDC serves not only the subsidiaries but also external users. The HQ-CDC firstly meets the internal space demands, i.e. the demands from the subsidiaries. The capacity of the HQ-CDC, CA, is not infinite but big enough to meet the total space demand from the subsidiaries $\sum_{i=1}^{n} s_i$. After the fulfilment of the space demands of the subsidiaries, the left space can be always leased to the outside users by the marketing price c_m.

The following notations are used in the paper.

Indices	
i	Index for subsidiaries, $i = 1, 2, \ldots, n$.
Parameters	
D_i	Mean demand per period for subsidiary i
CA	Total space capacity of the HQ-CDC
c_r	Basic price for unit space unit time
c_m	Marketing price for unit space unit time
p	Unit sale price
φ	Profit-splitting fraction $(0 \le \varphi \le 1)$
Decision Variables	
s_i	Reserved space of subsidiary i in one period
w	Hedging price in HQ-CDC
Functions	
P	Demand fulfillment probability
f_i	Profit function for subsidiary i, $i = 1, 2, \ldots, n$
F	Profit function for HQ-CDC
Π	Profit function for the group company

4 Decentralized Decision and Centralized Decision

4.1 Decentralized Decision Scheme Without Coordination

This model estimates that the profit of the headquarter-managed centralized distribution center and the subsidiaries based on the condition that there is no coordination scheme. The inventory space amount s_i is chosen by the subsidiary i. A larger s_i will lead to less risk to miss the customer demand, but will result in larger space charge for the subsidiary. Thus, the subsidiaries will choose an optimal space amount to maximize its own profit. The corresponding profit function for each subsidiary i, $i = 1, 2, \ldots, n$, is shown below,

$$f_i^{DD}(s_i) = pD_iP(s_i) - c_r s_i \tag{3}$$

In the first term of the above expression, pD_i represents the revenue that the subsidiary i can generate if the customer demand D_i can be fulfilled, and $P(s_i)$ shows the probability that the customer demand D_i can be fulfilled when the subsidiary i gets an inventory space s_i. Thus, $pD_iP(s_i)$ is the expected revenue for the subsidiary i. The second term is the cost of the inventory space the subsidiary has to pay.

Profit of the HQ-CDC can be described as follows:

$$F^{DD}(s_i) = c_r \sum_{i=1}^{n} s_i + c_m \left(CA - \sum_{i=1}^{n} s_i \right) \tag{4}$$

The first term in the above expression is the revenue of the internal inventory space demand, i.e. the demands from the subsidiaries. The second term is the revenue of the external inventory space demand.

If the exponential probability distribution function as shown in (2) is used, then the subsidiary's objective function and profit for the HQ-CDC are described as follows:

$$\begin{aligned} \max f_i^{DD}(s_i) &= pD_i P(s_i) - c_r s_i \\ F^{DD}(s_i) &= c_r \sum_{i=1}^{n} s_i + c_m (CA - \sum_{i=1}^{n} s_i) \end{aligned} \tag{5}$$

Demonstrated that $s_i \geq D_i$. That is, the optimized reserved space is always bigger than the demand.

Proposition 1 *The profit function for each subsidiary i, $i = 1, 2, \ldots, n$, is a concave function and the optimal solution s_i^{DD} is characterized by the following equation*:

$$s_i^{DD} = \begin{cases} D_i & \text{if } c_r > a\lambda p \\ D_i(1 - \frac{1}{\lambda} \ln \frac{c_r}{ap\lambda}) & \text{if } 0 < c_r \leq a\lambda p \end{cases} \tag{6}$$

Proof It is easy to see that $f_i^{DD}(s_i)$ is a continuous function. Its first derivative is

$$\frac{\partial f_i(s_i)}{\partial s_i} = ap\lambda \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i} - 1\right)} - c_r$$

And the second derivative is

$$\frac{\partial^2 f_i(s_i)}{\partial^2 s_i} = -\frac{ap}{D_i} \lambda^2 \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i} - 1\right)} \leq 0$$

Thus, the profit function is a concave function.

Since the space amount is no less than the demand, the optimal amount s_i can be obtained based on the following two cases:

Case I: $c_r > a\lambda p$. For this case, we have

$$c_r > a\lambda p > a\lambda p \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i}-1\right)}$$

$$\frac{\partial f_i(s_i)}{\partial s_i} = ap\lambda \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i}-1\right)} - c_r < 0$$

Because $s_i \geq D_i$, the optimal reserved space amount $s_i^{DD} = D_i$.

Case II: $0 < c_r \leq a\lambda p$. For this case, there exists a value for s_i^{DD}, $s_i^{DD} \geq D_i$, to make the first derivative equal to 0, and this value is the optimal reserved space amount s_i^{DD}. We have

$$\frac{\partial f_i(s_i)}{\partial s_i} = ap\lambda \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i}-1\right)} - c_r = 0$$

Then, in this case,

$$s_i^{DD} = D_i\left(1 - \frac{1}{\lambda}\ln\frac{c_r}{ap\lambda}\right) \tag{7}$$

Proposition 2 *The profit of the subsidiary i under this optimal solution*

$$f_i^{DD} = \begin{cases} D_i p(1-a) - D_i c_r & \text{if } c_r > a\lambda p \\ D_i p - \frac{D_i c_r}{\lambda}\left(1 - \ln\frac{c_r}{a\lambda p}\right) & \text{if } 0 < c_r \leq a\lambda p \end{cases}$$

and the profit under the condition $0 < c_r \leq a\lambda p$ is no smaller than that under the condition $c_r > a\lambda p$.

Proof Substituting the optimal s_i^{DD} into $f_i^{DD}(s_i)$, the optimal profit for subsidiary i is obtained. With $0 < c_r \leq a\lambda p$, the profit under the optimal s_i^{DD} is maximum. When $c_r > a\lambda p$, $s_i^{DD} = D_i$, $f_i^{DD}(s_i) = D_i p(1-a) - D_i c_r$. Under the condition $0 < c_r \leq a\lambda p$, we have

$$\begin{aligned} D_i p - \frac{D_i c_r}{\lambda}\left(1 - \ln\frac{c_r}{a\lambda p}\right) &= D_i p + \frac{D_i c_r}{\lambda}\left(\ln\frac{c_r}{a\lambda p} - 1\right) \\ &\geq D_i p - D_i pa \\ &\geq D_i p - D_i pa - D_i c_r \end{aligned}$$

Where the inequality

$$D_i p + \frac{D_i c_r}{\lambda}\left(\ln\frac{c_r}{a\lambda p} - 1\right) \geq D_i p - D_i pa$$

follows from the fact that $\ln\frac{c_r}{a\lambda p} \geq 1 - \frac{a\lambda p}{c_r}$ since $0 < c_r \leq a\lambda p$

Thus, it is more profitable for the subsidiaries to have the space amount bigger than the demand.

4.2 Centralized Decision Scheme

In the centralized decision model, the space hedging value is determined by considering the entire firm as a centralized system. From the global optimization point of view, the group company will choose an optimal space hedging value that maximizes the entire company's profit.

The group company's total profit is,

$$\begin{aligned} \max \quad & \Pi^{CD}(s_i) = F(s_i) + \sum_{i=1}^{n} f_i(s_i) \\ & = c_m\left(CA - \sum_{i=1}^{n} s_i\right) + \sum_{i=1}^{n} pD_iP(s_i) \\ & = c_m\left(CA - \sum_{i=1}^{n} s_i\right) + \sum_{i=1}^{n} pD_i\left(1 - a\mathrm{e}^{-\lambda\left(\frac{s_i}{D_i}-1\right)}\right) \\ \text{s.t.} \quad & s_i \geq D_i, \lambda > 0, 0 < a < 1, \end{aligned} \tag{8}$$

Proposition 3 *The profit function for the group company's total profit is a concave function and the optimal solution s_i is characterized by the following equation:*

$$s_i^{CD} = D_i\left(1 - \frac{1}{\lambda}\ln\frac{c_m}{ap\lambda}\right) \tag{9}$$

Proof The first derivative of $\Pi^{CD}(s_i)$ is

$$\frac{\partial \Pi^{CD}(s_i)}{\partial s_i} = -c_m + ap\lambda \sum_{i=1}^{n} \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i}-1\right)}$$

And the second derivative is

$$\frac{\partial^2 \Pi^{CD}(s_i)}{\partial s_i^2} = -\frac{ap}{D_i}\lambda^2 \sum_{i=1}^{n} \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i}-1\right)} \leq 0$$

Thus, the group company's total profit function is a concave function.

Optimal s_i^{CD} can be obtained from the following equation:

$$-c_m + ap\lambda \sum_{i=1}^{n} \mathrm{e}^{-\lambda\left(\frac{s_i^{CD}}{D_i}-1\right)} = 0$$

5 Hedging Price with Revenue Sharing

With the growing focus on supply chain management, companies realize that inventories across the entire supply chain can be more efficiently managed through greater cooperation and better coordination. This section addresses to propose an effective coordination scheme between the HQ-CDC and the subsidiaries.

5.1 Coordination Scheme Through Hedging Price

In the decentralized decision scheme without coordination, the subsidiaries has enough power in which they can sacrifice the HQ-CDC in order to benefit itself. In the proposed coordination scheme, HQ-CDC has more power so it can mitigate the potential revenue loss caused by the inventory hedging strategy implemented by the subsidiaries. The measure taken by the HQ-CDC is introducing a fair hedging price for the subsidiaries.

A Stackelberg game is played for this coordination scheme. In the game, the HQ-CDC, as a Stackelberg leader, decides a fair hedging price, w, for the subsidiaries to maximize the HQ-CDC's profit, taking into account the expected subsidiaries' behavior on the first stage. On the second stage, the subsidiaries, acting as a Stackelberg follower, decides the space amounts after the HQ-CDC's decision on price is given. All conditions and settings are the same as for the model without coordination, profit functions for the HQ-CDC and the subsidiary i, $i = 1, 2, \ldots, n$, are shown as follows:

$$\begin{aligned} \max \quad F^{HP}(w) = {} & c_r \sum_{i=1}^{n} s_i \\ & + c_m\Big(CA - \sum_{i=1}^{n} s_i\Big) + w \sum_{i=1}^{n} (s_i - D_i) \end{aligned} \tag{10}$$

$$\begin{aligned} \max \quad f_i^{HP}(s_i) &= pD_i P(s_i) - c_r s_i - w(s_i - D_i) \\ &= pD_i\left(1 - a e^{-\lambda\left(\frac{s_i}{D_i} - 1\right)}\right) - c_r s_i - w(s_i - D_i) \\ \text{s.t.} \quad & s_i \geq D_i, \lambda > 0, 0 < a < 1, \end{aligned} \tag{11}$$

Proposition 4 *Under the Stackelberg game setting for a headquarter-centered distribution center (HQ-CDC) and several subsidiaries, if* $0 < \frac{c_r + w}{a\lambda p} \leq 1$, *the* *optimal strategies for both parties can be obtained by computing the Stackelberg equilibrium* $(s_1^{IP}, s_2^{IP}, \ldots, s_n^{IP}, w^{IP})$ *in the following equations*:

$$\frac{c_r - c_m + w^{HP}}{c_r + w^{HP}} + \ln\left(\frac{c_r + w^{HP}}{ap\lambda}\right) = 0 \tag{12}$$

$$s_i^{HP} = D_i\left(1 - \frac{1}{\lambda}\ln\frac{(c_r + w^{HP})}{ap\lambda}\right) \quad (i = 1, 2, \ldots, n) \tag{13}$$

If $\frac{c_r + w}{a\lambda p} > 1$, then $s_i^{HP} = D_i$.

Proof The first derivative of $f_i^{HP}(s_i)$ is

$$\frac{\partial f_i^{HP}(s_i)}{\partial s_i} = ap\lambda \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i} - 1\right)} - c_r - w$$

And the second derivative is

$$\frac{\partial^2 f_i^{HP}(s_i)}{\partial^2 s_i} = -\frac{ap}{D_i}\lambda^2 \mathrm{e}^{-\lambda\left(\frac{s_i}{D_i} - 1\right)} \leq 0$$

Thus, the subsidiary's profit function is a concave function.

Optimal $s_i^{HP} = \left(1 - \frac{1}{\lambda}\ln\frac{(c_r + w)}{ap\lambda}\right)D_i$.

Substituting this optimal s_i^{HP} into the HQ-CDC's profit function, we have

$$\begin{aligned} \max \quad F^{HP}(w) &= c_r\sum_{i=1}^{n} s_i + c_m\left(CA - \sum_{i=1}^{n} s_i\right) \\ &\quad + w\sum_{i=1}^{n}(s_i - D_i) \\ &= (c_r - c_m)\sum_{i=1}^{n} D_i \\ &\quad - \frac{(c_r - c_m + w)}{\lambda}\ln\frac{(c_r + w)}{ap\lambda}\sum_{i=1}^{n} D_i + c_m CA \end{aligned}$$

The first derivative of $F^{HP}(w)$ is

$$\frac{\partial F^{HP}(w)}{\partial w} = -\frac{1}{\lambda}\left[\frac{c_r - c_m + w}{c_r + w} + \ln(c_r + w) - \ln ap\lambda\right]\sum_{i=1}^{n} D_i$$

And the second derivative is

$$\frac{\partial^2 F^{HP}(w)}{\partial w^2} = -\frac{1}{\lambda}\frac{(c_m + c_r + w)}{(c_r + w)^2}\sum_{i=1}^{n} D_i \leq 0$$

Thus, the HQ-CDC's profit function is a concave function.

Optimal w^{HP} can be obtained by computing $\frac{c_r - c_m + w^{HP}}{c_r + w^{HP}} + \ln(c_r + w^{HP}) - \ln ap\lambda = 0$.

Since $F^{HP}(w)$ and $f_i^{HP}(s_i)$ are both concave, the Stackelberg equilibrium always exists.

Note here in our setting $s_i \geq D_i$. It means that $0 < \frac{c_r + w}{a\lambda p} \leq 1$ based on the first deviation of $f_i^{HP}(s_i)$. If $\frac{c_r + w}{a\lambda p} > 1$, it is easy to see that the optimal solution is $s_i^{HP} = D_i$.

5.2 *Revenue Sharing Contract*

Since the coordination scheme through hedging price increases the HQ-CDC's profit but decreases the subsidiaries' profit, a splitting fraction of the HQ-CDC's additional profit $(F^{HP} - F^{DD})$ has to be negotiated to induce the subsidiaries to get involved in the coordination. In this paper, a fraction φ $(0 \leq \varphi \leq 1)$ is nominated. The fraction φ of the HQ-CDC's additional profit will be split to the subsidiaries and the rest $(1 - \varphi)$ reserved to the HQ-CDC. The value of φ represents the subsidiaries' negotiation ability. The greater the value of φ, the more powerful the subsidiaries' negotiation ability. If the negotiated φ approaches 1, the subsidiaries will share all of the HQ-CDC's additional profit. In contrast, when the negotiated φ approaches 0, the HQ-CDC will enjoy all the benefits that come from the coordination. From the subsidiaries' perspective, they are willing to involve in the coordination scheme only if the amount of the offset can compensate their decreased profit. That is,

$$\varphi\left(F^{HP}(w) - F^{DD}(s)\right) \geq \sum_{i=1}^{n}\left(f^{DD}(s) - f^{HP}(s)\right)$$

When there are homogeneous subsidiaries, the expression is,

$$\varphi\left(F^{HP}(w) - F^{DD}(s)\right) \geq n\left(f^{DD}(s) - f^{HP}(s)\right) \tag{14}$$

Then, we get

$$\varphi \geq \frac{c_r \ln(c_r/(c_r+w)) + w\ln(ap\lambda/(c_r+w)) + w}{(c_r - c_m)\ln(c_r/(c_r+w)) + w\ln(ap\lambda/(c_r+w))}$$

Since we already set $0 \leq \varphi \leq 1$, thus

$$\frac{c_r \ln(c_r/(c_r+w)) + w\ln(ap\lambda/(c_r+w)) + w}{(c_r - c_m)\ln(c_r/(c_r+w)) + w\ln(ap\lambda/(c_r+w))} \leq \varphi \quad \varphi \leq 1 \tag{15}$$

The coordination scheme will be promoted and implemented by the two parties only if the profit-splitting fraction φ belongs to the interval expressed in (15).

6 Numerical Studies

Firstly, the sensitivity analyses of the demand proportion retained in the primary stock-keeping location W_{ii} and the unit transshipment charge t_{ij} are studied. Specifically, the proportion of average demand at market i transferred to each of the secondary facilities is assumed to be evenly divided, equal to $(1 - W_{ij})/(n-1)$. Note that when $W_{ij} = 1$ no transshipments occur, and when $W_{ij} = 1/n$ demand is allocated evenly among the n locations.

Note: Fixed $\begin{matrix} D_i = 10{,}000{,}000, c.v._i = 0.5, h_i = 0.1, \\ K = 20{,}000, k = 500, z_i = 1.28, L_i = 0.15 \end{matrix}$

Table 1 lists the group company's performance in the transhipments in scenarios with different demand proportions retained W_{ii} and the unit transportation charges $t_{ij}t_{ij}$ in the Order Consolidation policy and the Order Coordination policy, respectively. Note that when t_{ij} changes, the saving of the safety stock in transshipments Iss is fixed, while the transportation cost Tp is linearly changes, e.g., Tp increases to twice when t_{ij} increases to twice.

Table 1 Transshipment performance in scenarios with different W_{ii} and t_{ij}

W_{ii}	$t_{ij} = 0$		$t_{ij} = 0.005$		$t_{ij} = 0.01$		$t_{ij} = 0.015$		$t_{ij} = 0.02$	
	Itr	*ITC*	*Itr*	*ITC*	*Itr*	*ITC*	*Itr*	*ITC*	*Itr*	*ITC*
1/8	10.5	18.7	−4.5	8.4	−22.4	−0.6	−38.9	−8.9	−56.3	−19.7
1/4	19.7	23.1	5.2	15.1	−8.5	8.4	−25.6	−0.4	−39.6	−8.5
3/8	26.3	26.5	13.8	19.2	1.3	14.2	−9.3	6.9	−20.5	0.0
1/2	28.4	27.9	17.9	22.7	8.1	17.3	−1.0	12.3	−9.4	6.7
5/8	26.3	26.5	18.7	24.1	12.6	19.4	4.4	15.2	−1.4	11.9
3/4	19.7	23.1	14.3	20.3	10.9	18.8	6.1	16.7	0.8	13.2
7/8	10.5	18.7	6.7	16.7	5.9	15.9	3.9	14.8	2.3	14.7
1	0.0	0.0	0.0	11.3	0.0	12.8	0.0	12.8	0.0	12.8

There are two general findings from the tables. First of all, when there is no transportation cost, i.e., $t_{ij} = 0$, the percentage savings of the transsshipments *Itr* reach the peak at $W_{ii} = 1/n$. However, if the transportation cost of the transhipments is considered, which are the more common situations, *Itr* reaches the peak at a higher value of W_{ii}. Moreover, the optimal value of W_{ii} increases with the unit transportation charge t_{ij}. It indicates that in order to get the largest improvement from the transhipment, the demand retained at the first location should be more than that allocated to the secondary location, and the retained proportion should be increased in face of expensive transportation charge.

Secondly, in several situations with negative improvement of the transhipments, the improvement of the total cost still can be positive. Besides the implementation of transshipments, other cost components are improved when a group company applies Headquarter-centered Common Warehousing Management (HQ-CWM). The relative cost improvements include the ordering and holding cost already analyzed in previous sections. Hence, the group company should make the decision whether to use the transshipments in HQ-CWM after the comprehensive evaluation of its characteristics.

Next, when W_{ii} and t_{ij} are fixed (e.g., $W_{ii} = 1/n$ and $t_{ij} = 0.01$), the change of the safety stock cost and the transportation cost in different demand means and demand variations are analyzed. The formula of the safety stock cost reflects that the safety stock cost changes with the sum of the demand variation. It indicates that the safety stock of one subsidiary is not only impacted by the demand variation of itself but also by the ones of other subsidiaries. Therefore, even one subsidiary is with low demand variation, it has to pay for a high safety stock cost when its coordinators have high demand variation. In such situations, the implementation of transshipments may bring benefits for the whole group company but not for the subsidiary with low demand variation.

Secondly, the formula of the transportation cost of the transshipment reflects that it changes linearly with the demand mean. It validates that the subsidiary with more demand needs to pay more for the transportation. The above analyses suggest two points. Firstly, the subsidiary with less demand mean but high demand variation gains more benefits in the transshipment. Secondly, the whole group company may benefit when the subsidiaries involved in the transshipment are with low demand mean but high demand variation.

The managerial implication can be drawn from the above analyses. By sharing stocks, the transshipment reduces the total inventory level and the corresponding holding cost noticeably. In the same time, the corresponding transportation cost should not be neglected. Therefore, the group company has to take comprehensive considerations before it decides to implement the transshipments. It is worthwhile to pursue the transshipment in situations of high holding cost rate and low transportation charge. An example is for the computer industry. As the prices of computer depreciate rapidly, computer manufacturers often adopts “zero” inventory strategy through placing high holding cost rates. In another case, the subsidiaries in the group company are geographically concentrated, leading to the relatively low transportation cost.

7 Conclusion

This paper proposes to implement transhipments in a group company with a headquarter-centered distribution center. By sharing safety stocks, the transhipment is supposed to enable the group company to reduce inventory level and improve inventory availability. The numerical studies reveal that the transhipment reduces the holding cost noticeably and improves the robustness of the group company's performance against demand uncertainties. The benefits of the group company are gained by taking advantage of risk pooling effect. However, the corresponding transportation cost should not be neglected. It is worthwhile to pursue the transshipment in situations of high holding cost rate and low transportation charge.

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Research on the Effect of Zonal Spring Mattress on Spine Alignment and Mattress Comfort

Yu-ding Zhu, Xiao-chun Zhang, Li-ming Shen and Fei Fang

Abstract Taking zonal spring mattress as the research object, the paper studied the effect of spring mattress zonal changes on spine alignment and mattress comfort through the methods of mattress sinkage measurement and body pressure distribution test. The results showed that, the back and waist clearance of four types of spring mattresses was in the range of 2–3 cm, and the ratio of back to hip sinkage was in the range of 0.6 to 0.8. the ratio of back to hip sinkage of men subjects in the four types of spring mattresses was larger than women subjects'. The back clearance of men subjects was larger than women subjects' on zonal spring mattress, which had a certain relationship with male and female body shape. Reasonable zonal spring mattress could get better body pressure distribution parameters than non-zonal spring mattress. More zonal number could live up to requirements of human body on mattress elasticity distribution. Research results provided the basis for zonal mattress design.

Keywords Spring mattress · Zonal mattress · Comfort · Spine alignment

1 Introduction

The elasticity of each zone in zonal spring mattress was precisely calculated according to the weight of each body part, in accord with the dimension of every body part and biomechanical characteristics, in order to achieve the optimal

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matching of mattress and body shape. It means that as far as possible, make spine alignment close to the natural state and muscles relax, and eventually reach the requirements of healthy sleep [1]. As the improvement of rest and sleep quality requirements, people demand more of the mattress. Ordinary mattress already cannot satisfy people's needs, so the emergence of zonal spring mattress just meets people's demand for high quality sleep.

As to sleep comfort, mattress firmness is very important to reduce or prevent pain and stress. It means that a mattress should provide enough support for the body, and body weight should be evenly distributed. Some experts think the spine support is the most important factor affecting sleep quality. Lahm et al. conducted comfort research on three mattresses in different firmness and the results showed that the mattress firmness had no significant effect on subjects' EMG, heart rate and subjective comfort, but had a larger effect on spine alignment [2].

Based on an approximate anthropometric model, Inhyuk et al. presented an air-cell mattress which could prevent bedsore and control pressure. The air mattress had eighteen cylindrical air cells made of porous material. The body was divided into four sections such as head, trunk, hip and leg. The pressure of each section was independently calculated from the weight of each part based on the individual body height and weight and the approximate anthropometric model. The experimental results showed that the proposed air-cell mattress was effective in preventing pressure ulcer [3].

Yosuke studied the relationship between sleep posture and sleep comfort. Pocket spring mattress can be divided into four regions: the head, chest, waist and legs. And using the 1.9 mm spring wire diameter for head and leg, application three levels of the spring hardness (spring wire diameter: 1.6, 1.9, 2.1 mm) for chest and waist area. Taking the nine different hardness distribution of mattress as the research object, the subjects including 20 healthy male students, aged between 19 and 23 years old, BMI was 18.5–20 standard body type. The results showed that the subsidence ratio (b/h) of chest and waist is 0.35–1.45. When $b/h > 1$, the subsidence of the chest and is greater than the waist, as "chest position"; When $0.5 \leq b/h \leq 1$, the subsidence of the chest and smaller than the waist, as" waist position I"; When $b/h < 0.5$, the subsidence of the chest and is far less than the waist, as "waist position II". The chest area soft (spring wire diameter 1.9 mm), the waist area hard (spring wire diameter 2.1 mm), the spine form is posture S spinal form type, good sleep comfort; the chest area hard (spring wire diameter 2.1 mm), the waist area soft (spring wire diameter 1.9 mm), spinal shape with flat back standing or concave back spine form similar posture, bad sleeping comfort [4].

The optimal sleeping system has a high conformity, i.e. it supports the human body in a way that human spinal column adopts its natural position that is assumed to be the same as it takes in the upright position. For lateral recumbency, an optimal body support gives rise to the spinal column being a straight line. Haex et al. [5] developed the finite element model of a mattress to predict the curvature of an individual's vertebral column when lying on it. Measurements are made and compared to the predicted results to adjust and to refine the model. By considering body contact pressure and subjective ratings of comfort, Buck et al. [6] analyzed body contact pressures (measured at the shoulder, elbow, hip, knee and ankle) and found no significant differences between experimental conditions such as mattress types.

Zonal spring mattress had already appeared on the market, and has been very popular. The zonal number varies from three to five zones and even seven zones. Though comfort evaluation research on zonal spring mattress is rare, it is necessary to do more research on zonal spring mattress.

2 Materials and Methods

2.1 Participants

The subjects consisted of a sample of healthy women (n = 5) and men (n = 5) who were all students from Nanjing Forestry University, aged from 20 to 30. The mean weight and body height of men subjects were 63.5 kg (SD = 8.2) and 168.2 cm (SD = 2.9). The mean weight and body height of women subjects were 50.0 kg (SD = 6.4) and 160.6 cm (SD = 6.1). The subjects wore the same clothes, with no belts, buttons and similar adornment.

2.2 Materials

Experimental mattresses were a non-zonal spring mattress and three types of zonal spring mattresses, including three zonal, four zonal and five zonal spring mattresses. The three zonal spring mattress was subdivided into three zones such as head and back, waist and hip, leg. The four zonal spring mattress was subdivided into four zones such as head, back and waist, hip and leg. The five zonal spring mattress was subdivided into five zones such as head, back, waist, hip and leg. The research shows the soft mattress had the lowest peak pressures in the buttocks zone. The medium mattress had the lowest peak pressure in the shoulder zone [7]. Pocket spring module parameters [8] were ② (1.8 65 5), ③ (2.0 65 6), ④ (2.0 65 5), ⑤ (2.2 65 6) and ⑥ (2.2 65 5); Common sponge was 30 mm thick; its density was 20 kg/m3, and composite fabric. The designing schemes of zonal spring mattress materials were listed in Table 1. Spring module ② (1.8 65 5) meant wire diameter was 1.8 mm, pitch diameter was 65 mm, and the number of cycle was five.

Table 1 The designing schemes of zonal spring mattress

zonal	Non-zonal	Three-zonal	Four-zonal	Five-zonal
Head	Whole ④	Head and back ④	Four-zonal	Head ④
Shoulder and Back			Back and waist⑥	Back ③
Waist		Waist and Hip ②		Waist ⑥
Hip			Hip ②	Hip ②
Thigh		Leg ⑤	Leg ⑤	Leg ⑤
Shank				
Foot				

2.3 Methods

(1) Mattress sinkage measurement [8].

Mattress sinkage measurement was done by use of spine alignment sinkage measurement system developed in our own laboratory. Taking the zonal spring mattress as the tested object, when subjects were lying on the mattress, with the spine alignment corresponding to the straight benchmark line, the extension of the benchmark on measurement points could be measured before and after subjects lying on the mattress. The sinkage of mattress measurement points was calculated and spine alignment was depicted when subjects were in lying position. According to the shoulder and back sinkage, waist and hip sinkage and horizontal distance, the back and waist clearance was calculated to reflect spine alignment in lying position.

The back and waist clearance was the vertical distance from the higher point on the back and waist to the tangent line of the lower points on the shoulder, back and hip. It could be calculated by the following equation.

$$S = \frac{l\left(h' - \frac{h \times l'}{l + l'}\right)}{\sqrt{l^2 + \left(h - \frac{h \times l'}{l + l'}\right)^2}}$$

In the equation, h stands for the sinkage difference of the lowest points between shoulder, back and hip; h' stands for the sinkage difference between the highest points on the waist and the lowest point on the hip; l stands for the horizontal distance between the lowest points on shoulder and back and the highest point on the waist; l' stands for the horizontal distance between the highest points on waist and back and the lowest point on hip; S stands for vertical distance from the higher points on the back and waist to the tangent line of the lower points on the shoulder, back and hip, namely the back and waist clearance, as shown in Fig. 1.

To quantitatively classify mattress sinkage distribution in lying positions, by measurement of the largest back and hip sinkage, the ratio of the largest sinkage

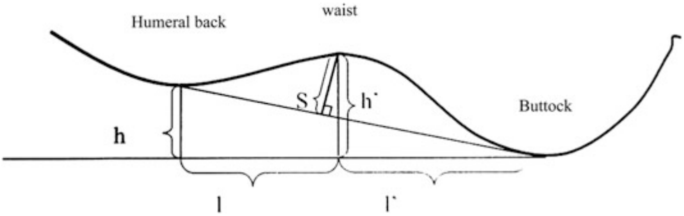

Fig. 1 The back and waist clearance

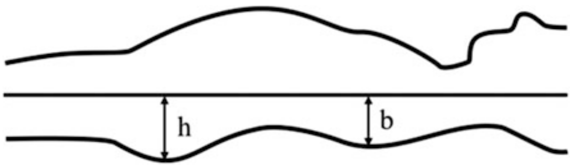

Fig. 2 The maximum back and hip sinkage

was calculated by the equation X = b/h. B and h respectively stands for the largest back and hip sinkage, as Fig. 2 showed.

(2) Body pressure distribution test

The test employed the Body Pressure Measurement System made by Tekscan. When subjects were lying on the mattress, the pressure distribution on the head, shoulder and back, waist, hip and legs and the total body were measured. The body pressure parameters included maximum pressure, mean pressure, contact area, pressure ratio and so on [9]. The pressure distribution ratio in supine position could be calculated by the following equation [10]

$$PR_i = \frac{P_i}{\sum_{i=A}^{E} P_i,} \quad (i = \text{head, back, waist, hip and leg})$$

3 Results and Analysis

3.1 Spine Alignment

When subjects were lying on a mattress, the test benchmark was corresponding to the human spine alignment. According to the mattress sinkage, the sinking curve was depicted, and that is the spine alignment in the supine position. According to the sinkage of male subjects in the four types of spring mattresses, the sinking curves (spinal alignment) of the four types of spring mattresses were illustrated, as shown in Fig. 3. According to the mattress sinkage of male and female subjects in

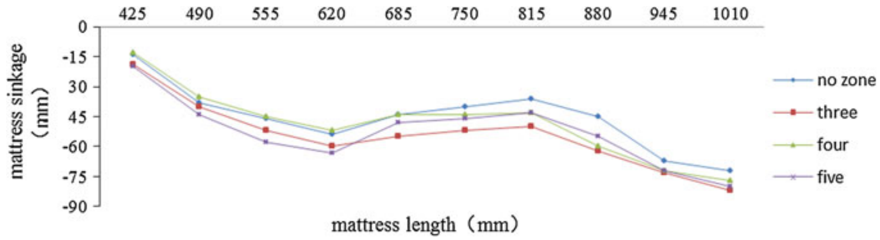

Fig. 3 Spine alignment of men subjects on the four types of mattresses in the supine position

Table 2 The ratio of back to hip sinkage and the back and waist clearance of different genders on the four types of mattresses in the supine position

	Male		Female	
	The ratio (%)	The clearance (mm)	The ratio (%)	The clearance (mm)
Non-zonal	75.0	24.97	61.8	24.92
Three-zonal	75.8	19.97	62.1	20.33
Four-zonal	69.7	20.56	60.9	22.81
Five-zonal	77.3	25.77	67.8	27.36

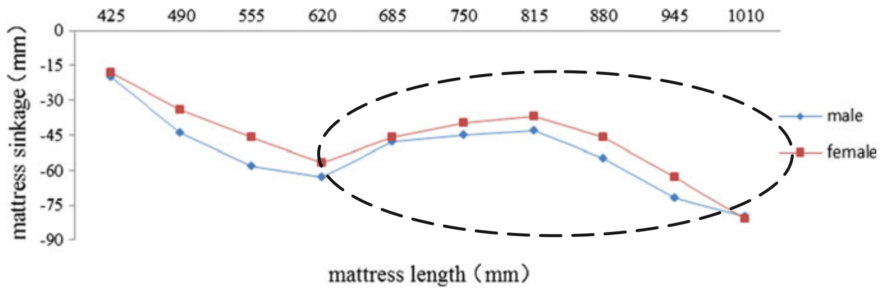

Fig. 4 Comparison of spine alignment of different genders on five-zonal mattress in the supine position

five-zonal spring mattresses, the ratio of back to hip sinkage and back and waist clearance were calculated, as shown in Table 2.

It could be seen from Fig. 4 and Table 2 that, the spine alignment on the three-zonal spring mattress was flat, and on the other mattresses it was curve. The waist and hip sinkage on three-zonal spring mattress were significant larger than that on the other three types of spring mattresses and non-zonal spring mattress got the smallest waist and hip sinkage. Among the three types of zonal spring mattresses, the back sinkage was the largest, the waist and hip sinkage were the smallest on the four-zonal spring mattress. It was due to the small elasticity of back and waist zones in four-zonal spring mattress. In the three-zonal spring mattress, the elasticity of waist and hip zones was large, with small elasticity of head, back and legs zones, resulting in a large sag on the mattress and large waist and hip sinkage.

The ratio of back to hip sinkage reflected the spine alignment in lying position. When the ratio was bigger than one, the spine alignment inclined to back area. The spine alignment inclined to hip area when the ratio was smaller than one. The ratio of back to hip sinkage on the four types of spring mattresses was in the range of 0.6–0.8, which was consistent with the weight ratio of back and hip. Whether male or female subjects, the ratio of back to hip sinkage on five-zonal spring mattress was larger than that on non-zonal, three-zonal and four-zonal spring mattresses. It was due to the elasticity of back zone in five-zonal spring mattress was relatively larger. The elasticity of zones in spring mattress had an effect on the mattress sinkage.

The back and waist clearance could reflect the spine bending degree to a certain extent. In upright position, S-form curvature of spine concaves four to six centimeters. To achieve sleep comfort spine curve is equivalent to the half of it, namely, 2–3 cm. Therefore, as the basis of whether the spine alignment is in natural state, when the back and waist clearance is generally in the range of 2–3 cm, it could be thought comfortable. The back and waist clearance on the four types of spring mattresses was in this range. The back and waist clearance on the three-zonal spring mattress was the smallest, followed by the four-zonal and five-zonal spring mattresses. The back and waist clearance on non-zonal spring mattress was the largest. It was due to the smallest maximum back and hip sinkage and minimum waist sinkage. The largest maximum back and hip sinkage and minimum waist sinkage on three-zonal spring mattress resulted in smaller back and hip clearance.

It could be seen from the spine curve of male and female subjects that, the male of the spine curve was relatively flat, while women's was crooked. The back and waist sinkage of men subjects were larger than ones of women subjects on five-zonal spring mattress, but the hip sinkage was smaller than women's and the ratio of back to hip sinkage of men was larger than women's. The back and waist clearance of men was relatively small than women's on zonal spring mattress, which had a certain relationship with male and female body shape.

3.2 Body Pressure Distribution

When subjects were in the supine position, the main stress areas were limited to occipital, shoulder, elbow, the sacrum and coccyx, ankle, etc. and these body parts would be under more pressure. Figures 5 and 6 showed pressure distribution profile and longitudinal pressure distribution profile of men subjects in the supine position.

It could be seen from Fig. 6 that, the longitudinal pressure distribution profile was in accordance with the stress body parts in the supine position. The pressure on occipital, shoulder, elbow, the sacrum and coccyx, and ankle were large.

After male and female subjects were lying on four spring mattresses in the supine position, the experimental data were statistically processed. Table 3 showed overall maximum pressure, mean pressure and mean contact area of different gender subjects on four different spring mattresses.

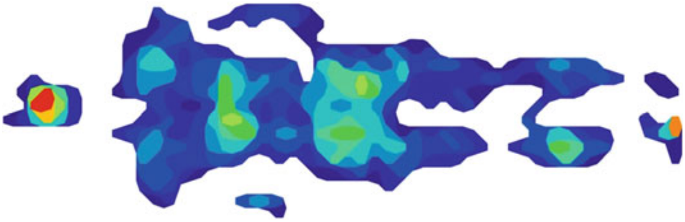

Fig. 5 Body pressure distribution in the supine position

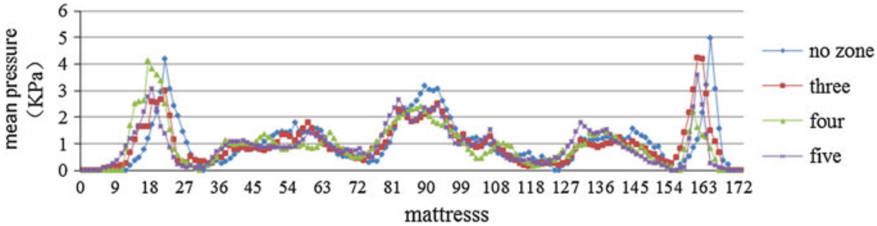

Fig. 6 The longitudinal pressure distribution profile in the supine position

Table 3 Pressure distribution on four types of spring mattresses in the supine position

		Contact area (cm^2)	Maximum pressure (Kpa)	Mean pressure (Kpa)
Male	Non-zonal	3876.42	11.19	1.54
	Three-zonal	4318.35	8.50	1.39
	Four-zonal	4285.48	9.09	1.40
	Five-zonal	4311.67	8.66	1.39
Female	Non-zonal	3547.67	10.78	1.33
	Three-zonal	3619.08	9.53	1.25
	Four-zonal	3555.14	8.36	1.26
	Five-zonal	3632.95	7.99	1.23

In three types of zonal spring mattresses, male subjects' total contact area was relatively the smallest on the four-zonal spring mattress. The maximum pressure and mean pressure were the largest. When male subjects using three-zonal spring mattress, total contact area was relatively the largest. The maximum pressure and mean pressure were the smallest. The total contact area of female subjects was relatively smallest and mean pressure was largest on four-zonal spring mattress. The maximum pressure was the largest on the three-zonal spring mattress. When female subjects using five-zonal spring mattress, the total contact area was relatively the largest, and the maximum pressure and mean pressure were relatively the smallest.

The total contact area, maximum pressure and mean pressure of male subjects were larger than that of female subjects. According to the pressure distribution

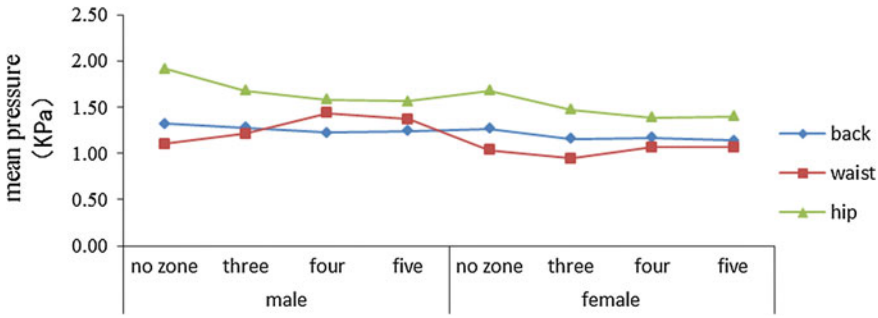

Fig. 7 Mean pressure on each body part in the supine position

parameters, the pressure distribution of male subjects on the three-zonal spring mattress was more reasonable and pressure distribution of female subjects on five-zonal spring mattress was more reasonable.

When subjects were lying in the supine position, the stress parts on the mattress were different and the pressure distribution of each body part was also different. So according to the five body parts such as head, shoulder and back, waist, hip and leg, the pressure distribution data of body parts on four types of spring mattresses were statistically processed. Figure 7showed the results of mean pressure of back, waist and hip on four types of spring mattresses.

It could be seen from Fig. 7 that, men and female subjects mean pressure on hip was largest, back and waist seconded in the supine position. The mean pressure of back, waist and hip on non-zonal spring mattress was larger than that of back and hip on three types of zonal spring mattresses. With the increase of zonal number, mean pressure on back and hip among male subjects decreased, as well as that of female subjects. The mean pressure of waist on three-zonal spring mattress was the smallest among male and female subjects, and mean pressure of back and hip on five-zonal spring mattress was minimum. It was due to the larger elasticity of waist and hip in three-zonal mattress, resulting in larger contact area and smaller mean pressure. The mean pressure of back area on four-zonal spring mattress was larger than that on other zonal spring mattress. It was due to the small elasticity of back and waist areas in four-zonal spring mattress, resulting small contact area and larger mean pressure.

When lying on the mattress, due to the different elasticity of mattress zones, force on each body part differed and contact pressure on spring mattress zones would be different. And due to the individual characteristics, such as fat upper trunk, thin lower trunk, broad shoulder and hip, the weight ratio of the human body part was also different. The results of pressure ratio of each body part on the four types of spring mattresses were showed in Table 4.

Table 4 Pressure ratio on each body part in the supine position (%)

		Head	Back	Waist	Hip	Leg
Male	Non-zonal	10.8	22.6	10.4	37.2	18.8
	Three-zonal	10.0	22.4	10.6	38.2	19.0
	Four-zonal	10.4	23.2	12.6	35.4	18.2
	Five-zonal	9.6	21.8	11.8	38.6	18.0
	Mean	10.2	22.5	11.4	37.4	18.5
Female	Non-zonal	10.8	23.8	8.6	37.8	19.2
	Three-zonal	9.4	23.2	11.0	35.6	21.0
	Four-zonal	10.2	22.6	13.8	31.8	21.8
	Five-zonal	10.6	23.4	12.8	33.2	20.0
	Mean	10.3	23.3	11.6	34.6	20.5

It could be seen from Table 4 that, the pressure ratio of head, back, waist, hip and leg among male subjects were respectively about 10.2, 22.5, 11.4, 37.4 and 18.5 % and those among female subjects were respectively about 10.3, 23.3, 11.6, 34.6 and 20.5 %.

4 Conclusions

The effect of zonal spring mattress on body pressure distribution and spine alignment in the supine position was studied in the paper. As to the spine alignment, the spine alignment on the three-zonal spring mattress was flat, and on the other mattresses it was curve. The back and waist clearance was in the range of 2–3 cm on the four types of spring mattresses. The ratio of back to hip sinkage on the four types of spring mattresses was in the range of 0.6–0.8, which was consistent with the weight ratio of back and hip. The ratio of back to hip sinkage of men was larger than that of women. The back and waist clearance of men was relatively small than that of women on zonal spring mattress, which had a certain relationship with male and female body shape.

In the case of pressure distribution, the total contact area was the smallest on non-zonal spring mattress, and maximum pressure and mean pressure were relatively the largest. The total contact area, maximum pressure and mean pressure of male subjects were larger than that of female subjects. The pressure distribution of male subjects was more reasonable on the three-zonal spring mattress and that of female subjects was more reasonable on five-zonal spring mattress.

With the increase of the zonal number of zonal spring mattress, it is beneficial to match the anthropometric measurement of each body part and biomechanical characteristics. But the elasticity distribution of each zone in zonal mattress decided whether the mattress is comfortable or not. The zonal mattress comfort mostly depends on the elasticity distribution. Therefore, it is necessary do further research on elasticity distribution of each zone and explore the relationship between elasticity distribution and mattress comfort in zonal mattress.

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Ergonomics Evaluation of Virtual Maintenance Process Based on Fuzzy and AHP Method

Fu-yang Yu, Qing Xue, Wei Meng and Min-xia Liu

Abstract Product maintainability is an inherent property, which is formed in the product design stage and is demonstrated through later use. Ergonomics is an important aspect of the maintenance. In this paper, virtual maintenance process was modeled according to actual maintenance process, and ergonomic factors, which affected maintenance process, was analyzed in terms of reachability, operation space, visibility and comfort. Analytic hierarchy process (AHP) method was utilized to assign a weight to each factor, and virtual maintenance process was evaluated by fuzzy comprehensive method. Finally, this method was applied and verified by installation of return module oxygenation wrench, through evaluating virtual maintenance process. Some potential ergonomic issues can be found and dealt earlier in the maintainability design of complex equipment.

Keywords AHP · Ergonomics · Fuzzy theory · Virtual maintenance

1 Introduction

As a key factor to determine product repair quality; maintainability is formed in the stage of product design, and influences the entire life cycle of product. Good maintainability can reduce maintenance costs and improve utilization rate of the product. Maintainability becomes an essential attribute of product characteristics. The principal factors affecting maintenance are reachability, simplified design, modularization, standardization and interchangeability, error-preventive design, testability and ergonomics. According to different analysis objects, maintainability can be divided into maintenance process attributes and product attributes. The former attributes, which are mainly related to human, demonstrate in the process of

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maintenance, and the latter is the factors mentioned above in addition to ergonomics. Automation technology in the industry is very mature and most of the industrial operation can be replaced by robots, however, due to the complexity of product maintenance process and skills required for maintainers, manual maintenance is still necessary, thus inevitably causes fatigue or even security risks. In order to make human fast, comfortable and safe to complete the maintenance, it is needed to consider ergonomics principle in maintenance and evaluate the maintainability. The evaluation results can give feedback to product design in order to improve the maintainability of products.

In early time, maintainability evaluation was mostly achieved through check list or the physical model. Check list classifies all factors that affect maintainability, and every factor has several grades. Then the check list will be reviewed by experts. This method relies much on the experience of experts, so quantitative analysis is missed. The method of the physical model is to create a physical prototype after the product design. The maintenance process will be simulated with actual maintenance tools. The product will be redesigned once maintainability problems are found. Maintainability problems in product design can be discovered through this method, but time is relatively delayed, which increases lead time and costs of product development. With the development of computer science, the analysis of product maintainability is mostly made with software. This method is much more intuitive and accurate than expert methods. Popular maintainability analysis software includes JACK, DELMIA and so on. These softwares support the import of 3D product model. Maintenance process is simulated and analyzed by creating virtual human. Ergonomic evaluation can also be made in this way. Huang et al. researched on the construction of qualitative evaluation system and revealed that ergonomics was a significant factor affecting product maintainability [1]. Regazzoni and Rizzi used digital human technology to simulate the process of maintenance and assembly. They evaluated the visibility, accessibility and fatigue and then gave an evaluation method based on simulation system. Their research changed the situation without virtual ergonomics simulation [2]. Liang Ma et al. analyzed the fatigue in the maintenance process. They divided the fatigue of manual operation into different levels and gave a fatigue analysis model of embedded virtual environment platform [3]. Geng et al. evaluated the safety of the product. The safety of human was also important in the maintenance process [4]. The above scholars concentrated on the selection and analysis of the maintainability-related ergonomics index. However, it is also important to build a proper ergonomics evaluation model. Because most ergonomics indexes in maintenance process are qualitative, which cannot be used to get an accurate ergonomics evaluation of product maintainability. So many researchers build evaluation models to make the evaluation more accurate. Slavila et al. evaluated the maintainability during the product design process with the fuzzy theory. They gave qualitative indexes some fuzzy values [5]. Lu and Sun built a virtual product maintainability evaluation model based on fuzzy multiple attributes decision making theory [6]. Xu et al. considered the relation between maintainability indexes and design indexes. They built an evaluation model with fuzzy gray correlation theory to guide the product design [7].

Generally speaking, the processes of maintenance of ergonomic evaluation are as follows. Firstly, put forward the factors affecting maintenance. Then, use virtual reality technology to establish a 3D simulation environment and make simulation of maintenance process to analyze the factors. Finally, make a comprehensive evaluation of product maintainability by an appropriate method.

Research in above has made great progress of ergonomic evaluation. However, there still are some deficiencies.

- First, product design attributes were more considered when establishing product maintainability index system, and under considered ergonomics indicators.
- Research of reachability was concerned if human body could reach repair parts, without considering the effect of operation space in the maintenance process. For example, human take maintenance work in a small space, even human can reach the maintenance site, but the space of human arm movement is insufficient and leads to maintenance task failure.
- In the maintenance process, the maintenance operator often needs to use the tool to carry out the disassembly. Most research hasn't considered the space of maintenance tools.

Based on the above literature review, this paper has analyzed the ergonomic factors in virtual maintenance process. Each ergonomic factor was given corresponding weight by AHP. After that, fuzzy comprehensive evaluation method was used to evaluate the maintenance process. At the end of this paper, the analysis model was applied to the assembly process of oxygenation wrench of return module.

2 Ergonomics Index Evaluation Methods

2.1 Ergonomics Index in Maintenance Process

Many ergonomic factors affect product maintenance. Analysis based on virtual maintenance process mainly includes reachability, visibility and comfort.

Reachability reflects the impact of working space and parts layout of maintenance work. Generally reachability includes entity reachability, visibility and operation space. Operation space can be divided into human operation space and operation space of tools. Within the maintenance process if space is insufficient or when there are obstacles, human activities or tools using will be limited. Visibility is to decide whether maintenance parts are in the observation fields. Comfort is a subjective feeling in the process of maintenance, which includes physical and psychological factors, such as human posture, work load, fatigue and etc. Improper maintenance posture and excessive operating load will cause maintenance work inefficiency or even affect people's health and life safety. In summary, based on the virtual maintenance process, an ergonomic index system was shown in Fig. 1.

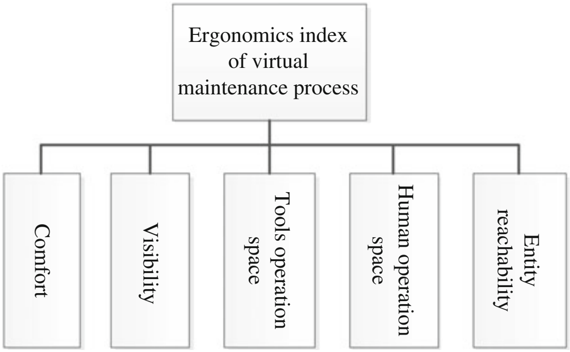

Fig. 1 Ergonomics index system

2.2 Entity Reachability Evaluation

Entity reachability reflects whether an operator can get repair parts during maintenance work. In the process of virtual maintenance, it can be judged based on whether maintenance parts are in the range of human arm movement. The operator's reach zone can be got in JACK, when maintenance part is in human reach zone, it can be reached, and otherwise, it is unreachable.

2.3 Human Operation Space Evaluation

It is required for an operator to reach maintenance parts. But for complex products, compact internal structure requires operator to pass through the passage or bypass other parts of maintenance. It is necessary to consider human operation space.

According to ergonomic principles of operating range, human body in standing posture, the operating range can be divided into horizontal and vertical operating range [8]. Fig. 2a, b give arm operation area division in horizontal and vertical directions. There are three work areas for each direction. Three work areas correspondingly represent, "fine operation area(I)", "valid operation area(II)" and "invalid operation area(III)". In Fig. 2, r_1 and r_2 represent the radius of comfortable and valid operation zone. d_1, d_2 and d_3 represent human operation space division parameters in vertical direction. According to the size of Chinese and 50th percentile Chinese males, each parameter values is as follows:

$$r_1 = 39\,\text{cm}, r_2 = 59\,\text{cm}.$$
$$d_1 = 750\,\text{cm}, d_2 = 1018\,\text{cm}, d_3 = 1370\,\text{cm}.$$

In the process of virtual maintenance, the analysis of operation space is as follows:

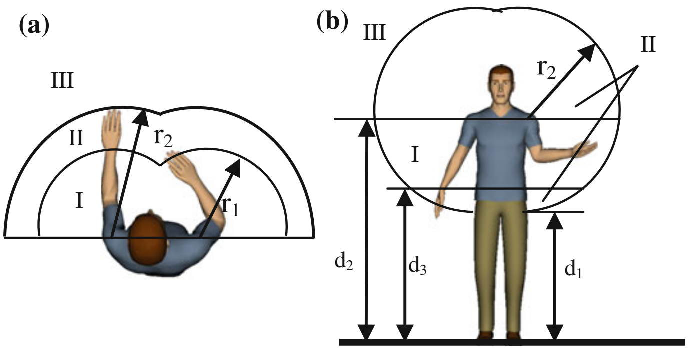

Fig. 2 Reach envelope in horizontal and vertical

(1) Use simulation software to generate maintenance process and arm reachable zone.
(2) Analyze maintenance work area of arm, it is represented by (H_i, V_j), H and V represent horizontal vertical directions, i and j represent area level (i, j = I, II, III).
(3) Evaluate maintenance operation space. Make Boolean operations for H_i and V_j to get the evaluation results, evaluation method is in Table 1

2.4 *Tools Operation Space Evaluation*

Most of the maintenance operation should be matched with the tools. In the product design stage, designer focuses more on maintenance reachability but overlooks maintenance tools working space. Within the maintenance process, it often occurs that a maintainer can reach the repair site, but there is no enough space when using tools. So it is important to analyze tools' working space. Collision detection can quickly analyze if tools have interference with components.T_i (i = 1,2,3,…,n) represents the tools in the maintenance process. β_{T_i} represents whether tools interfere with other parts. For tool T_i, when there is no collision, $\beta_{T_i} = 1$, else $\beta_{T_i} = 0$. All tools' work space evaluation results is,

Table 1 Evaluation of human operation space

Boolean operation for H_i and V_i	Evaluation grade
$H_I \wedge V_I$	A
$(H_I \wedge V_{II}) \vee (H_{II} \wedge V_I)$	B
$H_{II} \wedge V_{II}$	C
$H_{III} \vee V_{III}$	D

$$\Gamma = \sum \beta_{T_i}/n, \quad \Gamma \in [0, 1], \tag{1}$$

Table 2 shows evaluation criteria.

2.5 Visible Evaluation

Visual evaluation is to ensure an operator has a clear vision to maintenance parts. When human in natural stand, the normal line of sight in the vertical direction is 15° below horizontal line. This is the most comfortable body's natural line of sight angle. In the line of sight up and down 15° is the best human view field. The normal line of sight 40° up to 20° down is the human maximum vertical view field. In horizontal direction, human eyes center line about 15° is the best visual angle range of the human eye, and the center line about 35° is the eye of the maximum range of vision in the horizontal direction [9]. According to the above mentioned criteria, the optimal angle of view and the maximum angle of view can be set up, and from the physiological characteristics of the human eye, we can know the two regions are oval, as showed in Fig. 3. According to the visual angle of the eye, the visual cone can be created in the simulation software. The evaluation of the control is in Table 3.

2.6 Human Comfort Evaluation

Because operator needs to withstand the pressure of tools and repair parts during maintenance, working at a fixed position for a long time may cause damage to the body.

Table 2 Evaluation of tools operation space

Γ	Evaluation grade
$\Gamma > 0.9$	A
$0.7 < \Gamma \leq 0.9$	B
$0.5 < \Gamma \leq 0.7$	C
$0 < \Gamma \leq 0.5$	D

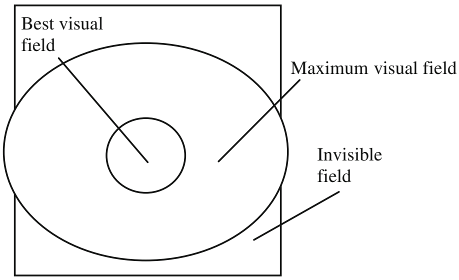

Fig. 3 The human eye's visual field

Table 3 Maintenance visibility evaluation

Maintenance site location in the cone	Evaluation grade
Best visual field	A
Part in the best visual field	B
Maximum visual field	C
Part or full in invisible field	D

Fast upper evaluation (RULA) is the most widely used method for evaluation of the risk of human upper limb currently [10]. Process using RULA method to evaluate operation comfort is as follows:

(1) Establish the virtual simulation of the maintenance process, virtual simulation should meet actual maintenance process.
(2) Select the key maintenance posture to make RULA analysis. JACK can be used to make the RULA analysis. Finally, the RULA score was obtained by entering the actual operation index.

Evaluate human posture according to RULA score (1–8). Table 4 gives evaluation of human comfort.

3 Ergonomics Comprehensive Evaluation

In order to evaluate maintenance ergonomics, this paper developed a comprehensive solution with fuzzy and AHP theory. And the basic steps are as follows [11].

3.1 Establishment of Fuzzy Matrix

(1) Establish factors set

$U = \{u_1, u_2, \ldots u_m\}$ $u_i(i = 1, 2, 3, \ldots, n)$ is the factors that affect the maintenance process.

(2) Establish alternative set

Table 4 Human comfort evaluation

RULA score	Posture evaluation	Evaluation grade
1–2	Don’t need to change posture for a long time	A
3–4	Need to change posture after a long time maintenance	B
5–6	Need to change posture from time to time	C
7–8	Need to change posture immediately	D

$V = \{v_1, v_2, \ldots v_n\}$ $v_i(i = 1, 2, 3, \ldots, n)$ is the evaluation grade for ergonomic factors.

(3) Construct the judgment matrix

Make single factor evaluation for factor u_i. Determine the membership r_{ij} of u_i to $v_j(j = 1, 2, 3, \ldots, n)$, $r_{ij} \in [0, 1]$.

Then the fuzzy relationship R from U to V can be got:

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}$$

3.2 Establishment of Weight Set

In the comprehensive evaluation process, determining the weights is very important. AHP method was used to figure out the weight of various layers and give various factors $u_i(i = 1, 2, 3, \ldots, n)$ to appropriate weight w_i(i = 1, 2, 3, …, n), the steps are:

(1) Construct the judgment matrix

Judge the importance of factors named from $P_1$to P_n in the same layer by the scale of 1–9, then the judgment matrix P is constructed:

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix}$$

p_{ij} refers to the result of the comparison of p_i and p_j.

(2) Calculate the maximum characteristic radix and eigenvector

Solving the weight of each factor is actually the calculation of the maximum characteristic radix and eigenvector. The calculation method can refer to Saaty's paper [12]. Finally, we can get the factors weight:

$$W = \{w_1, w_2, \ldots w_m\}$$

3.3 Fuzzy Comprehensive Evaluation

After getting fuzzy matrix and weight of factors, the comprehensive evaluation for single level factors is:

$$B = W \cdot R = (b_1, b_2, \ldots, b_n)$$

B is fuzzy comprehensive evaluation set in alternative set *V*. $b_j(j = 1, 2, \ldots, n)$ is the membership degree of fuzzy evaluation set *B* for the alternative set *V*.

4 Results

4.1 Case Study: Assembly of Return Module Oxygenation Wrench

Oxygenation wrench has to be installed manually on an oxygenation valve, which is the key equipment for environmental control and life support subsystem of spacecraft. It is located on the wall of return module. Due to lack of operation space, heavy operating tools and human factors, the assembly of oxygenation wrench can't meet the requirement of the process, so it is necessary to analyze ergonomics factors in the assembly process. The assembly of oxygenation wrench is given in Fig. 4.

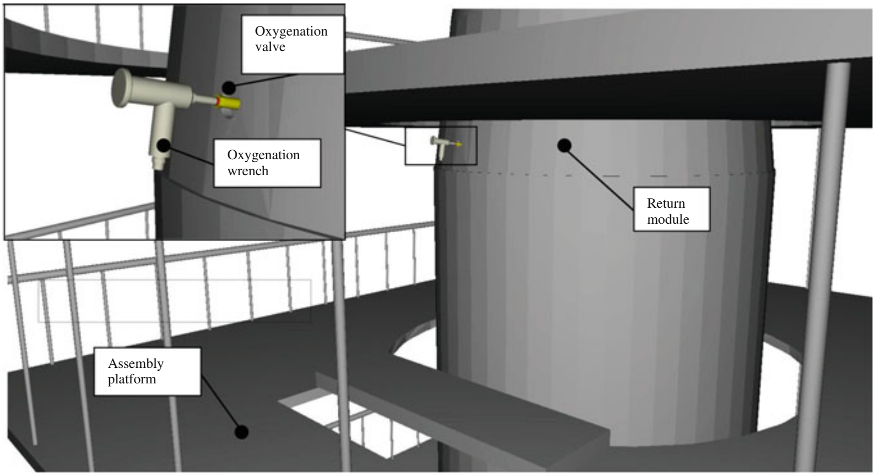

Fig. 4 The installation of oxygenation wrench in virtual environment

Table 5 Weight distribution of evaluation factors

Evaluation factor	u_1	u_2	u_3	u_4	Weight
u_1	1	5	3	7	0.580
u_2	1/5	1	1	3	0.158
u_3	1/3	1	1	5	0.205
u_4	1/7	1/3	1/5	1	0.057

4.2 Ergonomics Evaluation of Assembling Oxygenation Wrench

Above solution has been applied to the ergonomic evaluation of assembling oxygenation wrench. First, the evaluation factors set U and alternative set V were created:

$$U = \{\text{Human operation space, Tools operation space, Visibility, Comfort}\}$$
$$V = \{A, B, C, D\}$$

Then, the assembly process was simulated in JACK. Human operation space (u_1), tools operation space (u_2), visibility (u_3) and comfort (u_4) have been analyzed. The fuzzy comprehensive evaluation matrix is as follows.

$$R = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Through experts' assessment, we got the weight for each factors by AHP, finally result was show in Table 5. So the evaluation result was:

$$B = w \cdot R = \{0.000, 0.738, 0.057, 0.205\}$$

5 Discussion

The aim of evaluation is helping a person make decision according to evaluation results. Above evaluation result show that the final grade is "B", there are still several items to be discussed.

(1) For weight analysis of the ergonomics factors, human operation space was more focused, and human comfort was less. Because if human operation space is not met, maintenance cannot be carried on, and human body can overcome the discomfort in some conditions.

(2) There are still 20.5 % of evaluation results focusing on “D” grade. The main reason for this result is that visibility is too bad in the oxygenation wrench assembly process, so human visibility must be improved.
(3) This case just used to illustrate the application of the methodology and more detailed recommendations will not be discussed here because of length constraint.

6 Conclusion

In this paper, an ergonomics evaluation model is proposed, which is based on the simulation of maintenance process, we use linguistic variables and fuzzy theory to evaluate unquantifiable factors. For each ergonomics factor, we get the weight by AHP and give a grade score method. This evaluation method can be used in the stage of product design and improve the ergonomics features in future.

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Real-Time Visibility and Traceability Framework for Discrete Manufacturing Shopfloor

T. Wang, Y.F. Zhang and D.X. Zang

Abstract Modern manufacturing shopfloors suffer from a bottleneck of capturing and collection of real-time field information. According to the analysis of the new requirements of the shopfloor management faced by current discrete manufacturing enterprises, a real-time visibility and traceability framework is proposed. Under this framework, the main modules including the configuration of the IoT-enabled sensing environment, manufacturing information process, cloud based real-time manufacturing services, are integrated. The presented framework and modules will provide an important foundation for enhancing the capabilities of real-time sensing, dynamical tracing, real-time predication and intelligent management of the discrete manufacturing system.

Keywords Real-time · Discrete manufacturing · Shopfloor management

1 Introduction

With the increasing competitiveness and globalization of today's business environment, manufacturing enterprises have to seek new solutions to achieve the economic objective for better surviving. As a result, real-time visibility and traceability play an important role for shopfloor management.

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According to Zhang et al. [1, 2], the discrete manufacturing systems suffer from a bottleneck of capturing and collection of real-time field information. For example, the availability of raw materials is not known at the time of production scheduling; Work In Progress (WIP) inventories are highly dynamic—changing frequently between production stations or lines; The loading level of work orders at specific machine is unknown to the scheduler and production planner, leading to further line unbalances; the real-time status of production orders and production scheduling are not known.

Therefore, it is essential to integrate the advanced technologies such as the Internet of Things (IoT) and cloud computing to capture the real-time manufacturing data and support further optimal production decision.

In the recent decades, rapid developments in wireless sensors, communication and information network technologies (e.g. radio frequency identification - RFID or Auto-ID) have provided technologies for automatically capturing the moveable objects. In 1990s, Udoka [3, 4] discusses the roles of Auto ID as a real-time data capture tool in a computer integrated manufacturing (CIM) environment. Johnson [5] presents a RFID application in a car production line to implement data track for quality management. Shmitted et al. [6] analyze the main factors that affect the application of RFID technology in automobile industry. Zhang et al. [7] describes an optimization method for shopfloor material handling based on real-time and multi-source manufacturing data. A conceptual Wireless Manufacturing (WM) framework is discussed by using the RFID technology to collect and manage the real-time data from manufacturing shop-floors [8]. Equipped with active RFID tags, an innovative and ecological packaging/transporting unit named MT has been implemented by the Spanish company Ecomovistand for the grocery supply chain [9]. An RFID-based smart Kanban system is designed to implement JIT (Just in Time) production and control the WIP (Work in progress) stock [10]. In order to bring traditional machines together for remote machining, a framework called Wise-Shop-Floor [11] is developed by Wang et al., which provides basic functions for sensor data collection as well as for Web-based monitoring and control. By combing agent and RFID technologies, a creative concept of Smart Gateway [12] is presented and designed to capturing the real-time manufacturing data of the workstation side for implementing Ubiquitous Manufacturing.

Despite of the above progresses, the following research questions still exist in applying real-time visibility and traceability of discrete manufacturing enterprises. The first challenge is how to establish an overall manufacturing data capturing and integration framework to track and share the data between the up-level enterprise information systems and manufacturing execution layer? The second challenge is how to process the manufacturing data through the timely captured events of the sensors? The third challenge is how to use cloud computing technology to provide easily using manufacturing application services.

Considering the advantages of the Internet of Things and sensor technology, in this research, a real-time visibility and traceability framework is proposed. Under this framework, the main models including the configuration of the IoT-enabled sensing environment, manufacturing information process, cloud based real-time manufacturing services, are integrated. The real-time visibility and traceability tools will be published as cloud service and its output can be easily invoked and visited by the up-level enterprise information systems.

2 Literature Review

The term of the IoT has first been proposed by Kevin [13]. It refers to uniquely identifiable objects (Things) and their virtual representations in an Internet-alike structure.

Currently, typical challenges that manufacturing enterprises are facing are compounded by lack of timely, accurate, and consistent information of manufacturing resources during manufacturing execution. Real-time manufacturing tracking and tracing plays a significant role in improving enterprises performance so as to fulfill customers' needs in time [14–16]. A conceptual Wireless Manufacturing (WM) framework is discussed by using the RFID technology to collect and manage the real-time data from manufacturing shop-floors [17]. Equipped with active RFID tags, an innovative and ecological packaging/transporting unit named MT has been implemented by the Spanish company Ecomovistand for the grocery supply chain [18]. The RFID technology is used to be a promising technology to track movements of goods in supply chain [19]. For better management in real-time warehouse operations, a RFID case-based resource management system is designed in [20]. A market-based approach for dynamic vehicle deployment planning using RFID information is present in [16]. In order to explore the potential business cases for RFID, a case study using actual RFID data collected by a major retailer for the cases shipped by one of its major suppliers is reported in [21]. The positive value of location-enabled RFID information on delivery chain performance is analyzed in [22]. Several relevant models incorporating with RFID technology have been applied to real-time manufacturing cases, an agent-based smart gateway for RFID-enabled real-time wireless manufacturing [23], RFID-enabled fixed-position assembly [24], wireless shop-floor inventory management [25] and wireless production line [26]. A distributed work flow management model from shop-floor level [27] is established to define, configure and execute the real-time RFID enabled manufacturing processes. By applying the RFID technologies, the real-time shop-floor material management is implemented in [28].

3 Real-Time Visibility and Traceability Framework

The overall framework of real-time visibility and traceability for discrete shopfloor designed in this research is shown in Fig. 1. It aims to apply the conception and technologies of IoT and sensor technology to capture the real-time manufacturing

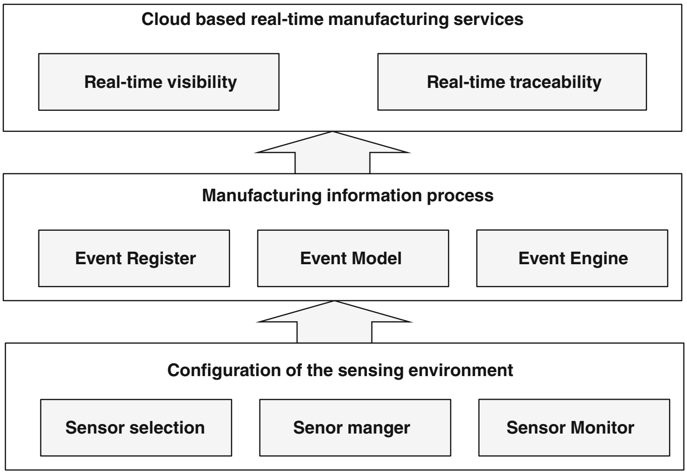


Fig. 1 Real-time visibility and traceability framework

status of different manufacturing resources. Its input is the real-time data captured by the installed sensor devices such as bar-code, RFID etc. Its output is the real-time manufacturing information of the shopfloor such as real-time production progress, real-time WIP stocks etc.

Three modules are designed in the real-time visibility and traceability framework. They are briefly described as follows.

3.1 Configuration of the Sensing Environment

Because the real-time manufacturing data comes from the sensor devices, it is necessary to configure the sensors. Configuration of sensor environment is responsible for building up a low-cost and high-reliability network for capturing the real-time manufacturing data. It consists of four steps. At first, a configuration model of sensor networks should be established to measure the different parameters. This model is used to describe and define not only the manufacturing things such as operators, pallets, materials, machines etc. equipped with all kinds of sensors but also the positions of the fixed sensors. Then, the objectives and constraints of the formed sensors networks should be established, for example, the total cost of the sensors can be the objective function. After solving, an optimal configuration solution of the sensor networks can be obtained. This module includes three components, namely sensor selection, sensor manger and sensor monitor.

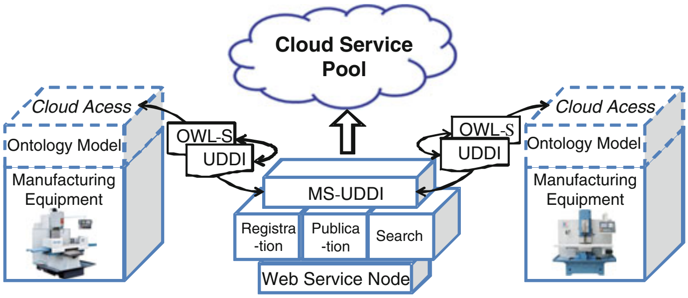


Fig. 2 Cloud based real-time manufacturing services

3.2 Manufacturing Information Process

It is difficult to share the manufacturing information of execution with the heterogeneous systems due to the different manufacturers adopting the different information management systems. Therefore, manufacturing information process is used to deal with the insignificant data captured by sensors to form meaningful manufacturing information. Take RFID technologies as an example, in sensing and capturing stage, the EPC of each tag attached to the manufacturing things is sensed and captured. To implement this objective, the event based architecture is used. This module includes three components, namely event register, event model and event engine.

3.3 Cloud Based Real-Time Manufacturing Services

As seen in Fig. 2, cloud based real-time manufacturing services are used to provide important real-time information of the key points of the manufacturing system. It can be regarded as the top level services of the manufacturing system. Four types of services namely real-time process monitor service; real-time production progress service; real-time machine status service; and real-time manufacturing tracing service are designed in this framework. These services can work as an independent tool, as well as a plug-in unit integrated with the third part systems. The real-time data of the manufacturing resources is the basic input to this module.

4 Application Scenario

For simplicity understanding, some basic manufacturing resources are selected for configuring a practical proof-of-the-concept sensible manufacturing shopfloor. This demo discrete shopfloor consists of the following main components, namely,

- Six main workstations for producing part/assembly/product;
- Some shelves for storing materials, WIP and finished products;
- Six robot arms for loading and unloading items;
- One AGV for transporting items (Table 1).

After configuring the sensors across the shopfloor, the real-time manufacturing information can be captured. For example, when an operator (man) comes to the machine, this event can be tracked by the sensor installed at the machine. Next, the operator can check materials or tools needed according to his task. The check materials process is also executed by the sensor reader installed at the machine because each pallet with all kinds of materials is attached tag. During operation stage, the tagged critical component's status can be tracked by the same senor, and the consumed materials can be calculated based on the product Bill of Materials (BOM). Therefore, the real-time visibility and traceability of manufacturing resources such as men, machines, materials and orders can be achieved.

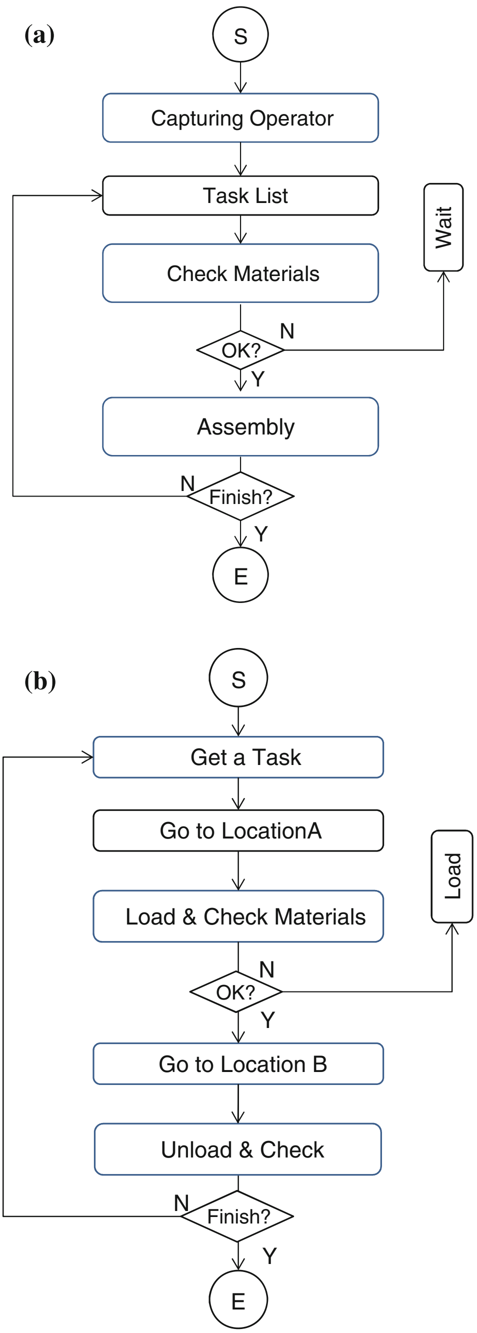
For better understanding, we would like to introduce how to track and trace the real-time information of manufacturing resources under the IoT enabled sensing environment.

Generally, there are two types of manufacturing activities in shopfloor, namely manufacturing operation and material logistics. Figure 3a, b illustrate how the real-time information of manufacturing resources can be tracked during the two manufacturing activities execution stages separately.

Table 1 Development information of auto-Id devices in a manufacturing shopfloor

Sensor type	Manuf. resources	Objective
RFID reader	Machine	Track the operators
RFID reader	Machine	Track the pallets, the critical component and the critical tools
RFID reader	AGV	Track the pallets
RFID reader	Robot arm at the shelf	Track the pallets
Tag	Man	This tag is used by staff. The real-time information of each man can be tracked and traced
Tag	Pallet	This tag is used by pallet. The real-time information of each pallet with materials can be tracked and traced
Tag	Each position of the shelf	The real-time materials information of each position of the shelf can be tracked
Tag	Critical component	This tag is attached to the critical component of a product as a mobile memory for tracking and tracing the real-time information from materials to product
Tag	Critical tool	This tag is used to track and trace the real-time information of the critical tools

Fig. 3 Work flows of real-time manufacturing information tracking. **a** Manufacturing operation flow. **b** Logistics flow



As seen in Fig. 3a, a manufacturing operation can be regarded as a series of relevant processes, namely check a manufacturing job, check materials, assembly, finish one WIP, repeat assembly and finish job. At first, when an operator (man) comes to the machine, this event can be tracked by the RFID HF reader installed at the machine. Next, the operator can check materials or tools needed according to his task. In fact, because each pallet with all kinds of materials is attached tags, the check materials process is also executed by the RFID UHF reader installed at the machine. If the materials and tools are well prepared, the operator can work at this machine. During operation stage, the tagged critical component's status can be tracked by the RFID UHF reader installed at the machine, and the consumed materials can be calculated based on the product BOM (Bill of Materials). Therefore, the real-time information of manufacturing resources such as men, machines, materials and orders can be tracked during execution stage. The above processes repeat until all the tasks allocated to this machine and operator are accomplished.

Figure 3b shows the real-time information capturing of a logistics activity. When an AGV is assigned a move task, firstly, it will go to the source location (e.g. Location A) for taking items. On the way, the reader on the AGV knows its current location by reading the tags attached to the different locations. Once the AGV arrives at the right location (e.g. Site A), it is ready for picking up items. During the picking up, each item entering the AGV will be captured until the required quantity is met. Then, the AGV will go to the target location (e.g. Location B) for unloading items similarly. At each stage, the real-time changes of status of the AGV and material items could be tracked and traced.

5 Conclusion

This paper has introduced the techniques of IoT to discrete manufacturing shopfloors to implement real-time visibility and traceability. The overall framework and its main modules are put forward. By attached sensors to manufacturing resources, the manufacturing machines can be smart and have the sensing capability. Under this framework, the main modules including the configuration of the IoT-enabled sensing environment, manufacturing information process, cloud based real-time manufacturing services, are integrated.

The above framework and relevant methods of real-time visibility and traceability of discrete shopfloors just provide a kind of useful infrastructure to make the manufacturing objects be real-time visible and traceable. Future research works will focus on how to apply the architecture and methods to real-life manufacturing enterprise such as automotive industry.

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Study on the Improvement of Outpatient Business Process in Some 3-A Grade Hospital

Ming-jie Wang, Peng Liu, Sheng-qian Jiang, Hong Gao, Yu Yang and Xin Chen

Abstract This paper carried out an optimal method of the out-patient process in some 3-A grade hospital with queuing theory. Firstly, a simulating model was construct, and then the operation indicators was analyzed. Next, the bottlenecks and quantitative improvement of out-patient system were identified so as to make the optimization scheme more convincing. After the improvement and optimization, the waiting time of patients within the out-patient system and operating costs were greatly reduced, which could improve the hospital's revenue.

Keywords System simulation · Out-patient department · Process optimization · Queuing theory

1 Introduction

With the enhancement of people's health consciousness, patients' requirements of the health service level are constantly increasing. The rational optimization of hospital resources, as well as obtaining the maximum economic benefit and social benefit, has become a great challenge to the current hospital management [1, 2]. Healthcare managers should analyze the operation law of out-patient service process, explore the point link of process reengineering, find out the "bottleneck" in each medical link among various processes in the out-patient clinic and resolve these problems one by one, so as to attain the purpose of reducing the waiting time of patients. As for the above discussed problems, this research has a certain theoretical significance and practical application value.

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2 Background and Hypothesis

Nowadays, the application of the theory of process reengineering in hospitals has become more and more mature. Preater [3] have made lots of researches on the queuing model in simulation mode, and verified the effectiveness of various service modes in different treatment environment; According to Fehrman et al. [4], they have reset and optimized operation process, and reconfigured resources in the operating room, thus effectively improving the treatment efficiency of patients and the resources utilization; Yancer Bar-Yam [5] has discussed multi-scale complex system; Roth et al. [6] have believed to regard the process as guide and improve it from the interests of both the hospital and the patients. This paper will regard outpatient clinic of a certain large tertiary comprehensive hospital as the research object, and establish a system simulation model. This paper focuses on the study of patients flow in general outpatient clinic.

In order to remove some unrealistic expectations or misunderstandings in the simulation process, we firstly make the following assumptions:

1. There is no function of making an appointment in the outpatient clinic.
2. Patients queuing structure: the model of many service stations with queuing in a single line; the queuing rule: first come first served.
3. There are only three kinds of patients: ones with newly diagnosis, subsequent visit and the third diagnosis, without taking other types of patients into consideration.
4. The system of outpatient clinic is passive. In the passive system, solid flow is determined by the requirements of the rest steps in the process. Once a patient arrives at the clinic and registers, he or she can be treated after waiting for the doctor to get free, and then proceed to the next step, ignoring the phenomenon of patients' leaving without be treated.
5. The outpatient clinic is a perfect service and information system.
6. In this paper, the simple model is mainly to avoid the interference of some artificial factors in implementation and efficiency of the treatment process.

3 Model and Validation

3.1 Arrival Rate and Service Structure

Each link in the outpatient process involves the problem of patients' waiting in line. Each queuing system involves in the following three aspects: the arrival pattern, queuing rules, service station number and the service rate distribution [7].

The system set up two registered windows in total, which are independent respectively. This paper determines the period of observation for 5 days, and each sample for a minute. So 290 min collected from Monday to Friday are equal to 290 samples, and then the number of patients' arrival per minute will be made a statistical analysis.

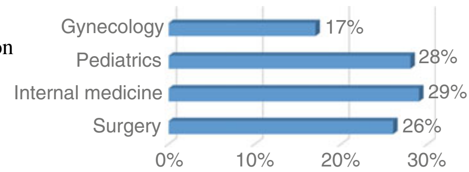


Fig. 1 Probability map of patients' distribution

According to the statistical results, an average rate of outpatients is 2.57 persons/min, and the paper will regard the possibility of outpatients' arrival at each department as the probability of patients' transition to each department by using the research method of relevant literature [8]. As is shown in Fig. 1, the results that are reached by multiplication between the average rate of registration and transition probability will be as the average arrival rate of visiting patients in each department, which can be seen as Table 1.

The outpatient service systems researched by this paper are all multi-service counter queuing system, the service time distributions of system are also independent with each other. We can successively obtain the service time functions in hospital system, as shown in Table 2.

3.2 *Model Outline*

Concept model of outpatient service system is shown in Fig. 2, corresponding system queuing model is shown in Fig. 3.

From the simulating model of the whole system, we can see that we only need to get the disjunction distribution of patients' arriving time at registration office of hospital's outpatient service department. We can know the disjunction distribution of arriving time of producer from the statistics, and we have already got the service parameter of each service counter, as shown in Table 2; we can set the manufacturing time of entity in model directly according to the data in Table 2 in simulating model. In this paper, radiology department model, and charging and medicine taking model. Outpatient service system model is mainly taken apart into following subsystem models: registration model, doctor visiting model.

Table 1 The average arrival rate of visiting patients in each department

Department	Internal medicine	Surgery	Pediatrics	Gynecology	X-ray department	Fare collection	Pharmacy
λ	0.75	0.67	0.43	0.71	0.74	1.84	1.84

Table 2 Service parameter of each search counter

Technical office	Average service time (s)	Distribution of Average service time	Number of service counter
Registration office	48.49	Negative exponential distribution	2
Medicine	361.26	Negative exponential distribution	4
Surgery	183.00	Negative exponential distribution	2
Paediatrics	441.00	Negative exponential distribution	3
Gynaecology	418.00	Negative exponential distribution	4
Registration office of radiology department	98.49	Negative exponential distribution	2
Casher of radiology department	49.46	Negative exponential distribution	1
Radiography room of radiology department	554.82	Negative exponential distribution	3
CT inspection chamber	539.84	Negative exponential distribution	2
Casher	78.64	Negative exponential distribution	2
Medicine receiving	147.43	Negative exponential distribution	3

3.3 Model Validation

Two steps shall be processed for testing if established model is reasonable: test and conformation [9, 10].

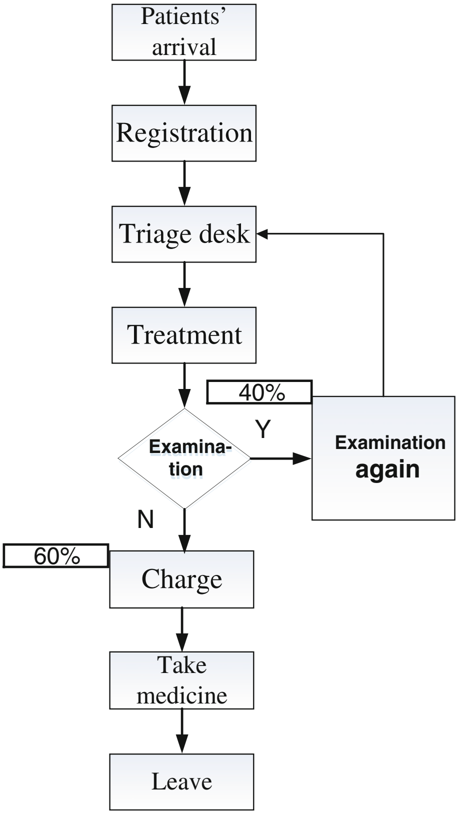
1. Model test

In Flexsim simulating software, the system has self-test function, which can automatically test if the simulating model established by user has logical fault or unreasonable input and output.

2. Model confirmation

This paper uses the length of queue waiting time as evaluation index to evaluate various links of outpatient service system then improve it. Before having simulating test, we shall confirm the time of required simulation and use statistics method to analyze the simulation result of registration office; it can finally confirm the expected 95 % queuing waiting time's confidence interval is within and it need to be stimulated for 28 times. It can be known from the result that the average waiting time at registration office for patient is 72.0359 s, but we can see the statistics data that the time is 1–2 min in actual system, therefore, the result gain from the

Fig. 2 Concept model of outpatient service system



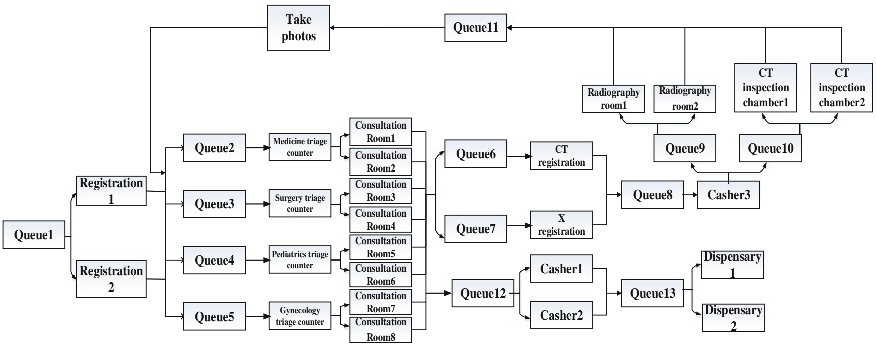


Fig. 3 Queuing model of outpatient service system

established model here accords with actual system. We can get the average waiting time of patient at other queue of links, and have overall statistics with these values, which is shown in Table 3.

In actual hospital system, the factors required to be considered are usually more complex than those in stimulating model, but it can be accepted if it is in reasonable range. Comparing with the result of Table 3, we can know that the difference of these two is quite small; therefore, we can conclude that the stimulation of original plan can reflect the basic performance of real system.

Table 3 Simulating result statistics analysis of original plan

Queue line	Maximum number waiting in queue	Average number of people waiting in queue	Maximum waiting time (s)	Average waiting time (s)	Data collection
Registration and queuing	16	2.2492	426.4139	72.0359	76.13
Medicine triage counter	57	31.5706	4647.6079	2521.3125	2610.41
Surgery triage counter	19	6.0061	2189.0686	570.9852	535.19
Pediatrics triage counter	11	4.1241	1853.4597	646.3920	600.51
Gynecology triage counter	10	2.1668	1239.0865	213.3453	241.05
X registration and queuing	4	0.3939	480.8000	71.6618	68.37
CT registration and queuing	3	0.1047	259.1248	28.7119	30.72
Charge and queuing	8	0.3582	386.4287	39.6017	38.04
X examination and queuing	14	3.6336	2797.0996	650.5896	613.53
CT examination and queuing	8	3.2119	1972.4139	899.2765	903.53
Taking photo and queuing	10	0.6375	824.5283	74.8850	70.38
Charge	19	6.0168	880.9848	247.7802	260.26
Queuing of medicine fetching	38	19.1958	1365.5768	819.0677	784.84

4 Results and Optimization

Analyzing the data in Table 3 and comparing it with regulated standard of "top 100 hospitals", it shows that the equipment resource of radiology department hasn't reached the optimized configuration and the use ratio of equipment is too low. Therefore, the point is having optimized analysis to internal radiology department in the following process of simulation optimization.

Getting the statistical result by operating simulation model, we know that the equipment use ratio of two registration office and a casher in radiology department are respectively 21.4, 43.2 and 32.4 %, resource configuration is unreasonable and waste phenomenon is quite serious. Improving plan 1 is using single queue and multi queuing model to replace model queue and multi queuing model. Combine two registration offices as one integrity registration window and the operating indexes before and after improvement are shown in Table 4.

We can see from the result that the average waiting time and the average number of patients waiting in line of X-ray department are reduced to some degree.

Merging the Prescription Pricing and the Cashier into one is Scheme 2. The arrival distribution law of the Prescription Pricing and Cashier is equal to the arrival distribution law of Registration Department, because the function of Registration Department is prescription pricing. The total of average service time of prescription pricing and charging is the average service time of Cashier Registration Department. By operating Scheme 2, the result comparison chart is shown in Table 5.

After improving the simulation result, we can see that the maximal waiting time of the Prescription Pricing and Cashier Department is 34.16 min and the average waiting time is only 1.12 min. The waiting time of the Prescription Pricing and the Cashier are 6.04 and 15.71 min respectively and the total of them is far more than 1.12 min. So the improvement effect of Scheme 2 is significant and it has large feasibility.

Although operating Scheme 2 largely reduces the average waiting time, it has some disadvantages. We can see from the simulation result that the equipment utilization of these three parts is only 38.2, 19.7 and 6.8 %. The utilization is extremely low and the resource wasting is serious.

Table 4 The operation index at queuing office of radiology department

Queue	Maximum number of waiting people in queue	Average number of waiting people in queue	Maximum waiting time (s)	Average waiting time (s)
Before improvement	4	0.25	480.80	50.18
After improvement	2	0.05	224.86	6.04

Table 5 The operating parameter values of scheme 1 and 2

Queue	Maximal number of waiting people	Average number of waiting people	Maximal waiting time (s)	Average waiting time (s)
Scheme 1 prescription pricing	2	0.05	224.86	6.04
Scheme 1 cashier	3	0.12	177.27	15.71
Scheme 2	2	0.01	34.16	1.12

In order to find out the best service capability design scheme, we can only make the experiment through increasing the charging windows gradually to find the best number of service window. Here we proposal the following schemes:

Scheme 3: set 1 Prescription Pricing and Cashier window;
Scheme 4: set 2 Prescription Pricing and Cashier windows;
Scheme 5: set 4 Prescription Pricing and Cashier windows;

According to the setting of different numbers of Prescription Pricing and Cashier window, we get 3 new configuration schemes. Operating Scheme 3–5, we can get the operating parameter as shown in Table 6. The best scheme is determined by the result analysis.

Comparing the above schemes with each other, we can see that Scheme 3 is better than Scheme 4 and 5. Therefore, one Prescription Pricing and Cashier window is the best service capability configuration scheme.

Make the Consulting Room and the X-ray department as an interconnected system. Then the film and report will be sent to the Consulting Room directly and the part of getting the film is omitted. Then we get Scheme 6 and we build the simulation model after the above improvement.

Let's summarize the improvement of the above checking process of X-ray Department: merging the registrations of CT checking and X checking into one integrated registration window. We can see from the simulation result that configuring one Prescription Pricing Registration window is the most reasonable and the sector of getting the film is canceled. After a series of improvement, we can get Scheme 6. Operating the model, the result shows that the time that the patient stays

Table 6 The operating parameter and unit cost of the above 3 schemes

Scheme	Maximal number of waiting people	Average number of waiting people	Maximal waiting time (s)	Average waiting time (s)	Utilization (%)	Total unit cost (RMB)
Scheme 3	9	1.56	840.26	2.66	73.4	26.4424
Scheme 4	4	0.11	261.97	1.52	30.9	25.3602
Scheme 5	1	0	53	0.21	15.9	47.5392

in the X-ray Department reduces from 35.77 to 27.19 min which is reduced by 23.99 %. The effect of improvement is significant and the number of patients receiving service in the X-ray Department improves from 232 to 244. Not only the patient satisfaction is improved, but the resource configuration in the hospital is optimized. The operating costs of the hospital are reduced and it achieves the mutual benefit of patients and the hospital.

5 Conclusion

The paper focuses on the improvement and optimization of problems existing in the medical process of large integrated hospital. We can see from the quantitative analysis result that these improvements can bring certain benefits to the hospital and it's adoptable in the actual system. In the research process in the future, further research should be made on the process management to form the process management model of "patient focus", reducing the waiting time, improving the efficiency of seeing a doctor and reducing the hospital cost.

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Fault Tree and Bayesian Network Based Scraper Conveyer Fault Diagnosis

Si-sheng Xue, Xin-chun Li and Xiang-yu Xu

Abstract With the introduction of large-scale mechanized coal mining equipment, the mechanical and electrical equipment of the fully mechanized face is becoming more and more complex. The fault tree of coal mining compressors is obtained by means of artificial deduction. Fault tree is transformed to Bayesian network by the mapping relationship between fault tree and Bayesian network. The reliability of scraper conveyor was obtained by Bayesian networks and fault trees and the occurrence rate of the fault. The Bayesian network is transformed into a connecting tree. The calculation method of the belief is obtained according to the connecting tree. According to the calculation method of the belief and the reliability that have been calculated, the probability of failure can be obtained under all kinds of conditions and then can help the maintenance staff to figure out the reason of the fault quickly.

Keywords Scraper conveyor · Fault tree · Bayesian network · Fault diagnosis

1 Introduction

China is the world's largest coal production and consumption country. Mechanization, automation and intelligentization are the trends of China's coal mining industry. In this case, it is necessary to reduce and cancel the fault of coal mine machinery. In Recent years, the mechanization of China coal enterprises has a rapid progress, but still lagged behind the advanced countries. One of the reasons is the poor diagnosis and repair management which mainly based on worker's experience and the regulations. This paper focuses on the scraper conveyer diagnosis by Bayesian network methodology on the basis of constructed scraper conveyer fault

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tree. Firstly, the scraper conveyer Fault tree was constructed by analyzing the logic relationship of the events which could induce work failure scraper conveyer with a quantitative analysis. Secondly, the scraper conveyer diagnosis Bayesian network was derived by the Fault tree to Bayesian network mappings. Lastly, the reasons event were derived by Bayesian network deducing for the purpose of quick repair.

Although having some limitations, FTs are extensively used in the field of risk analysis of process systems [1, 9, 10] and fault diagnosis [11–13]. Standard FTs are not suitable for analyzing large systems, particularly if the system presents redundant failures, common cause failures, or mutually exclusive primary events. More importantly, events in a FT are assumed independent, which is not usually a valid assumption [2, 14].

In recent years, a Bayesian network (BN) methodology has begun to be used in engineering applications. A BN is a graphical inference technique used to express the causal relationships among variables. BNs are used either to predict the probability of unknown variables or to update the probability of known variables given the certain state of other variables (evidence) through the process of probability propagation or reasoning. The reasoning is based on Bayesian theory. Due to this ability, BNs have provided a promising framework for system safety analysis and risk management [16].

BNs are increasingly used in reliability assessment [2], fault diagnosis, and updating the failure probability of safety systems have examined the parallels between BNs and FTs and have shown the obvious superiority of BNs over FT terms of modeling and analysis capabilities. Bobbio et al. [14] showed that the limitations of FTs can be relaxed to a great extent by relying on BNs. Other relevant works have been done by either mapping static FTs to BNs [15] or mapping dynamic FTs into the corresponding dynamic BNs.

2 About Fault Tree and Bayesian Network

2.1 Fault Tree Analysis (FTA)

Fault tree analysis is a deductive, structured methodology to determine the potential causes of an undesired event, referred to as the top event. The top event usually represents a major accident causing fault problem. In a FTA, events are seen as top events, primary events and middle events. The symbols in FTA to describe the relationships of events are AND-gates and OR-gates. The OR gate means that the output occurs if any input occurs. The AND gate means that the output occurs only if all inputs occur (inputs are independent).

Let the probability of X1, X2, X3 be $X1 = (\alpha, 1 - \alpha)$ $X2 = (\beta, 1 - \beta)$ $X3 = (\gamma, 1 - \gamma)$

The probability of OR gate can be calculated from

$$P(T) = (1 - (1 - \alpha)(1 - \beta)(1 - \gamma), (1 - \alpha)(1 - \beta)(1 - \gamma)) \quad (1)$$

The probability of AND gate can be calculated from

$$P(T) = (\alpha * \beta * \gamma, 1 - \alpha * \beta * \gamma) \quad (2)$$

2.2 Bayesian Network

Bayesian networks are increasingly used for the construction of system reliability models, risk management, and safety analysis based on probabilistic and uncertain knowledge. Similar to FTs, BNs consist of both qualitative and quantitative parts. BNs are directed acyclic graphs, in which the nodes represent variables, arcs signify direct causal relationships between the linked nodes, and the conditional probability tables assigned to the nodes specify how strongly the linked nodes influence each other. Probability inference can be used to the probability of a variable from related variables. Based on this, Bayesian network can be used to solve the problem with incomplete and uncertainty, which works well in complex machine related problem and correlative faults.

Bayesian network contains a set of random variables and their conditional dependencies via a directed acyclic graph (DAG). Bayesian networks are DAGs whose nodes represent random variables in the Bayesian sense: they may be observable quantities, latent variables, unknown parameters or hypotheses. Edges represent conditional dependencies; nodes that are not connected represent variables that are conditionally independent of each other. Each node is associated with a probability function that takes, as input, a particular set of values for the node's parent variables, and gives (as output) the probability (or probability distribution, if applicable) of the variable represented by the node.

In a Bayesian net, if the probability of parent node is known, then the probability of son node can be derived by probability formula. The rest can be done in the same manner for the purpose of belief propagation and probability update [2]. Also the probability of basic events can be calculated from the top event.

2.3 Transition from FTA to BNs

FTA is suitable for cause analysis and estimation occurrence probability, but not at probability inference which BNs can do well in inference. So this paper makes the combination of FTA and BNs in the scraper conveyer diagnosis.

The nodes and the probability of the Bayesian networks are expressed the events and the characteristics of its uncertainty. The fault tree of the system will be

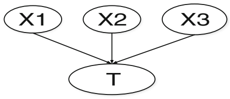

Fig. 1 AND OR gates' the Bayesian network

transformed into a Bayesian network. By the analysis of the fault data of equipment, we can get the probability distribution of failure cause (basic events). The probability distribution of the system failure (top event) is calculated by using Bayesian network. The probability distribution of the systems' failure (top event) is calculated by using Bayesian network [3]. When the event and the logic gate regard as a node and the connection strength, FTA can be converted into a Bayesian network. The event in the fault tree is considered as the node in Bias network. Connection strength of the Bayesian networks that are involved of logical gates of the FTA is expressed by probability. Generally according to the logical relationship of the logical gate we list the corresponding conditional probability table. Transition from logical relationship into a mathematical expression to calculate the probability distribution is as following. And the input and output relationship of the Bayesian network must is same as the input and output relationship of the fault tree logic gate. The fault tree AND OR gates of the fault tree are transformed into the Bayesian network such as Fig. 1. X1, X2, X3 are expressed as the basic events. T is expressed as the top event. X1, X2, X3 resulted in the occurrence of T.

3 Mechanical and Electrical Fault Tree and the Bayesian Networks

3.1 Establishment of the Fault Trees and the Bayesian Networks

The fault tree of scraper conveyor is obtained by the artificial deduction method including the collection of data and the experience of the maintenance workers. There are 5 kinds of faults that cause the failure of the scraper conveyor. They are the motor failure, the failure of the hydraulic coupler, the failure of the reducer, the failure of mechanical components. These 5 events regard as the next layer of the failure of the scraper conveyor. There are two kinds of failure that are mechanical failure and control failure lead to the failure of the motor. These two events are the next layer of motor failure. The next layer of mechanical fault is the stator fault and the rotor fault. The reasons of the stator fault are core fault and winding fault. Core failure and winding failure cannot be continued to decompose. They are the basic events (bottom events). At the same time the motor failure, mechanical failure, stator failures are regarded as intermediate events.

According to the father logical gate in fault tree is transformed into the probability distribution of the Bayesian network. The basic event, the Intermediate event and top events are regarded as the nodes of the Bayesian network.

Events of the fault tree has only two kinds of state failure that are occurs or normal operation. The state of the basic event is described as follows:

$$Xi = \begin{cases} 1 & \text{basic events i occur} \\ 0 & \text{basic events i not occur} \end{cases}$$

The top events are described as follows:

$$\Phi X = \begin{cases} 1 & \text{basic events i occur} \\ 0 & \text{basic events i not occur} \end{cases}$$

The Bayesian network can assign the probability of event to the basic events and the top events. The basic event states are described as follows:

$$xi = \begin{cases} 1 & \text{basic events i occur} \\ \alpha & \text{basic events i occur with prob } \alpha \\ 0 & \text{basic events i not occur} \end{cases}$$

Description of top event:

$$\Phi X = \begin{cases} 1 & \text{basic events i occur} \\ \alpha & \text{basic events i occur with prob. } \alpha \\ 0 & \text{basic events i not occur} \end{cases}$$

The winding fault is the basic events of the failure of the scraper conveyors the parent node of the fault of the stator. Two basic events are pointed to the stator fault through the directed line. While the stator faults and rotor faults are the parent nodes of the mechanical fault, they point to the mechanical fault through a directed line. Finally, the failure of the mechanical failure point to the top event is that failure of scraper conveyer. The nodes of the Bayesian network are nodes of the probability. The Bayesian network of the failure of the whole scraper machine is obtained by using this kind of the backward recurrence of fault tree.

4 Quantitative Analysis of the Failure of Scraper Conveyor

On the basis of scraper conveyer failure analysis and statistical data analysis, the Fault Tree of scraper conveyer can be derived in Fig. 2 and the probability of relative event can be obtained (as shown in Table 1).

The reliability of scraper conveyer can be obtained by logical calculation.

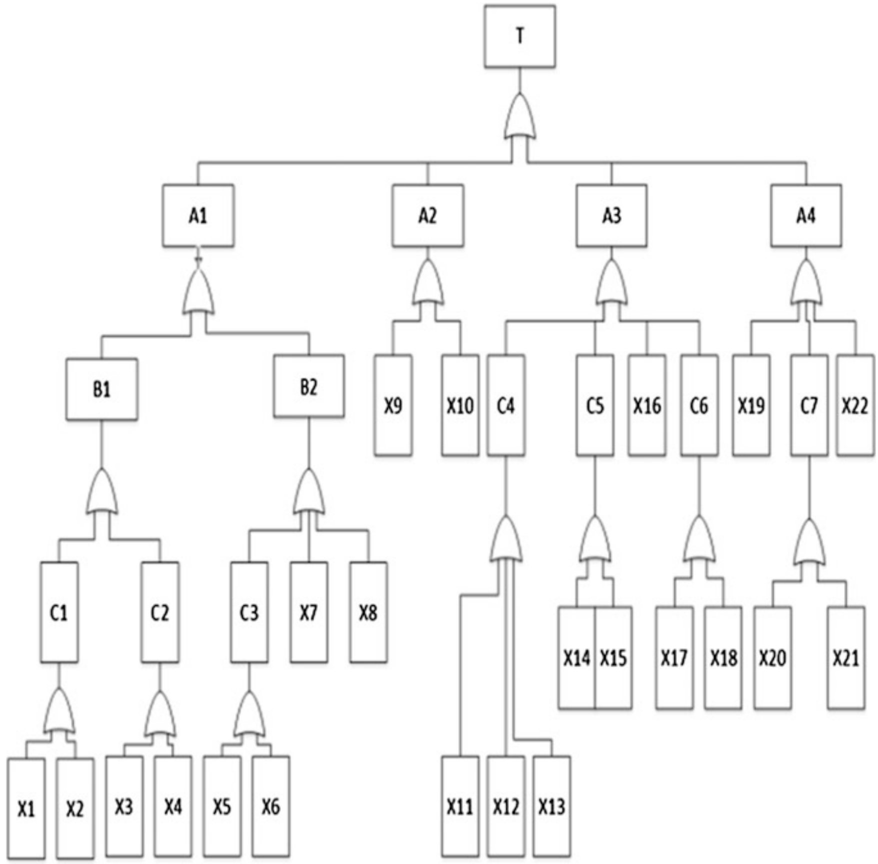

Fig. 2 Scraper conveyer failure FTA

P(X1) = (0.001, 0.999)
P(X2) = (0.010, 0.99)
$\alpha = 0.001$, $\beta = 0.99$

Using the expansion for the joint probability function and the conditional probabilities from the conditional probability tables (CPTs) stated in the diagram, one can evaluate each term in the sums in the numerator and denominator.

P(C1) = (1-0.99 * 0.999, 0.99 * 0.999)
P(T) = (0.101, 0.899)

The reliability of scraper conveyer is 0.899.

Table 1 Probability of basic event of scraper conveyer

Symbol	Event	*P*	Symbol	Event	*P*
T	Scraper conveyer	–	X5	Abrasion	0.003
A1	Electric fail	–	X6	Burn	0.002
A2	Coupler fail	–	X7	Circuit fault	0.003
A3	Reducer fail	–	X8	Insulation fault	0.002
A4	Mechanical part	–	X9	Overload	0.003
B1	Mechanical fail	–	X10	Oil blockage	0.002
B2	Controlf	–	X11	Broken tines	0.002
C1	StatorF	–	X12	Wheel fracture	0.006
C2	Rotor fail	–	X13	Case abrasive	0.030
C3	Bearingf	–	X14	Cracks	0.001
C4	GearF	–	X15	Fissures	0.002
C5	Shaftf	–	X16	KeyF	0.009
C6	Bearingf	–	X17	Wear	0.003
C7	Sprocketf	–	X18	Burn	0.001
X1	Coref	0.001	X19	Chain fracture	0.003
X2	WindF	0.010	X20	Broken teeth	0.001
X3	CoreF	0.001	X21	Wear	0.002
X4	WindF	0.010	X22	Scraper wear	0.010

5 Fault Diagnoses by Bayesian Net

5.1 Probability Inference in Bayesian Net

In order to complete the inference of probability on the Bayesian network, firstly we should complete the structural transformation; transform the Bayesian network into a connected tree. In order to satisfy the constraint condition, the prior probability of Conveyor failure assigned to the corresponding lap and edge that is the connecting trees' Initialization of belief. For a random variable x and its parent node, we contains the X and parent node in the circle that we can get the corresponding conditional probability P(X|C). Each circle and edge set the belief potential for P(X|C) [4].

In order to satisfy the consistency condition, we should deliver the belief of the connection tree. Finishing the belief distribute and belief collect in the failure of the scraper conveyor in the two directions. The A3, C4, C5, C6 and X16 is set to the root nodes, which is called, collect belief and distribute belief.

As shown in Table 2, calling collect belief at the node A3C4C5C6X16, belief is transferred from the leaf nodes X11X12X13C4, X14X15C5, C6X17X18 to the root

Table 2 Prior probability of failure of the reducer

Node	Prior probability	Node	Prior probability
X11	P(X11)	X17	P(X17)
X12	P(X12)	X18	P(X18)
X13	P(X13)	C4	P(C4|X11, X12, X13)
X14	P(X14)	C5	P(C5|X14, X15)
X15	P(X15)	C6	P(C6|X17, X18)
X16	P(X16)	A3	P(C4|C4, C5, C6, X16)

node A3C4C5C6X16. The corresponding belief are φ1, φ2, φ3; Calling distribute belief at the root node A3C4C5C6X16, Beliefs is transferred from A3C4C5C6X16 to X11X12X13C4, X14X15C5, C6X17X18. The corresponding belief are ψ1, ψ2, ψ3, ψ4.

Calculation method of prior probability: The prior probabilities are established with 0, 0.15, 0.25, 0.5, 0.75, 0.85. As a result of the research of scraper conveyor is very much, and the prior probability can be determined by the expert evaluation. For example, the prior probability of the reducer failure is shown in Table 3.

A calculation method of the prior probability when Distribute belief is spread.

The probabilities of the basic events are used when we calculate the priori probability in Distribute belief. For example, P(C4|A3), the priori probability indicates the probability of occurrence of C4 when event A3 happened.

Step 1: Add up the all probability of the events that can lead to the occurrence of A3 event probability. The probability is event A3.

Step 2: P(C4) P(A3, C4) P(A3) been divided by P(C4, A3), that we can get P(C4|A3).

By this method, the prior probability of all distribute belief is obtained.

Calculation of φ1:

Belief φ1 represents occurring probability of C4 that is leaded by X11, X12, X13. Three events X11, X12 and X13 lead the occurrence of the event C4.

$$\varphi 1 = \mathrm{P(C4)} = \mathrm{P(X11)P(C4|X11)} + \mathrm{P(X12)P(C4|X12)} + \mathrm{P(X13)P(C4|X13)}$$

Table 3 Importance coefficient assignment table

Prior probability	Number	Prior probability	Number
P(C4|X11)	0.85	P(C6|X17)	0.15
P(C4|X12)	1	P(C6|X18)	0.75
P(C4|X13)	0.25	P(A3|C4)	0.75
P(C5|X14)	0.85	P(A3|C5)	0.85
P(C5|X15)	0.15	P(A3|C6)	0.85
P(A3|X16)	0.5		

φ2 Calculation Method:

Belief φ2 represents occurring probability of C5 that is leaded by X14, X15. Two events X14, X15 lead to the occurrence of the event C5.

$$\varphi 2 = \mathrm{P(C5)} = \mathrm{P(X14)P(C5|X14)} + \mathrm{P(X15)P(C5|X15)}$$

φ3 Calculation Method: belief φ3 represents occurring probability of C6 that is lead by X17, X18. Two events X17, X18 lead to the occurrence of the event C6.

$$\varphi 3 = \mathrm{P(C6)} = \mathrm{P(X17)P(C6|X17)} + \mathrm{P(X18)P(C6|X18)}$$

Take the retarder failure A3 as the top event. The event can be caused by intermediate events C4, C5, C6 or basic event X16. Distribute belief ψ1 represents the probability of A3.

$$\begin{aligned}\psi 1 = \mathrm{P(A3)} &= \mathrm{P(C4)P(A3|C4)} + \mathrm{P(C5)P(A3|C5)} + \mathrm{P(C6)P(A3|C6)} \\ &\quad + \mathrm{P(X16)P(A3|X16)}\end{aligned}$$

ψ2 Calculation Method: belief ψ2 represents the probability of C4 when A3 happen. We can get ψ2 by using the probability of A3, the probability of C4 and the probability of A3 when C4 happens

$$\psi 2 = \mathrm{P(C4|A3)} = \frac{\mathrm{P(C4)P(A3|C4)}}{p(\mathrm{A3})}$$

ψ3 Calculation Method: belief ψ3 represents the probability of C5 when A3 happen. We can get ψ2 by using the probability of A3, the probability of C5 and the probability of A3 when C5 happens.

$$\psi 3 = \mathrm{P(C5|A3)} = \frac{\mathrm{P(C5)P(A3|C5)}}{p(\mathrm{A3})}$$

Ψ4 Calculation Method: belief ψ4 represents the probability of C6 when A3 happen. We can get ψ2 by using the probability of A3, the probability of C6 and the probability of A3 when C6 happens.

$$\psi 4 = \mathrm{P(C6|A3)} = \frac{\mathrm{P(C6)P(A3|C6)}}{p(\mathrm{A3})}$$

Distribute belief spread to basic events. The calculation is to the probability of the intermediate events under the top event multiply by the probability of the basic events under the intermediate events:

$$P(X11|A3) = P(X11|C4)\ P(C4|A3)$$
$$P(X12|A3) = P(X12|C4)\ P(C4|A3)$$
$$P(X13|A3) = P(X13|C4)\ P(C4|A3)$$
$$P(X14|A3) = P(X14|C5)\ P(C5|A3)$$
$$P(X15|A3) = P(X15|C5)\ P(C5|A3)$$
$$P(X16|A3) = \frac{P(X16)P(A3|X16)}{p(A3)}$$
$$P(X17|A3) = P(X17|C6)\ P(C6|A3)$$
$$P(X18|A3) = P(X18|C6)\ P(C6|A3)$$

The results can be calculated according to formula 4-1.

The reasonable use of the calculation method when collect and distribute belief spread. In particular, distribute belief can help repair staff to find fault location quickly.

5.2 *Using the Bayesian Network to Carry Out the Fault Diagnosis of the Scraper Conveyor*

For example the failure of the reducer as Fig. 3, we infer the probability of the occurrence of various cause sunder the occurrence of the failure of the reducer. Its purpose is to find out the cause of the incident.

With the A3 occurrence, the basic event can be calculated as shown in Table 4.

Step 1 calculate the probability of C4, C5, C6 and A3.

Step 2 calculate the probability of C4, C5, C6 when A3 occurs.

Step 3 calculate the probability of basic vents when A3 occurs.

Step 4 sort these events.

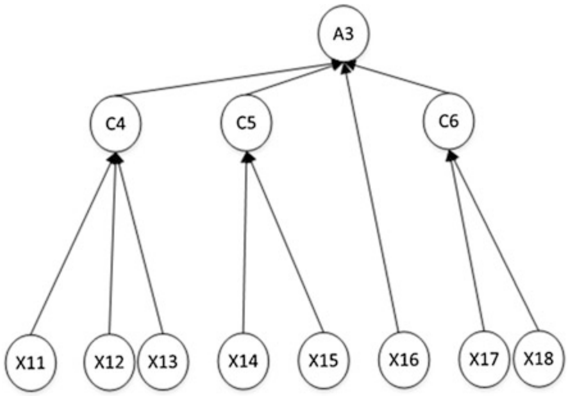

Fig. 3 Bayesian network of reducer failure

Table 4 reducer failure table

Code	Event	Probability
A3	Retarder fail	
C4	Gear fail	
C5	Shaft fail	
C6	Bearing fail	
X11	Pick broken	0.002
X12	Wheel fract	0.006
X13	Case abrasive	0.030
X14	Fracture	0.001
X15	Crack	0.002
X16	Key fail	0.009
X17	Abrasion	0.003
X18	Burn	0.001

1. According to calculation method of collect belief, We can get the probability of the Intermediate events C4, C5, C6 and top event A3

$$\begin{aligned} \mathrm{P(C4)} &= 0.0152\mathrm{P(C5)} = 0.00115 \\ \mathrm{P(C6)} &= 0.0012\mathrm{P(A3)} = 0.0173 \end{aligned}$$

2. According to calculation method of distribute belief, We can get the probability of the Intermediate events when A3 occurs

$$\begin{aligned} \mathrm{P(C4|A3)} &= 0.659\mathrm{P(C5|A3)} = 0.0565 \\ \mathrm{P(C6|A3)} &= 0.0590\mathrm{P(X16|A3)} = 0.265 \end{aligned}$$

The probabilities of C4, C5, C6, X16 are 0.659, 0.0565, 0.0590 and 0.265 when A3 occurs.

With the probability of P (C4|A3), P (C5|A3), P (C6|A3), P (X16|A3) and the probability of Intermediate event, the probability of basic events can be calculated.

$$\mathrm{P(X11|C4)} = \frac{P(X11)\mathrm{P(C4|X11)}}{p(C4)} = 0.1184$$

$$\begin{aligned} \mathrm{P(X12|C4)} &= 0.3947\mathrm{P(X13|C4)} = 0.4934 \\ \mathrm{P(X14|C5)} &= 0.7391\mathrm{P(X15|C5)} = 0.2609 \\ \mathrm{P(X17|C6)} &= 0.3750\mathrm{P(X18|C6)} = 0.6250 \end{aligned}$$

3. According to Eq. (1), the probability of basic event can be calculated.

$P(X11|A3) = 0.078P\ (X12|A3) = 0.26$

$$P(X13|A3) = 0.3251$$
$$P(X14|A3) = 0.0144$$
$$P(X15|A3) = 0.0289$$
$$P(X16|A3) = 0.265$$
$$P(X17|A3) = 0.0221$$
$$P(X18|A3) = 0.0369$$

With the occurrence of A3, the probability of X11, X12, X13, X14, X15, X16, X17, X18 are 0.078, 0.26, 0.3251, 0.0144, 0.0289, 0.265, 0.0221, 0.0369.

$$P(X13|A3) > P(X16|A3) > P(X12|A3) > P(X11|A3) > P(X18|A3) > P(X15|A3) > P(X17|A3) > P(X14|A3)$$

In this paper, we study the failure of event A3 as an example, this method can also be used to other fault diagnosis of the conveyor. Through the faults that we had known we can predict the possibility of the occurrence of the basic events so that shorten the maintenance time and reduce the economic loss of the enterprise.

6 Conclusions

Fault diagnosis and maintenance of scraper conveyor is a time-consuming work. Conventional fault diagnosis method has been difficult to meet the requirements of the coal enterprise rapid maintenance. At present, the most common fault diagnosis of the fully mechanized coal mining equipment is the uncertainty problem. Therefore, the main work of this paper is to find a method to diagnose the fault of the equipment.

Fault tree and Bayesian network are respectively for the uncertainty and certainty of equipment failure. We combine Fault tree and Bayesian network through the failure rate for completing the diagnosis of fault.

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Large Scale Parallel Algorithms for 3D Grain Burnback Analysis of Solid Propellant Rocket Motors

Yang Liu, Jiu-ling Sui, Yu Zhao, Fu-ting Bao and Wei-hua Hui

Abstract To simulate the 3D grain burnback process and analysis the performance of the solid rocket motor (SRM) in a more efficient and more generalized way, a large scale parallel computing algorithm was put forward by discrete the 3D structure of grain into million voxels. Based on highly paralleled graphics process units (GPU) computing architecture, the bounding box space of the grain was discretized into a 3D voxels matrix firstly, and Z-Buffer testing was used to confirm the calculation boundary of the grain. Then, paralleled burning state filling algorithm was adopted to calculate the distance fields between initial burning surface and voxels matrix. For a given web, modified marching cubes iso-surface extraction technologies were also used to extract the burning surface in real time. Finally, taken an irregular grain as the example, which had complex inhibitors, the calculation accuracy and computational efficiency verified the validity of this grain burnback simulation method.

Keywords Large scale parallel algorithm · Burnback analysis · Solid rocket motor · Grain design

1 Introduction

In the SRM grain design processes, to get the accurate performance of SRM, the key point was how to get the curve of burning surface area verses burning web. Since it was really hard to get the precise 3D envelop surface of arbitrary complex 3D initial burning surface, so researches around the world were attempt to get the approximate

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result by some discrete algorithms. Professor Smit had try to employ the level set method to perform coupled grain burn back analysis in solid rocket motor simulations [1]. Doctor Jave had proposed a minimum distance function approach for prediction of geometry evolution of SRM grains [2]. All those discrete algorithms were all need for massive calculations [3–15]. So we proposed a large scale parallel algorithm for 3D grain burnback analysis, and perform this algorithm in GPU (Graphics Process Units) massively parallel computing architecture. Thus, grain burnback analysis could be quickly carried out even with personal computers by designers.

2 Algorithm Frameworks

2.1 Definitions

Before we carried out the algorithm, some basic 3D geometric concepts in the grain burnback analysis processes were defined as follows:

Definition 1 The grain 3D solid was defined as G, where G must be a regular Boundary Representation (B-Rep) 3D entity.

Definition 2 The boundary face-sets of grain solid G was defined as F(G).

Definition 3 The coating surfaces was defined as W(G). In the burnback analysis processes, W(G) did not move.

Definition 4 The initial burning surfaces was defined as B(G, 0). In the burnback analysis processes, our goal was to calculate the burning surfaces B(G, w), where w was the giving burning web.

Thus, F(G), W(G) and B(G,0) satisfied formula 1.

$$\begin{aligned} F(G) &= W(G) \cup B(G,0) \\ W(G) &\cap B(G,0) = \varnothing \end{aligned} \tag{1}$$

Definition 5 At any given point P, the distance between P and W(G) was defined as L(P,B(G, 0)):

$$L(P, B(G,0)) = \min\{|P - Q|, Q \in B(G,0)\} \tag{2}$$

Obey to parallel layer combustion law, when the burning web was w, then the burning surface B(G, w) was the collection of spatial point P, where P obeyed to formula 3.

$$\mathrm{B(G,w)} = \{\mathrm{P}|\mathrm{P} \in \mathrm{G}, \mathrm{L(P,B(G,0))} \ = w\} \tag{3}$$

2.2 The Main Algorithm Flow

To calculate the burn surface area of a giving burning web, the bounding space of grain solid was discretized into an N * M * K vortex matrix [11]. As shown in Fig. 1, firstly we need to confirm which vortex was in the grain and which vortex was out of grain. Then, for the inside vortex, we could calculate the minimum distance between each vertex and the initial burning surface in a parallelized way. This minimum distance fields was stored in matrix L[N, M, K].

Giving a burning web w, we could extract the approximate burning iso-facets in each vortex. And finally we could get the burnback analysis curve of burning surface area versus burning web.

3 Algorithm Key Steps

3.1 Grain Discretization

To get the calculation boundary in an effective and parallelized way, we applied a series of Z-Buffer projection on grain solid. And get the Z-Buffer matrices in positive and negative direction of axis X, Y and Z, which named as x1, x2, y1, y2, z1, z2, as shown in Fig. 2.

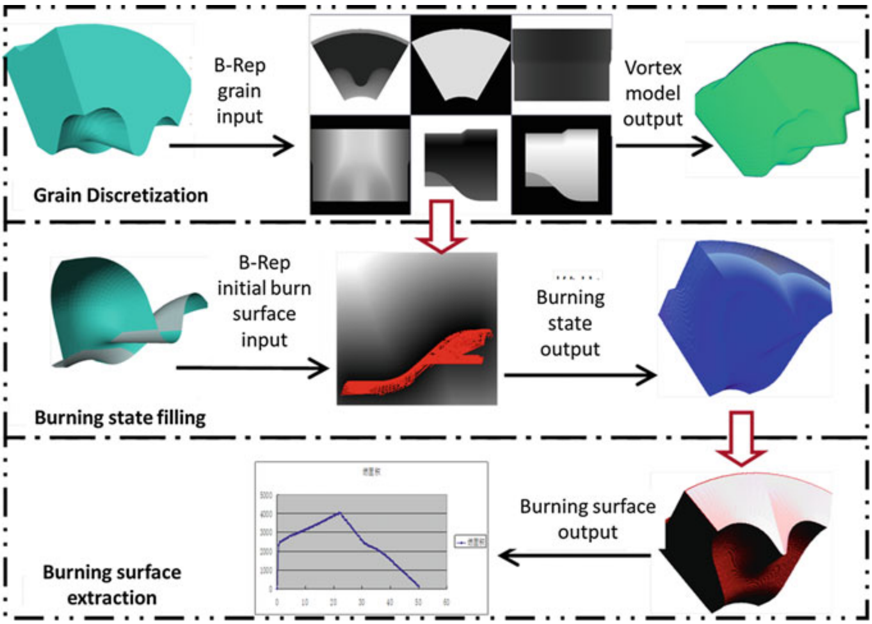

Fig. 1 The main algorithm flow

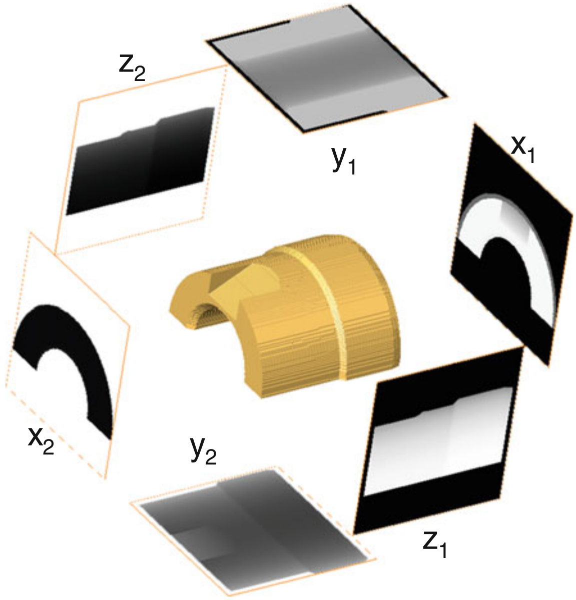

Fig. 2 Z-buffer projection of grain solid

For each vortex point, if it coordinate (i, j, k) obey to formula 4, we could confirm that this point was inside of the grain solid. Otherwise, the voxel point was outside of the grain solid.

$$\begin{cases} x1[j,k] < i < x2[j,k] \\ y1[k,i] < j < y2[k,i] \\ z1[i,j] < k < z2[I,j] \end{cases} \tag{4}$$

3.2 Burning State Filling

In the burning state filling process, distance calculation required massive computing. For example, as a grain solid, which was constructed by 1000 triangles and it was discrete in 1024 * 256 * 256 vortexes, we had to carry out 1000 * 1024 * 256 * 256 (about 64 billons) minimal distance calculation to get the minimum distance field [5]. To reduce computing time, we firstly applied delaunay triangulation on geometric entities of burning surface and get corresponding Voronoi diagram [8]. Thus, as shown in Fig. 3, for all geometric entities (a, b, …, k), we could get corresponding region (A, B, …, K). Among them, any vertex in each region was closest to corresponding geometric entity. Thus, for example, a grain, which was discrete in 1024 * 256 * 256 vortexes, only needs to carry out 64 million distance calculation. The computing time reduced to one-thousandth. And all those calculation could be

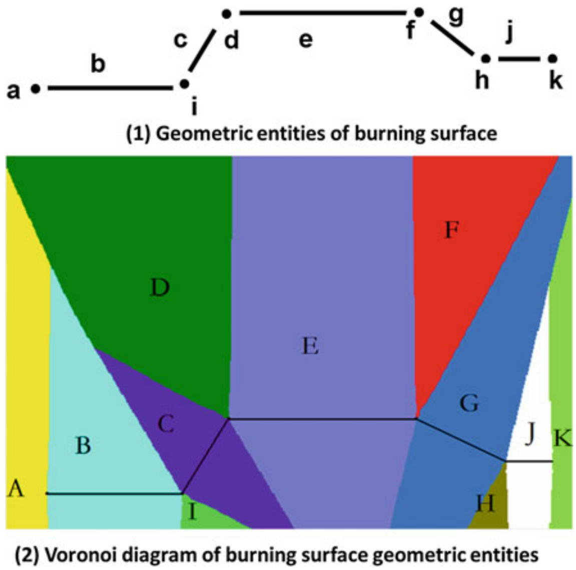

Fig. 3 Space subdivision

carried out in a parallelized way easily. While delaunay triangulation time of 1000 triangle was completely negligible.

Binding with grain discretization, Fig. 4 show the burning state filling result of a grain sample.

3.3 *Burning Surface Extraction*

Through above processes, we get the minimum distance fields matrix L[N, M, K]. And we need to extract iso-surface from the minimum distance fields. In this paper, we use a modified marching cubes [16] iso-surface extraction method.

When the web was given as w, then every vertex of the vortex cube would be labeled as tow state.

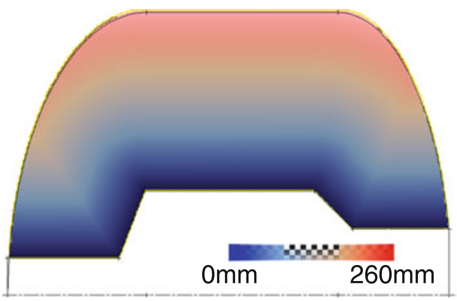

Fig. 4 Burning state filling result

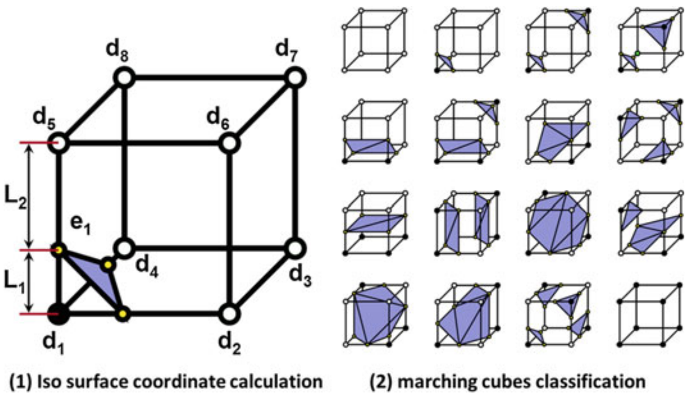

Fig. 5 Burning surface extraction

1. When the minimal distance of the vertex between initial burning surface was greater than w(d > w), it meant that this vertex was not burning yet. So we can labeled it as 0.
2. When the minimal distance of the vertex between initial burning surface was equal or less than w(d ≤ w), it meant that this vertex had been burn out. So we can labeled it as 1.

As shown in Fig. 5, in the cube spaces constructed by 8 adjacent vortexes, we could label those cube in 2^8 (256) categories. since we Since the cube is rotationally symmetrical, we could classify the cube into 16 categories.

In any labeled cube, if all of its vertexes were labeled as 0 or 1, burning surface did not exist in this cube space. In other categories, the vertex of burning surface in this cube space could be calculated as follow.

As shown in Fig. 5(1), if the vertexes of an edge was labeled in different label (for example, e1 with vertex d5 and d1), then a vertex of burning surface must exist in this edge. We can calculate the position of this vertex, as shown in Eq. (5).

$$\begin{cases} L_1 = \frac{(d_1 - w) \cdot L}{d_1 - d_5} \\ L_2 = \frac{(w - d_5) \cdot L}{d_1 - d_5} \end{cases} \quad (5)$$

Because cubes were independent with each other, so it was convenient to carry out parallel iso-surface extraction process.

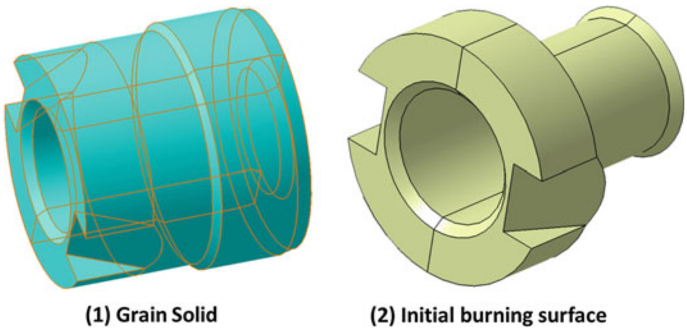

Fig. 6 Grain solid and initial burning surface modeling by CAD software

4 Example

4.1 Burnback Simulation

To verify the algorithm of this paper, we use a complex grain as the design example, the grain solid and the initial burn surface were shown in Fig. 6.

the grain solid was discretized into a 256 * 256 * 256 vortex matrix. And the grain burning processes was simulated in Fig. 7.

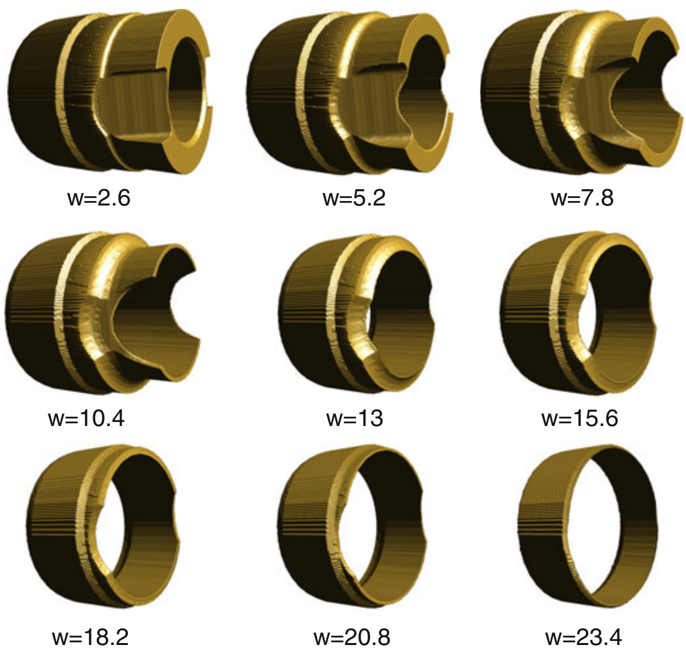

Fig. 7 Grain burnback evolution

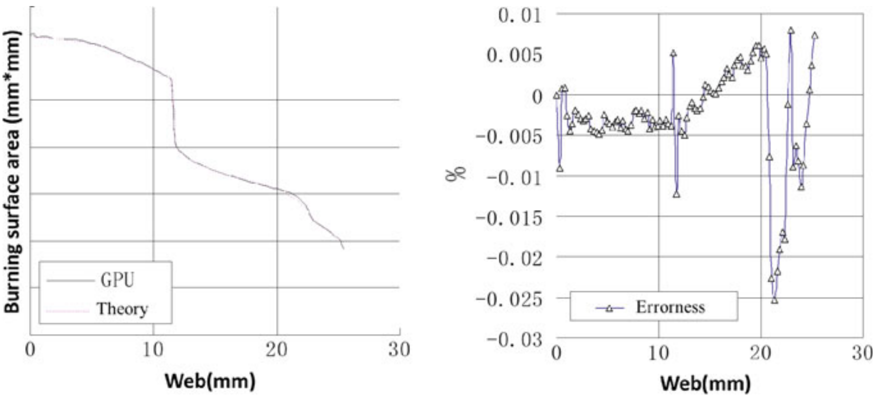

Fig. 8 Result comparison and errorness analysis

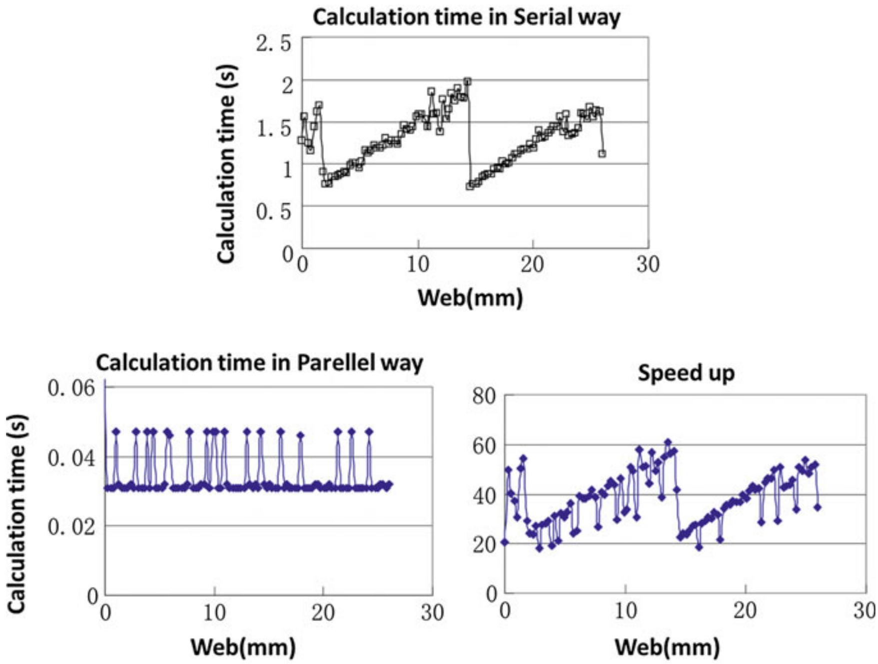

Fig. 9 Computing time comparison

4.2 Result Analysis

The curve of burning surface area versus burning web was shown in Fig. 8. The average errorness was no more than 1 %. The accurate was enough for SRM performance analysis.

When we run this example in a personal computer with a I5-540 CPU and Nvidia Quadro FX1800 M GPU. Since the algorithm was carried out in a parallel way, the calculation speed increased by almost 40 times over traditional method [4], as shown in Fig. 9.

5 Conclusions

The parallel SRM grain burnback analysis algorithm could solve complex 3D cases in a discrete and uniform way. And the calculation accuracy and computational efficiency also verified the validity of this grain burnback simulation method.

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Component Reliability Life Analysis Based on Uncertain Life Distribution Type

Jian-jun Wu, Xiao-ming Wu and Jia-wei Wu

Abstract Life is an important index of component reliability. Aiming at difficulty in determining the life distribution type from the experiment data, this paper improves the determination method on the base of analyzing common distributions' application, characteristics and rules, by using the method of goodness-of-fit tests and hypothesis testing. After determining the reliability life of the model, the model parameters are estimated and hypothesis testing is applied to the model. Finally, taking a component scraper conveyor as research object, the results show that the new method can solve problem that the type of life distribution would not be determined directly from the experimental data for reliability life analysis. This method can provide reference for component usage, repair and maintenance.

Keywords Parts · Life model · Goodness of fit test · Reliability analysis

1 Introduction

Typical parts failure cause the device overall performance degradation and unplanned renewal, and the equipment operating costs will rose sharply. Manufacturers determine their initial life and corresponding maintenance interval at the parts factory based on past experience and life testing, but the actual conditions of use may be expected different and parts of life in use may be different from the initial life. Accordingly, the use of data to assess the life of components is essential, and it can provide guidance to equipment maintenance.

Currently, according to the use of data to assess the life of components research methods can be broadly divided into physical models and statistical modeling approach. In actual operations, the company generally does not have the physical model methods to assess component life limited by technology funds, instead of

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adopting the method of statistical model for evaluation. therefore, appropriate research model approach is important for companies. Statistical model method is to use probability model fitting parts failure time or the distribution of life, and then get the life curve [1]. Component life is a random variable and subject to certain statistical distributions. However, the data obtained from the experiments are haphazard, and the type of life distribution is varied, it is difficult to directly determine obedience which kind of distribution [2].

In order to solve life distribution that can not directly determine the type from the test data, based on the analysis of the common life of the distributions' applicable, the characteristics and laws, goodness of fit test is used for the failure data and then the optimum fitting model is chosen through the use of Minitab. After determining the reliability of the model, it is the model parameters estimation and hypothesis testing. Finally, the actual failure data are calculated, analyzed and applied.

2 Select a Model of Reliability Life

In the reliability life analysis, there are many kinds of failure data modeling, common types of life distribution is Weibull distribution, normal distribution, lognormal distribution, exponential distribution and Z distribution [3, 4]. The following describes the exponential distribution, Weibull distribution and lognormal distribution.

2.1 Exponential Distribution

Exponential distribution is the most common kind of basic life distribution, its most important features is no memory, that device after a period of time after use. If component still not failure, device is still the same as the new device, it does not affect the total life length of the later. For most of the electronics and non-redundant complex system, its life obey Exponential Distribution [5, 6].

Its probability density function $f(t)$ is:

$$f(t) = \frac{1}{\theta} \mathrm{e}^{-\left(\frac{t-a}{\theta}\right)}, \quad t \geq a \tag{1}$$

wherein θ for the average life expectancy and a for a minimum service life.

Distribution function $F(t)$ is:

$$F(t) = \int_0^t \frac{1}{\theta} \mathrm{e}^{-\left(\frac{t-a}{\theta}\right)} dt = 1 - \mathrm{e}^{-\left(\frac{t-a}{\theta}\right)}, \quad t \geq a \tag{2}$$

Reliability function $R(t)$ and failure rate function $\lambda(t)$, respectively

$$R(t) = 1 - F(t) = e^{-\left(\frac{t-a}{\theta}\right)}, \quad \lambda(t) = \frac{f(t)}{F(t)} = \frac{1}{\theta} \tag{3}$$

2.2 Weibull Distribution

In recent years, Weibull distribution is the most widely used in distribution reliability analysis. A lot of practice has proved that all global function as a local failure or malfunction caused stop running components, equipment and systems, its lifetime distribution obey Weibull distribution [7, 8].

Its probability density function $f(t)$ is:

$$f(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} \mathrm{e}^{-\left(\frac{t}{\alpha}\right)^{\beta}} \tag{4}$$

wherein β is the shape parameter, α is the scale parameter.

Distribution function $F(t)$ is:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right], \quad t \geq 0, \quad \alpha \geq 0, \quad \beta \geq 0 \tag{5}$$

Reliability function $R(t)$ and failure rate function $\lambda(t)$, respectively

$$R(t) = 1 - F(t) = \mathrm{e}^{-\left(\frac{t}{\alpha}\right)^{\beta}}, \quad \lambda(t) = \frac{\beta}{\alpha}\mathrm{e}^{\left(\frac{t}{\alpha}\right)^{\beta}} \tag{6}$$

2.3 Lognormal Distribution

The fatigue life of mechanical products and electronic products often obey lognormal distribution and repair time of repair products can be described by a lognormal distribution. So the lognormal distribution is widely applied in reliability engineering.

Its probability density function $f(t)$ is:

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{(\ln t - \mu)^2}{2\sigma^2}\right], \quad t > 0, \quad \sigma > 0 \tag{7}$$

where μ and σ are the parameters for the number of positions and logarithmic scale parameter.

Distribution function $F(t)$:

$$F(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^t \frac{1}{x} \exp\left[-\frac{(\ln t - \mu)^2}{2\sigma^2} \right] dx, \quad t > 0, \quad \sigma > 0 \tag{8}$$

Reliability function $R(t)$ and failure rate function $\lambda(t)$, respectively

$$R(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_t^\infty \frac{1}{x} \exp\left[-\frac{(\ln t - \mu)^2}{2\sigma^2} \right] dx, \quad t > 0, \quad \sigma > 0 \tag{9}$$

When we do not know that which kind of distribution model is the best with a set of failure data, firstly, assuming the group failure data meets all alternative models, then fitting for each distribution model, selecting the best distribution model of goodness of fit, and conducting parameter estimation and hypothesis testing for model to verify the correctness of the chosen model, the process shown in Fig. 1.

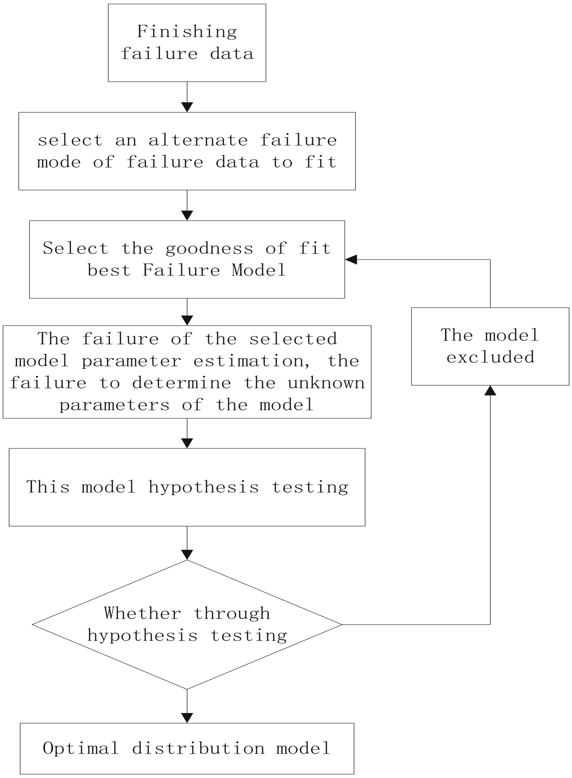

Fig. 1 Reliability life model selection flowchart diagram

3 Goodness of Fit Test

Failure data fail to fit with a set of alternative models, this method can assess the degree of fit and choose the best fitting model. Anderson-Darling (AD) statistic is a relatively common goodness fit statistics used to show the degree of fit. The statistics are point to the weighted squared fit line distance, closer to the distribution of the tail, the bigger the weight. The specific expression of

$$\begin{aligned} A^2 &= -n - \sum_{i=1}^{n} \frac{2i-1}{n}\{\ln F(t_1) + \ln[1 - F(t_{n+1-i})]\} \\ &= -n - \sum_{i=1}^{n} \{\frac{2i-1}{n}\ln F(t_1) + \frac{2n+1-2i}{n}\ln[1 - F(t_i)]\} \end{aligned} \tag{10}$$

where the value of A is smaller, the better the distribution fits the data, it is suitable for maximum likelihood and least squares method.

AD statistical measurement data follow a particular degree distribution. Distribution fit the data better, the smaller the statistics. Using AD statistics can compare number of distribution fitting situation and see which profile is the best distribution, or to verify whether the data samples from populations with the specified distribution.

4 Paramerer Estimation and Hypothesis Testing

In determining the reliability of the model failure data, the parameter of the reliability model is estimated for group data corresponding. Parameter Estimation are two broad approaches: graphics and analytical methods [9]. Graphical method estimate model parameters based on data in a particular probability graph paper. Analytical methods include a variety, more commonly used method of maximum likelihood and least squares method. From a statistical point of view, it is generally recommended for large samples using maximum likelihood method, because this method is generic and applicable to most models and different types of data, and will produce the most accurate estimates [10, 11].

After determining the type and parameters of the model, its hypothesis testing to determine whether the failure is determined with the distribution of data. Hypothesis testing usually have χ^2 test and K-S test. K-S test rati χ^2 test fine, but also can use to small sample case. This selection of K-S test method to test the reliability of the model.

K-S test steps are as follows: the n data are arranged by ascending order, based on the assumed distribution, calculated for each data t_i corresponding fault probability function $F(t_i)$. It compares with the empirical distribution function $F_n(t_i)$, wherein the difference between the maximum absolute value of the test statistic that is D_n. The observations D_n are compared with the threshold value D'_n, to meet the conditions, the null hypothesis is accepted, otherwise reject the null hypothesis.

5 Typical Components Reliability Lifetime Analysis

This paper chooses typical equipment parts run part of the data, as shown in Table 1. Data types for the failure data and data to the data collection is still normal work (suspension data), wherein the unit of time in hours (h).

First, this group of failure data use Minitab to distribute goodness fit, there are four kinds of alternative distribution model, fitting results shown in Table 2 and Fig. 2.

Table 2 shows the fitting result Weibull distribution AD statistic smallest, this article chooses Weibull distribution as reliability analysis model of parts and components. Can be seen in Table 1 parts failure data conform to the weibull distribution.

Weibull cumulative failure distribution function is:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right], \quad t \geq 0, \quad \alpha \geq 0, \quad \beta \geq 0 \tag{11}$$

where β and α are called shape parameter and scale parameter.

The formula (11) Represented by the Weibull distribution parameters specific do not know, so it is necessary to estimate the parameters of the model. Due to the

Table 1 Device components running test state data table

No.	Failure time	Status	No	Failure time	Status
1	1257	F	16	3002	F
2	1309	S	17	3252	S
3	1465	S	18	3374	F
4	1479	F	19	3423	S
5	1582	S	20	3542	F
6	1716	F	21	3626	S
7	1832	S	22	3713	S
8	1967	S	23	3887	F
9	2140	S	24	3929	S
10	2281	F	25	4071	F
11	2432	F	26	4179	S
12	2598	S	27	4265	F
13	2615	F	28	4395	S
14	2742	S	29	4475	S
15	2857	S	30	4627	F

Note F represents failure data; S represents censored data

Table 2 Statistical distribution fitting component failures

Distribution model	AD statistic
Exponential distribution	11.699
Weibull distribution	10.706
Lognormal	10.711
Normal distribution	10.704
3 parameter distribution Weibull	10.707
Least extremal	10.761

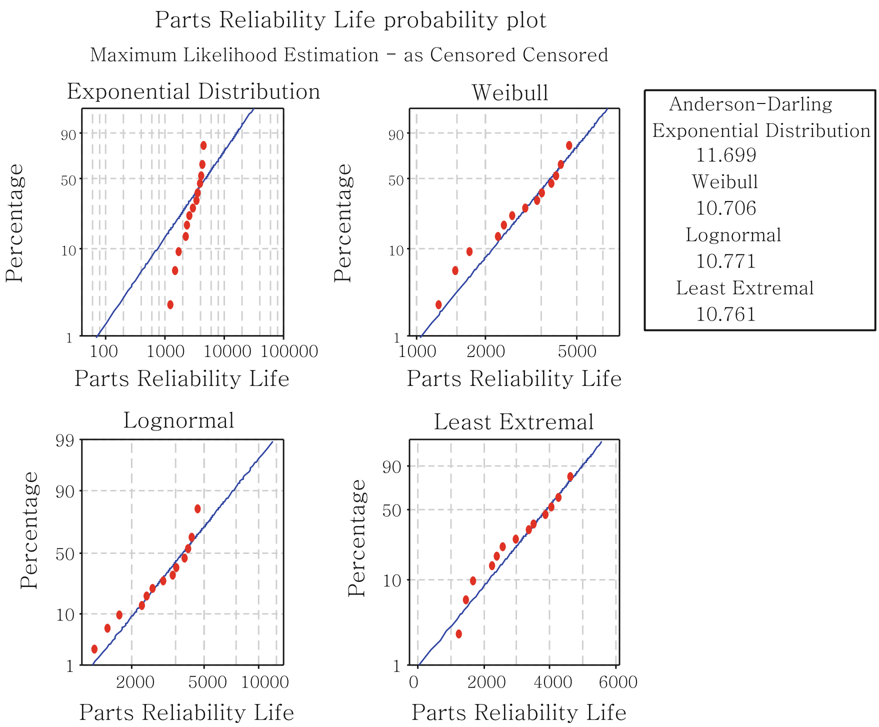

Fig. 2 Four models fit

maximum likelihood method for deleting data loss of data samples with high precision of parameter estimation, so this selection of the maximum likelihood method to estimate the parameters of the Weibull distribution. Its parameter estimation results are shown in Table 3.

Finally, the model need hypothesis testing, determining typical equipment failure data is character $\beta = 3.2521, \alpha = 4263.81$ of the Weibull distribution on Table 1. In this paper, the model test method is the K-S hypothesis testing. Firstly, calculating the value of theory and experience in distribution, the biggest absolute difference D_n is 0.0895, results are shown in Table 4:

Table 3 Parts weibull distribution parameter estimation

Parameters	Estimate	Standard error	Lower limit	Upper limit
Shape	3.25207	0.736189	2.08674	5.06817
Scale	4263.81	384.823	3572.52	5088.87

Table 4 K-S test statistic

Failure order i	$F_0(t_i)$	$F_n(t_i)$	D
1	0.0186	0.0230	0.0044
2	0.0315	0.0583	0.0268
3	0.0505	0.0949	0.0444
4	0.1226	0.1364	0.0138
5	0.1488	0.1780	0.0292
6	0.1845	0.2218	0.0373
7	0.2735	0.2711	0.0024
8	0.3732	0.3238	0.0494
9	0.4214	0.3810	0.0404
10	0.5229	0.4509	0.0720
11	0.5769	0.5307	0.0462
12	0.6324	0.6265	0.0059
13	0.7287	0.8182	0.0895

With sample size $n = 30$ and a significant level $\alpha = 0.1$ and look-up table, it can threshold $D'_n = 0.2227$ as $D_n < D'_n$, so accepting the null hypothesis that the data are consistent with $\beta = 3.2521, \alpha = 4263.81$ of the Weibull distribution. The cumulative distribution function of the Weibull distribution failure is:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{4263.81}\right)^{3.2521}\right] \quad (12)$$

Reliability function is:

$$R(t) = \exp\left[-\left(\frac{t}{4263.81}\right)^{3.2521}\right] \quad (13)$$

When failure distribution model determine the components, it easily calculate the batch components in a given operating time reliability and reliability in a given case corresponds to the working hours. This type of components is determined to be too original life-limited parts, depot overhaul every 5000 h. Calculated by the formula, the average time between failures of this type of components (MTBF) is

3821 h, this result is far lower than originally planned overhaul time, and consistent with the actual work. When given component reliability R = 0.95, from (13) shows that life is reliable components:

$$t_{0.95} = 4263.81(-\ln 0.95)^{\frac{1}{3.2521}} = 1710.6\ (\mathrm{h})$$

From the above calculation, given the reliability of the component R = 0.95, the reliability life is 1710.6 h, when working time in less visible parts 1710.6 h, the component is on high reliability, it is only small-scale inspection and maintenance. Similarly the Weibull distribution can be calculated median 3809.4, that part of the batch job is 3809.4 h when 50 % have failed.

Assuming the existing 50 parts are used on the device and the monthly average working time for each component is 360 h. According to Eq. (12) shows that the probability of component failures that may occur after six months:

$$F(2160) = 1 - \exp\left[-\left(\frac{2160}{4263.81}\right)^{3.2521}\right] = 0.1037$$

It can be seen, there are about 50 × 0.1037 = 5.18 component failures after six months, that there are about six component failures. It is best to prepare eight spares within six months.

6 Conclusion

In order to solve the problem that it does not directly determine the type of life distribution from the test data, the paper firstly analyze the common distributions' application of the type, characteristics and laws. then building various types of life distribution model of failure data to fit testing Goodness and choosing the best fitting model through the use of Minitab software. After determining the reliability of the model, it is the model parameter estimation and hypothesis testing. Finally, the actual failure data analysis components were calculated and applied to, this new method can improve equipment reliability and reduce the failure rate.

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Research on Energy Saving and Emission Reduction of Liaoning's Power Energy Based on the Electric Supply Chain

Tong-bing Ma and Chao Sun

Abstract Describes the current situation in the basis of production management of power and energy enterprises in Liaoning Province, the paper constructed the electricity supply chain concept model for the power energy enterprises. Analyze the characteristics of electric power enterprises in Liaoning, we propose an integrated mode of operation of the electricity supply chain. According to the structure of the electricity supply chain, proposed Liaoning Energy saving and emission reduction policy from suppliers, power suppliers, power transmission suppliers, marketers, users and integrated management of six aspects.

Keywords The electric supply chain · Liaoning's energy · Energy saving and emission reduction

1 Introduction

The power industry is an important supplier of energy, electricity supply undertaking to provide for the basic mission of national socio-economic development. In China's power industry, about 75 % of coal-fired power generation, due to geographical and other natural endowments relationship, Liaoning power industry a greater proportion of coal-fired power, there is a serious pollution emission, environmental protection and other outstanding issues. Revitalizing northeast old industrial base in Liaoning Province strategy and economic and social development, energy industry needs to do important support, thus inevitably lead to conflicts of

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energy shortage and environmental protection [1]. Therefore, energy conservation, green power has become an important issue for sustainable development process in the electric power industry in Liaoning solved, and electricity supply chain management is one of the effective means to solve the problem.

Electricity supply chain from the manufacturing supply chain management thinking, the power supply chain management based on power generation, transmission, distribution and sales processes in a flexible form of business organization, according to the market demand of electrical energy to end-users, adopting flexible production management, rely on strict and meticulous organization and management, to play a leading role and advantages of the core business of enterprise collaboration, starting from the overall planning, control, coordination and integration of system resources, so as to realize the power companies low-power, low cost, high quality and high efficiency the overall objective of profit maximization.

2 Methodology the Status of Power Energy Companies

At present, China's electricity consumption showed a steady and rapid growth trend, power generation capacity continued to grow, accelerate structural adjustment, and gradually increase the level of technical equipment, energy saving technology and methods to achieve new development. In 2011 amounted to 4.6928 trillion kwh of electricity, adding 90.41 million kilowatts of installed capacity, power generation capacity by the end of 2011 to reach 1.056 billion kilowatts, of which hydropower, nuclear power, wind power and other power generation capacity reached 27.50 % share, higher than the 2010 0.93 %; power supply standard coal consumption of 330 g/kWh, compared with last year fell 3 g/kWh; line loss rate of 6.31 %, a decrease of 0.22 % over the previous year. A number of key national electrical energy, power grid construction projects put into operation on schedule in 2011, making the country's electricity industry reasonable layout configuration optimization [2].

Currently, Liaoning Province thermal power installed capacity 27923.4 MW, where single unit installed capacity of 50 MW or less 3646.19 MW, accounting for 13.05 percent of the province's thermal power installed capacity [3]. Unit capacity below 50 MW of thermal power companies totaled 99, mainly responsible for the large-scale metallurgical, chemical, mining and other power, power, heat supply and heating in winter. It features a small capacity, high consumption, low efficiency, high cost.

It is predicted that in the next few years, annual GDP growth of more than 11 % of Liaoning, the economy will continue to maintain a rapid growth momentum; investment in fixed assets grew more than 30 %. It is predicted that the "Twelve Five", Liaoning Province electricity consumption will reach 258 billion kwh, an average annual growth rate of 7.04 %; electricity supply to reach 229 billion kwh, an average annual increase of 7.1 %; maximum 32.5 million kilowatts electricity supply, average annual growth of 8.5 %. Liaoning Province power installed capacity will reach 536.2 MW. To this end, Liaoning Province should focus on long-term goals of economic development, electricity supply chain based on optimal regional allocation of resources, energy conservation, improve efficiency and protect the electricity demands of economic and social development in Liaoning Province.

3 The Construction and Operation of the Electricity Supply Chain

3.1 The Construction of the Electricity Supply Chain

While the power industry is different from the manufacturing industry, although it is not a tangible product, but provides is relatively invisible, production, supply of electricity while completing special products, therefore, logistics, capital flow and information flow are also present in the electricity production process in. Logistics is a natural energy (water and wind, etc.), primary energy (coal, oil, etc.) providers and equipment suppliers, converted into electricity by power suppliers, to transmission providers, marketers, and finally to the user's energy flow, logistics flow from upstream to downstream. Cash flow is the customer's purchase funds to flow process marketers, transmission providers, and suppliers of power generation, cash flow from downstream to upstream by the user flow. Information flow in the core business under a comprehensive control, all aspects of customer demand customer demand, power generation, load conditions, the sale of electricity and other two-way transfer of information in the supply chain. Three flow throughout the whole process of the electricity supply chain operations. The conceptual model shown in Fig. 1:

1. *Supplier*

Currently, Liaoning Province, the power companies are the main suppliers of coal production and power generation equipment suppliers and vendors, whose main task is to provide raw materials and power generation equipment for power

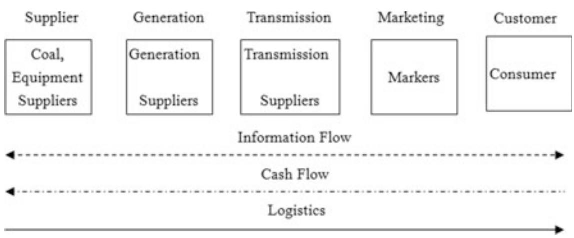

Fig. 1 The concept model of electricity supply chain

generators. This session, coal production enterprises are the main fuel supplier of thermal power plants, power generation equipment manufacturing enterprises are mainly hydro and wind power equipment supplier companies.

2. *Power suppliers*

Energy production is done by the generation companies, major business is power plant. Mainly in the form of thermal power generation, hydroelectric power, nuclear power and new energy (solar, wind, tidal power, geothermal, biogas). Liaoning Province, mainly in coal-fired power generation group based its power generation capacity of the total generating capacity of more than 80 %.

3. *Transmission Suppliers*

Transmission Suppliers main task is to transport electricity, mainly to complete this task by the grid company, power is completed in the electricity transport network, electric transport has high technical requirements, high reliability, and low power consumption.

4. *Marketers*

Marketer's task is distribution and electricity sales, electricity distribution is the distribution of products, mainly by the Power Supply Bureau (the company) is complete, responsible for distribution network operation and security, customer marketing.

5. *Customer*

Since many of the special nature of power products, power user's classification, the paper will be divided into industrial electricity users, agricultural electricity, commercial electricity and residential electricity and other customers. In 2011, the national total electricity consumption 4.6928 trillion kwh, an increase of 11.74 % over the previous year.

3.2 The Operation of Electricity Supply Chain

Power industry supply chain is different from the manufacturing supply chain, their production and transportation process closely together, power products production, supply and complete the same time, in space and time continuous indivisible, the entire process is a set of electricity generation, transmission, distribution, sales and applying a continuous flow of the industrial chain.

Each node on the electricity supply chain companies rely only on their own if limited resources and inherent management mode, you cannot meet the demands of a rapidly changing energy market. Each node enterprise supply chain, only to give up the power behind the management, in order to adopt a new management model, build business alliances, the integration of internal and external resources, rapid response to customer needs in order to improve efficiency, reduce costs and improve service quality, achieve the overall maximize efficiency.

Electricity supply chain is a dynamic alliance formed by several companies, in management there must be a member of the unstable and difficult to manage, coordination disorders, poor communication, system is not perfect and so on, in order to improve the competitiveness of the electricity supply chain must use the information management, organization and coordination, new management methods collaborative decision-making and integrated management. This power mode supply chain operations centralized management model-based, with a core business as the mainstay for the entire electricity supply chain decisions, integration of the entire supply chain resources, eliminate regulatory barriers and technical barriers, ensure power supply smooth, stable power price, grid security and stability, a high level of customer service, bringing the total cost of the supply chain of the smallest businesses get the maximum benefit.

4 The Policy of Liaoning Energy Saving and Emission Reduction

Liaoning power industry on the one hand to accelerate the pace of development, improve security and stability level and quality of power supply, effectively alleviate the power shortage situation; on the other hand, strengthen energy conservation, improve the level of energy saving. In this paper, Liaoning Energy saving and emission reduction policy from the perspective of the electricity supply chain.

4.1 Supplier Angle

Coal suppliers should improve coal quality, reduce coal ash and sulfur, to improve coal heat, can reduce serious wear and tear to equipment, reduce power plant electricity consumption, improve power generation efficiency; but also can reduce the desulfurization unit super negative, improve the desulfurization efficiency and protect the environment.

4.2 Generation Enterprise Angle

Power generation companies are energy saving in the supply chain the most important role. To achieve reduction of carbon emissions, optimization of coal resources, the use of clean energy, promote the construction of large coal base energy, shutting down small thermal power, small units, and promote carbon-free hydro, nuclear and wind and other renewable energy development and other aspects of play a crucial role. Currently, Liaoning wind power capacity exceeded 400 million kilowatts, reached 4.42 million kilowatts of wind power as Liaoning's second-largest power installed capacity ranked second in the country.

4.3 Transmission Provider's Angle

Development of UHV power grid, reduce line losses, conservation of land, environmental protection, access to savings capacity, inter-basin compensation, water and fire mutual agent peer networking staggering load efficiency, efficient use of energy resources. Liaoning Province actual binding power, from simulation technology, control technology, transmission technology to enhance the management and equipment, such as multi-pronged approach to improve the load characteristics, improve the safety performance of power systems, improve power quality and supply reliability, and promote energy saving.

4.4 Marketers Angle

Substations and transmission lines to promote universal optimized design and build a resource-saving and environment-friendly industrialization substation and resource-saving and environment-friendly, new technologies, new materials, new technology transmission lines. In the design concept, the implementation of the whole life cycle of the most optimal design, implement standardized design and differentiated design, integration, application of new technologies, new materials, new technology, construction and operation of the overall cost savings.

4.5 Consumer Perspective

Construction demand side management demonstration projects, to promote electricity storage, green lighting, efficient motors and other energy saving technologies, promote energy-saving society.

4.6 Integrated Management Perspective

Implementation of integrated supply chain management system from the perspective of power, can be used the following measures: (1) Implementation of a comprehensive environmental management, environmental protection section proposed initiatives, the potential of the existing power grid allocation of energy resources. (2) The implementation of standardized construction, energy conservation and raise the overall level of resources. (3) Specification to carry out energy-saving power generation scheduling pilot. Develop energy-saving power generation scheduling technology support system, priority scheduling of renewable energy, nuclear energy, cogeneration units, reducing energy consumption and pollution emissions.

Active in electricity trading. The company through “the big-generation small”, fire and water replacement and other forms of power generation depth trading. (4) Promotion of renewable energy development, promote the use of green electricity. Companies in full accordance with the law clear commitment to purchase renewable energy generating capacity, to encourage users to use green electricity, promote green lifestyle, to support renewable energy development.

5 Fund Project

1. 2014Liaoning Province Education Department of Humanities and Social Science Research Projects: The Study on Construction and Operation of the Electricity Market in Liaoning Province Based on Lean Management Model
2. 2015 Liaoning Province Social Science Planning Fund Projects: The Research on the Development Strategy of Manufacturing Innovation Center in Liaoning Province based Chinese Manufacturing 2025

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Study on Liaoning's Rural Energy Saving Based on Low Carbon Economy Environment

Chao Sun and Tong-bing Ma

Abstract In the low carbon economy, for rural energy consumption gradually increasing, energy conservation and emission reduction is a very important position. On the analysis of the Liaoning rural energy consumption characteristics, Liaoning rural energy construction problems are systematic studied. The management system innovation, management innovation and technology innovation method proposed in three aspects of rural energy construction and application of energy-saving reduction strategy.

Keywords Energy saving · Liaoning rural · Low carbon economy

1 Introduction

Low-carbon economy is a new concept came into being in response to climate change, following the industrial revolution and the information revolution two new ways of world economic development. Development of low-carbon economy is to address unsustainable high carbon emissions impact for a long time to bring the development of human society, building low energy consumption, low pollution, low-emission, sustainable economic development model for the basic features, significantly reduce carbon dioxide and other greenhouse gas emissions and achieve sustainable economic and social [1].

Both the old industrial base in Liaoning Province, is a major agricultural province, energy consumption in rural areas have a pivotal position. Structure, and use patterns Liaoning Province rural energy consumption is not only related to the sustainable development of energy and the environment, but also to the development of rural economic development in Liaoning province and energy master planning. Therefore, the implementation of energy conservation, energy

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optimization strategies to improve energy efficiency in Liaoning Province, has the importance of developing a low-carbon economy.

2 Rural Energy Consumption in Liaoning Province

With the rapid development of Liaoning and new rural construction and low-carbon economy, Liaoning Province experienced growth in energy consumption in rural areas, especially the rapid growth of household energy consumption. Liaoning Province due to the current situation of energy consumption in rural areas showed the following characteristics:

(1) The total amount of Liaoning Rural energy consumption continues to rise

According to the 2011 Statistical Yearbook of Liaoning, Liaoning Province, rural electricity consumption as shown in Table 1, in 2000 10.35 billion kilowatts-hour, in 2006 the rapid increase in large 21.9 billion kilowatts hours of electricity, more than doubled in 2010 in rural areas in Liaoning Province residents reached 35.95 billion kilowatts hours of electricity, an increase of 247.3 % compared to 2000 [2].

Residents living in rural Liaoning Province overall trend continues to increase energy consumption, compared with urban energy consumption gap is still large. As Table 2 shows, the energy consumption of urban residents in Liaoning Province from 2006 to 2010 continued to grow steadily, with an average annual growth of around 8 %, while rural energy consumption from 2006 to 2009 change is not great, but in 2010 consumption growth is large, exceeding the growth rate of energy consumption of urban residents reached 19 %, higher than the growth rate of 14 % of urban residents.

(2) The construction of small hydropower steady growth in rural Liaoning Province

Liaoning Province attaches great importance to the construction of small hydropower in rural areas, from 119 in 2000 to 165 developments and steady growth in 2010 for rural effective to provide effective support.

Table 1 Liaoning province, rural electricity consumption (Unit: 100 million kilowatt-hours)

2005	2006	2007	2008	2009	2010
153.3	219	265.4	270.8	283.9	359.5

Table 2 Liaoning province residential energy consumption (Unit: million tons of standard coal)

	2006	2007	2008	2009	2010
City	867.12	929.51	993.67	1023.37	1175.58
Rural	203.42	203.77	216.84	212.27	252.72

(3) The new energy has become an important growth point

In the environment of low-carbon economic development, along with scientific and technological progress and development, Liaoning Rural new energy and renewable energy industry gradually developed. (a) biomass power generation, Liaoning Province crop stalks per year to 31.958 million tons the amount of physical resources, which are likely sources of straw utilization of up to 13 million tons, 6.8 million tons of standard coal equivalent. (b) wind power generation, the best wind resources in Inner Mongolia region to landlocked Xinjiang area, located in Liaoning wind power density of 200–300 W/m, 3–20 m/s wind speed cumulative 5000–6000 h in northern Liaoning, Jilin and Inner Mongolia provinces border, the terrain better conditions, abundant wind energy resources. (c) biogas and solar energy: they are an important renewable energy, application of the scale is expanding in Liaoning Province, Liaoning Province, while rural biogas and solar energy industry is also stable and rapid development.

3 Liaoning Rural Energy Saving and Emission Reduction Policy

3.1 Liaoning Province Rural Energy Construction Problems

(1) *Low degree of rural energy construction market*

Because of China's rural energy industry started late, low degree of commercialization and industrialization, yet the vast majority of energy products market competitiveness, heavily dependent on government support. Environmental and resource issues will become a necessary condition for rapid restricting economic development, which will promote rural energy products and improve technical standards and quality, which is relatively backward in Liaoning Province rural energy industry is bound to bring more challenges.

(2) *The Government of varying degrees of emphasis on rural energy construction*

Currently the implementation of rural energy construction in Liaoning basically government action, the implementation appeared spotty situation. In rural energy construction, although the government in institutional settings, staffing and funding support given the high degree of attention, but still with a big gap between the needs of rural energy construction. Mainly in the provincial and municipal agencies set up sound, adequate personnel, funding in place, and set below the county level Energy Agency is not uniform, their own ways, the emphasis is not high.

(3) *Lack of capital investment in rural energy construction*

Although Liaoning Province invested a lot of money every year in rural energy construction, but compared with the importance of rural energy construction and far from reality. Related pilot demonstration, insufficient research and development funding, demonstration projects are small, small number, do not form the leading role of the rural energy and new technologies and new achievements difficult to translate into timely and promotion, limiting the role should be played.

(4) *The utilization rate of rural energy*

Rural Liaoning Province is very rich in renewable energy resources, but because of lack of financial resources and insufficient financial resources of farmers, new energy and renewable energy sources do not have full and widely used. Currently, Liaoning Province, a considerable number of farmers do not get a good energy services, energy is still primarily agricultural wastes (straw, firewood, etc.), even deforestation, destruction of ecology, a low efficiency of energy use in rural areas of the root causes.

(5) *Rural energy management and technical service system lags*

Currently, regulations Liaoning Province rural energy construction is not perfect, imperfect. Some areas of rural energy facilities to promote more use of small, build more, save less, facilities management and technology management weak link. While the rural development of renewable resources, a wide range of content and more new technology, less outlets in rural areas to maintain, less maintenance staff, in case of failure, it is difficult timely maintenance, we cannot guarantee the farmers a long-term stable use of high quality clean energy, affect the farmers to build enthusiasm.

(6) *Energy consumption increases, increasing pollution*

With the rural economic development in Liaoning Province, to improve the living standards of farmers, the total consumption of energy resources greatly increased, resulting in an increase of the total emissions of the pollutants, the formation of new energy and environmental pressures. At the same time, increase rural enterprises may also produce pollution-related energy consumption; this healthy development of the province's rural energy ecological construction constitutes a severe test.

3.2 Energy Saving Policy

Rural Liaoning Province has abundant natural energy and raw material resources, full of natural energy and biomass energy, improve management and service levels, the development and utilization of biomass energy and renewable energy sources, construction of new low-carbon rural Liaoning proposed energy saving Strategy:

(1) *Management System Innovation*: *strengthen government responsibility*, *increasing government support efforts.*

To form a government to actively support and promote rural energy development, environmental protection and economic efficiency in rural areas a combination of renewable energy utilization patterns. Popularity of farmers with biogas, saving stoves and solar cookers and other technologies to solve the basic problems of life with energy; with local characteristics and ecological agriculture, the construction of "Trinity" and "four in one"; combined with small towns, promotion of large biogas biomass heat electric regeneration technology, supply live gas, electricity and heat energy commodities such as small towns and villages.

Foreign experience in renewable energy and the developed areas of rural energy development, combined with the actual situation in Liaoning province, the rural renewable energy construction in the overall planning of Liaoning Province, the new rural construction, the development of renewable energy development in rural areas of our province's plans and objectives, encourage the development of relevant policies and measures to increase financial support for efforts to secure energy supply at the same time, and gradually improve the quality of rural energy, improve and improve farmers' living conditions, further implemented by the previous single rural renewable energy to diversify the way change and to promote prosperity and development of the rural economy.

(2) *Management of innovation*: *improve the management system*; *establish a systematic*, *three-dimensional security system.*

Formed on the management of rural energy construction in Liaoning innovation, establish and improve the establishment of rural energy management system, the formation of specialized and standardized management. At the same time the formation of the government, farmers, enterprises as overall management, construction, maintenance and use of systematic, three-dimensional security system. Basic rural energy construction management system, first, to integrate the advantages of enterprise resources, the establishment of enterprise groups, and research together to accelerate the new energy technology research and development focused on rural areas, promote rural energy construction. Secondly, the establishment of technical service system, the consolidation, verification planning and design qualification; the role of rural energy management agencies at all levels, training and development of rural local energy management and technical service personnel, the establishment of integrated services at all levels of base and service stations, improve service team quality and size. Finally, to improve the farmers' awareness of the use of new energy sources, recognize that new technologies bring new energy efficiency and energy saving, environmental protection, comfortable living and other long-term benefits; change the traditional concept, and gradually formed a new energy efficient and low-carbon lifestyle.

(3) *Technical methods Innovation*: *system planning new energy and renewable energy development.*

Biomass is the main source of energy in Liaoning province rural life, with a wide range of sources, low cost. The use of modern biomass energy in rural areas can not only improve energy security in rural areas, it can also slow down global warming and environmental protection issues. Currently, traditional biomass accounts for more than 50 % of the total amount of rural life can be. While only a small part of the energy commodity has a very good development. Biogas and solar energy use to improve the rural energy structure, environment, agriculture development, rural landscape has an important role, with significant ecological, economic and social benefits. Liaoning Province should actively promote the technology is more mature, great potential for development of wind power, solar power and biomass power and other renewable energy development; accelerate the construction of distributed renewable energy, electricity and remote rural areas to solve energy problems. Promoting rural economic development and farmers' living standards.

4 Conclusion

Under the low-carbon economy, rural energy is the material basis of rural harmonious development, the development of agricultural production and protects farmers' life; improve the rural environment an important resource. In the low-carbon economy and the continuous development of new countryside construction, the rural energy demand structure and the number of changes have taken place in Liaoning Province, while the growth rate of rural energy consumption will be higher than the growth of urban energy consumption, and efficient low-carbon energy is higher than in rural areas the problem of shortage will gradually appear, the future of rural energy construction in Liaoning challenging.

Liaoning Province of new energy and renewable energy is in its infancy, the economic development model for the province's rural energy development put forward higher requirements, rural energy as an integral part of the energy system in our province, and its development will inevitably affect energy supply and demand situation in our province. Rural energy construction in our province to the sustained and healthy development, will need to integrate into the market economy, investments in technology, improve the technological innovation, reduce production costs, improve the quality of products and services, the development of rural energy policy guide the healthy and orderly development, improve rural energy systems operation, management and service levels.

5 Fund Project

[1] 2014 Liaoning Province Education Department of Humanities and Social Science Research Projects: The Study on Construction and Operation of the Electricity Market in Liaoning Province Based on Lean Management Model
[2] 2015 Liaoning Province Social Science Planning Fund Projects: The Research on the Development Strategy of Manufacturing Innovation Center in Liaoning Province based Chinese Manufacturing 2025

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Study of Workshop Production System Based on Petri Nets and Flexsim

Bo Huang and Hua-jun Tang

Abstract This paper develops a method on the analysis of process efficiency, based on the combination of Petri nets and Flexsim, to solve a typical discrete event in the workshop production system. Specially, this study utilizes Petri net theory to model the event, and then uses the Flexsim software to dynamically simulate the Petri-net based model, making the system bottleneck intuitive and visible. Finally it realizes the purpose of optimizing the system process efficiency by improving the system objects. The simulation results show that, this method can quickly find out the potential problems in the system compared to the traditional method. On the basis of this method, the efficiency is greatly improved. Furthermore, this study offers effective means to the scientific decision of workshop production system.

Keywords Simulation · Workshop production system · Petri net · Flexsim

1 Introduction

The design and optimization of workshop production have drawn people's wide attention. It is well known that the workshop production is a typical discrete event system (DES) in production logistics system. In a DES, it is fundamental for researchers to identify which machine has high idle rate, which production line gets over-production, which stacker obtain the highest efficiency, and so on.

Traditionally, people mainly use quantitative methods and experience to arrange facilities. Using the mathematics method is not only complicated and time-consuming, but cannot test the feasibility of the model in practice. In recent years, simulation technology has developed rapidly. Application of simulation technology

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in the design, verification and analysis can effectively improve the work efficiency, reduce the operating cost and avoid potential risks for enterprises.

In the literature, there exist some methods on the modeling of production systems, such as GRAY, IDEE, SIM, Petri nets and so on [1]. Petri nets were proposed by Carl Adam Petri [2] in 1962. Petri net is a powerful modeling technique for problems involving coordination in a variety of domains. As an important modeling method, a petri net can conduct mathematical analysis as well as visually describe the operational process of the system. Hence Petri nets are widely used for production system modeling (see [3–6]).

By following Murata [7], a basic Petri net is defined as $PN = (P, T, F, W, M_0)$, where $P = \{p_1, p_2, \ldots, p_m\}$ is a finite set of places; $T = \{t_1, t_2, \ldots, t_n\}$ is a finite set of transitions; $F \subseteq (P \times T) \cup (T \times P)$ is a set of arcs (flow relation); $W: F \to \{1, 2, 3, \ldots\}$ is a weight function, which means a transition t_i is enabled if each place p_j directing to t_i contains at least $w_{ij}(p_j, t_i)$ tokens; $M_0: P \to \{0, 1, 2, 3, \ldots\}$ is the initial marking indicating the numbers of token in each place; $P \cap T = \emptyset$ and $P \cup T \neq \emptyset$.

Based on the weight function, the transition node may be enabled, which will fire. A transition node fires by moving its tokens from its input place node to the transition node, and then deposits the tokens into the output place node that is directed from the transition node. Figure 1 shows the legend of a Petri net, where p_1 is input places of t_1; p_2 is the output place of t_1, as well p_2 is input places of t_2; p_3 is the output place of t_2; t_1 and t_2 are output transitions of p_2 and p_3, respectively.

In a production system, there are some simulation software, such as Flexsim, Witness, AutoMod, Arena and so on, in which FlexSim is a popular simulation research in manufacturing systems (see [8–11]). Furthermore, Flexsim is used in a number of fields, such as Manufacturing [12], Logistics and distribution [13], Transportation [14], Network flow [15], and so on.

Flexsim adopt C++ programming languages. The process of the module structure like Fig. 2.

This paper is organized as follows. In Sect. 2 a case is analyzed with Petri net and Flexism. Section 3 discusses the results. Section 4 draws the conclusion.

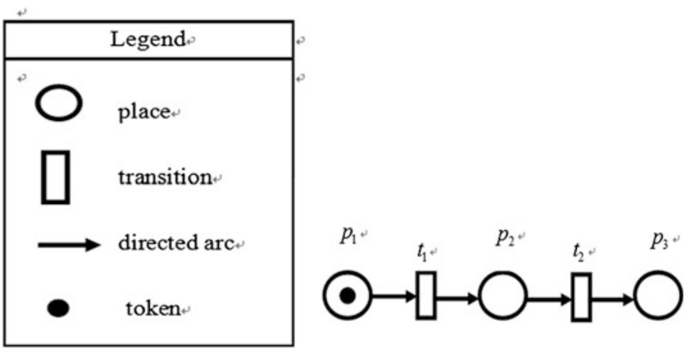

Fig. 1 The legend and elements of a Petri net

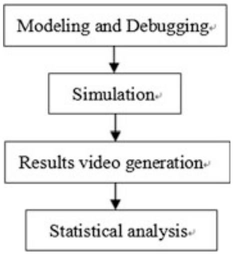

Fig. 2 The process of the module structure about Flexsim

2 Workshop Fabrication System with Petri Nets and Flexsim

2.1 Case Introduction

A workshop produces "A", "B", "C" three types of products every day. Three workers are responsible for handing the raw materials from staging area about raw materials to the production lines at the appointed time. There are three production lines "L1", "L2", "L3" and each production line processes the products "A" "B" "C", respectively. After the production, all the finished products will be sorted by the type and tested in the inspection area. If the products are qualified, they will be sent to the staging area about the qualified products. Otherwise, they will be sent back. Meanwhile, the qualified goods are delivered to the corresponding shelves.

According to the introduction, a production flow chart about the workshop can be set up in Fig. 3.

2.2 The Descriptions of Petri Nets

A Petri net model corresponding to Fig. 3 is shown in Fig. 4, and Tables 1 and 2 describe the variables.

2.3 The Simulation of Petri Nets Model by Flexsim

According to the Petri nets model, needed entity is shown in the Table 3.

In addition, the main technical parameters are listed in Table 4 as follows.

Based on the above introduction, the final simulation model is obtained in Fig. 5.

In the end, with the simulation of 28,800 s (8 h of work time), the summery is reported in Table 5.

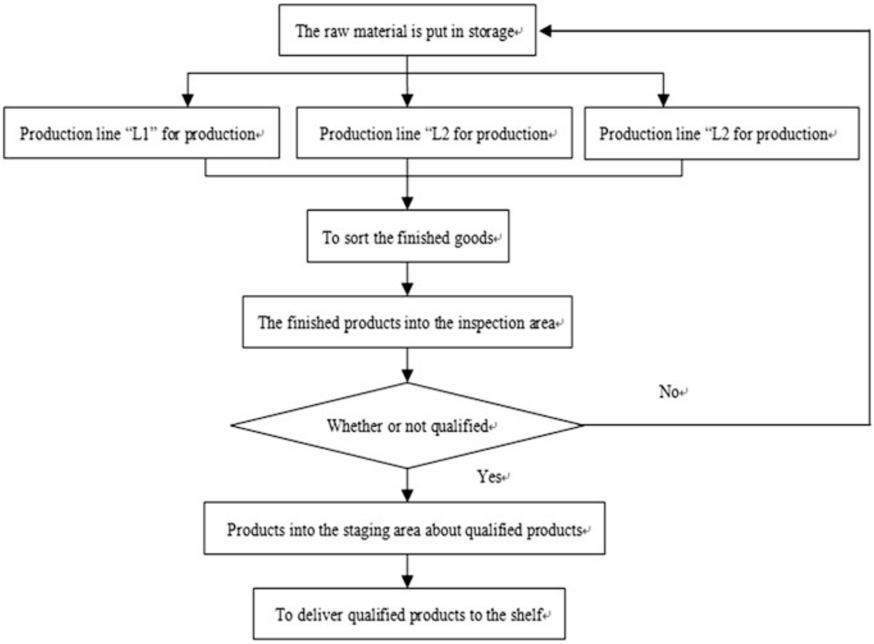

Fig. 3 The production flow chart about the workshop

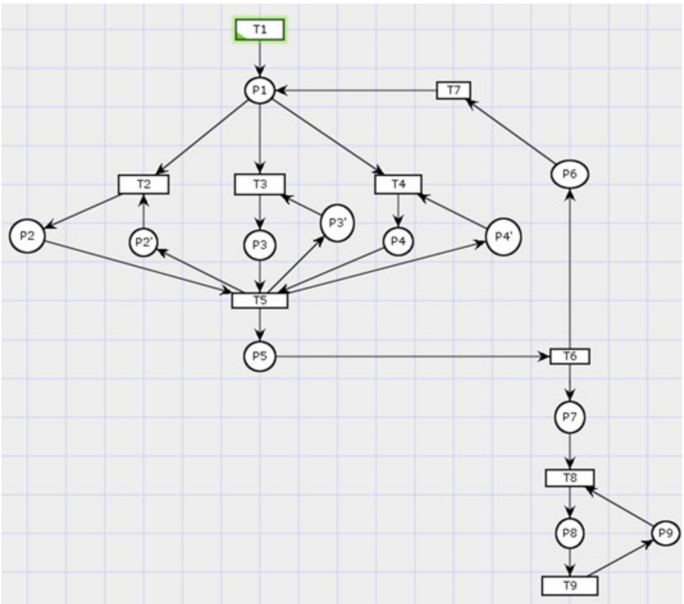

Fig. 4 The production process descriptions by Petri nets

Table 1 Interpretation of places in the Petri nets in Fig. 4

Place name	Description
P1	Raw material storage
P2	Production line “L1” is working
P2′	Production line “L1” is idle
P3	Production line “L2” is working
P3′	Production line “L2” is idle
P4	Production line “L3” is working
P4′	Production line “L3” is idle
P5	Sorting system “S1” is sorting
P6	Defective good
P7	Qualified product
P8	Storage
P9	Shelf is empty

Table 2 Interpretation of transitions in Petri nets of Fig. 4

Transition name	Description
T1	Raw materials have arrived
T2	Worker “M1” handling raw materials to “L1”
T3	Worker “M2” handling raw materials to “L2”
T4	Worker “M3” handling raw materials to “L3”
T5	Finished goods into the sorting process
T6	Finished goods into the testing area
T7	Defective good into the return process
T8	Forklift truck “F1” handling qualified product to the staging area.
T9	Qualified product into the shelf

Table 3 Needed entity in the Flexsim model

Entity name	Number	Description
Source	3	Generate three kinds of products of raw materials
Queue	4	One shows the staging area about the raw material Three shows the staging area about the qualified products. Expressed in D1” “D2” “D3”
Sink	1	Shows the defective good area
Processor	3	Means three production line “L1” “L2” “L3”
Conveyor	7	Four representative sorting process Three mean the testing area about three different kinds of products
Operator	3	Three workers are expressed in “M1” “M2” “M3”
Transporter	1	A Forklift truck is expressed in “F1”

Table 4 The main technical parameters

Entity name	Description
Set color of source	Set three different colors, in which A is read, B is green, and C is blue. Defective good is black
Set content of queue	Set the maximum content is 1000
Set job pattern of processor	Use operator setup
Set exit point of conveyor	Set 1,2,3 three kinds of output port

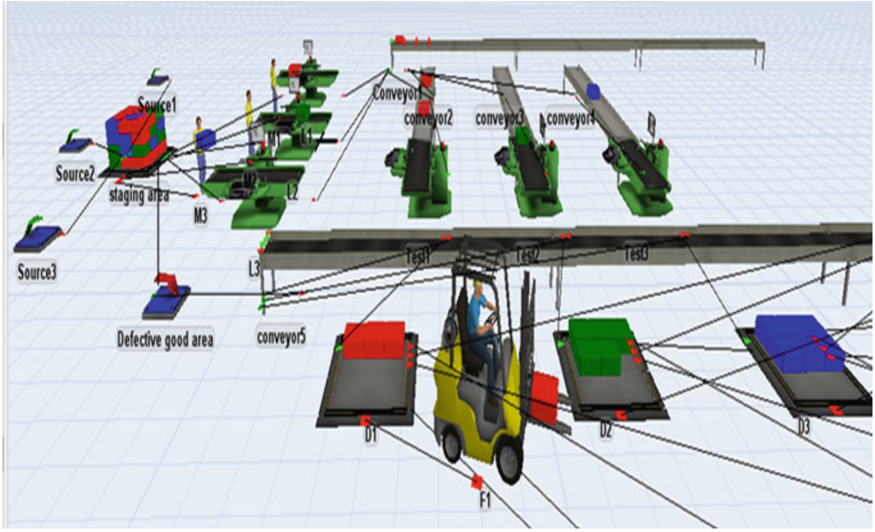

Fig. 5 The Flexsim simulation model

3 Results and Discussion

In Table 5, there are 4584 raw materials entering the workshop to be produced in one day (28,800 s). Every day the workshop can produce 1173 products, including, 538 products "A", 331 products "B" and 304 products "C".

It can be seen that the idle rate of all the processors are more than 50 %. The idle rate depends on the speed of the production line and inspection area. Hence, in the case, it is normal.

Table 5 Flexsim summary report

Flexsim summary report							
Time: 28,800.36 s							
Object	Class	Status input	Status output	Idle	Processing	Idle rate (%)	Waiting for transporter
Source1	Source	0	1933	0	0		0
Source2	Source	0	1672	0	0		0
Source3	Source	0	979	0	0		0
L1	Processor	1232	1232	16,483.33	12,316.59	57.23	0
L2	Processor	1373	1373	15,060.91	13,726.27	52.32	0
L3	Processor	979	979	18,990.74	9790	65.98	0
Test1	Processor	1220	1220	16,600.36	12,200	57.64	0
Test2	Processor	1372	1371	15,085.49	13,714.87	52.38	0
Test3	Processor	979	979	19,010.36	9790	66.01	0
Conveyor1	Merge sort	21,436	21,433	0	0		0
Conveyor2	Conveyor	19,082	19,074	0	0		0
Conveyor3	Conveyor	1372	1372	0	0		0
Conveyor4	Conveyor	979	979	0	0		0
Conveyor5	Merge sort	230	230	0	0		0
Staging area	Queue	4532	3532	0	0		10.992416
D1	Queue	1097	538	0	0		28,551.68911
D2	Queue	1293	331	0	0		28,748.28513
D3	Queue	950	304	0	0		28,731.31549
F1	Transporter	1173	1173	0	0	0.00	0
M1	Operator	1232	1232	12,328.25	0	42.80	0
M2	Operator	1373	1373	13,752.93	0	47.80	0
M3	Operator	979	979	15,520.23	0	53.90	0
Defective good area	sink	0	0	0	0		0
Shelf1	Rack	538		28,800.4		100	
Shelf2	Rack	331		28,800.4		100	
Shelf3	Rack	304		28,800.4		100	

3.1 The Problems of the Simulation

From the statistical analysis of the model, a few problems can be investigated as follows.

1. The inventory levels of “D1” “D2” “D3” is higher. According to the status input and status output about queues in Table 6, the corresponding inventory levels are obtained. The average inventory rate of “D1”, “D2” and “D3” is 64.45 %.

Table 6 The inventory lever of queue

Object	Class	Status input	Status output	Inventory lever (%)
D1	Queue	1097	538	50.96
D2	Queue	1293	331	74.40
D3	Queue	950	304	68.00

2. The idle rate of operators is higher. “M1” is 42.80 %, “M2” is 47.80 % and “M3” is 53.90 % (see Figs. 6, 7, and 8).
3. The idle rate of transporter “F1” is 0 %. It means that the state of the forklift truck “F1” is overworked.

3.2 The Improved Scheme

To improve the problem, the following solution to optimization model is proposed. In order to reduce the inventory levels of “D1” “D2” “D3” and improve the working

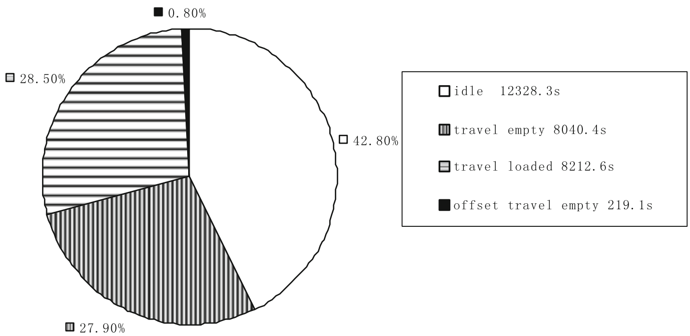

Fig. 6 The pie chart of “M1”

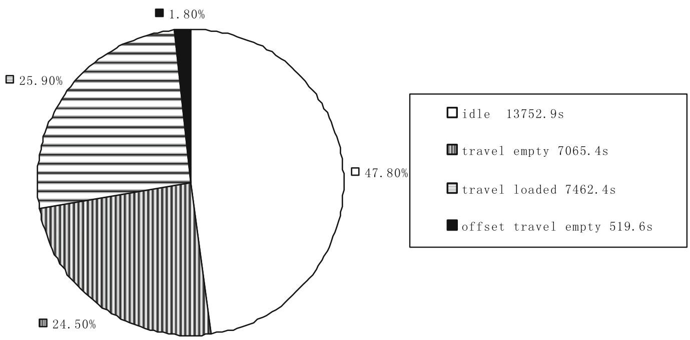

Fig. 7 The pie chart of “M2”

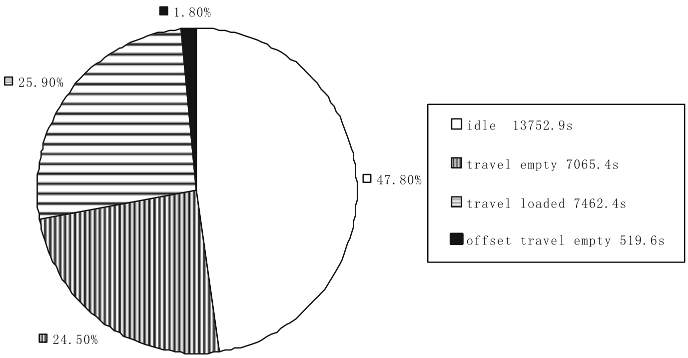

Fig. 8 The pie chart of "M3"

condition of "F1", the transporter will be changed. We use stacker instead of forklift truck "F1" in Fig. 9. Considering the idle rate of "F1" is 0, we add three stackers to improve the efficiency of inventory. The modified model is shown in Fig. 9.

We find that the idle rates of operators are improved. Stacker1 is 0.1 %, Stacker2 is 0.2 %, and Stacker3 is 0.2 % (see Figs. 10, 11 and 12).

Furthermore, it can be seen that, with the improvement of inventory efficiency, the inventory lever of the staging area about the qualified products is also improved (Table 7).

Reducing the number of operators can improve the idle rate about operators. It is known that the high idle rat may be instructions that there is redundancy. So in Fig. 13 we only hire one worker in the improved scheme. The idle rate of operator is 15.2 %. This measure can help reduce the cost.

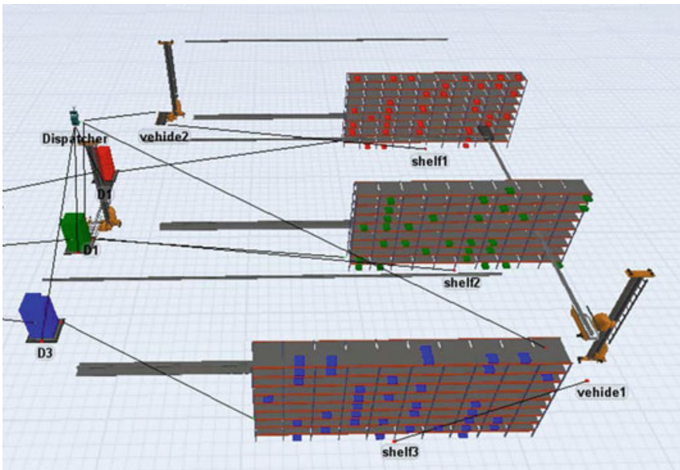

Fig. 9 The improved simulation about transporter

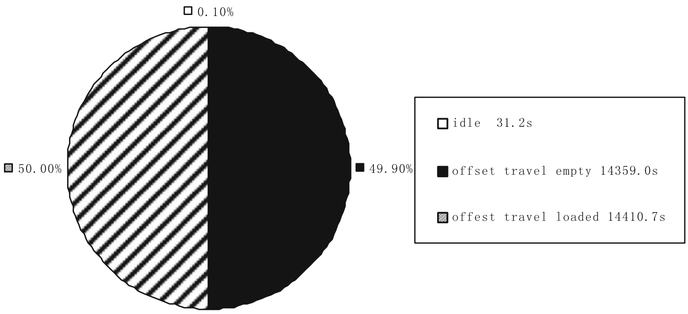

Fig. 10 The pie chart of stacker1

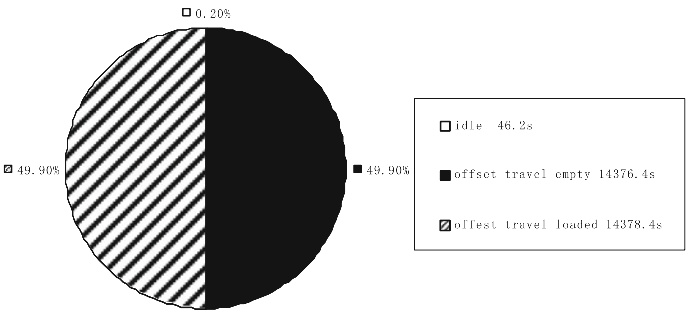

Fig. 11 The pie chart of stacker2

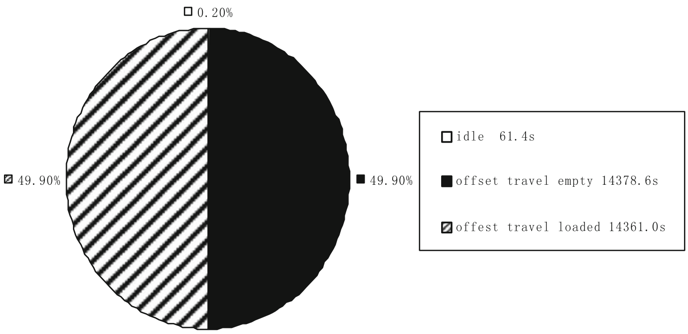

Fig. 12 The pie chart of stacker3

Table 7 The improved inventory lever of queue

Object	Class	Status input	Status output	Inventory lever (%)
D1	Queue	1097	688	37.28
D2	Queue	1293	490	62.10
D3	Queue	950	428	54.95

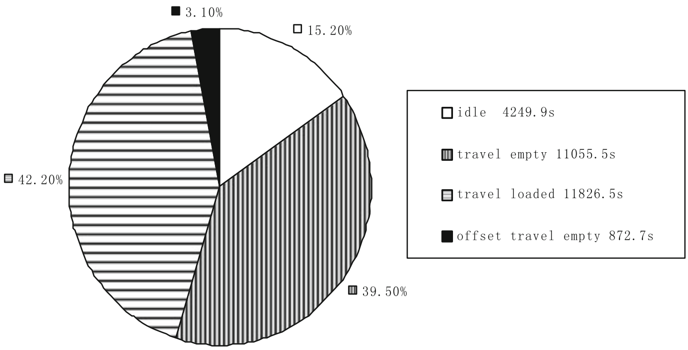

Fig. 13 The pie chart of operator

4 Conclusion

This paper utilizes Petri net theory and Flexism simulation to improve the problems in production systems. It analyzes the production flow chart about the workshop, applies Petri nets to model the workshop production system, and run the simulation with Flexsim for physical simulation. As a result, this method can quickly find the system problems, and improve the model by changing the object.

The simulation results show that, in reality the method based on the combination of Petri nets and Flexsim is better to solve a problem, compared with traditional mathematical method in the workshop production system.

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On Parallel Machine Scheduling with Rejection

Li-si Cao, Zi-xian Liu and Da-kui Jiang

Abstract In this paper, we study a parallel machine scheduling model with rejection where a set of n jobs and a set of m identical parallel machines are considered. Each job is either rejected with job-independent penalty or processed on one of the machines. The objective is to minimize the makespan of completing all accepted jobs plus the total cost for rejecting jobs. We consider the setting that the rejection cost of all jobs are identical and develop a polynomial-time heuristic with a worst-case.

Keywords Heuristic · Parallel machine · Rejection · Scheduling

1 Introduction

Machine scheduling with rejection (MSR) has attracted considerable attention from scheduling researchers as well as production managers who practice it in the past a few decades. The problem is to maximum the total revenue by rejecting part of jobs and processing the remaining ones. Excellent literature review articles on MRS were provided by Slotnick [1]. In traditional MRS models, the rejection cost is job dependent such that the rejection cost is unique for different jobs. However, in many practical environments, the rejection cost of all jobs are identical and the total rejection penalty only depends on the number of rejected jobs, thereafter we call it as a job-independent penalty. In this paper, we study a parallel machine scheduling model with job rejection option. In this model, it is allowed to reject some jobs. When a job is rejected, a job-independent penalty will occur. The manufacturer

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needs to balance the makespan of the accepted jobs (the maximum completion time for processing all the accepted jobs) and the total cost for rejecting jobs.

MSR was first introduced by Bartal et al. [2]. They considered the model with identical parallel machines, the objective of which is to minimize the sum of the makespan of the accepted jobs and total penalty of the rejected jobs. An $O(n \log n)$ heuristic with a worst-case bound of $2 - 1/m$ was proposed for the model, where n is the number of jobs and m is the number of machines. Recently, Ou et al. [3] developed a heuristic to solve the problem with a worst-case ratio bound of $1.5 + \varepsilon$, where $\varepsilon > 0$ can be any small given constant. Clearly, the job rejection option can be viewed as a special case of job subcontracting. Motivated by a problem commonly faced by time-sensitive product manufacturers, Chen and Li [4] proposed a model for the joint decisions of subcontracting and detailed job scheduling. After that, Jiang et al. and Jiang et al. extended the model from production system to supply chain system, in which both job processing and job delivering are involved [5, 6]. Jiang et al. [5] studied a supply chain scheduling model with subcontracting option to minimize the total cost, including subcontracting cost, production cost and distribution cost, with the constraint that all the orders which are produced in-house should be finished no more than a given deadline. Jiang et al. [6] considered another model, the objective of which is to minimize a weighted sum of the maximum lead time and total cost. Besides, some other works (e.g. Jiang and Li [7], Jiang et al. [8], Hao et al. [9]) have been done for a more generalized problem with multiple decentralized machines. As was pointed out by Ou et al. [3], it becomes much more complicated to design efficient heuristics with low running time complexity and good worst-case bounds when job rejection is allowed. However, when penalty cost is job-independent, the model will be simplified and it is possible to design more efficient and effective heuristics.

The rest of the paper is organized as follows. In Sect. 2, we introduce the problem mathematically. Then, we design polynomial time heuristic for the special case with fixed number of rejected jobs and the general case in Sect. 3. In Sect. 4, we adopt a simulated instance to verify the designed algorithm. Finally, in Sect. 5, we conclude the paper.

2 Formulation

The problem we study can be described as follows. Given a set of m identical parallel machines $M = \{1, 2, \cdots, m\}$ and a set of n independent jobs $N = \{1, 2, \cdots, n\}$. Associated with each job $j \in N$ is a processing time $p_j > 0$ and a rejection penalty $w > 0$. Job j is either rejected and then the rejection penalty w is paid, or accepted and then processed by one of the m machines. Job preemption is not allowed during job processing, and each machine is available for processing jobs at time zero. Each machine can process at most one job at a time. Denote $A \subseteq N$ as the set of jobs to be accepted, and $R = N/A$ as the set of jobs to be rejected. The objective is to determine A and a feasible schedule for the jobs in A on the m machines, so as to minimize the makespan of all accepted jobs plus the total cost for rejecting jobs.

3 Heuristic

To solve the problem, we first consider a special case of the problem in which the number of the rejected jobs is fixed. Let r be the number of the rejected jobs. Clearly, in this case, r jobs in N should be rejected and the remaining $n - r$ jobs are processed in the processing facility. The following result holds for this case.

Lemma 1 *There exists an optimal solution for the case in which the first r jobs with largest processing time are rejected.*

Proof Because the rejection cost of all jobs are identical, the total cost for rejecting jobs is equal to rw, which is a constant. Thus, the problem reduces to minimizing makespan. It can be seen that the job rejection method given in the statement of the lemma could generate an optimal solution. If a solution violates this method, such as there exist two jobs $j_1 \in R$ and $j_2 \in A$ in this solution that $p_{j_1} < p_{j_2}$, we can exchange these two jobs, i.e., accept j_1 but reject j_2, without increasing the objective function value.This establishes the lemma.

In the following, we design a polynomial-time heuristic to solve this special case.

In the following heuristic, an LPT (largest-processing-time first) order of a given set of jobs denotes that the jobs are sequenced in a non-increasing order of their processing times p_j. Also, we use the first available machine rule(FAM), where the first unscheduled job is scheduled to the earliest available machine of the processing facility until all the jobs are scheduled.

Heuristic HA-1

Step 1. Sort all jobs in LPT order.
Step 2. Reject the first r jobs and schedule the remaining $n - r$ jobs by applying the FAM rule. Denote the resulting solution by σ.

Given a solution π for this case, we denote the makespan of completing all accepted jobs and the objective value by $C_{\max}(\pi)$ and $F(\pi)$, respectively. Clearly, it is easy to have $F(\pi) = C_{\max}(\pi) + rw$. Let σ^* denote the optimal solution for the case. A performance analysis leads to the following worst-case ratio.

Theorem 1 *The worst-case performance ratio of heuristic HA-1 for the case is no more than* $4/3 - 1/3m$, *i.e.,* $F(\sigma) \leq (4/3 - 1/3m)F(\sigma^*)$.

Proof Denote the optimal makespan for processing the $n - r$ jobs generated in Step 2 by $C^*_{\max}$.

It is well known that the worst-case performance ratio bound of the heuristic for $p||C_{\max}$ by applying the FAM rule to the list of jobs sequenced by LPT order is $4/3 - 1/3m$ [10, 11]. Thus,

$$C_{\max}(\sigma) \leq \left(\frac{4}{3} - \frac{1}{3m}\right) C^*_{\max}$$

Then, we have

$$F(\sigma) \leq \left(\frac{4}{3} - \frac{1}{3m}\right) C^*_{\max} + rw \leq \left(\frac{4}{3} - \frac{1}{3m}\right) \left(C^*_{\max} + rw\right)$$

By Lemma 1, the first r jobs with largest processing time are rejected in σ^*. Hence,

$$C_{\max}(\sigma^*) = C^*_{\max}$$

Consequently,

$$\left(C^*_{\max} + rw\right) = F(\sigma^*)$$

This implies that

$$F(\sigma) \leq \left(\frac{4}{3} - \frac{1}{3m}\right) F(\sigma^*)$$

This establishes the theorem.

In the reminder of this section, we present a polynomial-time heuristic for the general case and analyze its worst-case performance. Given a solution π for the general case, we also denote its objective value by $F(\pi)$.

Heuristic HA-2

Step 1. Sort all jobs in *LPT* order.
Step 2. For $i = 0, \cdots, n$, generate a solution σ_i by rejecting the first i jobs and applying FAM rule to schedule the remaining $n - i$ jobs. Let $\bar{\sigma}$ denote the solution with the lowest objective value $F(\sigma_i)$.

Note that sorting jobs in LPT order takes $O(n \log n)$ time and generating solution σ_i takes $O(i^2 \log m)$ time. Thus, the time complexity of the algorithm is bounded by $O(n \log n + n^2 \log m)$.

In the following, we analyze its worst-cast performance. Let $\bar{\sigma}^*$ denote the optimal solution for the problem.

Theorem 2 *The worst-case performance ratio of heuristic HA-2 for the problem is no more than* $4/3 - 1/3m$, *i.e.,* $F(\bar{\sigma}) \leq (4/3 - 1/3m)F(\bar{\sigma}^*)$.

Proof Let r^* be the number of the rejected jobs in $\bar{\sigma}^*$. By Theorem 1, we have

$$F(\sigma_{r^*}) \leq (4/3 - 1/3m)F(\bar{\sigma}^*)$$

From Step 2 of heuristic HA-2, we have $F(\sigma_{r^*}) \geq F(\bar{\sigma})$. Then $F(\bar{\sigma}) \leq (4/3 - 1/3m)F(\bar{\sigma}^*)$ this establishes the theorem.

4 Numerical Analysis

In this section, we adopt the numerical experiment to evaluate the designed heuristic in a simulated instance. The heuristic was coded in the Visual C++ 2005. The computation was executed using an Intel Core2 Duo CPU 2.2 GHz processor and 1.0 GB of RAM.

We select a small instance with 10 independent jobs. The parameters of the simulated instance are as follows: the number of machines $m = 4$; the rejection cost of each job $w = 15$; the processing time of each job p_j are listed in Table 1.

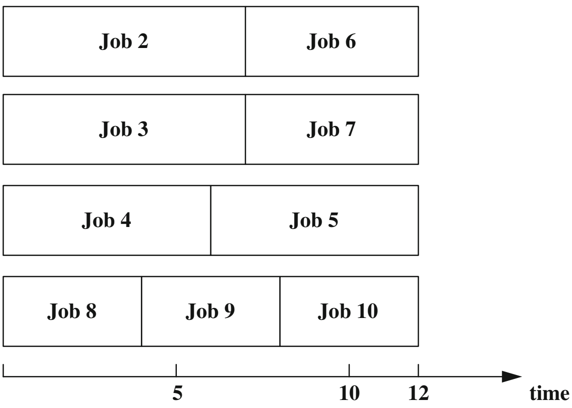
The optimal solution of the instance is shown as follows: the set of the rejected jobs $R = \{1\}$, the set of the accepted jobs $A = \{2, 3, 4, 5, 6, 7, 8, 9, 10\}$, and the production schedule is shown as Fig. 1. Clearly, the objective value of this solution is equal to 27.

We use Heuristic HA-2 to solve the above instance and obtain a feasible solution as follows: the set of the rejected jobs $R = \{1\}$, the set of the accepted jobs $A = \{2, 3, 4, 5, 6, 7, 8, 9, 10\}$, and the production schedule is shown as Fig. 2. The

Table 1 The parameter of the processing time of jobs

Job j	1	2	3	4	5	6	7	8	9	10
p_j	15	7	7	6	6	5	5	4	4	4

Fig. 1 Production schedule of an optimal solution



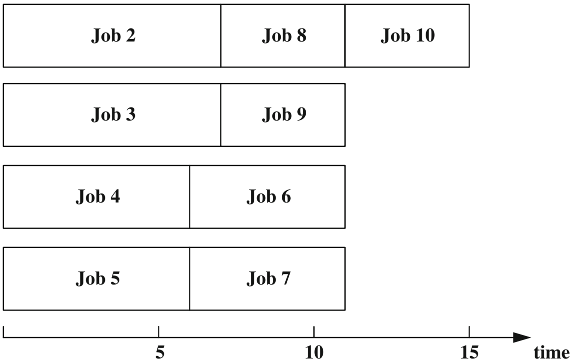


Fig. 2 Production schedule of the solution obtained by heuristic ha-2

objective value of this solution is equal to 30. Hence, it is obvious that the heuristic HA-2 can obtain a satisfied solution effectively and efficiently.

5 Conclusion

In this paper, we study the classical parallel machine scheduling model with rejection, where the objective function is to minimize the makespan of completing all accepted jobs plus the total cost for rejecting jobs. In this model, the penalty cost is job-independent such that the penalty cost of all jobs are identical. We develop a polynomial-time heuristic to solve the problem with a worst-case bound of $4/3 - 1/3m$, which is tighter than that of the current best known heuristic for solving the model with job-dependent penalty.

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Optimization of Facilities Layout Based on Lean Manufacturing

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Abstract According to facilities layout has significant influence on reduction of process waste, increasing of production flexibility and improvement of productivity, optimization of current assembly line in company B seems under such a circumstance. Based on the concrete analysis of existing assembly line, two points, operation balance and production flexibility, were raised up. After systematically analyzing, lean line designing, production cycle time optimizing, flow oriented layout planning and before-after result tracking and comparing, final target was achieved according to the expectation. The investigation proved that lean line design, production balancing and flow oriented layout planning are meaningful in productivity increasing, stock and cost reduction.

Keywords Lean line design · Operation balance · Flow oriented layout

1 Introduction

Lean production concept is one of the most important concepts in enterprise management in recent years. It is essential for enterprises future development if balanced production and flexible layout can be implemented. In past decades, extensive researches were done by domestic and foreign scholars. For example: Based on the production system overall scales of measurement with short lead time circumstance, Azdivar raised up the idea of layout planning considering the time period and productivity [1]. Immer [2] mentioned that the main task for layout planning is optimization of existing layout plan to fulfill the continuous changed market demand. Megumi Oohara in "Extreme Toyota" explained the successful factors of Toyota [3]. Lean concept is aimed at eliminating or minimizing all kinds of production wastes from the beginning of product design phase, layout planning phase to series production and daily sales business. In this article, combined with

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predecessors theoretical research, the existing production line cycle time model and lean concept flexible cycle time model were designed, and based on existing line cycle time model, the cycle time structure of semi-automatic line was analyzed and the problems were found during analyzing. Meanwhile, the lean concept flexible cycle time [4] model and SLP (Systematic Layout Planning) [5] were used for existing line optimizing and re-planning of layout. Based on the empirical application, the existing line cycle time unbalanced problem [6] and low flexibility problem were solved by new layout concept.

2 Model Building

Lean line design includes prediction of customer demand, conceptual design of manufacturing line and layout design [7]. The prediction of customer demand is assumed as known conditions. The relationship between production quantity and cost in conceptual design phase as following:

$$\begin{cases} F(q,c) = Opt\{A|(Q,C)\} \\ s.t. Q \geq D \ \& \ KPI_{finance} \end{cases}$$

where q means production quantity, c means cost (include such as production, labor and investment cost), $Opt\{A|(Q,C)\}$ means the optimum between production quantity and cost, D means customer demand, $KPI_{finance}$ means key performance indicator of finance. Combined with production Pareto principle [8], the automation degree of manufacturing equipment, station quantity, production layout, internal logistics and production frequency of different type (runner or exotic) were defined.

Different from new line cycle time design, the existing production line cycle time function described as:

$$\begin{cases} CT = \delta \times Max(T_i) \\ s.t. \forall i \in R \end{cases} \tag{1}$$

$$T_i = T_{manuali} + T_{machinei} - T_{paralleli} \tag{2}$$

$T_{manuali}$ means the i stage of production manual operating time, $T_{machinei}$ means the i stage of production machine operating time, $T_{paralleli}$ means the i stage of production parallel time of manual and machine operating time, R means assemblage of stage of production $R = \{1, 2, \cdots, n\}$, i means the i stage of production, δ means deviation of cycle time gene $(\delta \geq 1)$.

$$\begin{cases} T_{manuali} = \sum_{j=1}^{m} t_{manualj} \\ T_{machinei} = \sum_{j=1}^{m} t_{machinej} \\ T_{paralleli} = \sum_{j=1}^{m} t_{parallelj} \end{cases} \tag{3}$$

where t means different step operating time (manual, machine, parallel time), j means step j.

Based on (1), the existing production line cycle time depends on the longest operating time in whole process chain which named as bottleneck process time. And based on (2), it is better for process cycle time reduction if the manual operating time could be paralleled with machine operating time as much as possible.

Combined with the relationship between production quantity and TCO (Total Cost Ownership) [9] cost in conceptual design phase, lean concept flexible production cycle time model as following:

$$\begin{cases} CT = \delta \times \xi \times \sum_{i=1}^{n} \sum_{j=1}^{m} t_{manualij}/n \\ s.t. \forall i \in R, \forall j \in I \end{cases} \tag{4}$$

where R means assemblage of stage of production $R = \{1, 2, \ldots, n\}$, I means assemblage of step of production $I = \{1, 2, \ldots, m\}$, i means the i stage of production, j means step j, n means number of processes or operators, δ means deviation of cycle time gene $(\delta \geq 1)$, ξ means un-split gene $(\xi \geq 1)$, $t_{manualij}$ means each step manual operating time. The precondition of this model is the machine operating time will never be the bottleneck time of production line. Based on (4), the idea process cycle time is determined by manual operating time and depended on operators which are assigned in line.

Production cycle time balance ratio Br calculation model

$$B_r = \sum_{i=1}^{n} T_i/(n \times CT) \times 100\% \tag{5}$$

where T_i accord with function (2), CT accord with (1), i means the i stage of production, n means number of stages or operators.

3 Empirical Application

3.1 Situation Analysis of Production Line

Take B enterprise one common rail assembly line as example. The general layout overview as Fig. 1 looks like "Circle" with transmission chain. Communication and different tasks distribution are not possible in different operators and processes. The production line will completely shut down if one operator is absent.

Based on the existing production line cycle time function (1) and after analyzing for each processes, the real production cycle time is 33 s, bottleneck processes [10] are process 9 and 10. Production cycle time balance ratio Br [11] accords with (5). The actual balance ratio Br is 69.3 %.

In summary, current layout has following problems: (1) Unbalanced cycle time caused the waste of production capacity; (2) Low flexibility of current line layout limited the tasks distribution and against with “more variety and minor batch’s production” [12] mode.

3.2 *Optimization of Production Cycle Time*

Based on conceptual design model and combined with Pareto principle and after systematically analyzing the real production situation, the process 5, 6, 7, 9 and 10 are runner processes (the demand quantity > 80 % in total). The Process 8-1 and 8-2 will be used during exotic type production (the demand quantity < 20 % in total), so these 2 stations are designed as offline. Grounded on process 9 and 10 cycle time, production quantity Q can’t fulfill customer demand D. Meanwhile, considering the relationship between equipment automation degree and investment cost, maintenance cost, utilization cost; considering the difference between required cycle time and actual cycle time, the process 7, 8 and 9 can be split as Fig. 2.

5W1H technology was used for each process and systematically analyzed the whole process chain based on ECRS method [13], the cumulated pure operating time is 80 s. When 2, 3 or 4 operators are assigned in production line, n = 2, 3 or 4, the cycle time is 40, 28 and 20 s. Deviation of cycle time gene δ and Un-split gene ξ genes will not be considered during theoretical calculation.

3.3 *Flow Oriented Layout Design*

Based on the cycle time optimization result and combined with SLP method, the production line were redesigned. The operation stations as Table 1.

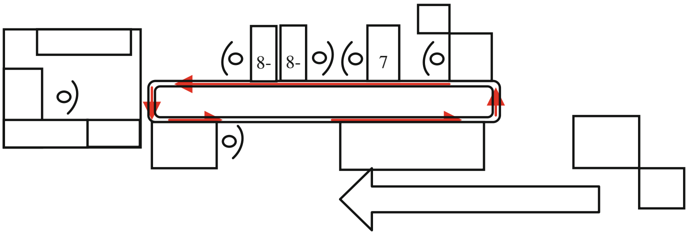

Fig. 1 Overview of existing layout

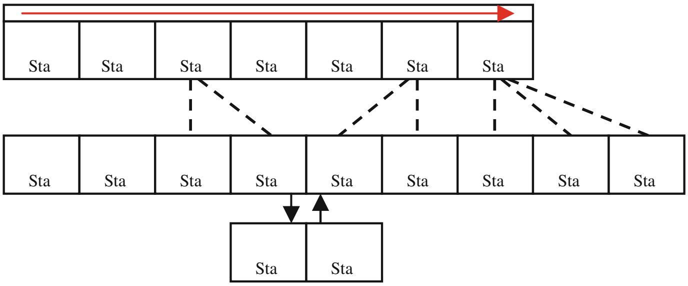

Fig. 2 Process conceptual design chart

Table 1 Summary of operation stations

No.	Operation name	Function	Space/ (m × m)	Station name
1	Raw material SM	Raw material stock	20 × 10	
2	Endoscope inspection	Quality inspection	1.5 × 1	Sta. 10
3	Throttle pressing	Throttle assembly	2.5 × 2.5	Sta. 20
4	Washing	Cleanliness control	5 × 3	Sta. 25
5	Label sticking	Identification	2 × 1.5	Sta. 30
6	Sealing-surface checking	Quality inspection	1.5 × 1.5	Sta. 32
7	Pre/final assembly	Assembly	2.5 × 1.5	Sta. 65-1, 2
8	Auxiliary assembly	Auxiliary assembly	2.5 × 1.5	Sta. 45, 55
9	Function testing	Function testing	5 × 4	Sta. 80-1, 2
10	Visual inspection/package	Quality control and package	3 × 1	Sta. 100-1, 2, 3
11	Final product SM	Product stock	6 × 5	

The assembly line from-to chart as Table 2 and based on SLP method, the material flow intensity summary as following: grade I = 6, grade E = 5, grade A = 8 and others are grade U. During layout planning, the relationship between stations accords with the priority of A, E, I, O, U.

Accorded to grade of the material flow intensity and relationship of internal logistics, the correlation of operation stations refers to Fig. 3. Comprehensive arrange sequence: 7, 10, 1, 2, 4, 3, 5, 6, 8, 9 and 11. Based on the sequence of operation, the redesigned layout likes Fig. 4.

Moveable design will be implemented in process 8-1 and 8-2. When exotic type produced, process 8-1 and 8-2 changeover can be finished in 5 min. The exotic type material flow and tasks distribution will be switched through the flexible layout change.

Table 2 Assembly line from-to chart

To	From											
	1	2	3	4	5	6	7	8	9	10	11	Sum
1	0	2800	9.4				85	6.5		20		2920.9
2		0	2500	300								2800
3			0	2509.4								2509.4
4				0	2809.4							2809.4
5					0	2749	60.4					2809.4
6						0	2749					2749
7							0	483.2	241.1	2170.1		2894.4
8								0	50	433.2		483.2
9									0	291.1		291.1
10										0	2914.4	2914.4
11											0	0
Sum	0	2800	2509.4	2809.4	2809.4	2749	2894.4	489.7	291.1	2914.4	2914.4	23181.2

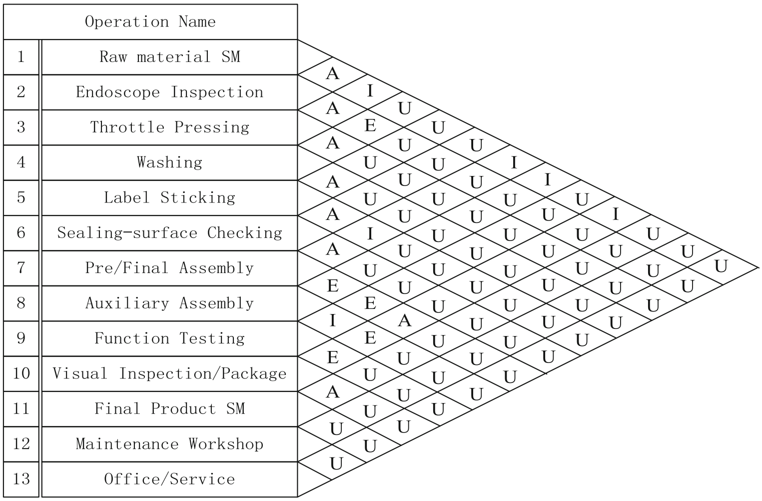

Fig. 3 Correlation of operation stations

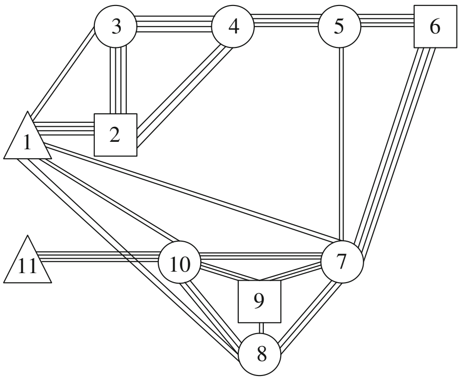

Fig. 4 Stations position relevant chart

3.4 Implementation of New Layout Plan

The new layout plan was implemented and production data were tracked based on 3 or 4 operator production mode. The designed anticipation was achieved. Production cycle time balance ratio Br is 97.7 % in 3 operators mode and 95.2 % in 4 operator mode. Compared with original Br 69.3 %, it made the significant improvement. The flow oriented layout achieved: (1) Flexible production cycle time with different operator number. (2) Flexible layout planning with less than 5 min quick change over [14]. (3) "One piece flow" [15] with "multispecies, small quantity" production mode. (4) Low WIP with high productivity.

4 Conclusion

The production cycle time structure was systematically analyzed and two were found during analyzing. The lean concept flexible production cycle time model was raised up and SLP technology was used for problem solving. Through empirical application, it has been proved that the lean concept flexible production cycle time model has the high practicability for production cycle time optimizing and flexible layout planning.

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A Novel Prediction Model of Integrate Energy Consumption Per Ton Crude Steel Using Gene Expression Programming

Li-ping Zhang, Qiu-hua Tang, C.A. Floudas, Yong-nian Mao and Cai-fu Zheng

Abstract The iron and steel industry is a fundamental part of national economy, but it is also the large energy user. The accurate predictability of the energy consumption is beneficial to seize the energy development trends and reduce the energy waste. According to the historical data of integrate energy consumption per ton crude steel (IECPTCS) about our country, a novel prediction model of the IECPTCS is proposed by using Gene expression programming (GEP). Firstly, the IECPTCS is divided into equal time intervals. The functional expression is represented by some symbols. A parameter, which is stored as constant, is defined in the terminal set. Secondly, the prediction model is obtained by genetic operation, which contains selection operation, mutation operation, recombination operation, transposition operation, etc. Finally, the experimental results show that the average error between the predicted value and the real value is 0.649 via GEP, which is superior to other approaches. It also illustrates that the novel prediction model can forecast the development trends of the IECPTCS accurately.

Keywords Gene expression programming · Prediction model · Integrate energy consumption per ton crude steel

1 Introduction

The iron and steel industry, which is one of the most important fundamental sectors of the national economy of a country, is one of the significant indicators of the economic power and comprehensive national strength of a country [1]. Iron and steel, which is an important foundational material and the strategic resource for the

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national economic development and defense industry, has been widely applied in the mechanical industry, military industry, aerospace industry, et al. Our country takes first place at the total iron and steel output, amount of consumption, net exports so far. But the IECPTCS has a wide gap compared with the developed countries. Due to the limited resources, supply of the energy and carrying capacity of the development environment, research is focusing on reducing the resource consumption, the energy consumption and the waste discharge in the iron and steel industry and adjusting the measure of the iron and steel development.

The tendency of the energy consumption can be deduced by the historical data. An accurate prediction model is helpful to acquaint with the situation of the energy consumption and can be used to control the energy storage, reduce the waste energy. It is of great significance to explore the potential of energy saving for the iron and steel enterprises. But how to improve the accuracy for the prediction model hasn't been studied well. Many prediction approaches [2–4], including grey system GM(1,1), linear regression, neural network, support vector machine, and partial least squares regression, has been addressed to solving this problem. Because there are too many assumptions and the model is overly simple, it is difficult to make sure the prediction accuracy. Though the neural network performs well in self-learning and has been widely applied in the prediction field, its internal parameter doesn't show the physical interpretation and the relation between the internal parameter and the output vector of the network cannot be expounded clearly.

The GEP algorithm [5] is a new technique of evolutionary algorithm for data analysis and a recent extension to Genetic programming (GP). It is one of the robust linear GP techniques. GEP uses fixed length, linear strings of chromosomes to represent computer programs in the form of expression trees of different shapes and sizes, and implements a genetic algorithm (GA) to find the best program. The feature that the separation of genotype and phenotype ensures the flexibility and search capability of GEP. Moreover, the multi genetic organization of GEP chromosomes makes GEP a truly hierarchical discovery technique. GEP surpasses the old GP system in 100–10,000 times, and has been successfully applied in a large variety of problems, including symbolic regression, time series prediction, classification, optimization, etc. [6].

The energy consumption in the iron and steel process, which involves many aspects such as the technique conditions and the equipment status, is a kind of mixed complex system. Therefore, we introduce an efficient GEP algorithm with the powerful ability of the function finding. This approach finds the optimal non-linear function, which is a new prediction model of the energy consumption with non-linear feature, via the training sample from the original data. This prediction model shows the relation between the parameters and the energy consumption, which maybe find out the obvious change rule, and provides the reference for the production planning established and the lower carbon development realized.

2 The Energy Consumption of the Iron and Steel Industry

Now, the energy consumption in the iron and steel industry accounts for about 15 % of total amount in all industry. The latest data reveal that our crude steel production reaches to 823 million tons in 2014 and grows by 0.89 % than last year. At the same time, the IECPTCS is 584.7 kg coal equivalent, and drops down by 1.22 % than last year. Fresh water consumption for producing per ton steel is 3.33 cubic meter, and drops down by 4.83 %.

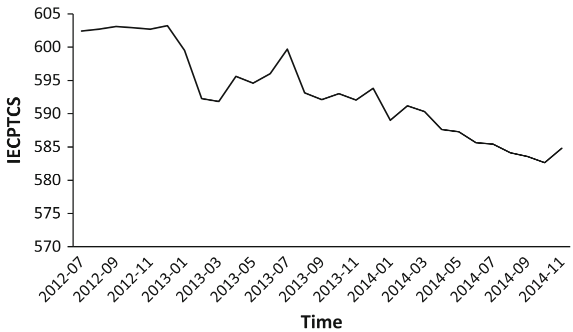
The IECPTCS is a measure to map the comprehensive strength about the machine status, technology level and the information management level. According to the national situation, two effective measures about the IECPTCS contain the IECPTCS for single enterprise and the comparable energy consumption of per ton steel among enterprises. But there are a great variety of the enterprise products and secondary products, the IECPTCS generally acted as the measure. It can be calculated by the ratio of the total energy consumption to the crude steel production [7].

According to the definition, if the crude steel production is fixed, the IECPTCS will drop down with the lower energy consumption in the iron and steel industry [8]. China Iron and Steel Industry Association (CISIA) published a series of reports about the IECPTCS each month from July 2012 to November 2014, as shown in Fig. 1. As of July 2012, the overall IECPTCS have declined with small fluctuation in some months.

3 The IECPTCS Prediction Model

The GEP algorithm, which is a general self-adaption random search algorithm, comes from the natural selection and natural genetic mechanism. And it has been proved that the GEP algorithm can find out the more accurate function with the lack of the pre-knowledge. It has been successfully used in many fields with the stronger universality and the higher accuracy. The basic idea is that the GEP algorithm applies the genetic operator, including selection, mutation, transposition, and recombination, and the evaluation mechanism to choose the higher fitness and

Fig. 1 The IECPTCS in the CISIA member



generate the next generation from an initial population. Lastly, the genotype of the chromosome with highest fitness will be transferred to a phenotype, which expresses the relation between the IECPTCS and the time, also called the IECPTCS prediction model.

3.1 The Coding and Encoding for the Energy Consumption Prediction

According to the nonlinear relation between the IECPTCS and the time, each GEP chromosome, which is composed of a list of symbols with a fixed length, is generated with gene from a function set (FS) and a terminal set (TS) at the beginning of the search. Then read each gene one by one, and translate it into a function expression. The accuracy of the function expression is evaluated by the historical data and the fitness function.

We notice that each gene comes from the FS, including operational symbol, mathematical function and conditional expression and TS including variables, constant and the function without parameters. And each GEP chromosome contains more than one gene. Each gene consists of two parts: the head and the tail. Generally, the gene at the head comes from the FS or TS, the gene at the tail must come from the TS.

One of the improvements of GEP compared with GP is the separation of genotype and phenotype. Here, the genotype is the GEP chromosome. The phenotype is the expression tree. The genotype and phenotype are corresponding to and can be transformed into each other. However, in order to make sure that each chromosome contains a complete K-expression, we often set the length of the head via the problem feature. The length of the tail must be satisfied with the Eq. (1).

$$t \geq h * (n - 1) + 1 \tag{1}$$

Here, n denotes the maximum number of the function arguments.

The process of how to transform the genotype into phenotype is addressed as followed. Each symbol is read one by one from left to right. Then, an expression tree with semantics richness will be constructed on the basis of the syntax rule. Moreover, the function expression corresponding with the genotype can be obtained by traversing the expression tree from top to bottom and from left to right. For example, set $FS = (+, -, *, /)$, $TS = \{a\}$, $n = 2$, $h = 5$. Then, $t = 6$ according to the Eq. (1). The total length of the gene $g = h + t = 11$. It is assumed that one chromosome is $+ - a * /\underline{aaaaaa}$. As shown in Fig. 2, it shows the process of how to transform the genotype into phenotype.

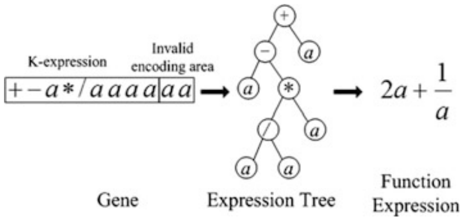


Fig. 2 The schematic diagram for the transformation between gene and function expression

3.2 The Genetic Operator

Due to the GEP chromosome with the fixed length, the genetic operator for the GEP algorithm is similar with the genetic algorithm. Except the selection, mutation and recombination, the GEP algorithm also owns the unique genetic operator, transposition. The main characteristic is simple, flexible and to avoid generating the infeasible solution. The detail genetic operator will be described as below.

(1) *Selection*

Selection operator makes sure that the good gene segments can be carried into next generation, which is helpful to the convergence of algorithm. Ferreira have proven that roulette-wheel sampling with elitism can play a best performance than others [9]. In roulette-wheel sampling with elitism, the individual with larger selection probability will have more chance to be copied into next generation. The larger the fitness of the chromosome is, the larger the selection probability is.

(2) *Mutation*

To avoid the premature convergence, each individual will be perturbed by chance. The mutation position will appear at any position of the chromosome. The detail process is: a position is chosen randomly and replaced by other symbol. We know that the gene at the tail must come from the TS, otherwise the chromosome maybe not express a complete expression tree. Therefore, we define the replacement rule. If the position locates the head, the gene can be replaced by any symbol from FS or TS, Otherwise, only from TS. As shown in Fig. 3, the position 2 is chosen and replaced by "*" randomly.

(3) *Transposition*

This operation is unique for GEP. It activates one gene segment to join in the next generation. The detail process is: one gene segment is chosen randomly and

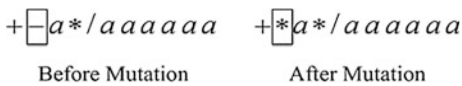


Fig. 3 An example for mutation

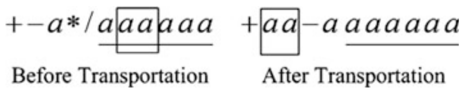


Fig. 4 An example for transposition

inserted at the random head position. At the same time, the end of the head is deleted to keep the same length with the gene segment. As shown in Fig. 4, the gene segment between position 7 and 8 is chosen and inserted in the position 2 and 3. And the gene segment "*/" at the end of the head is cut.

(4) *Recombination*

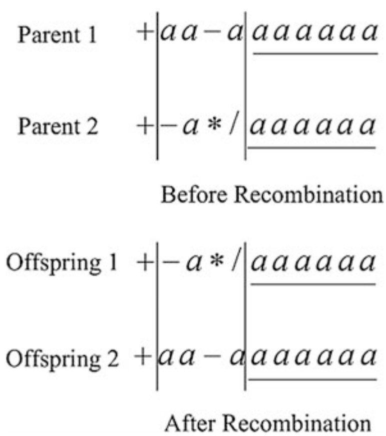
This operator exchanges some gene segments from two parents to generate new generations. It can enhance the solution space and improve the global search ability. The detail process is: two positions are chosen by chance. The gene segment among them is swapped. As shown in Fig. 5, positions 2 and 5 are selected randomly. The new generations generates by swapping the gene segment among the position 2 and 5.

(5) *The fitness function for the energy consumption deviation*

The main effect of this function is to control the direction and speed of the evolution. In most cases, the evaluation of each individual spends most of the CPU time. The success of a problem greatly depends on the way the fitness function designed. An improper fitness function will cause the poor convergence or a unrelated solution. We use Eq. (2) to reflect the difference between the theoretical value and the actual value.

$$f = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - Y_i)^2} \tag{2}$$

Fig. 5 An example for recombination



Here, n denotes the number of the training sample from the IECPTCS historical data. y_i means that the theoretical value from the prediction model. Y_i means that the actual value from the IECPTCS historical data.

3.3 The General Frame for the Prediction Model

The steps of the GEP algorithm are as follow.

Step 1 According to the IECPTCS historical data, design the FS and TS. Generate the initial population randomly.

Step 2 Transform each individual into a function expression, and evaluate each individual based on Eq. (2).

Step 3 Reach to the terminal condition which is the prediction accuracy or the maximum iteration. If it reaches, stop and output the optimal solution, go to *Step* 10. Else, continue.

Step 4 Keep the best individual by the elitism strategy.

Step 5 Generate the next population by using the selection operator.

Step 6 Mutate the selected individual by chance.

Step 7 Transpose the selected individual by chance.

Step 8 Recombine the selected individual by chance.

Step 9 The new generation is formed by the above genetic operator, go to *Step* 2.

Step 10 The algorithm stops. Output the best individual and the prediction model.

4 Experiments and Results

In order to show the trend of the energy consumption, the data from the report on the CISIA website [10] between July 2012 and November 2014 are used to test the performance of the GEP algorithm and to build the prediction model, which forecast the IECPTCS at 2015, as shown in Table 1.

4.1 Parameters Setting

Due to the non-linear feature of the CISIA, the FS is defined as Eq. (3).

$$FS = \left\{ +,\ -,\ *\ ,\ /,\ \sqrt{\ } \right\} \tag{3}$$

We notice that constant is very important part for most of mathematical models. Though the GEP algorithm can search the solution space without constraints and generate the effective model structure, the improper parameter may cause the

Table 1 The data from the CISIA

Time	IECPTCS	Time	IECPTCS
2012-07	602.42	2013-10	593.02
2012-08	602.71	2013-11	592.05
2012-09	603.11	2013-12	593.80
2012-10	602.92	2014-01	589.02
2012-11	602.71	2014-02	591.19
2012-12	603.21	2014-03	590.32
2013-01	599.51	2014-04	587.61
2013-02	592.25	2014-05	587.28
2013-03	591.84	2014-06	585.65
2013-04	595.60	2014-07	585.43
2013-05	594.60	2014-08	584.13
2013-06	596.00	2014-09	583.58
2013-07	599.70	2014-10	582.65
2013-08	593.14	2014-11	584.82
2013-09	592.10		

Note The units of the IECPTCS is kg coal equivalent per ton

instability structure. Therefore, it is crucial to design the constant. The TS contained variable and constant is defined as Eq. (4).

$$TS = \{x,\ C\} \quad (4)$$

There, x means the time serial with equal interval. C is the constant. As showed in Table 1, we transfer the time July 2012 into 1, August 2012 into 2, and so on. x also represents the set of $\{1, 2, 3, \ldots, 29\}$. Through testing the performance of C many times, we find that the GEP algorithm plays a better performance when C is equal to 601.5. The detail parameter setting is shown in Table 2.

4.2 *The Prediction Model and Results*

The proposed GEP algorithm has been implemented in C++, and run on a PC with an Intel, 2.20 GHz processor with 2.00 GB of RAM. From Table 1, there are a total number of 29 simulation experiment sets, which are divided into 2 groups with

Table 2 Parameters setting

Parameters	Value	Parameters	Value
Population size	50	Mutation probability	0.25
Max iterations	500	Transposition probability	0.6
h	5	Recombination probability	0.35
t	6		
C	601.5		

$$+,-,\sqrt{\ },+,+,x,x,x,x,C,C$$

Fig. 6 The best individual

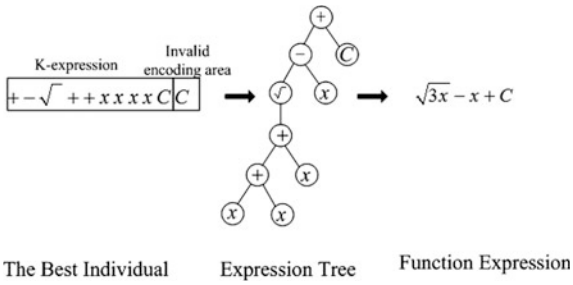


Fig. 7 The process of the transformation between genotype and phenotype

23 and 6. All data in group one are used as a training set to evolve the function expression by GEP. And the best individual of the function expression is applied to the problems in another group for validation. Each simulation experiment consists of 10 different runs. The best results over the 10 different runs are recorded as shown in Fig. 6.

The prediction model, which is the phenotype of the best individual, can be obtained from Fig. 2. The process of how to transform the genotype into phenotype is addressed as Fig. 7.

As illustrated in Fig. 7, the prediction model of the IECPTCS with $C = 601.5$ is shown in Eq. (5).

$$y = \sqrt{3x} - x + 601.5 \tag{5}$$

"The twelfth five year plan for industrial energy saving" pointed that the IECPTCS should be decreased from 605 kg coal equivalent per ton at 2010 to 580 kg coal equivalent per ton at 2015. According to the above prediction model, the IECPTCS of our iron and steel industry will be decreased to 580.14 kg coal equivalent per ton at January 2015 and 579.29 kg coal equivalent per ton at February 2015 less than 580 kg coal equivalent per ton. This coincides with the goal of the energy saving.

4.3 Discussion

In order to do efficient comparison, several other approaches, contained linear regression, quadratic regression, cubic regression and logarithmic regression, are selected. All of these approaches are realized by SPSS software. The comparison results in Table 3 are compared to the GEP algorithm and the four selected

Table 3 The comparison results

Time	AV	Linear regression		Quadratic regression		Cubic regression		Logarithmic regression		GEP	
		PV	Deviation	PV	Deviation	PV	Deviation	PV	Deviation	PV	Deviation
2014-06	585.65	587.03	1.38	578.49	−7.15	333.133	−252.51	600.18	14.53	585.98	0.33
2014-07	585.43	586.32	0.89	577.20	−8.22	298.962	−286.46	600.09	14.66	585.16	−0.26
2014-08	584.13	585.62	1.49	575.89	−8.23	261.927	−322.20	600.00	15.87	584.33	0.20
2014-09	583.58	584.91	1.33	574.56	−9.01	221.908	−361.67	599.91	16.33	583.5	−0.08
2014-10	582.65	584.21	1.56	573.22	−9.42	178.785	−403.86	599.82	17.17	582.66	0.015
2014-11	584.82	583.51	−1.31	571.86	−12.95	132.438	−452.38	599.74	14.92	581.82	−2.99
Total			7.98		55.00		2079.10		93.50		3.89
AD			1.33		9.16		346.51		15.58		0.649

Note AV, PV and AD is the short of the actual value, the predicted value, and the average deviation respectively approaches. There, the deviation is equal to the prediction value minus the actual value.

Table 3 shows that the predicted value of the GEP algorithm is closest to the actual value among these approaches. The average deviation of the GEP algorithm is equal to 0.649, which is the minimum one. The average deviation of linear regression is equal to 1.33, comes second. Other three approaches are inferior obviously. These illustrate that the GEP is superior to these approaches. Otherwise, each predicted value is close to the actual value. These show that the predicted error is stability and the GEP algorithm is robust.

5 Conclusions

A novel predicted of the IECPTCS is proposed by using the GEP algorithm. The predicted of the IECPTCS displays the correlation between the IECPTCS and the time serial, which is $y = \sqrt{3x} - x + 601.5$. Moreover, the experimental results show that the average deviation between the predicted value and the real value is 0.649 via GEP, is the minimum one. It illustrates that the GEP algorithm have better performance among these approaches, contained linear regression, quadratic regression, cubic regression and logarithmic regression. And it also shows that the novel predicted can forecast the development trends of the IECPTCS accurately.

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Reliability Optimization of the System with Common Cause Failures Based on Importance Measures

Zhi-qiang Cai, Yang Li, Shu-ai Zhang and Can Xiang

Abstract In industrial engineering, the reliability analysis, modeling and optimization for complex systems are very important. Although the works about reliability optimization with the traditional method are numerous, researchers still study more efficient and accurate methods to solve these reliability problems. The common cause failures are the multiple failures with a common cause, which is typical and serious in practical systems. Therefore, on the basis of normal optimization methods of system reliability, this paper proposes an optimization method of system with common cause failures based on importance measures. The optimization models of parallel system and the series-parallel system are built and are solved with hybrid genetic algorithm. By analyzing the system reliability and cost increasing, the proposed method gives the more accurate, valid and robust optimization results. Meanwhile, the method provides an idea for the reliability optimization of multistate systems.

Keywords Common cause failure · Importance measure · Optimization · System reliability

1 Introduction

In industrial engineering, the reliability analysis, modeling and optimization for complex systems are very important. Although the works about reliability optimization are numerous, the traditional optimization method regards the elements of this complex system as independent variables. Common cause failures are one of the key features in complex systems [1]. Therefore, it is important to study more efficient and accurate methods to solve these reliability problems with common cause failures.

System reliability is the ability of a system to perform its specified functions under the stated conditions during a given period of time [2]. The existing reliability optimizations consider results of reliability optimization without high efficiency and

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quickness, especially for large systems. Nazari-Heris and Mohammadi-Ivatloo provided methods to solve the optimal phasor measurement unit placement problem based on different heuristic optimization, in which optimal solutions were not achievable using existing methods in finite time [3].

The common cause failures are the multiple failures with a common cause, which exist in the engineering system generally [4, 5]. It increases the combined failure probability of each failure mode, and then reduces the system reliability largely [6]. Current studies of common cause failures problems mainly focus on binary system.

In optimization, in order to solve the reliability problems efficiently, it is important to apply the importance measures scientifically. The importance measures mean the extent which external factors impact on the system, and then these factors can be solved one by one according to the importance measures. Cai et al. presented an integrated importance measure based maintenance decision making method, which was introduced into the modeling process to provide reasonable maintenance schemes for decision makers [7].

This paper proposes the optimization method of system reliability with common cause failures based on importance measures. The method optimizes the reliability of the parallel system and the series-parallel system by the hybrid genetic algorithm.

2 Optimization Model of System with Common Cause Failures

2.1 *Reliability of the Series-Parallel System*

The parallel system and the series-parallel system are studied in this paper. For the series-parallel system, assume that the system with common cause failures consists of m parallel subsystems connected in series and each subsystem has n components [8].

The failure probability of the subsystem k [9] is

$$\begin{aligned} F_k = & \prod_{l^0} (I_{l^0})^{z^{l^0,i}} + \sum_{l^1} x_{l^1} CC_{l^1} \prod_{l^1 \neq l^2} (I_{l^2})^{z^{l^2,i}} \\ & + \sum_{l^1,l^2} x_{l^1,l^2} CC_{l^1,l^2} \prod_{\substack{l^1,l^2 \\ l^1 \neq l^2 \neq l^3}} (I_{l^3})^{z^{l^3,i}} \\ & + \cdots + \sum_{l^1,l^2,\ldots,l^{n-1}} x_{l^1,l^2,\ldots,l^{n-1}} CC_{l^1,l^2,\ldots,l^{n-1}} \prod_{\substack{l^1 \neq l^2 \neq \cdots \neq l^{n-1} \\ k \geq 2}} (I_{l^n})^{z^{l^n,i}} \\ & + x_{l^1,l^2,\ldots,l^n} CC_{l^1,l^2,\ldots,l^n}, \end{aligned} \quad (1)$$

where

$$x_{l^1} = \begin{cases} 1, & z^{l^1,i} \geq 1 \\ 0, & others \end{cases},$$

$$x_{l^1,l^2,\cdots,l^n} = \begin{cases} 1, & (z^{l^1,i} \geq 1) \wedge (z^{l^2,i} \geq 1) \wedge \cdots \wedge (z^{l^n,i} \geq 1) \\ 0, & others \end{cases},$$

$z^{l^j,i}(j = 1, 2, \ldots, n,\ i = 1, 2, \ldots, m)$ is the number of component j in subsystem i, $x_{l^1,l^2,\cdots,l^n} \in \{0, 1\}$ is the pointer variable, I_j is the independent probability of component j in current subsystem, CC is the probability of common cause failures, $F_k(k = 1, 2, \ldots, i, \ldots, m)$ is the failure probability of subsystem k.

Therefore, reliability of this system is

$$R = \prod_{k=1}^{m} R_k = \prod_{k=1}^{m} (1 - F_k), \tag{2}$$

where R is the system reliability, R_k is the reliability of subsystem k.

2.2 Optimization Model of the Parallel System

The parallel system consists of m paralleled components, which are shown in Fig. 1 [10].

1. *Single objective optimization*

The system reliability in single objective optimization is R, and the increased cost is C, which caused from improved reliability. The optimization model is

$$\min C = \sum_{i=1}^{m} (c_i \times \Delta x_i), \tag{3}$$

$$R = 1 - \prod_{i=1}^{m} (1 - P_i) \geq R_0, \tag{4}$$

where $c_i(i = 1, 2, \ldots, m)$ is the unit cost of component i, which caused from improved reliability, Δx_i is the reliability increment of the component i, P_i is the reliability of component i. Equation (3) is the objective function which making the

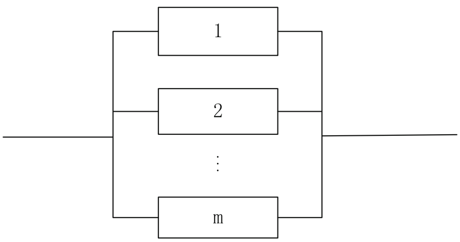

Fig. 1 The structure of the parallel system

increased cost of the system is minimum, (4) is the constraint which making the system reliability is not less than the acceptable value R_0.

2. *Multiple objectives optimization*

The reliability in multiple objectives optimization is R. The increased cost is C and the increased weight is W which caused from improved reliability. The optimization model is

$$\min C = \sum_{i=1}^{m} (c_i \times \Delta x_i), \tag{5}$$

$$\max R = 1 - \prod_{i=1}^{m} (1 - P_i), \tag{6}$$

$$W = \sum_{i=1}^{m} (w_i \times \Delta x_i) \leq W_0, \tag{7}$$

where w_i is the increased weight of component i, which caused from improved unit reliability, and meanings of other symbols are the same as single objective optimization.

Equations (5) and (6) are the objective functions which making the system has minimum increased cost and the maximum improved reliability. Equation (7) is the constraint which making the increased weight is not greater than the acceptable value W_0.

2.3 Optimization Model of the Series-Parallel System

The series-parallel system consists of m tandem subsystems, and each subsystem has n_i paralleled components, which are shown in Fig. 2 [11]. The reliability of each component is $P_{ij}(i = 1, 2, \ldots, m,\ j = 1, 2, \ldots, n_i)$, and this paper only adopts the common cause failures between two components in current subsystem [12, 13].

1. *Single objective optimization*

The optimization model is

$$\min C = \sum_{i=1}^{m} \sum_{j=1}^{n_i} \left(c_{ij} \times \Delta x_{ij}\right), \tag{8}$$

$$R = \prod_{i=1}^{m} (1 - F_i) \geq R_0, \tag{9}$$

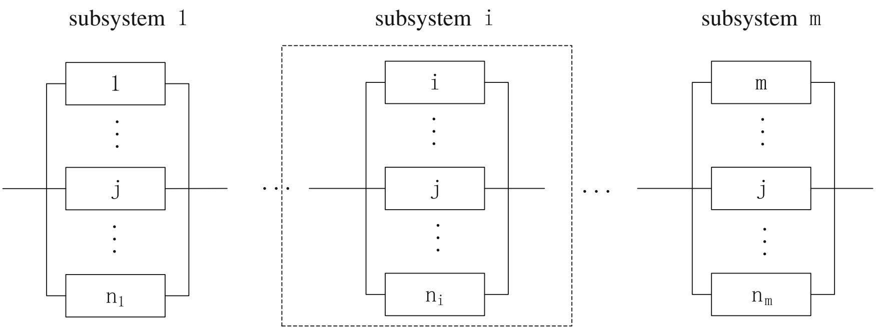

Fig. 2 The structure of the series-parallel system

where c_{ij} is the unit cost of the component j in the subsystem i, which caused from improved reliability, Δx_{ij} is the reliability increment of the component j in the subsystem i, F_i is the common cause failures probability of the subsystem i.

2. *Multiple objectives optimization*

The optimization model is

$$\max R = \prod_{i=1}^{m} (1 - F_i), \tag{10}$$

$$\min C = \sum_{i=1}^{m} \sum_{j=1}^{n_i} (c_{ij} \times \Delta x_{ij}), \tag{11}$$

$$W = \sum_{i=1}^{m} \sum_{j=1}^{n_i} (w_{ij} \times \Delta x_{ij}) \leq W_0, \tag{12}$$

where w_{ij} is the increased weight of component j in the subsystem i, which caused from improved unit reliability, and meanings of other symbols are the same as single objective optimization.

3 Algorithm for Optimization Model Based on Importance Measures

3.1 The Importance Measures

The importance measure evaluates how basic components impact on the system [14]. This paper analyzes the reliability based on the Birnbaum importance measure of binary system. The calculation of Birnbaum importance measure is

$$I(BM)_{C_i}^{S} = \frac{\partial R(S)}{\partial R(C_i)} = P(S=1|C_i=1) - P(S=1|C_i=0), \tag{13}$$

where $R(S)$ is the reliability of the system, and $R(C_i)$ is the reliability of the component $i(i = 1, 2, \ldots, n)$.

1. *Parallel system*

According to Fig. 1, the Birnbaum importance measure of parallel system is

$$\begin{aligned} I(BM)_{C_i}^{S} &= P(S=1|C_i=1) - P(S=1|C_i=0) \\ &= \prod_{k=1,\neq i}^{m} (1 - P_k) \end{aligned} \tag{14}$$

where P_k is the reliability of component k.

2. *Series-parallel system*

According to Fig. 2, the Birnbaum importance measure of the series-parallel system is

$$\begin{aligned} I(BM)_{C_i}^{S} &= P(S=1\big|C_{ij}=1) - P(S=1\big|C_{ij}=0) \\ &= \prod_{l=1,l\neq j}^{n_i} (1 - P_{il}) \times \prod_{k=1,k\neq i}^{m} P_k \\ &= \prod_{l=1,l\neq j}^{n_i} (1 - P_{il}) \times \prod_{k=1,k\neq i}^{m} (1 - \prod_{j=1}^{n_i} (1 - P_{ij})) \end{aligned} \tag{15}$$

where P_k is the reliability of subsystem k, and P_{ij} is the reliability of component j in the subsystem i.

3.2 Optimization Algorithm Based on Importance Measures

This paper optimizes the system reliability with the hybrid genetic algorithm based on the improvement of standard genetic algorithm [15] and importance measures. The algorithm processes are shown as follows.

1. *Encoding*

The encoding adopts real numbers. For different systems, each individual is defined as $u_k = (\Delta x_1, \Delta x_2, \ldots, \Delta x_i, \ldots, \Delta x_n),\ (k = 1, 2, \ldots)$ for the parallel system, $\Delta x_i \in (0, 1 - P_i)$. And the encoding for series-parallel system is

$$v_k = (\Delta x_{11}, \Delta x_{12}, \ldots, \Delta x_{1n_1}, \Delta x_{21}, \Delta x_{22}, \ldots, \Delta x_{2n_2}, \ldots, \Delta x_{m1}, \Delta x_{m2}, \ldots, \Delta x_{mn_m}) \quad (16)$$

where $\Delta x_{ij} \in (0, 1 - P_{ij})$.

2. *Generating the initial population*

Then $M_{popsize}$ individuals are generated, the value of each individual is random in the value ranges.

2. *Calculating the fitness value*

In this section, the system reliability is R_s after improvement, and the values of c_i (or c_{ij}) and w_i(or w_{ij}) are obtained for each individual. For the constraint, the penalty function is defined as

$$g_i = c_i + k \times (\max\{0, 1 - R_s/R_0\}) + \max\{0, w_i/W_0 - 1\} \quad (17)$$

There will be no penalty, if the constraint is satisfied. The value of k is a huge positive number.

4. *Selection*

The individual can be selected by roulette method [16]. The fitness value will be calibrated at first as

$$g'_i = (g_{\max} - g_i + \beta)/(g_{\max} - g_{\min} + \beta), \quad (18)$$

where $g_{\max}$ and $g_{\min}$ are the best fitness value and the worst fitness value respectively, in this population. β is a small positive real number which to avoid a meaningless denominator.

5. *Crossover*

The offspring is generated from their parents with single point crossover. The crossover probability is defined as P_c, and then two parents will be selected. There is a crossover point at random, and the gene site of the two parents is exchanged after crossover. So the two offspring are generated.

6. *Mutation*

The mutation rate is defined as r_m, the random number in [0, 1] is generated from each individual gene site. All gene sites, which r_m is less than one, are regarded as variant gene sites. For the variant chromosome selected, the two gene sites are exchanged randomly.

7. *Local optimization with hill climbing method based on importance measures*

The hill climbing method is a convenient and efficient search method. For an individual of the population, the importance measure of each gene site has been calculated, and the gene site with maximum importance measure has been selected. Then a local optimization of the gene site is obtained. In order to improve the local search ability of the hybrid genetic algorithm and ensure the computing efficiency, this paper only conducts once local search for each generation population. There is no the hill climbing method in standard genetic algorithm. Take the series-parallel system as example, the basic flow is shown as follows.

Calculating the importance measure of each gene site in v_k. Assume that the gene site Δx_{ij} has a maximum importance measure in this individual.

Select a random number $a \in (0, 1 - P_{ij})$, where P_{ij} is the reliability of the component j in the subsystem i after the improvement. And the gene site Δx_{ij} will be replaced by a. So the individual is

$$v_k^{'} = (\Delta x_{11}, \Delta x_{12}, \ldots, \Delta x_{1n_1}, \Delta x_{21}, \Delta x_{22}, \ldots, a, \ldots, \Delta x_{2n_2}, \ldots, \Delta x_{m1}, \Delta x_{m2}, \ldots, \Delta x_{mn_m}) \tag{19}$$

If the fitness value of v_k' is less than the fitness value of v_k, the individual v_k will be replaced by v_k'. Otherwise, the individual will be invariant.

Optimizing other individuals in the current generation until all individuals has been optimized.

8. *Generating new population*

The new population will be generated from individuals of the parents after selection, crossover and mutation.

9. *End*

The process is repeated till the maximum generation equals to the specified value $M_{\max-\mathrm{gen}}$.

4 Case Study

The optimization of system reliability with common cause failures is shown in this section. Assume that $k = 100{,}000$, $\beta = 0.002$, $M_{\max-\mathrm{gen}} = 300$, $M_{popsize} = 300$, $p_c = 0.8$ and $r_m = 0.05$.

4.1 Optimization of System Reliability with Common Cause Failures Not Based on Importance Measures

1. *Parallel system*

In this section, assume that the system consists of 3 paralleled components, and these parameters are listed in Table 1.

Table 1 The parameters of components

Component types	P_i	$c_i(/1)$	$w_i(g/1)$
1	0.72	2600	240
2	0.87	4000	150
3	0.66	1500	360

For single objective optimization, let $R_0 = 0.95$, the optimization objective is to have a minimum increased cost. The standard genetic algorithm will be run 50 times in MATLAB software. The optimal solution is shown in Table 2.

For multiple objectives optimization, let $W_0 = 450$, and the optimization objectives are to have the minimum increased cost and maximum system reliability. The values of other symbols are the same as single objective optimization. The optimal solution is shown in Table 3.

2. *Series-parallel system*

The system consists of 3 tandem subsystems, and each subsystem has 3 paralleled components. The parameters are shown in Table 4.

For single objective optimization, the standard genetic algorithm will be run 50 times in MATLAB. The optimal solution is shown in Table 5. For multiple objectives optimization, the optimization results are shown in Table 6 similarly.

Table 2 The results of single objective optimization

Δx_i	R	C	g'
(0.0061,00006,0.2484)	0.9502	391.0048	391.0048

Table 3 The results of multiple objectives optimization

Δx_i	R	C	W	g'
(0.0014,0.0044,0.2522)	0.9508	399.4613	91.7926	399.4613

Table 4 The component parameters

Subsystem	Component types	P_{ij}	c_{ij}	w_{ij}
1	1	0.73	3000	450
	2	0.80	3500	420
	3	0.78	3400	400
2	1	0.82	4500	300
	2	0.74	3400	400
	3	0.81	4100	320
3	1	0.85	5000	220
	2	0.68	2000	500
	3	0.72	2800	470

4.2 Optimization of System Reliability with Common Cause Failures Based on Importance Measures

In this section, the optimization results with the hybrid genetic algorithm are listed.

1. *Parallel system*

For single objective optimization, the results are shown in Table 7. For multiple objectives optimization, the results are shown in Table 8.

2. *Series-parallel system*

For single objective optimization, the results are shown in Table 9. For multiple objectives optimization, the results are shown in Table 10.

Table 5 The results of single objective optimization

Δx_{ij}	R	C	g'
$\begin{bmatrix} 0.2249 & 0.2144 & 0.2183 \\ 0.1631 & 0.1749 & 0.0709 \\ 0.0094 & 0.0094 & 0.1958 \end{bmatrix}$	0.9523	3115	3115

Table 6 The results of multiple objectives optimization

Δx_{ij}	R	C	W	g'
$\begin{bmatrix} 0.1576 & 0.1800 & 0.3032 \\ 0.0181 & 0.1290 & 0.1365 \\ 0.1773 & 0.0112 & 0.0040 \end{bmatrix}$	0.9503	4233	395.4223	4233

Table 7 The results of single objective optimization

Δx_i	R	C	g'
(0.0005,0.0005,0.2526)	0.9504	382.5024	382.5024

Table 8 The results of multiple objectives optimization

Δx_i	R	C	W	g'
0.0033, 0.0032, 0.2491	0.9503	395.1946	90.9685	395.1946

Table 9 The results of single objective optimization

Δx_{ij}	R	C	g'
$\begin{bmatrix} 0.2279 & 0.1342 & 0.3117 \\ 0.1176 & 0.2123 & 0 \\ 0 & 0.0049 & 0 \end{bmatrix}$	0.9516	2442	2442

Table 10 The results of multiple objectives optimization

Δx_{ij}	R	C	W	g'
$\begin{bmatrix} 0 & 0.2978 & 0.1697 \\ 0 & 0 & 0 \\ 0.2978 & 0 & 0 \end{bmatrix}$	0.9505	3633	353.8718	3633

4.3 Optimization Results Analysis

According to the comparison results, the optimization with common cause failures based on importance measures is quite efficient and accurate. When the system reliability is largely identical, the cost drops by 3 % in the parallel system. In the series-parallel system, the cost of single objective optimization and multiple objectives optimization drop by 21.6 and 14.2 % respectively. The increased weight of series-parallel system has declined by up to 10.1 %. Therefore, the optimization of system reliability with common cause failures based on importance measures has remarkable results.

5 Conclusion

For the systems with common cause failures, the reliability optimization models are developed. On the basis of importance measures, the system reliability of parallel system and the series-parallel system are optimized by the hybrid genetic algorithm. From the comparison results, the optimization results with common cause failures based on importance measures are remarkable. The optimization accuracy and efficiency problems can be improved by this method. And the optimization method also has provided an idea for the reliability analysis of the multistate system. The reliability optimization based on importance measures has broad application prospects in the future.

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Comfort Analysis and Evaluation of an Assembly Operation Based on DELMIA

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Abstract With the idea of "people oriented" more and more popular, the analysis and evaluation of the assembly operations take into more consideration of human factors. In this paper, the comfort analysis and evaluation of an assembly operation were performed. Firstly, a thorough analysis of the assembly operation was carried out. According to the characteristics of the assembly operation and the main points of assembly comfort. Besides, the evaluation method of assembly comfort was developed, and the concrete procedure of the comfort evaluation was introduced in this paper. Finally, the evaluation method was verified by using an assembly case of an industrial manipulator which was simulated by using DELMIA (Digital Enterprise Lean Manufacturing Interactive Application) as the simulation platform. The evaluation results show that the comfort evaluation can truly reflect the comfort level of assembly and has a good application value.

Keywords Assembly operation · Comfort evaluation · DELMIA · Ergonomics

1 Introduction

With the development of science and technology, the structure of assembly products is becoming more and more complex. Digital design and simulation are playing a more and more important role in manufacturing. Based on this background, virtual assembly technology was developed [1]. Virtual assembly technology can simulate and optimize process plan. And it's helpful to formulate

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scientific, reasonable and economical assembly operation plan and guide workers' work effectively [2].

The traditional assembly operation is still based on manual work [3]. With the increasing demand for product quality and the descending of production time, the assembly workers are given more tasks and higher requirements. However, some unreasonable assembly process and operating environment affects the operating status of the staff, leading to the wrong operation and the decrease of working efficiency. Consequently, it is necessary to propose a method to analyze and verify the assembly plan before the product assembly.

In this paper, the simulation of the assembly scheme was carried out by using DELMIA as the simulation platform. Based on DELMIA and ergonomics, a method was performed to analyze and evaluate the comfort of an assembly operation. An industrial manipulator was used as an example to show how to perform the proposed method.

2 Comfort Evaluation of an Assembly Operation

2.1 Selection of Evaluation Index

The main factors which influence the comfort of the assembly worker include the rationality operation posture, the intensity and duration of operation, the assembly environment, the psychological load and the matching degree between equipments and workers [4]. On the basis of the work fatigue assessment as in [5] and the physical and mental load index as in [6], the main concern of the operating comfort is the load level of the operator which is affected by the psychological, physical, working posture and the external environment. In view of the characteristics of virtual assembly environment, the following evaluation index is selected: physical load, working time, mental workload, operating posture, cooperation mode, working layout and the operation mode of hands.

2.2 Definition and Evaluation Method of the Evaluation Index

(1) Physical load

The definition of physical load is the size of the manual workload for the operator to complete the required tasks in unit time. Over load operation will not only affect the quality and efficiency of assembly work, but also increase the risk of the operator's personal safety.

For the assessment of physical load, we will use the prediction model of human action energy consumption which was proposed by Grag et al. [7] from

University of Michigan to make a quantitative analysis of the labor intensity. Human action energy consumption is equal to the energy consumption and the energy required to maintain the posture, as in (1).

$$E_T = \sum_{i=1}^{n} E_i + \sum_{i=1}^{3} E_p \tag{1}$$

where:

E_T the total energy consumed by the assembly process
E_i the energy consumption of ith assembly operation
E_p the energy consumption required to maintain the posture.

For the energy which is required to keep the assembly posture, the consumption is mainly related to the duration of the posture and the weight of the operator, as in (2).

$$E_P = K_p \times weight \times T_p \tag{2}$$

where:

weight the assembly operator's weight
K_p operating energy consumption coefficient
T_p the time of maintaining the assembly posture

In reference to China's grade standard of physical labor intensity (GB 3869-1983) and the improvement of standards (GB 3869-1997). The criteria for the evaluation of the physical load is shown in Table 1.

(2) Operation time
Assembly operation time is an important index for the evaluation of operation time and production cost. It is also an evaluation basis for judging the quality of assembly process plan. The operation time evaluated in this paper is the time in which operators work continuously without having a rest.
In terms of the evaluation criteria, a standard table of the assembly operation time is developed by referring to national guidelines of assembly operation time determination, which is listed in Table 2.

Table 1 Standard of physical load

Result	Energy consumption	
	kJ/min	Kcal/min
Perfect	10	2.5
Good	20	5.0
General	30	7.5
Bad	40	10

Table 2 Standard of operation time

Result	Duration of operation (h)
Perfect	0.5
Good	0.5–1
General	1–2
Bad	>2

(3) Mental workload

The main work of psychological load analysis is to summarize the psychological activities of the workers in unit time. These psychological activities generally include three aspects: cognition, emotion and will. As the main evaluation data is generated from the virtual assembly simulation platform, the mental workload is defined as a kind of consumption of internal resources caused by the long cognitive activities in the process of completing the current job tasks. Based on Siegel and Wolf's psychological load analysis method [8], the time-pressure model is used as the evaluation method of mental load. Equation (3) is the specific evaluation formula. In the evaluation process, the bigger the *MWL* is, the more mental workload the operator suffers from.

$$MWL = (TS + TL)/T \tag{3}$$

where:

MWL operator's mental workload
TS basic operation time of assembly task
TL cognitive reaction time for assembly task
T working time period of an assembly station

(4) Operating posture

When the operator performs different assembly tasks, different kinds of operating postures are needed. Bad posture will increase the operator's physical fatigue. Therefore, the operating posture should be taken into consideration in the evaluation of the operation comfort.

An analysis module, RULA (rapid upper limb assessment), was provided for the rapid evaluation of operating posture. RULA was developed by McAtamney and Corlett [9]. Its main function is to investigate the exposure of individual workers to risk factors associated with work related upper limb disorders. It can analysis the force and posture of human arm, neck, wrist and trunk to give the level and score of posture comfort.

The highest score of RULA is 7 points. The higher the score is, the worse the level of comfort is. The standard of operation posture is shown in Table 3.

(5) Cooperation mode

As the assembly operation requires several operation parts, most of the operations need to be done by two or more workers to complete the assembly task. And the operator's workload will change with the number of workers. The total number of assembly operators will lead to different ways of

Table 3 Standard of operation posture

Result	Grade	Content of operation posture
Perfect	1–2	The posture is considered acceptable
Good	3–4	The posture need to be farther studied
General	5–6	The posture can not continue for a long time and need to be changed as soon as possible
Bad	>7	The posture is very uncomfortable and must be changed immediately

cooperation, which affects the assembly efficiency. Therefore, it is important to study the cooperation mode in the process of assembly operation. Based on the criteria developed by Zhao et al. [4] to determine the optimal number of assembly jobs, the standard of cooperation mode is shown in Table 4.

(6) Working layout
The working layout evaluation is mainly to analyze the layout of the assembly objects, working tools and facilities. When the job layout is unreasonable, the assembly workers need to make the body front, reverse, bend and squat. It is easy to result in fatigue because workers' operating load increases. Based on the layout of all kinds of equipments and auxiliary facilities, the evaluation of the working layout is divided into four grades: perfect, good, general, bad. The standard of working layout is shown in Table 5.

(7) The operation mode of hands
In the assembly operation, there are many tasks that require the operation mode of a single hand operation, such as the installation of bolts and screws, grabbing the weight, connection with wire, welding and so on. As the single hand operation leads to the uneven force of the hand, it is easy to result in fatigue of operator's hand muscle. According to the rationality of the operation mode of hands, the evaluation is divided into four grades: perfect, good, general and bad. Specific evaluation criteria are shown in Table 6.

Table 4 Standard of cooperation mode

Result	Number of workers
Perfect	1
Good	2–3
General	3–5
Bad	>5

Table 5 Standard of working layout

Grade	Content of working layout
Perfect	The operator can take out parts smoothly
Good	The operator need bend or turn his trunk occasionally
General	The operator often need bend or turn his trunk
Bad	The operator usually need bend or turn his trunk

Table 6 Standard of the operation mode of hands

Grade	Content of the operation mode of hands
Perfect	Hands work allocation is reasonable and hands can rotate to ease muscle tension
Good	Occasionally operate in a single hand
General	Often operate in a single hand
Bad	Usually operate in a single hand

3 Application of the Comfort Evaluation

3.1 Introduction of the Simulation Platform

DELMIA, the Dassault launch digital lean manufacturing application software, has strong functions. As a subsystem of manufacturing maintenance process simulation, DELMIA can simulate and analyze the whole manufacturing and maintenance process. In addition, it provides e-commerce solutions for enterprises to help customers set up digital business, simulation from the concept design to product maintenance of the entire life cycle process [10].

3.2 Construction of the Simulation Environment

In order to show simulation process of the assembly operation, a virtual model of an industrial manipulator is established in this section. The industrial manipulator consists of thousands of components: motion components (such as motor, rack, cam driven parts), the guide device (rail, a screw rod) and arm (cylinder, a pull rod, control), etc. [11]. The digital prototype model of the actual structure is shown in Fig. 1.

Many auxiliary tools are needed in the process of robot arm assembly. It is necessary to establish the tools models before building the virtual model of

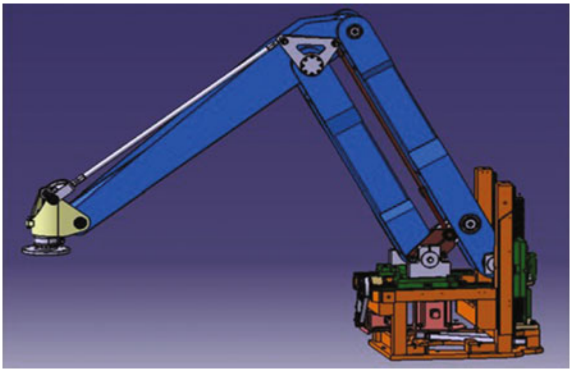


Fig. 1 Prototype model of the industrial manipulator

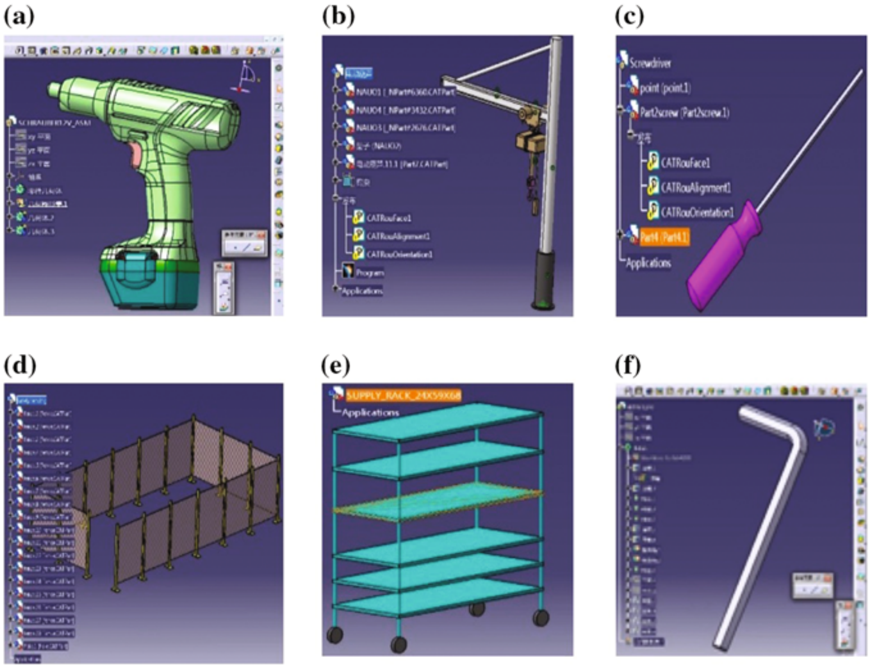


Fig. 2 Assembly tool model. **a** Electric wrench. **b** Electric block. **c** Screwdriver. **d** Guard rail. **e** Storage rack. **f** Wrench

industrial manipulator. In addition, since some components are very heavy, which take the assembly workers a lot of energy to carry, the hoisting equipment needs to be built up in the assembly environment. Figure 2 shows the model of the lifting device and other tools.

All the installation assistant tools are imported into the resource list in PPR (Process, Product and Resource) tree of DELMIA, and all the product need be imported into the product list in PPR tree of DELMIA as well. Then all the products and tools are set up in a reasonable layout. Figure 3 shows the final assembly work environment.

3.3 Construction of the Manikin Model

Manikin can be established by using Human Builder module of DELMIA. However, in DELMIA only the human data of USA, Canada, France, Japan, South Korea, Germany and China (Taiwan) are provided. As the human body model of Chinese people is lack, it will lead to errors in the final analysis if other data is used as the replacement. Therefore, it is necessary to build a virtual human model which is suitable for Chinese human body in the simulation software.

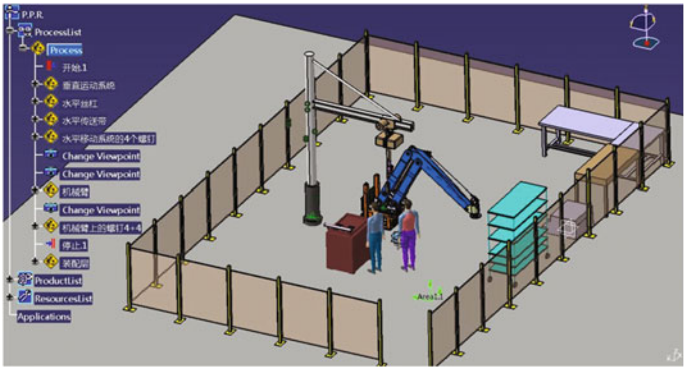
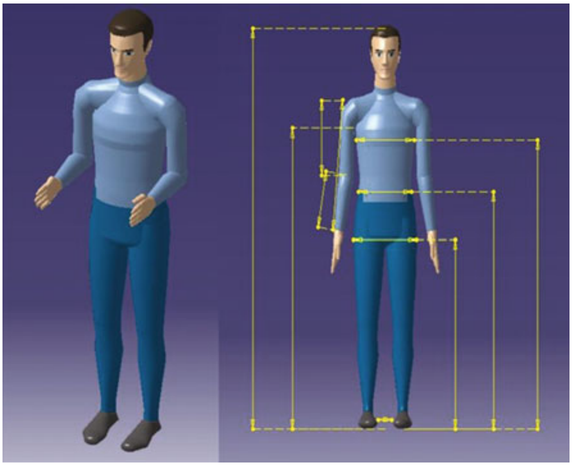


Fig. 3 The virtual assembly simulation scene of an industrial manipulator

Fig. 4 The human model of virtual assembly workers



In the process of building the virtual human with Chinese characteristics, a standard file containing the size of China's human data is created. The data in this file needs to be organized into the corresponding data segments, where each row of the data must begin with a keyword and end with a keyword [12]. The relevant data of "Human dimensions of Chinese adults GB10000-88" is used in the process of creating the human body model.

After the standard file is created, it can be loaded by the Human Builder module of DELMIA. The virtual human model can be built as shown in Fig. 4.

3.4 Evaluation Results of the Industrial Manipulator Assembly

In this section, the assembly model of an industrial manipulator is used to verify the comfort evaluation method. Firstly, the process of carrying the industrial manipulator is used to explain the application of physical load's evaluation. Energy consumption in the assembly operation can be provided by the energy consumption analysis module of the DELMIA. The concrete operating interface is shown in Fig. 5.

Based on the energy analysis module of DELMIA, the energy consumption of each action is listed in Table 7.

From Table 7, it can be seen that the total energy consumption is 10.4219 kcal/min. Based on the standard of physical load, it is classified as poor grade. Hence, this process requires the use of electric equipment to reduce the workload of operators.

Besides, the operation time can be evaluated by provided functions in DELMIA. It's necessary to predict the working time of each working procedure before

Fig. 5 The energy analysis module of DELMIA

Table 7 The energy consumption of each action

Action	Metabolic energy (Kcal/min)	Posture energy (Kcal/min)	Total
Walking	0.589	0.0945	0.6835
Grabbing	1.616	0.0699	1.6859
Carrying	4.586	0.1299	4.7159
Installing	0.946	0.0419	0.9879
Placing	1.525	0.0279	1.5529
Leaving	0.784	0.0118	0.7958

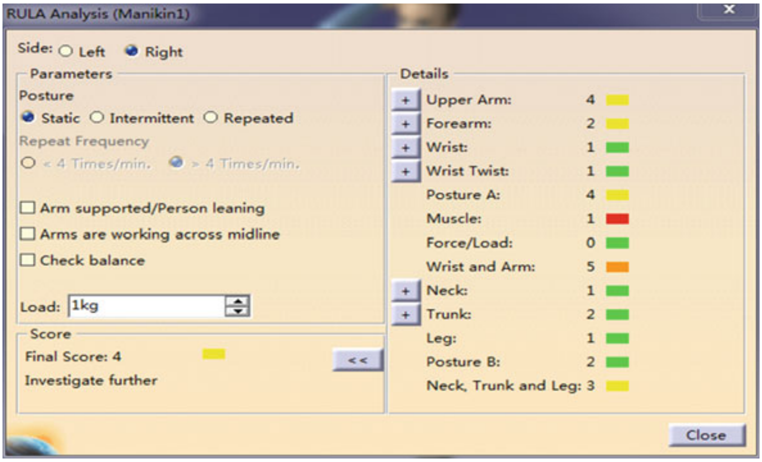


Fig. 6 The evaluation interface of the operation posture

Table 8 The grade of each posture

Operation posture	Score of RULA	Grade
Moving to the wrench	2	Perfect
Grabbing the wrench	4	Good
Mounting screw	3	Good
Alignment screw hole	4	Good
Tightening screw	6	General
Placing the wrench	2	Perfect
Leaving	1	Perfect

evaluating the assembly operation time. In this case, the total time of assembly is 0.8 h and the index of operator's mental workload calculated by working hours is 0.35. Both of them meet the requirements generally.

The process of screw assembly is used to explain the application of operation posture's evaluation. DELMIA provides the function module of RULA analysis, and the operating interface is shown in Fig. 6.

Based on the RULA module of DELMIA, the grade of each posture is listed in Table 8.

From Table 8, it can be seen that the whole operation process meets the requirements generally. But some postures of assembly operation are unreasonable and need to be modified.

Finally, the evaluation result of cooperation mode is general because there are only two workers to complete the operation. And due to the lack of the assembly path optimization, the evaluation result of working layout is bad.

Above all, the assembly plan of the industrial manipulator is reasonable and feasible. But there are still some problems in detail, such as the unreasonable operating posture, lack of professional equipment, single mode of cooperation and so on. Since this assembly operation is a practical tested case and the evaluation results are basically consistent with the actual situation, the comfort evaluation model can reflect the comfort level of assembly operators and has a good application value.

4 Conclusions

In order to improve the comfort of the assembly workers, the technology of assembly evaluation are studied to modify and optimize the assembly plan in this paper. A systematic analysis of the relevant issues in the virtual assembly and ergonomics simulation is carried out, and a set of research ideas from the virtual simulation to ergonomics evaluation is presented. The main research work and conclusions are as follows:

(1) The method of comfort evaluation for assembly operation is established. Based on ergonomics and related evaluation criteria, the evaluation system of seven evaluation indexes is presented. In the evaluation, each index is given a corresponding evaluation method and evaluation criteria.
(2) The virtual simulation model of an industrial manipulator assembly is established based on DELMIA. The human models of virtual assembly workers are in accordance with Chinese characteristics. The virtual model can truly reflect the situation in the assembly, and provides the object for the comfort evaluation.
(3) The final evaluation result of the industrial manipulator assembly is basically consistent with the actual situation. It shows that the comfort evaluation model can reflect the comfort level of assembly operators and provide a reference for the design of the assembly plan.

Acknowledgments Our deepest gratitude goes to the anonymous reviewers for their careful work and thoughtful suggestions that have helped improve this paper substantially.

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Optimal Capacity Allocation in a Tourist Transportation Network Using a Gradient-Based Heuristic

Liang Huang, Su-xin Wang, Jian-yong Sun and Meng Geng

Abstract This paper presents a capacity allocation approach to design or redesign a transportation network in a tourist area. The solutions for capacity allocation can be adding or removing tourist bus services between every two scenic spots. A bi-criteria objective function comprising mean flow time and mean waiting time is used to evaluate each solution. A modified simulated annealing procedure coupled with a simulation model is used, and convergence is accelerated through a gradient-based heuristic based on bottleneck analysis. A case study in a tourist area is provided to reveal the feasibility and validity of the proposed approach. The results show that the proposed approach can significantly reduce the computation time of the capacity allocation compared with the traditional simulated annealing algorithm using a random neighborhood-generation method.

Keywords Transportation network · Capacity allocation · Simulation · Optimization · Simulated annealing

1 Introduction

In recent years, customer demand for tourist service is increasingly diversified and customized. The tourist management is complex when a large fraction of customer need to be transported to each scenic spot with different routings under a transportation capacity limit. In many related studies, it is generally assumed that the transportation capacity between two spots is determined. However, in practice, it is often needs to be changed dynamically [1, 2] in order to reduce the mean flow time

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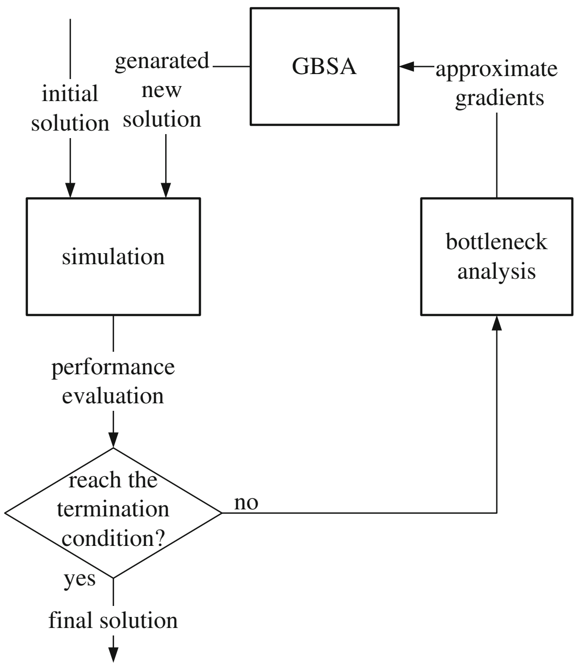
and the mean waiting time for customer satisfaction. This paper will address optimal planning for capacity allocation in a tourist transportation network to support long term (several months to years) decisions for the tourist managers.

For capacity allocation, most problems need to allocate multiple transportation capacities of different roads simultaneously. These are complex optimization problems. Some studies use simulation models as well as meta-heuristics algorithms in the design of transportation systems. Mathew and Sharma [3] presented a traffic network design problem, which attempts to find optimal network expansion policies under budget constraints. In their study, genetic algorithm (GA) is used to determine the optimal link capacity expansion vector. Xu et al. [4, 5] used GA embedded with Monte Carlo simulation to solve the optimization for determining network capacity with transportation time reliability constraints. Sun and Turnquist [6] formulated a model of investment planning for transportation networks and used simulated annealing (SA) to solve the model.

In all these studies, the optimization algorithms usually use neighborhood search to reach the optimum solution from an initial solution. Coupled with simulation models, many alternatives were examined by simulation in the search procedure. This generally caused the algorithms to be time consuming in solving large-scale problems.

An effective neighborhood-generation method is helpful in accelerating convergence and controlling the run time of the neighborhood search procedure.

Fig. 1 Framework of the capacity allocation tool



Salomon [7] introduced an evolutionary-gradient-search (EGS) procedure using the gradient of the objective function to guide the neighborhood generation in an evolution algorithm. Computational experiments showed that in some problems, the hybrid method EGS yielded noticeably faster convergence than pure evolution strategies. Similar notions can be found in a few other studies on hybrid algorithms, each consists of a gradient-based method and a meta-heuristics algorithm [8–10].

In this paper, bottleneck analysis is used as approximate discrete gradients of the objective function of the mean flow time. A modified SA is also presented, in which the neighborhood-generation is guided by the approximate discrete gradients in order to reduce the run time of the optimization procedure. Based on the proposed method, a capacity allocation tool is implemented by using Microsoft SQL Server 2008, which consists of an optimization model, a simulation model, a bottleneck analysis method and a modified SA named gradient-based simulated annealing (GBSA), as shown in Fig. 1. This capacity allocation tool is applied to an actual transportation network in a tourist area and the results reveal the feasibility and validity of the proposed approach.

2 Optimization Model

In this section, we present the conceptual optimization model for capacity allocation in a tourist transportation network. A central issue is how much transportation capacity should be allocated between each two scenic spots under a total capacity limit to satisfy the customers with the shortest mean flow time and mean waiting time.

In this study, the alternatives for capacity allocation are assumed to be adding or removing bus service shifts an hour between two scenic spots. It is assumed that in a tourist transportation network that consists of m roads, a linear array $c = [c_1, c_2, \ldots, c_m]$ is the solution vector of the capacity allocation problem, where c_j is the alternative number of the capacity level in road j, for $j = 1, 2, \ldots, m$. The upper bounds of the capacity level in road j may be different to each other, denoted as u_j. The total capacity in all the roads is also limited by the fixed cost in the tourist area, denoted as $u_{\max}$.

For customer satisfaction, mean waiting time is commonly used as one of the performance measure of a transportation service system. When the mean waiting time at a bus station is unbearable to the customers, it's necessary to add the capacity in the related road. Then, the mean waiting time at the departure station of road j, denoted as $t_{wj}(c)$, will be varied when the solution vector c of the capacity allocation is changed. In this paper, $t_{wj}(c)$ for each solution vector c will be calculated by the simulation model of the capacity allocation tool.

Because most customers have a time plan to visit a group of determinate scenic spots with a given routing, mean flow time become another important performance measure of a transportation service system in a tourist area. Assuming that n groups of customers will visit k scenic spots (each scenic spots has one bus station) in a tourist area, we denote the mean flow time of group i as $t_{fi}(c)$, for $i = 1, 2, \ldots, n$, to measure the transportation system in the tourist area. In this paper, $t_{fi}(c)$ will also be calculated by the simulation model of the capacity allocation tool.

The two performance measures are considered together in this study. Hence, the optimization model with a bi-criteria objective function is

$$\min w_{\mathrm{w}} \sum_{j=1}^{m} n_{\mathrm{w}j} t_{\mathrm{w}j}(c) + w_{\mathrm{f}} \sum_{i=1}^{n} n_{\mathrm{f}i} t_{\mathrm{f}i}(c) \tag{1}$$

$$\text{subject to: } 0 \le c_j \le u_j \quad j = 1, 2, \ldots, m. \tag{2}$$

$$\sum_{j=1}^{m} c_j \le u_{\max} \tag{3}$$

where w_{w} is the weight of mean waiting time, w_{f} is the weight of mean flowing time, $n_{\mathrm{w}j}$ is the mean length of the waiting queue at the departure station of road j, $n_{\mathrm{f}i}$ is the mean sizes of customer group i. In the capacity allocation tool, w_{w} and w_{f} are assumed to be given, and each $n_{\mathrm{w}j}$ and $n_{\mathrm{f}i}$ will be calculated by the simulation mode.

3 Simulation Model

The simulation model is used to simulate the transportation and visiting process for each given solution in order to compute the objective function value in the optimization model.

The following assumptions are made in the simulation model:

Customers are grouped into classes. The customer routings are predetermined for various customer classes. Each customer class has its own inter arrival time distribution.

The size is same for each group at every scenic spots, but it might be different for different customer groups, even if the customer groups belong to the same class.

A customer group might visit a scenic spot just one time. The processing of a customer group at a certain scenic spots is called an activity in this paper. Each activity has its own visiting time distribution. The resting time and the meal time is included in the visiting time. The main reason for this simplification is that only the start and completion times of an activity are recorded in the actual case.

The transportation time has its own distribution in each road. The transportation time's distribution in a road is same for all customer classes.

The stochastic parameters in the simulation model include the inter arrival times of customer groups, the transportation times and the visiting times. We performed the Kolmogorov-Smirnov (K-S) goodness of fit tests in the data samples to determine the probability distributions of the parameters with the aid of software SPSS v19.0. In the actual case, most of the parameters can be approximated by exponential distributions with a significance level of α = 0.2.

These assumptions seem to be reasonable for medium to long term decisions in the case study. Some assumptions are subject to the collected data in the case study. They can be expanded in some other cases with more sufficient data.

4 Gradient-Based Simulated Annealing

Kirkpatrick et al. [11] firstly presented SA in 1983. In its neighborhood search, SA accepts inferior solutions according to a probability in order to bypass local optimums. But it is time consuming in solving large-scale optimization problems coupled with simulation models.

The result of the bottleneck analysis can aid in pointing toward the direction of the maximal decrease of the objective function. Taking this result as an approximate gradient of the objective function, the neighborhood generation in the meta-heuristic procedure for capacity allocation can be guided to accelerate convergence and thus, reduce the computing time. A similar approach can be found in a few other studies [7–10] on the hybrid algorithms, each of which consists of a gradient-based method and a meta-heuristics algorithm. But these hybrid methods do not deal with the condition of an absence of an effective method to calculate the gradient of the objective function except by simulation. In this paper, using the results of the bottleneck analysis as approximate gradients, we couple the approximate gradients with simulated annealing and present a hybrid method named GBSA as follows:

Step 1: Input the control parameters of GBSA: Initial temperature T_i, termination temperature T_f, cooling rate α, freeze limit Φ and accept limit β. Take T_i as current temperature T. Generate an initial solution c_0. In the experiments of this study, the c_0 is generated according to the practical current solution in the actual case. Perform a simulation to calculate the objective-function value z_0 of the solution c_0.

Step 2: Detect the bottlenecks in the transportation network. To detect and measure the shifting bottlenecks in a complex network, a state equations method has been presented by Huang et al. [12]. Although this method is not an exact one, it is very robust, easy to apply and has the ability to detect the bottlenecks in steady state systems or non-steady state systems.

Step 3: Suppose there are M solutions $c_{0h}(h = 1, 2, \ldots, M)$ neighboring to solution c_0 (only the capacity level in a road is modified by plus 1 or minus 1 in the ordinal number of the solution space). Based on the results from the bottleneck analysis, an estimated objective-function value $z(c_{0h})$ for each

$$P(c_1 = c_{0h}) = \frac{(z_{\max} - z(c_{0h}))^{\gamma}}{\sum_{h=1}^{M} (z_{\max} - z(c_{0h}))^{\gamma}}, \quad (4)$$

neighbor c_{0h} is computed by state equations. Then, a new solution c_1 is chosen from the M solutions according to a probability shown as follows: where $z_{\max}$ is the maximum in $z(c_{0h})$, $h = 1, 2, \ldots, M$. Therefore, the neighbor of a better estimated objective-function value has a higher probability to be chosen in order to accelerate convergence. Parameter γ in Eq. (4) is a control parameter used to adjust the impact of the estimated gradient on the neighborhood generation. Based on pilot experiments, we observe that when the objective-function value has a large improvement in the previous iteration indicating that the guidance of the gradient works well at this stage of the search procedure, γ should be set to a larger value to make full use of the guidance of the gradient, or else γ should be set to a smaller value to have a better chance to move from one local minimum area to another one. For this consideration, in this study γ is set to 1 at the beginning of the search procedure and will be adjusted at each iteration as stated in Step 4.

Step 4: Perform a simulation to calculate the objective function value z_1 in the new solution c_1. Let $\Delta z = z_1 - z_0$. If $\Delta z < 0$, the new solution c_1 will replace the current solution c_0; otherwise, apply a probability $P(A) = e^{-\Delta z/KT}$, where K is a constant, to determine whether the new solution will replace the current one. Set $\gamma = |\Delta z|/(|\Delta z|)_{\max}$, where $(|\Delta z|)_{\max}$ is the maximum among all the $|\Delta z|$ values in the past iterations.

Step 5: The current temperature T is adjusted after every Φ iterations according to α. If it's below T_f or the solution has not been improved for too many consecutive iterations to overstep β, stop the neighborhood search; otherwise, go to Step 2.

Step 6: Report c_0 and z_0 as the final solution and its objective function value, respectively.

In GBSA, the neighborhood-generation is according to a probability obtained by the bottleneck analysis, which is different from the random method in the traditional SA. This method speeds up the search for a better solution in the area with the most potential while still allows the search to move away from a local area to another. Thus, the neighborhood search may stop earlier as controlled by β and the computing time is reduced.

5 Computational Experiments

In this paper, a case study is tested using the proposed GBSA. The case consists of 3 customer classes and 5 scenic spots. There are 6 roads between the 5 scenic spots, as shown in Fig. 2. All the customers start their visits at spot 1 and finish them at spot 5. But their routings may be different when they are in different classes.

There are 2–6 bus shifts an hour in each of the 6 roads. The total capacity limit of the 6 roads is 20 shifts an hour. The capacity of a bus is set to be 10 persons for all the bus shifts. The queue rule at all the bus stations are first come first service (FCFS), as it is commonly applied in service systems.

According to the tourist manager's suggestion, we make an assumption that a bus will always waiting at the departure station until it is filled with customers and it will return to the departure station immediately when it reach the terminal station. A customer group may be divided into two parts when there are not enough buses at the departure station.

In the simulation model, the weight of mean waiting time and the weight of mean flow time are both set to be 1. The size of customer groups are set to be 1–10 follow a uniform distribution. Inter arrival times of the customer classes, visiting times and transportation times are generated in exponential distributions. These data is shown in Tables 1 and 2. For instance, "1-2-3-5" means the routing involves 5 steps transported in the sequence of roads 1, 2, 3 and 5.

The simulation software was developed in Microsoft SQL Server 2008. The simulation for any given solution was performed in the duration of 24,000 h. The simulations were all performed in a personal computer with 3.6G CPU and 16G memory. The mean simulation time of each simulation (including the time for bottleneck analysis) is 6.5 s in this case.

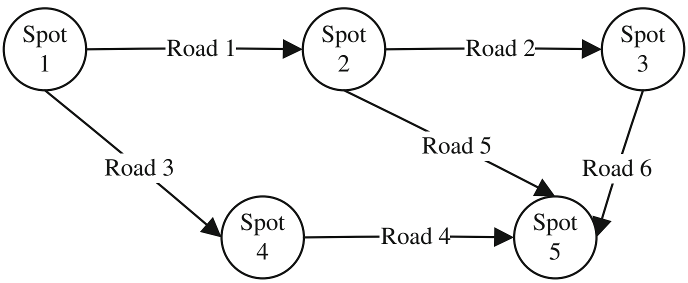


Fig. 2 Tourist transportation network

Table 1 Information of customers

Customer class	Mean inter arrival time (min)	Routing
1	5	1-2-3-5
2	10	1-2-5
3	10	1-4-5

Table 2 Information of transportation network

Scenic spot	Mean visiting time (min)	Road	Mean transporting time (min)
1	20	1	5
2	60	2	10
3	25	3	25
4	45	4	10
5	30	5	15
–	–	6	10

Table 3 Control parameters

	Type	Control parameter values				
		T_i	T_f	α	Φ	β
A1	GBSA	1	0.1	0.9	10	20
A2	GBSA	1	0.3	0.7	5	10
A3	Traditional SA	1	0.1	0.9	10	20
A4	Traditional SA	1	0.3	0.7	5	10

Table 4 Results of the computational experiments

	Objective function value (min)	Run time (min)
A1	951	6.25
A2	967	5.06
A3	1020	40.67
A4	1104	28.10

According to the pilot runs, two groups of control parameters are used to both the traditional SA and GBSA. Therefore, there are 4 kinds of algorithm with different control parameter values or different neighborhood-generation methods applied to the case study, which is denoted as A1, A2, A3, and A4. Their control parameter values are shown in Table 3. The results are shown in Table 4.

6 Conclusion

In this paper, a modified SA, named GBSA, is used as an optimization tool to optimize capacity allocation in a tourist transportation network. With less computing time, GBSA found better solutions compared to the traditional SA. These results show that the proposed method can often finds better solutions with a shorter computation time compared to the traditional method. These optimal solutions for capacity allocation can be very useful to support decisions in performing tradeoffs between the quality of service and the cost of capacity allocation.

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Analysis on Credit Risk Assessment of P2P

Lei Xia and Jun-feng Li

Abstract After the third Plenary Session of eighteen, the financial reform has been put on the agenda, Thinking about the development of inclusive finance monetary authorities is a particular concern. P2P is a financial innovation, but also brings some trouble, in the P2P lending market many non institutional borrowers will be together. In a typical mortgage market, borrowers must present their projects, lenders must decide lending conditions and requirements. Many of the loans has not collateral mortgage, Credit evaluation of the borrower is the most important task. We show that, in the absence of high quality data, the bank the right of investors under the right to the money to invest in the market activities, which will threaten the current ideas of the new credit. Therefore, we propose a model to evaluate the investment risk of default, based on the analysis, we can accurately assess the risk of default improve return on investment.

Keywords P2P · Financial risk · Repayment rate

1 Introduction

Financial development is the core issue of the whole national economy, especially for full deepen reform, as a whole Chinese upgrade key stage to promote the economy. Since China's reform and opening up, the financial industry has been repressed relative to other industries, resulting the unreasonable allocation of financial resources, so that it is difficult to play a lubricant role for finance as the transformation of function to the drive the economic development. At the same time, this also provides the soil and environment for the folk financial innovation. On the one hand, the medium and small and micro enterprises and individual industrial and commercial households in urgent need of funds management are

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difficult to obtain financial support from a large state-owned financial institutions [1]; on the other hand, in recent years, China has emerged a large number of idle funds of the wealthy middle class.

In addition, China's current legal system, there lending behavior is not allowed between the enterprise and enterprise (and therefore, as a financial intermediary, the private financial institutions lending (P2P) connecting of capital supply and demand both sides between individual and individual appeared. After the Third Plenary Session of the party's eighteen, the financial reform has been put on the agenda, the monetary authorities on the development of inclusive finance raise concern [2].

P2P is a financial innovation, but also brings some trouble, while in the general extent, these micro economic integrity and ethics does not have problem [3]. But in practice, they can not be repaid in time, and the default rate is high, especially in the virtual network transactions, single line mode can appear sometimes no certification and prone to fraud and breach of contract disputes, there are many failures, run, overdue, run away and other risk events. Therefore, a comprehensive analysis and study of all kinds of risks P2P lending [4] face as soon as possible and the introduction of relevant laws and regulations, are very important to better promote the development of P2P lending and the maintenance of financial stability.

From the perspective of the transaction scale, the amount of the transaction, P2P lending, the number of transactions and single turnover differences, P2P lending company in 2012, the highest amount of transactions has more than 2,000,000,000 yuan, the number of transactions up to 70,000, the highest single turnover of 564,000 yuan, has more than a certain size, as shown in the Tables 1 and 2.

2 Methodology

2.1 Problems and Analysis of P2P Lending

In theory, the lender is willing to invest their interest with the increased risk of default. The main challenge of the risk pricing is the lender must be through P2P lending platform. Many P2P lending market investors to provide some information about the borrower, for example, the number of credit, the current default, the borrower's debt to income ratio or in the past six months credit. This type of information, explaining 95 % of the credit risk of the release (Iyer et al. 2014). The measurement model is better than that in the data bank of the predictive ability of the market.

In myc4.com, the small business Africa would like to apply for a loan, go to a local partner (called providers) to put forward his project [5], he needs the amount listed, he can pay interest. Investors evaluate his business. The assessment did not report to the potential investors. However, aggregate default rate report for each provider selection, reflecting their ability.

Table 1: Part of the P2P product comparison

The name of company	Credit standard	Mortgage standard	Guaranty standard	Net standard	Recommend standard	Friendship standard	Local standard
E fast loan	●	●	●	●	●	○	●
Hongling venture	●	●	●	●	○	○	○
365 easy loan	●	●	●	●	○	○	○
The new loan	●	●	○	●	●	○	○
Everyone nrichment	●	○	●	○	○	●	○
Net borrowing	●	●	○	○	●	○	○
Wenzhou loan	●	●	○	●	○	○	○
PO INVESTMENT	●	●	○	○	○	○	○
The sincere not loan	●	●	○	●	○	○	○
Sheng Rong Online	●	○	●	○	○	●	○
808 credit	●	●	●	○	○	○	○
National loan	○	●	○	○	○	○	○
Peer-to-peer lending	●	○	●	○	○	○	○
A pat on the loan	●	○	●	●	○	○	○
Net loan chang	●	○	●	○	○	○	○
Number	14	10	7	7	4	2	1

Source First Financial Financial Research Center: “Chinese P2P lending industry white paper (2013)”, China Economic Publishing House 2013

Table 2 Comparison of P2P transaction data in 2012

Company name	Number of transactions (pen)	The amount of the transaction (100 million yuan)	Single turnover (million)
Wenzhou loan	39	21.8	5.6
Sheng Rong Online	3.2	17.8	56.4
Hongling venture	68.4	14.9	2.2
PO INVESTMENT	2.4	11.4	48.5
365 easy loan	27.1	6.4	2.4
805 credit	14.1	6.4	4.5
E fast loan	15.6	5.5	3.5
Peer-to-peer lending	5.1	3.5	7
National Loan	0.7	2.2	32.7
A pat on the loan	19.7	2	1
The sincere not loan	2.3	1.5	6.5
Everyone enrichment	1.1	0.8	7.6
Net loan change	1	0.8	3.2
The new loan	1	0.6	5.7

If passed, the loans request to be uploaded [6]. In addition to screening the credit requirements, the supplier is responsible for the issue of the amount of the credit and collection of payment. The supplier is usually composed of local banks, and the process cost. The actual cost of the different between different suppliers. It usually contains a (small) clearing fees and interest charges [7]. Interest expense charge only as long as the loan is repaid. It can be said, and clearing fees may urge the supplier to accept the bad creditors, interest expense is the incentive compatibility of the investors of the full repayment problems. The cost plus the required fee (2–4 %) and investor interest is the total cost of the borrower (annual percentage rate (APR)). The mean APR was higher than that in typical interest rates in Europe and the United States 44.6 %, but still for small enterprises in Africa is still quite cheap [8].

All types of investors to fund projects and project bid through the auction market. Auction is an open auction. The whole auction process, investors can track the other investors bid. On the contrary, the static information provided by the borrower, the bidding information (for example, the number of investors, the average interest rate) changes with each new bid. In the bidding process is closed, the project was canceled (because the average interest rate is too small or too high a price) or funding. If funding the project, these investors to provide the lowest loan interest rate together. These investors receive what he put in his bid rate. As a result, it is possible, in the same project, some investors received a 0 % interest rate, interest rate and other people to a maximum of 50 %.

Figure 1 shows the distribution of individuals in the example of a fully funded project investor interest rate. The X axis represents a different interest rate; in the Y axis, the accumulation display. It can be seen that the changes between the interest rate range of 5 and 23 %. The vertical line shows the average interest rate (I_{want} t), the maximum acceptable average interest rates of borrowers (I_{want}), the highest rate (I_{want}). It can be said that a part may take the following altruistic motives (left part of Fig. 1). The lender on the right side of Fig. 1, however, demand for interest rate is almost a few times, show that the pursuit of profit maximization of the investors to invest in the project bid the highest rate.

Figure 2 shows the default rates and rates of repayment rate, the solid line shows the distribution of the default rate, the dotted line represents the distribution of the repayment rate, both uniform from the normal distribution, the default rate and the repayment rate is higher in the rate of 10 % or so.

2.2 *Establishment and Estimation of the Model, the Repayment Rate*

We use our analytical model is a linear regression model, to estimate the rate of return(repayment) as a measurement variable. The rate of return is the sum of all costs than the payments received commitments and time, ignoring the change of monetary and exchange rate possible values [9] presents a complete financial losses.

Due to the high degree of variance explained, we decided to use this variable to the repayment rate of value. All other variables have been used to form function. Please note, some independent variables specified which are encoded in the category, therefore, each class has its own parameter β. For example, the variables of the model "in" beta, β with parameters [10], including 7 dummy variables coding

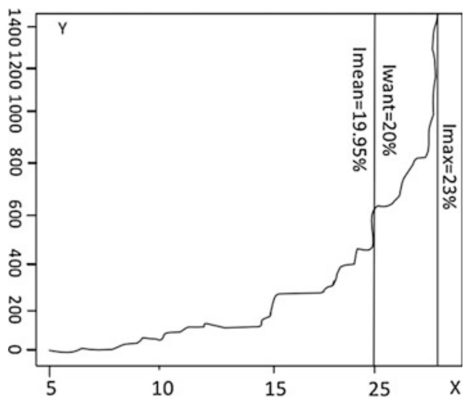

Fig. 1 The interest rate distribution

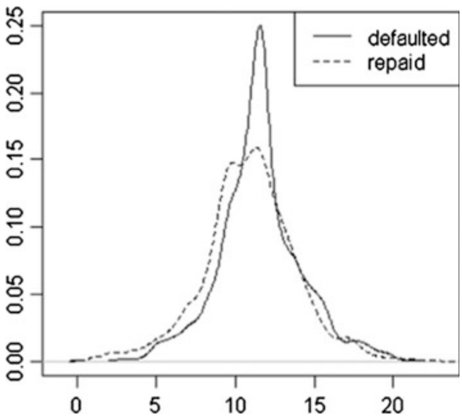

Fig. 2 The default rates and rates of repayment rate. *Note* The horizontal axis is the average interest rate, the vertical axis is the density

and corresponding parameter β, for each country for investment decisions will soon before the end of the auction, we think of I_{MAX}, I mean, the number of investors will be known at this point [11].

$$\begin{aligned} repaid = \beta_1 + \beta_2 gender + \beta_3 \log(amount) \\ + \beta_4 I_{want} + \beta_5 \sec urity + \beta_6 currency \\ + \beta_7 payback + \beta_8 areactivity + \beta_9 industry \\ + \beta_{10} I_{\max} + \beta_{11} I_{mean} + \beta_{12} APR \end{aligned}$$

Where repaid is the repayment rate, amount is number of borrowers, I_{want} is the number of expected borrowing. Payback is before the repayment, including extraction, (wholesale) other wholesale. Industry refers to the industries including consumer goods (consumer goods) and durable goods (durable goods), agriculture and fisheries (farming and fishing) etc. Analysis of a sample revealed an adjustment coefficient between a prediction coefficient value and the actual value of 42 % and the actual repayment. The market and the interpretation of a degree (2 %), we get a high coefficient of determination of 20 times. Next, we examined the parameters of the model. The payback period is longer and higher credit to reduce the repayment rate. Previously existing loans(paid) have a positive impact on the repayment.

In the process of establishing the model, we estimate the linear regression model to assess the risk of default, according to the information provided by the potential provider. The model can explain 42 % variance, indicating that there is enough information, not by investors to help them become wise investment decisions. In the further development of the platform [13], a new variable has been provided by the borrower, which may improve the prediction ability. However, may need to consider the anti discrimination requirements of specific countries when using some variables such as age or gender. The linear regression model provides the convenience simple which can explain the non expert and infectious, further research could better prediction ability and other models.

We simulate the different investment decisions in different time windows, and the results compared with the market. On each virtual observation set, decision support tools are better than the market in each time window. In addition, from a decision support tool [12], the worst results can still be higher than the best results from the market to generate more profits. In addition, omission of the old data in our study on the models have great positive influence. Summarizes the performance of the model, it can be said, to improve the quality of decision-making to make losses into profit. Appropriate risk assessment is in many aspects. Clearly, to generate profits interest, so investors will only stay in the market if the promised rate of return can be achieved.

Predictions of the growth of the industry so strongly depend on tool, to improve the quality of the investment decision-making. In addition, the operator should be in the lending market to improve the quality of decision-making of interest as its business model, is usually based on the proportion of the cost of turnover. Potential borrowers, this depends on the effect of a decision support tools to their credit. Evaluation of credit default risk will be conducive to good and bad borrowers loan, the borrower will not be able to continue to raise funds in the market. The latter may seek to microfinance institutions financing loans mainly to solve the problem. Although our analysis restricted to a single loan market, we believe that the application of decision support tools can be beneficial for P2P lending market in general, particularly in the absence of "hard" information, you can use the credit data of potential borrowers. Future research is needed to more P2P lending market wide assessment of the results of our study.

3 Conclusions

This research analyses the various risk factors of P2P lending model facing our country mainly from the folk financial innovation point of view, from the macro environment for its development, its growth has been speculation that is wandering in the edge of the living space of law and policy, legal policy impact, because of this, the industry risk is not good measure. On the whole, China's domestic P2P lending more and more innovation and derived from different models, to create a favorable environment for development for its at the same time but also to guard against the risk, to make it more stable and healthy development. In the past loans from the traditional banking institutions.

With the advent of the Internet in the form of a new credit business, the traditional bank loans suffer by the P2P. P2P lending market will bring many non institutional borrowers together. In a typical mortgage market, borrowers must present their projects, lenders must decide lending conditions and requirements. Many of the loans without collateral mortgage, credit evaluation of the borrower is the most important task. We show that, in the absence of high quality data, the bank the right of investors under the right to the money to invest in the market activities, which will threaten the current ideas of the new credit. Therefore, we propose a model to evaluate the investment risk of default, based on the analysis, we can accurately assess the risk of default, improve return on investment.

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Study on Multi-depots Vehicle Transshipment Scheduling Problem and Its Genetic Algorithm and Ant Colony Algorithm Hybrid Optimization

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Abstract To get global solution in multi-depots vehicle transshipment scheduling problem (MDVTSP), MDVTSP models are established. Genetic algorithm and particle swarm hybrid optimization is established to solve MDVTSP. The optimization course is as follow: first set up chromosome vector to get goods' transshipment point, and assign goods to vehicles. Second, establish tabu matrix for ant colony optimization (ACO) to get vehicle route. Then evaluate and filtrate vehicle scheduling results by optimization aim, circulate until meet terminate qualification. Illustration results show that Hybrid arithmetic is effective for multi-depots vehicle transshipment scheduling problem.

Keywords Multi-depots · Vehicle transshipment scheduling problem (MDVTSP) · Genetic algorithm (GA) · Ant colony optimization (ACO)

1 Introduction

Vehicle routing problem (VRP) was first proposed by Dantzig and Ramser in 1959. Multi-depots vehicle scheduling problem is complex to single depot VRP, many algorithms are used to deal with MDVSP, such as Tabu Search Algorithm with Variable Cluster Grouping [1], near-exact solution approach [2], multi-phase modified shuffled frog leaping algorithm [3], genetic algorithm [4], Exact and

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meta-heuristic approach [5] and so on. These algorithms transform MDVSP into single depots VRP, depot is visited only once, and easy get into local minima.

To deal with this issue, and get the global solution, genetic algorithm and ant colony algorithm Hybrid Optimization is proposed in this paper for multi-depots vehicle transshipment scheduling problem (MDVTSP).

2 MDVTSP Parameter Demarcate and Model

Assumption: (1) O_{ij} can be transshipped only once. (2) There are enough vehicles, vehicle position is random. (3) When vehicle finish all O_{ij} consignment, it needn't go to its start point.

Graph G = (V, A), where V is the depots set, depots i, j and $u \in$ V, A is the arc set. Q_v is vehicle capacity. N_v is vehicle numbers, n_v is vehicle serial number, $n_v \in N_v$: If vehicle n_v departs from depot i to j, $x_{ij}^{n_v} = 1$, other wise $x_{ij}^{n_v} = 0$. d_{ij} is the distance of depot i to j. $L_{v\max}$ is vehicle route length limit. O_{ij} is the goods which need to consign from depot i to j, O_{ij} start and end depots are linked by arrowhead, we can see this relationship in Fig. 1, and $O_{i(j+4)}$'s transshipment depot is $j - 2$. q_{ij} is O'_{ij} quality, $Q_j^{n_v}$ is vehicle load when vehicle n_v departs from depot j, N_O is O_{ij} sum number; If O_{ij} is on vehicle n_v, $o_j^{n_v} = 1$ otherwise $o_j^{n_v} = 0$; If O_{ju} is going to load on vehicle n_v, $y_{ju}^{n_v} = 1$, otherwise $y_{ju}^{n_v} = 0$.

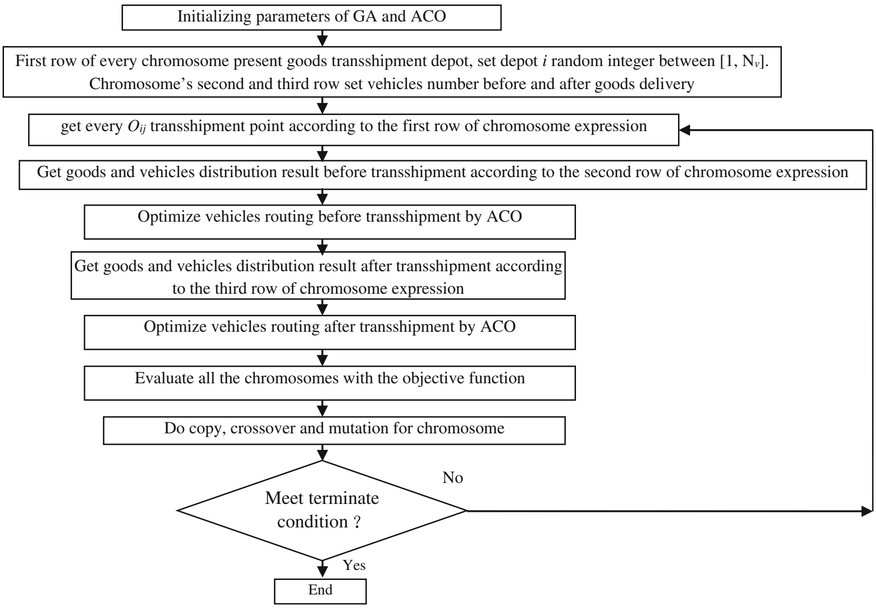

Fig. 1 GA and ACO hybrid optimization procedure for MDVTSP

Objective function:

$$\min \sum_{n_v \in N_v} \sum_{i \in V} \sum_{j \in V} (d_{ij} x_{ij}^{n_v}) \tag{1}$$

Subject to:

$$0 < q_{ij}, \quad q_j^{n_v} \le Q_v \tag{2}$$

$$\sum_{i \in V} \sum_{j \in V} (d_{ij} x_{ij}^{n_v}) \le L_{v\max} \tag{3}$$

$$1 \le \sum_{n_v \in N_v} o_{ij}^{n_v} \le 2 \tag{4}$$

$$\text{When } x_{ij}^{n_v} = 1, q_j^{n_v} = q_i^{n_v} - \sum_{i \in V} o_{ij}^{n_v} q_{ij} + \sum_{u \in V} q_{ju} y_{ju}^{n_v} \tag{5}$$

In the above proposed model, the objective function (1) is to minimize vehicle route length. The constraints for vehicle load and goods quantity are showed in (2). The constraint for vehicle route length is showed in (3). The same goods are ferried by one or two vehicles are showed in (4). Vehicle load and unload information can see (5).

3 MDVTSP Model Strategy Based on Hybrid Optimization

3.1 Set Up Genetic Algorithm Chromosome Vector

Genetic algorithm is member of computational method's family which is inspired by evolution [6]. To get goods' transshipment point, and assign goods to vehicles, chromosome vector is set up for genetic algorithm. Set up goods number dimension chromosome vector, vector's every column corresponds to goods. Chromosome vector has three rows, first row corresponds to goods' transshipment point, second row corresponds to vehicle serial number before goods transshipment, and third row corresponds to vehicle serial number after goods transshipment, thus we can get goods' transshipment point, and assign goods to vehicles. structure of genetic chromosome vector is presented in Table 1.

3.2 Get Single Vehicle Route by Ant Colony Optimization

The ant colony optimization (ACO) [7] is a kind of simulant evolution algorithm. Considering multi-depots and multi-vehicles ferry goods, O_{ij} denotes the goods that

Table 1 Structure of genetic chromosome vector

O_{ij}	O_{ij}	$O_{(i-2)j}$	$O_{(i-4)(j+2)}$	…	O_{ju}
O_{ij} start depot	i	$i-2$	$i-4$	…	j
O_{ij} end depot	j	j	$j+2$	…	u
Oij transshipment depot	i	i	$i-2$	…	$i+1$
O_{ij} carriage vehicle before goods transshipment	n_v	n_v+1	n_v-3	n_v-4	n_v
O_{ij} carriage vehicle after goods transshipment	n_v	n_v-2	n_v	n_v-2	n_v-3

Table 2 Tabu matrix expression

O_{ij}	O_{ij}	$O_{i(j+3)}$	…	O_{ju}
O_{ij} start depot	i	i	…	j
O_{ij} end depot	j	$j+3$	…	u
O_{ij} start depot visit state	0	1		0
O_{ij} end depot visit state	1	1		0
Vehicle serial number that ferry O_{ij}	n_v	n_v-3	…	n_v

should be ferried from depot i to j, we can make one ant denotes one vehicle, so ants number m in colony equals to vehicle number N_v. We change single ant tabu$_k$ to ant colony tabu [3] [N_O]. Tabu matrix's every column corresponds to an O_{ij}. Tabu matrix has three row, the first row correspond to O_{ij} start depot, second row correspond to O_{ij} end depot, third row correspond to vehicle n_v that ferry O_{ij}, tabu matrix expression is presented in Table 2. Vehicle serial number that ferry O_{ij} initialize as −1, when O_{ij} is load, O_{ij} start depot visit state is 0, vehicle serial number is the vehicle that ferry O_{ij}, and otherwise O_{ij} start depot visit state is 1. O_{ij} end depot visit state is 0 when O_{ij} is unload, otherwise is 1.

To avoid direction mistake and single goods is ferried by different vehicles, depot states in tabu should be set as: (1) If O_{ij} start depot i is not visited, depot j is inaccessible, so the tabu column set as {1, 0, −1}. (2) When O_{ij} start depot i is visited by vehicle n_v, depot j is accessible, the tabu column set as {0, 1, n_v}. (3) When O_{ij} end depot j is visited, the tabu column set as {1, 0, n_v}.

In MDVTSP, if ant k has more than one depot with biggest p_{ij}^k, select one random depot j to improve the possibility of getting the global solution. If $j = i$, the solutions are: (1) If O_{ij} is on vehicle and needs unload at depot j, the next depot is j. (2) If there are more goods to load, random select O_{ju} to get the global solution.

3.3 Step of the Algorithm

Genetic algorithm and ant colony algorithm hybrid optimization procedure is given in Fig. 1.

Table 3 Depots information

Depot	Coordinate/km	
	x	y
1	3	25.5
2	7.1	27
3	15.6	23.7
4	25.2	27
5	7.5	24.9
6	12	21
7	18.8	22.8
8	24.6	21
9	1.5	21
10	2.5	6
11	7.5	7.5
12	24	9
13	28.5	3
14	0	0
15	7.2	1.5
16	20.5	2.1
17	25	3

Table 4 Goods consign information

O_{ij}	O_{ij} start depot	O_{ij} end depot	quality/t
$O_{(1)(6)}$	1	6	2.0
$O_{(4)(6)}$	4	6	2.0
$O_{(11)(6)}$	11	6	2.6
$O_{(13)(6)}$	13	6	3.5
$O_{(14)(6)}$	14	6	2.0
$O_{(13)(17)}$	13	17	4.2
$O_{(12)(8)}$	12	8	1.4
$O_{(10)(3)}$	10	3	0.6
$O_{(12)(1)}$	12	1	3.8
$O_{(12)(14)}$	12	14	4.7
$O_{(2)(10)}$	2	10	1.4
$O_{(10)(2)}$	10	2	3.3
$O_{(15)(4)}$	15	4	1.6
$O_{(11)(15)}$	11	15	2.1
$O_{(9)(15)}$	9	15	1.2
$O_{(9)(16)}$	9	16	2
$O_{(5)(9)}$	5	9	3.3

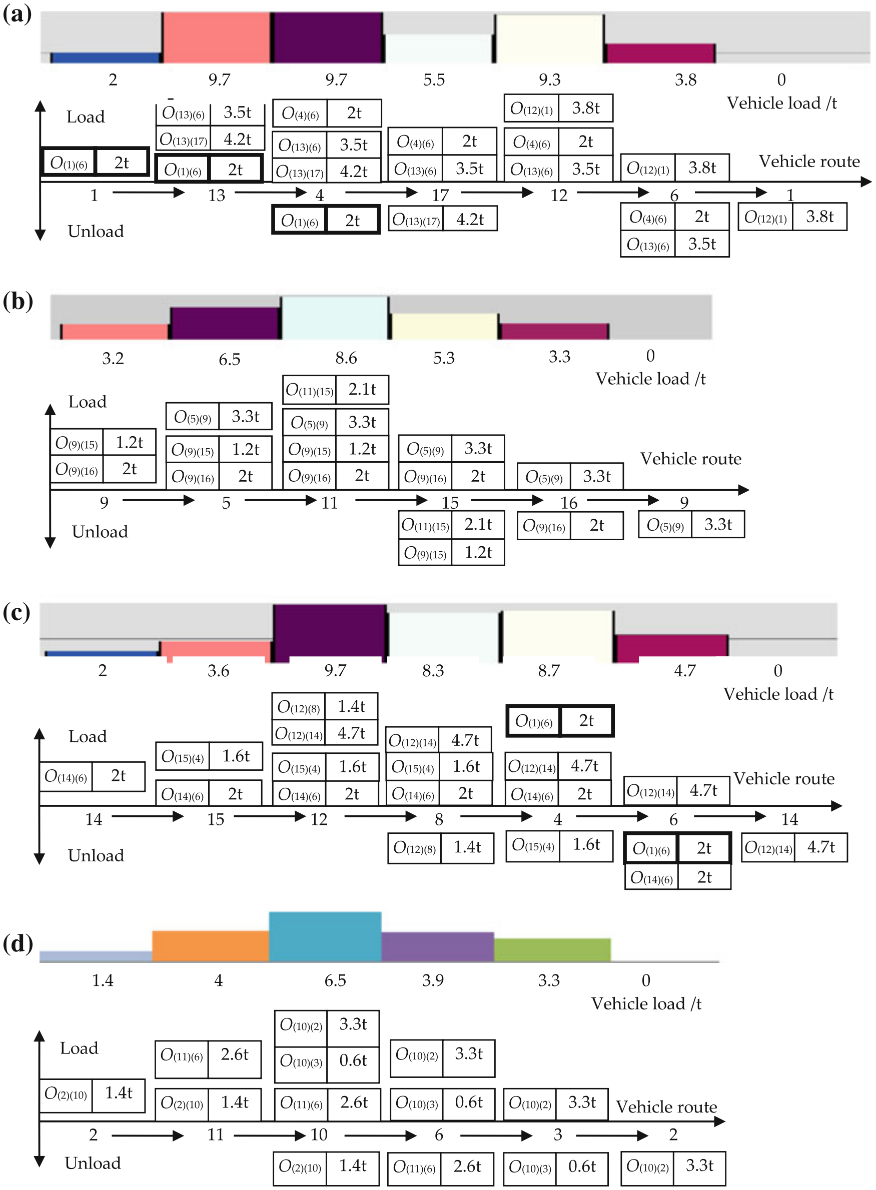

Fig. 2 Vehicle route and load change diagram. **a** Route and load and unload information for vehicle 1; **b** route and load and unload information for vehicle 2; **c** Route and load and unload information for vehicle 3; **d** route and load & unload information for vehicle 4

4 Computational Results

4.1 Example

In one area and certain time, depots information are showed in Table 3. Goods consign information is showed in Table 4, set Q_v = 10t, $L_{v\max}$ = 100 km, it is required to finish goods consignment with optimized vehicle route and without overload.

4.2 Optimized Solution

Genetic algorithm parameters are set as follow: populations are 150, crossover probability is 0.7, mutation probability is 0.1, iterate 200 times. ACO parameters set as follows: $\alpha = 1$, $\beta = 5$, $\rho = 0.7$, Q = 100, iterate 20 times.

Run hybrid optimization 20 times, vehicle optimized sum route length is 270.3 km, and there are 4 vehicles, the detailed information can be seen in Fig. 2, transshipment goods are show in bold box. In Fig. 2 we can see, $O_{(1)(6)}$ is transshipped in depot 4.

5 Conclusions

There are two reasons to get the global solution. First, in MDVTSP model, goods with start and end depots are denoted as O_{ij}, goods consignment relation is clear. Second, set up chromosome vector to get goods' transshipment point, and assign goods to vehicles, establish tabu matrix for ant colony optimization (ACO) to get single vehicle route, vehicle route to all goods is searched with optimized route by genetic algorithm and ant colony algorithm Hybrid Optimization, optimization processes are depended, and tend to get the global solution.

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An Automatic Modulation and Control System Based on ANN

Jun Xi

Abstract A control system includes a device or a set of devices that are able to manage, directs or regulates the behaviors of other devices or systems. Currently, most of the control systems is constructed with programmable logic controllers (PLCs) or microcontrollers. The notation of ladder logic is still in use as a programming idiom for PLCs. Fuzzy logic is an attempt to apply the easy design of logic controllers to the control of complex continuously varying systems. Basically, a measurement in a fuzzy logic system can be partly true, that is if yes is 1 and no is 0, a fuzzy measurement can be between 0 and 1. This paper introduces an automatic modulation and control system by using artificial neural network (ANN) to automatically manage the control system. In this system, each power point is regarded as a smart node in the neural network. The automatic control heavily relies on the algorithms which should be real-time and parallel. Therefore, BP algorithm is selected to adoption in the FPGA for designing and developing this system.

Keywords Control system · ANN (artificial neural network) · Automatic · Modulation · Fuzzy

1 Introduction

A control system includes a device or a set of devices that are able to manage, directs or regulates the behaviors of other devices or systems [1]. For example, in the industrial field, the control systems are used for controlling equipment or machines. There are two common classes of control systems, open loop control systems and closed loop control systems [2]. In open loop control system, output is generated based on inputs and in closed loop control system, current output is taken into consideration and corrections are made based on feedback [3]. A closed loop

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system is also called a feedback control system such as the human body that is a classic example of feedback systems. Fuzzy logic is also used in systems.

Logic control systems for industrial and commercial machinery were historically implemented at mains voltage using interconnected relays, designed using ladder logic [4]. Currently, most of the control systems is constructed with programmable logic controllers (PLCs) or microcontrollers. The notation of ladder logic is still in use as a programming idiom for PLCs [5]. Logic controllers may respond to switches, light sensors, pressure switches and can cause the machinery to start and stop various operations. Logic systems are used to sequence mechanical operations in many applications [6]. PLC software can be written in many different ways—ladder diagrams, SFC—sequential function charts or in language terms known as statement lists, for example, elevators, washing machines and other systems with interrelated stop-go operations [7]. Logic systems are quite easy to design, and can handle very complex operations and some aspects of logic system design make use of Boolean logic.

Fuzzy logic is an attempt to apply the easy design of logic controllers to the control of complex continuously varying systems. Basically, a measurement in a fuzzy logic system can be partly true, that is if yes is 1 and no is 0, a fuzzy measurement can be between 0 and 1 [8]. Automatic modulation classification (AMC) is an intermediate step between signal detection and demodulation, and plays a key role in various civilian and military applications [9–11].

This paper introduces an automatic modulation and control system using artificial neural network (ANN) to automatically manage the control system based on the neurons. In this system, each power point is regarded as a smart node in the neural network. The automatic control heavily relies on the algorithms which should be real-time and parallel. Therefore, BP algorithm is selected in the FPGA for designing and developing this system.

The rest of this paper is organized by several sections. Section 2 reports on the artificial neuron model. Section 3 discusses the back propagation neural network with theoretical aspects. Section 4 demonstrates the automatic modulating and control system based on ANN with simulation results. Section 5 concludes this paper by giving future research directions.

2 Artificial Neuron Model

The basic unit of the ANN is neuron which could be expressed with a structure that a set of $X = (x_1, x_2, \ldots, x_N)$ with $W = (w_{i1}, w_{i2}, \ldots,_{iN})$ is input into a calculation mode. Thus, the input signal could be integrated by a specific calculation method. The output is defined as:

$$net_i = \sum_{j=1}^{N} W_{ij} x_j \tag{1}$$

The output y_i of the neuron i will be changed due to the status of the input of neuron. The status function is $g()$, which is the state of activation. The single neuron model is expressed as:

$$\begin{aligned} net_i &= \sum_{j=1}^{N} W_{ij} x_j - \theta_i \\ y_i &= g(net_i) \end{aligned} \tag{2}$$

where θ_i is the threshold of the neuron i. Given the input and output of the neuron which has the time delay, (2) could be expressed as:

$$y_i(k+1) = g(net_i) \tag{3}$$

This paper uses the Sigmoid function which is the S function. S is a continuous non-decreasing function whose output is limited between two values. It is expressed as:

$$y(k+1) = \tanh\left\{\frac{1}{u_0}[WX(K) - \theta]\right\} \tag{4}$$

For this function, the curvature of the curve could be adjusted by changing the value of u_0. The maximum and minimum values are +1 and −1. Through the coordinate change, the maximum and minimum values of S are +1 and 0. The change function is

$$\frac{1}{2}\left[1 + \tanh\left(\frac{u}{u_0}\right)\right] = \frac{1}{1 + e^{-2uu_0}} \tag{5}$$

When the single neuron uses the non-linear activation function with dynamic execution, the system is non-linear dynamic constructed with large number of neurons.

3 Back Propagation Neural Network

The back propagation neural network termed as BP algorithm uses the supervised learning approach which is based on gradient descent. Backpropagation, an abbreviation for “backward propagation of errors”, is a common method of training artificial neural networks used in conjunction with an optimization method such as gradient descent [12]. Using this technology, the error average deviation will be minimized from the actual output and expected output. A typical BP network architecture may contain M input nodes and L output nodes [13]. The network could be a non-linear mapping from M dimensions to L space. S function is continuous and differentiable. This function could be the activate function of the BP neuron.

BP network has n input and m output with i neuron. The hidden layer's output could be expressed as:

$$y_i = f(net_i) \tag{6}$$

where $net_i = \sum_i \omega_{ij} x_i - \theta_j$. $f(.)$ is the activate function.

$$f(x) = \frac{1}{1+e^{-x}}. \tag{7}$$

$$f'(net_i) = f(net_i)[1 - f(net_i)] \tag{8}$$

The output is:

$$z_l = f\left(\sum_j m_{l,j} - \theta_l\right) = f(net_l) \tag{9}$$

where

$$net_l = \sum_j m_{l,j} y_j - \theta_l \tag{10}$$

The error of output node is

$$E = \frac{1}{2}\sum_i (t_1 - z_1)^2 = \frac{1}{2}\sum_l (t_1 - f(\sum_j m_{j,i} f(\sum \overline{\omega}_{j,i} x_i - \theta_j) - \theta_l))^2$$

After getting the function difference, error function will be carried out differentiable operations. Then we can get:

$$\frac{\partial E}{\partial m_{ij}} = \sum_{k=1}^{n} \frac{\partial E}{\partial z_l}\frac{\partial z_k}{\partial m_{ij}} = \frac{\partial E}{\partial z_l}\frac{\partial z_k}{\partial m_{ij}} \tag{11}$$

And

$$\frac{\partial E}{\partial z_l} = \frac{1}{2}\sum_k \left[-2(t_k - z_k)\frac{\partial z_k}{\partial z_l}\right] = -(t_1 - z_1) \tag{12}$$

$$\frac{\partial E}{\partial m_{ij}} = \frac{\partial z_l}{\partial net_l}\frac{\partial net_l}{\partial m_{ij}} = f'(net_1) y_j \tag{13}$$

$$\frac{\partial E}{\partial m_{ij}} = -(t_1 - z_1) \cdot f'(net_1) y_j \tag{14}$$

The different of input node could be:

$$\delta_l = (t_1 - z_1) \cdot f'(net_1) \tag{15}$$

$$\frac{\partial E}{\partial m_{ij}} = -\delta_1 \cdot y_j \tag{16}$$

$$\frac{\partial E}{\partial \omega_{ji}} = \sum_l \sum_j \frac{\partial E}{\partial z_l} \frac{\partial z_l}{\partial y_j} \frac{\partial y_j}{\partial \omega_{ji}} \tag{17}$$

$$\begin{aligned} \frac{\partial z_l}{\partial y_j} &= \frac{\partial z_l}{\partial net_l} \cdot \frac{\partial net_l}{\partial y_j} = f'(net_1) \cdot \frac{\partial net_l}{\partial y_j} \\ &= f'(net_j) \cdot x_i \end{aligned} \tag{18}$$

$$\begin{aligned} \frac{\partial E}{\partial \omega_{ji}} &= -\sum_l (t_1 - z_1) \cdot f'(net_1) \cdot m_{lj} \cdot f'(net_1) \cdot x_i \\ &= -\sum \delta_l m_{lj} \cdot f'(net_1) \cdot x_i \end{aligned} \tag{19}$$

The error in the hidden layer is

$$\delta_j' = f'(net_1) \sum_l \delta_l m_{lj} \tag{20}$$

$$\frac{\partial E}{\partial m_{ji}} = -\delta_j' x_i \tag{21}$$

Due to the weight modification Δm_{lj} and Δw_{ji} is proportional to the decreased gradient of the error function.

$$\Delta m_{lj} = -\eta \frac{\partial E}{\partial m_{lj}} = \eta \delta_l y_j \tag{22}$$

$$\delta_l = -(t_1 - z_1) f'(net_1) \tag{23}$$

$$\Delta m_{ji} = \eta' \frac{\partial E}{\partial \omega_{ji}} = \eta' \delta_j' x_i \tag{24}$$

The weight adjustment is:

$$\begin{aligned} \Delta\omega_{ji}(k+1) &= \omega_{ji}(k) + \Delta\omega_{ji} \\ &= \omega_{ji}(k) + \eta' \delta_j' x_i \end{aligned} \tag{25}$$

$$\delta_j' = f'(net_j) \cdot \sum_l \delta_l m_{lj} \tag{26}$$

For adjusting the threshold, in the BP network, the training process with the threshold θ should be fine-tuned.

$$\frac{\partial E}{\partial \theta_l} = \frac{\partial E}{\partial z_l}\frac{\partial z_l}{\partial \theta_l} \tag{27}$$

where

$$\frac{\partial E}{\partial z_l} = -(t_1 - z_1) \tag{28}$$

$$\frac{\partial E}{\partial \theta_l} = \frac{\partial E}{\partial net_l}\frac{\partial net_l}{\partial \theta_l} = f'(net_l)\cdot(-1) \tag{29}$$

Put (28) and (29) into (27):

$$\frac{\partial E}{\partial \theta_l} = (t_1 - z_1)\cdot f'(net_l) = \delta_1 \tag{30}$$

The adjustment function is:

$$\Delta\theta_1 = \eta\frac{\partial E}{\partial \theta_1} = \eta\delta_l \tag{31}$$

$$\Delta\theta_1(k+1) = \theta_1(k) + \eta\delta_1 \tag{32}$$

$$\frac{\partial E}{\partial \theta_j} = \sum_l \frac{\partial E}{\partial z_l}\frac{\partial z_l}{\partial y_j}\frac{\partial y_j}{\partial \theta_j} \tag{33}$$

where $\frac{\partial E}{\partial z_l} = -(t_1 - z_1)$

$$\frac{\partial E}{\partial \theta_l} = \frac{\partial E}{\partial net_l}\frac{\partial net_l}{\partial \theta_l} = f'(net_l)(-1)$$

Thus, we can get:

$$\frac{\partial E}{\partial \theta_l} = (t_l - z_l)\cdot f'(net_l) = \delta_1 \tag{34}$$

The fine tune function for threshold is:

$$\Delta\theta_1 = \eta\frac{\partial E}{\partial \theta_1} = \eta\delta_1 \tag{35}$$

$$\Delta\theta_1(k+1) = \theta_1(k) + \eta\delta_1 \tag{36}$$

Then,

$$\frac{\partial E}{\partial \theta_j} = \sum_l \frac{\partial E}{\partial z_l}\frac{\partial z_l}{\partial y_i}\frac{\partial y_i}{\partial \theta_j} \tag{37}$$

where, $\frac{\partial E}{\partial z_l} = -(t_l - z_l)$

$$\frac{\partial z_l}{\partial y_i} = \frac{\partial z_l}{\partial net_l}\frac{\partial net_l}{\partial y_l} = f'(net_l) = \delta_1 \frac{\partial net_l}{\partial y_j} = f'(net_j) \cdot m_{lj}$$

$$\frac{\partial E}{\partial \theta_j} = \sum_l (t_1 - z_1) f'(net_j) \cdot m_{lj} = \delta'_j \tag{38}$$

$$\Delta\theta_j = \eta' \frac{\partial E}{\partial \theta_j} = \eta' \delta'_j \tag{39}$$

$$\Delta\theta_j(k+1) = \Delta\theta_j(k) + \eta' \delta'_j \tag{40}$$

4 An Automatic Modulating and Control System Using ANN

The control system using ANN includes four control modular. Figure 1 shows the control architecture with each modular is controlled by a neural network.

From Fig. 1, a modular is controlled by a small neural network, each of which contains three layers. The input layer is the differences of the real value and predefined value. There are five neural nodes in the network. The output is the power control thus all the neural networks compromise the controller of the power system. For the neural network, there are four input, one output and one middle layer. The input is $X = [x_1 \quad x_2 \quad x_3 \quad x_4]^T$ and output is $O = [x_1 \quad x_2 \quad x_3 \quad x_4 \quad 1]^T$. Sigmoid function is $f(x) = \frac{1}{1+e^{-x}}$.

Based on the architecture of the designed system, the simulation experiments are carried out for testing the system. Figure 2 shows the modular with BP algorithm with Simulink Neural Network Blochset of dotprod and logsig functions. There are five devices in the modular each of which is controlled by a neural network. The expressions are $y_1 = (x_1+1)^2$, $y_2 = (x_2+1.5)^2$, $y_3 = (x_3+2)^2$, $y_4 = (x_4+2)^2$, and $y_5 = (x_5+2.5)^2$.

From the above expressions, it could be observed that the response time is different. However, after 15 Unit of time, the system will reach the stable value which is pre-set. With the values, the designed system could meet the requirements. BP algorithm needs some time to learn processing. Since the simulation is carried

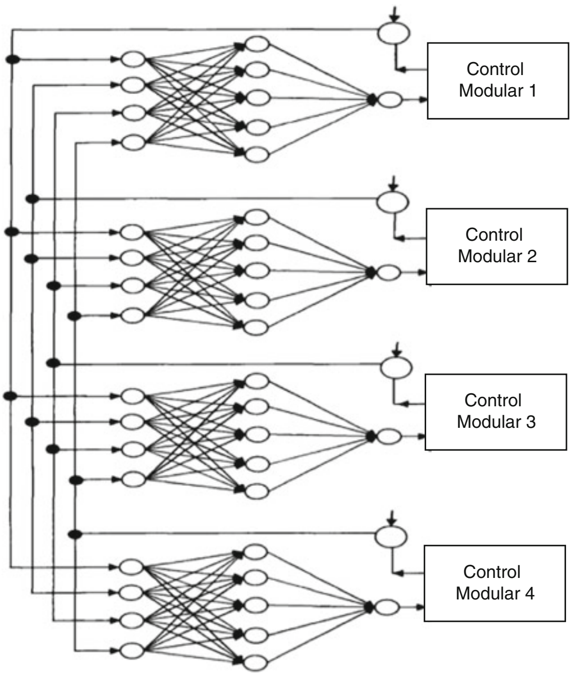

Fig. 1 System control architecture

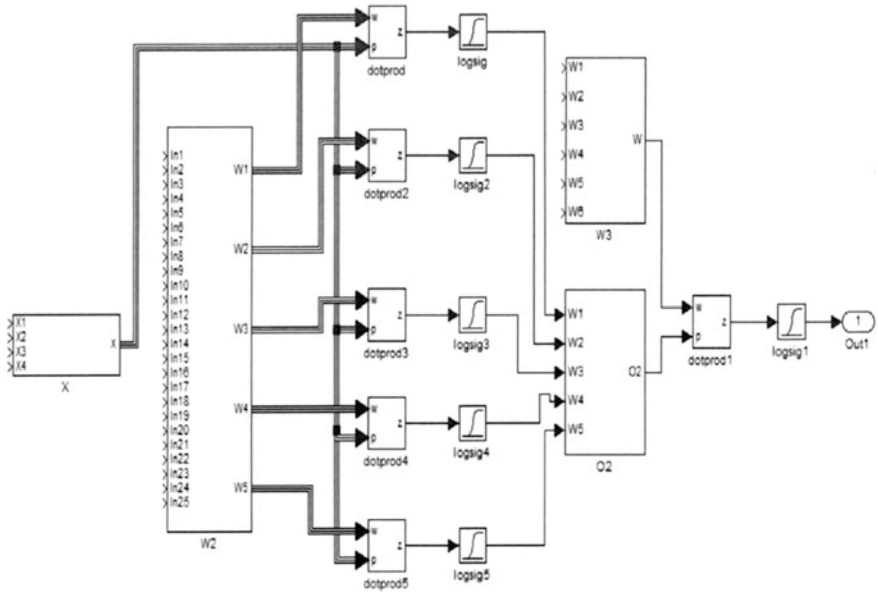

Fig. 2 Modular with BP algorithm

out in the computer-based system. In order to implement the system in FPGA-enabled chips, the processing speed may not as fast as that in a computer based system.

5 Conclusions

This paper introduces an automatic modulating and control system based on the ANN. Theoretical analysis is carried out with back propagation neural network. From experimental results, it could be observed that the response time is different. However, after 15 Unit of time, the system will reach the stable value which is pre-set. With the values, the designed system could meet the requirements. BP algorithm needs some time to learn processing.

Future research directions are carried out from several aspects. Firstly, the ANN model could be improved by adding the layer feedback mechanism to improve the accuracy of control. Secondly, with samples of control data, the efficiency and effectiveness of the system could be enhanced.

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Construction and Evaluation of Lean Team in Automobile Enterprise

Yu-chun Wang, Ze-yong Xu, Li-fang Wang, Wei Wang and Gang Ding

Abstract Lean team model is the elementary and essential cell for enterprise to promote its own the lean production. Based on researches of lean team models in both foreign and domestic advanced enterprise, we came up with the characteristic way to build the lean tem model for FAW Car as well as the correspondent evaluation standard of outstanding stars team. In this way, we accomplished the complete evaluation system of lean team model in FAW Car. This system played a profound and lasting role in achieving the noble ambition of FAW Car as "making first-class brand and becoming internationally competitive automotive enterprises".

Keywords Lean production · Lean team · Stars team · Evaluation standard

1 Background, Purposes and Significances

"Made in China 2025" is Chinese first ten-year program of action to fulfill its ambition—being a manufactured powerhouse and car manufactory. As a typical manufacturing, it needs huge promotion and breakthrough as one of the urgent and promising key fields. This brings god-given opportunities of transformation and upgrading to China automobile industry as well as grand challenges. In order to take advantage of this hard-won chance and overcome corresponding challenges, the achievement and performance of lean team model, the key to success, has become a very urgent mission to all automobile manufacture enterprises in China.

Nowadays, Chinese automobile industry seems large, but with the deficient of innovative capabilities. The application of intelligent manufacturing and network will definitely lead to reform of lean management whose final goal is to constantly decrease the resource and cost for management, running and production. The performance of lean production, in the basement for the utilization of new

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technology in the further, will boost Chinese automobile industry to achieve “actively refining, self-transcendence, and sustainable kaizen” [1, 2].

Team in the manufacture, as cell in the flesh and blood organization, is the primarily basic unit relied by cooperation to achieve its business activities. The work is to transform the entire core team in the company into lean team, and it is believed in this way will the innovation and competition of Chinese automobile enterprise be dramatically improved by construction and evaluation of lean team.

2 Present Situations at Home and Abroad

Across the world, US companies usually provide team leaders with a whole set of Training within Industry (TWI) course to improve their management abilities and skills. 4 J management skills are also involved, including Job method, Job safety, Job relations and Job instruction. Germany emphasizes heavily on professional technical education. For professional workers in Germany enterprises, there are complete training schedules focusing on talent reserve, innovation ability and pursuit of high-quality products. Japan attaches much importance to education and training within corporation as well as selection and cultivation of the front-line manager and team leaders. In Japan enterprises, there is a motto—“sharing same desire, focusing on the scene”. Enterprises in South Korea pay much importance on workers’ initiative, self-consciousness and creativity. Furthermore, they also emphasize target management, implementation of global equipment management and “four star” professional tutorial system [3–6].

Team management in Chinese firms has developed for sixty years since 1949. With the development of lean production especially in recent 30 years, researchers and entrepreneurs have widely and deeply researched the construction of lean team. They hope to find out a suitable model suitable for China. However, the methodology research and consequent application in lean team model construction and evaluation system development are not enough further or mature [7–10].

FAW Car, owned by China FAW Group, is an autonomous vehicle manufacturing enterprises with an annual production capacity of 300,000 vehicles. In the passing decade years, FAW Car has been constantly propelling lean production, with successes in lean team construction in several aspects. However, some disadvantages still exist: (1) Team leaders are lack of essentials. (2) Normal workers need education and tanning in improvement, cost-saving, and qualify-security. (3) Less systematic and scientific methods are used in Team management. (4) Accumulation on evaluation system of team management is not enough. According to those deficiencies, FAW Car gives great impetus to build and apply Hongqi production system (HPS) to improve the team management based on evaluation of star teams. Through the evaluation of main tasks, secure environment, quality, delivery, cost, and talent education, done by team, FAW Car has improved the team manage capabilities constantly to support the development and its grand ambition.

Taking FAW Car as an example, the work studied the construction of lean team model, standard and method of star team evaluation system through exploration on lean teams.

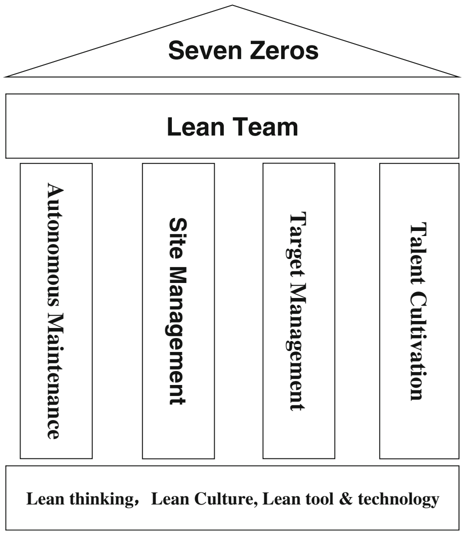
3 Construction of Lean Team Model

Team construction refers to construct culture, and study system and working system inside the group through effective method and ways. Thus, it is possible to mostly agitate team member's enthusiasm and initiative to improve their working skills and comprehensive qualifications during management activities.

As the essential of team construction, lean team construction also emphasizes the guidance of lean ideas. It also requires a shipshape and well-organized environment to autonomously improve both enterprise and employees through self-improvement. The final goal is Seven Zeros (Zero waste on switch hours, zero inventory, zero waste, zero bad quality, zero malfunction, zero suspense and zero disaster).

To achieve the goal of Seven Zeros, FAW Car built a lean team model based on lean thinking, lean culture, lean tool and technology (5S management, visual control, standard operation, QC improvement, management of changing point, non-conforming material conditions, location to ensure degree, operation easiness, production preparation database). This system was supported by autonomous maintenance, field control, target management, and talent cultivation (see Fig. 1). Seven Zeros is a perfect level for the construction of Lean Team, and also embodiment of lean culture. The four pillars in Fig. 1 are the bases of lean team,

Fig. 1 Construction of lean team model in FAW car



showing the promotion width and depth of lean team. Three basic ideas are the precondition and basement of lean team construction. Furthermore, achievements of Seven Zeros dependent on the solidity of basements and pillars.

After years of improvement, FAW Car has gained remarkable achievements in the construction of lean team according to team management ideas. Until now, there have been 177 teams titled “Hongqi vanguard team”, 15 teams “Outstanding team” and 8 teams “Quality trustworthy team”. Besides, 6 teams have been titled national honor of “Quality trustworthy team of national machinery industry” and 5 the honorable title of “Young pioneer team”.

4 Evaluation of Lean Team

Star-level team is an important content in the construction of lean team. To improve the management level of team, it is necessary to achieve the normalization, simplification, standardization and quantification of management. Besides, based on the evaluation criteria and conditions of star-level team formulated by enterprises, administers should regularly evaluate star teams. Furthermore, self-evaluation and improvement of star team is also of importance.

FAW Car has established project management system via the evaluation of star-level team to implement the construction of lean team.

4.1 Evaluation Process

In 2009, an affairs bureau was built, with a leader in charge of each industrial engineering and on-site teams from workshop or department as the crew. As a result, the construction of lean team has been implemented from top to bottom.

With the advancement of fixed goal, it is hopeful to achieve the three-star management level in 85 % of teams in 2015, and zero breakthrough of four-star team.

FAW Car has long been involved in the formulation and revision of evaluation criterion, perfection of training materials as well as training of section chiefs and team leaders. After six years of training, trainees have exceeded 1345, almost covering all the chiefs and team leaders.

Teams, workshops and factories should conduct evaluation and recommendation of outstanding teams stage by stage. Star teams will be awarded by the affairs bureau. Meanwhile, industrial engineering department will conduct random inspection on the self-evaluation of workshops and factories by a ratio of 20 % to verify the accuracy of self-evaluation. Thus, closed-loop management of Star team evaluation is formed.

4.2 Evaluation Criteria

Experts and skeleton staff in related fields have been organized to conduct researches in advanced management enterprises. Combined with the management status of FAW Car, the evaluation of star-level team has been determined, involving self-preservation, field management, goal management and personnel training. Furthermore, it also includes the safety, personnel, quality, cost and efficiency of team management.

Team evaluation is divided into six grades with corresponding values (see Table 1).

FAW Car's "Evaluation criteria of star-level team management" consisted of "Scoring sheet of star evaluation criteria", "Problem rectification report" and "Star summary sheet". Each sheet included different parts and evaluation elements.

There were four parts in "Scoring sheet of star evaluation criteria".

The first was the "Evaluation criteria of independent security", including eight evaluation elements, such as source countermeasures, reference book of compilation and independent inspection. Through monitor's organization of staff's 4S management in equipment operation, every tiny flaw could be found and improved to improve staff's maintenance efficiency and individual skills.

The second was "Evaluation criteria of on-site management", including ten evaluation elements, such as team's objective management, 4S management of team's field and standard operation management. These elements mainly reflected monitors' management of team's objective and the ability of decomposition and implementation. Furthermore, it also involved the grasp and application of management tools, such as on-site 5S management, standard operation management, management of changing points and conditions of qualified product.

The third was "Evaluation criteria of objective management", including six evaluation elements, such as dangerous source in security field, team's safety recording book and occurrence of environmental accidents. Guiding monitors should be familiar with relevant laws and regulations, as well as the identification, correct treatment and avoidance of risk resources. As a result, staff's safety consciousness was improved to reduce the risk of safety accidents. Besides, quality domain involved five elements, such as ratio of defects outflow, information collection and feedback of quality as well as cultivation of quality consciousness. So, it

Table 1 Evaluation criteria for star-level team in FAW car

Star level	Scores	Level	Level description
★★★★★★	600	Six-star team	Industry first
★★★★★	515	Five-star team	Advanced in industry
★★★★	410	Four-star team	Above average in industry
★★★	315	Three-star team	Excellent in enterprise
★★	210	Two-star team	Medium in enterprise
★	100	One-star team	Primary in enterprise

focused on the quality principles of non-acceptance, non-manufacture and non-outflow, ensuring the efficient use of quality loop tools and quality of products. Cost area included five elements, such as waste management, tool consumption management and cost reduction activities. Thus, monitors and the staff were all trained to reduce the cost on the trivial things. Activation and delivery included four elements, such as utilization rate of working time, production order management and work compiling efficiency. It was helpful to reduce risk of work stagnation during production process, thus improving production efficiency.

The fourth was "Evaluation criteria of talent development", including seven evaluation elements, such as award of improvement, skills competition and multi skills. It mainly focused on cultivation of teamwork, improvement of group staff's abilities to analyze problems, search for truth and improve methods, thus improving talent reserve and output.

Based on the evaluation elements in "Scoring sheet of star evaluation criteria", the problems found during evaluation were listed in "Problem rectification report". Through cause analysis, strategy formulation and responsibility clarity (department and person) according principles of PDCA, each problem could obtain closed-loop management and solution via rectification and verification. Then, monitors' ability to solve problems would be improved.

"Star summary sheet" intuitively reflected the score of each dimension and star level of each team. Through comparison of evaluation, it was obvious to find out the weakness of each team, so teams could consciously develop measures for reform and improvement.

4.3 *Equations Evaluation Effect*

There were seven departments involving in the star team evaluation in FAW Car. For the 385 teams evaluated in 2015, 295 teams achieved "three star team", while only one team met "four star team". After six years of training, every aspect of the teams in FAW Car has been improved, such as safety, personnel, quality, efficiency

Table 2 Data of quantitative index of team management elements

No.	Management elements	Quantitative index	2010	2011	2012	2013	2014
1	Safety	Minor accident occurrence (‰)	0.9	0.87	0.85	0.85	0.8
2		Implementation rate of pointing and calling (%)	8	10	30	50	80
3	Personnel	Annual multi skill rate (%)	28.50	30	34.50	39.80	45.50
4	Quality	Mazda6 vehicle DPU	0.81	0.78	0.72	0.45	0.61
5	Efficiency	Labor productivity (/person. year)	24.4	28.6	34.1	38.3	42.9
6	Activation	Device mobility rate (%)	94.80	95	95.20	96.20	96.80

and activation. Table 2 showed the comparison of actual data of quantitative index from 2010 to 2014.

5 Conclusion

After six years of exploration and practice on the construction and evaluation of lean team, FAW Car has achieved abundant innovative achievements and experiences. It not only lays the foundation to realize FAW Car's development strategy, but also provides reference for other enterprises.

5.1 Method Innovation

Quantitative evaluation should conducted on teams' safety, personnel, quality, cost and efficiency, rather than using past extensive management model. In this way, it is possible to comprehensively verify teams' management tools and management efficiency during production.

5.2 Tool Innovation

With the establishment of dimensions and elements of "evaluation criteria for star-level team", indexes can be quantified for convenient data statistics. Besides, these indexes can be used in all the teams with management elements of manufacturing enterprise.

5.3 Cultural Innovation

Lean team building model guides team leaders to manage the team, clarify management ideas and standardize content of team management. Based on the evaluation criteria of star team, each team can conduct self-evaluation to find out problems for self-improvement. Thus, team's working skills and comprehensive quality will be continuously improved.

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Toothpaste Industry Customer Satisfaction Survey Based on the CCSI Model

Yan-tao Gai, Fei Pei, Hua-li Cai and Yong Su

Abstract Based on the CCSI model, an indicator system for measuring the toothpaste industry's customer satisfaction is built in this paper, and the industry's customer satisfaction in 2015 is analyzed using the SPSS16.0 software. Analysis results show that shaping brand image is the core, improving teeth-cleaning effect is the focus, enhancing performance-price ratio is the key, and satisfying the young population is the crux.

Keywords Toothpaste industry · Customer satisfaction · Indicator system

1 Introduction

To get a deep insight into the status quo and development trend of the toothpaste industry's customer satisfaction, China Standard Science and Technology Group Co., Ltd. has conducted a toothpaste industry satisfaction survey in some major Chinese cities. Based on the CCSI (China customer satisfaction index) model [1], an indicator system is constructed in the paper to measure the toothpaste industry's customer satisfaction, and the industry's Year-2015 customer satisfaction survey data are analyzed using the SPSS16.0 software, in order to study the present situation of and problems with the industry's customer satisfaction and put forward effective strategies for improving such satisfaction.

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2 Model

According to classification of national economic sectors, the toothpaste industry belongs to the sector of non-durable consumer goods. For this reason, the authors of this paper use the model for non-durable consumer goods in the CCSI model as the basic model for measuring toothpaste industry's customer satisfaction [2], as shown in Fig. 1.

Based on the above basic model, the industry's measurement indicators are established [3] (shown in Table 1). The indicators are measured using a 10-point Likert scale ranging from "1" which stands for "very dissatisfied" to "10" which represents "very satisfied".

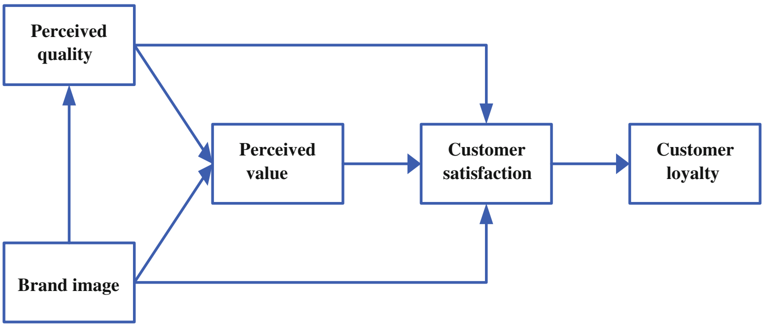

Fig. 1 Basic model for measuring toothpaste industry's customer satisfaction

Table 1 The toothpaste industry's satisfaction measurement indicators

Variables	Measurement indicators
Brand image	Q1: Overall impression of the brand
	Q2: Conspicuousness of brand characteristics
Perceived quality	Q3: Overall perceived quality
	Q4: Toothpaste flavour
	Q5: Toothpaste packaging
	Q6: Teeth-cleaning effect
Perceived value	Q7: Perception of quality at a given price
	Q8: Perception of price at a given quality
Customer satisfaction	Q9: Overall degree of satisfaction
	Q10: Degree of satisfaction in comparison with other brands
	Q11: Degree of satisfaction in comparison with the ideal
Customer loyalty	Q12: Probability of repeated purchase
	Q13: Reservation price

3 Analyses

The survey is conducted through a computer-aided telephone interview system supported by network survey, and a total of 1761 valid samples are collected. The age and gender structures of the samples are shown in Figs. 2 and 3, respectively.

To facilitate analysis, the paper converts 1–10 points into 10–100 points and uses the SPSS16.0 software to make a descriptive statistical analysis of the measured indicators of the toothpaste industry. The analysis result is listed in Table 2.

3.1 Overall Degree of Satisfaction

(1) *Consumers are very satisfied with brand image*
As shown in Table 2, respondents' overall impression of the brand scores 80.45 points, and the conspicuousness of brand characteristics scores 79.70 points. Respondents' arithmetic mean satisfaction with the industry's overall brand image is 80.45 points, a very high degree of satisfaction, which is mainly attributed to the remarkable advertising effect of mainly brands.

Fig. 2 Age structure of samples

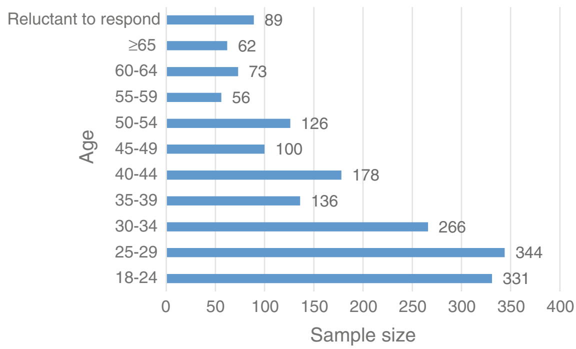

Fig. 3 Gender structure of samples

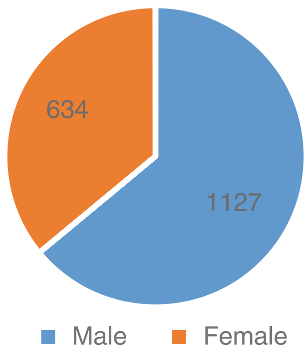

Table 2 Customer satisfaction indicators of the toothpaste industry

	Valid sample size (number)	Mean value
Q1: Overall impression of the brand	1761	80.45
Q2: Conspicuousness of brand characteristics	1761	79.70
Q3: Overall perceived quality	1761	79.31
Q4: Toothpaste flavour	1761	79.97
Q5: Toothpaste packaging	1761	80.54
Q6: Teeth-cleaning effect	1761	75.89
Q7: Perception of quality at a given price	1761	69.02
Q8: Perception of price at a given quality	1761	75.47
Q9: Overall degree of satisfaction	1761	77.03
Q10: Degree of satisfaction in comparison with other brands	1761	76.87
Q11: Degree of satisfaction in comparison with the ideal brand	1761	72.91
Q12: Probability of repeated purchase	1761	71–80 %
Q13: Reservation price	1761	16–20 %

(2) *Consumers are basically satisfied with perceived quality*
Seen from Table 2, respondents' satisfaction with overall perceived quality, flavour, packaging and teeth-cleaning effect is 79.31, 79.97, 80.54 and 75.89 points, respectively. It is observed that the respondents are most satisfied with toothpaste packaging but least satisfied with teeth-cleaning effect. Calculated via the arithmetic mean formula, respondents' satisfaction with perceived quality is 78.93 points, suggesting that consumers are basically satisfied with perceived quality but that there remains big room for improvement in this aspect, where enhancing teeth-cleaning effect is the focus.

(3) *Consumers are basically satisfied with perceived value*
As shown in Table 2, respondents' score of satisfaction with perceived quality at a given price and that with perceived price at a given quality are respectively 75.47 and 69.02 points, their arithmetic mean being 72.25, which indicates that consumers are basically satisfied with perceived brand value. However, compared with the scores given by the respondents to all the other indicators, the above two scores are both at a relatively low level, indicating that the industry's overall brand performance-price ratio is not high enough. Therefore, perceived value, or performance-price ratio, is the key factor that influences customer satisfaction.

(4) *Consumers are basically satisfied with the toothpaste industry*
According to Table 2, respondents' score of overall satisfaction is 77.03 points, their degree of satisfaction in comparison with other brands scores 76.87 points, and their degree of satisfaction in comparison with the ideal brand scores 72.91 points, in which the last score is the lowest, indicating that there remains a certain gap between the present brand and the ideal brand in

the heart of consumers. Calculated via the arithmetic mean formula, respondents' score of satisfaction with the toothpaste industry is 75.61 points, showing that consumers are basically satisfied with the industry but that there is still some room for improvement [4].

(5) *Consumers' brand loyalty is relatively high*
According to Table 2, respondents' probability of repeated purchase of a certain brand is between 71 and 80 % and their reservation price falls in the range of 16–20 %, indicating that consumers have a relatively high brand loyalty, brand transfer cost is relatively big, the toothpaste industry has entered into the stage of brand consumption, consumers increasingly stick to well-known brands, and that famous brands have become the first choice for most urban consumers.

3.2 Differences in Toothpaste Industry's Customer Satisfaction Between Different Genders and Different Age Groups

Differences in toothpaste industry's customer satisfaction between different genders and different age groups are studied via mean value analysis, as shown in Table 3. Results of the study indicate that the degree of satisfaction is significantly different

Table 3 Distribution of differences in toothpaste industry's customer satisfaction between different genders and different age groups

Demographic variables	Mean value (points)	Sample size	Significance of difference
Age			
18–24	73.20	331	F = 2.334, df = 10, sig. = 0.01
25–29	75.18	344	
30–34	76.18	266	
35–39	74.78	136	
40–44	75.96	178	
45–49	76.04	100	
50–54	78.55	126	
55–59	76.32	56	
60–64	78.22	73	
≥65	81.02	62	
Reluctant to respond	73.98	89	
Gender			
Male	75.90	1127	F = 1.087, df = 1, sig. = 0.297
Female	75.10	634	

between different age groups but insignificant between different genders. The degree of satisfaction rises with the increase in age. Younger groups (aged 18–40) have the lowest degree of satisfaction.

4 Results

4.1 Shaping Brand Image is the Core

With intensified industry competition and accelerated industrial structure re-adjustment, the toothpaste industry is entering the stage of brand consumption. Nowadays, consumers are more and more particular about brands and their brand loyalty is being established (the probability of repeated purchase is 71–80 %). In the meantime, enterprises are laying more and more emphasis on brand building. By strengthening marketing efforts such as advertising, toothpaste manufacturers have enhanced consumers' brand loyalty and thus increased the transfer cost of brand consumption (the reservation price falls in the range of 16–20 %).

4.2 Improving Teeth-Cleaning Effect is the Focus

According to the survey, consumers are quite satisfied with product packaging and flavour, two aspects to which most manufacturers attach great importance. Yet, the product's teeth-cleaning effect is often overlooked by enterprises. Since functionality is one of the key factors of product quality, toothpaste producers should pay more attention to the teeth-cleaning effect of their products.

4.3 Enhancing Performance-Price Ratio is the Key

Perceived quality is mainly embodied by the performance-price ratio of products. Through a comparative analysis of indicators, the lowest score (72.25 points) of satisfaction falls on perceived quality which is a key factor influencing the overall satisfaction of customers, though. Therefore, enhancing the performance-price ratio of products is the key to improving customers' satisfaction.

4.4 Satisfying the Young Population is the Crux

According to mean value analysis, the degree of satisfaction rises with the increase in age. A lower degree of satisfaction is seen in young people (aged 18–24) who are mainly unsatisfied with the teeth-cleaning effect and performance-price ratio of products.

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