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Sifeng Liu and Jeffrey Yi-Lin Forrest (Eds.)

Advances in Grey Systems Research

Springer

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ISBN 978-3-642-13937-6 e-ISBN 978-3-642-13938-3

DOI 10.1007/978-3-642-13938-3

Understanding Complex Systems ISSN 1860-0832

Library of Congress Control Number: 2010929357

Typeset & Cover Design: Scientific Publishing Services Pvt. Ltd., Chennai, India.

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Synopsis

This volume contains some of the highly selective, best quality research works presented at the 2009 IEEE International Conference on Grey Systems and intelligent Services (IEEE GSIS 2009), November 10 – 12, 2009, Nanjing, P. R. China. Grey systems theory was initiated by Professor Deng Julong in 1982 with the publication of the first paper in the international journal *Systems and Control Letters*. In the past 20+ years, this theory has been developed and matured rapidly and applied widely in almost all areas of scientific learning. Currently, many universities from around the globe offer courses and workshops on grey systems and information; and hundreds of graduate students are studying and/or applying grey systems theory in their works and their writing of dissertations. This book is appropriate as a reference for graduate students or high level undergraduate students, majoring in areas of science, technology, agriculture, medicine, astronomy, earth science, economics, and management. It can also be utilized by researchers and technicians in research institutions, business entities, and government agencies.

Editorial Board

Professor Dr. Sifeng Liu earned a BS degree in mathematics at Henan University, China, in 1981, an MS degree in economics and a PhD in systems engineering at Huazhong University of Science and Technology, Wuhan, China, in 1986 and 1998, respectively. He has attended Slippery Rock University of Pennsylvania and Sydney University in Australia as a visiting professor. Professor Liu is currently director of the Institute for Grey Systems Studies and dean of the college of economics and management at Nanjing University of aeronautics and astronautics, where he is a distinguished professor, academic leader, and a doctor tutor in management science and systems engineering disciplines.

Dr. Liu's main research activities are in grey systems theory and econometrics. He has published over 200 research papers and 16 books. He has been awarded 18 provincial and national prizes for his outstanding achievements in scientific research and applications, and was selected by the Personnel Ministry of China as a distinguished professor. He was recognized in 2002 by the World Organization of Systems and Cybernetics.

Dr. Liu is a member of teaching direct committee of management science and engineering of the Ministry of Education, China. He is also the expert of soft science at the Ministry of Science and Technology, China, and Development of Management Science of the National Natural Science Foundation of China. Professor Liu currently serves as a chair of the Technical Committee on Grey Systems of the IEEE Systems, Man, and Cybernetics Society, is president of the Grey Systems Society of China, vice president of the Chinese Society for Optimization, Overall Planning and Economic Mathematics, vice president of the Beijing Chapter of the IEEE SMC, vice president of the Econometrics and Management Science

Society of Jiangsu Province, and vice president of the Systems Engineering Society of Jiangsu Province. He is a member of the editorial board of over 10 professional journals, including The Journal of Grey System (UK), Scientific Inquiry (USA), Journal of Grey System (Taiwan), Chinese Journal of Management Science, Systems, Theory and Applications, Systems Science and Comprehensive Studies in Agriculture, and Journal of Nanjing University of Aeronautics and Astronautics, among others.

Dr. Liu was selected as National Excellent Teacher in 1995, was awarded Expert Enjoying Government's Special Allowance by the State Council of China in 2000, National Expert with Prominent Contribution in 1998, and Outstanding Managerial Personnel of China in 2005.

Professor Jeffrey Yi-Lin Forrest earned all his educational degrees in pure mathematics. His PhD degree was granted in 1988 by Auburn University, Alabama; and he did one year post-doctoral research in statistics at Carnegie Mellon University, Pittsburgh, during 1990 – 1991. Dr. Lin is currently a specially appointed professor in economics, finance, and systems science of Nanking University of Aeronautics and Astronautics, a specially appointed professor in mathematics and systems science of National University of Defense Technology, China, and a tenured professor of mathematics at Slippery Rock University of Pennsylvania. Dr. Lin is a founder and the present president of the International Institute for General Systems Studies (IIGSS), a non-profit organization registered in PA in mid-1990s. Since 1984, Lin has had over 300 research papers, over 20 monographs and edited volumes published by a large array of prestigious publishers, such as Springer, World Scientific, Kluwer Academic (currently part of Springer), Academic Press (currently part of Springer), Wiley, Taylor and Francis, Meteorological Press, etc. He serves or served on the editorial boards of 11 professional journals, including Kybernetes: The International Journal of Systems, Cybernetics and Management Science, Journal of Systems Science and Complexity, and International Journal of General Systems. He is currently a co- editor of the book series "Systems Evaluation, Prediction and Decision-Making," published by Auerbach, an imprint of Taylor and Francis.

Some of Dr. Lin's research was funded by the United Nations, the State of Pennsylvania, the National Science Foundation of China, and the German National Research Center for Information Architecture and Software Technology. Over the years, Dr. Yi Lin's scientific achievements have been recognized by various professional organizations and academic publishers. In 2001, he was inducted into the honorary fellowship of the World Organisation of Systems and Cybernetics. His research interests are wide ranging, covering areas like mathematical and general systems theory and applications, foundations of mathematics, data analysis, predictions, economics and finance, management science, and philosophy of science.

Preface

This book contains contributions by some of the leading researchers in the area of grey systems theory and applications. All the papers included in this volume are selected from the contributions physically presented at the 2009 IEEE International Conference on Grey Systems and Intelligent Services, November 11 – 12, 2009, Nanjing, Jiangsu, People's Republic of China. This event was jointly sponsored by IEEE Systems, Man, and Cybernetics Society, Natural Science Foundation of China, and Grey Systems Society of China. Additionally, Nanjing University of Aeronautics and Astronautics also invested heavily in this event with its direct and indirect financial and administrative supports.

The conference aimed at bringing together all scholars and experts in the fields of grey systems and intelligent services from around the world to share their cutting edge research results, exchange innovative ideas, promote mutual understanding, and seek potential opportunities for collaboration. The conference program committee received 1054 full paper submissions from 16 countries and geographical regions. Nine hundred sixty four papers were submitted for regular sessions and 90 papers were tunnelled directly for special topic sessions. All the submitted papers, including those aiming at special topic sessions, were rigorously reviewed by at least 3 reviewers. Based on the reviewers' reports, 251 papers were accepted for oral presentations, while 99 accepted for poster presentations. In other words, only slightly over 33% of the submitted papers were accepted by this conference. The rate of acceptance was lower than one third of the total submissions.

All the contributions selected for this volume are divided into 6 parts, entitled (1) Buffer operator and theoretical basis of grey systems theory. This part includes 9 papers. (2) Grey incidence analysis and application. This part contains 8 papers. (3) Grey cluster evaluation models. This part includes 7 papers. (4) Grey forecast model. This part includes 10 papers. (5) Grey decision-making, which includes 7 papers. (6) Grey cybernetics and intelligent services, which contains 10 papers. All of the 51 contributions were judged by a panel of scholars as among the best papers of the above-mentioned conference.

At this junction we would like to express our sincere appreciation to Professor Hans Kuijper who initially suggested such a book in grey systems theory, and our gratitude to Dr. Thomas Ditzinger of Springer for providing us his very timely support for this important project.

Finally, but not the least, we would like to thank all the authors, speakers, anonymous reviewers, and participants of the event for taking part in and contributing to the IEEE GSIS '09.

December 20, 2009

Sifeng Liu
Yi Lin

Contents

Part I
Buffer Operator and Theoretical Basis of Grey Systems Theory

The Design of the Driving-Coupling Algorithm in Unconventional Incidents Based on the Gerts Network

Zhigeng Fang, Hengwu Wei, Baohua Yang, Sifeng Liu, and Ye Chen

In this chapter, the concept of coupling has been proposed to tackle the issue of disaster derivative coupling in the GERTS network. Then we designed the logical structure of driving-coupling nodes based on GERTS and defined the driving-coupling algorithm as the idea acceleration model in physics, and we then studied the problem of estimating the parameters of the algorithm. The study provided a tool for analyzing the driving-couple of unconventional incidents and also provided new research ideas for the study of the coupling rules of unconventional incidents.

1 Introduction

The unconventional incidents are emergencies that have insufficient precursors, obvious complex features, potential hazards and huge destruction, and they are difficult to deal with. If we lack scientific knowledge of unconventional incidents and the coupling rules of its potential disasters, we cannot identify the incident conduction and variation, and the government will also have difficulty with effective early warnings and emergency measures for unconventional incidents. While studying the coupling rules of unconventional incidents will help us understand the unconventional nature of these events, mastering the laws of unconventional incidents can help us prevent or reduce the aftermath damage inflicted by these incidents. Therefore, how to quantify the coupling of unconventional incidents and how to make quantitative forecasts and estimates are important problems that need to be solved in today's emergency management theory and practice. For relevant studies on forecasting unconventional incidents, please consult with (Lin and OuYang, 2010; OuYang, et al., 2009; Lin, 2001).

In recent years, the study of coupling rules of unconventional incidents has become an important aspect in the study of emergency management.

(Zhang, 2002) presents a new method to couple the finite element method (FEM) and the discontinuous boundary element method (BEM) for fluid–structure

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interaction and 2D elastostatics. The converting matrix for coupling the FEM and the discontinuous BEM is obtained in an explicit form, and the relationship between the physical variables at the FEM nodes and those at the BEM collocation points is established. The proposed method overcomes the numerical difficulties caused by the discontinuous traction and corner nodes and was applied to a fluid–structure interaction problem in a time domain, a 2D elastostatics problem and the patch test given in Lu et al. [Comput. Meth. Appl. Mech. 85 (1991) 21]. The results indicate that the proposed method is accurate and efficient.

In (Lu and Chen, 2006), a general framework is presented for analyzing the synchronization stability of Linearly Coupled Ordinary Differential Equations (LCODEs). The uncoupled dynamical behavior at each node is general and can be chaotic or otherwise; the coupling configuration is also general, with the coupling matrix not assumed to be symmetric or irreducible. On the basis of geometrical analysis of the synchronization manifold, a new approach is proposed for investigating the stability of the synchronization manifold of coupled oscillators. Furthermore, the roles of the uncoupled dynamical behavior on each node and the coupling configuration in the synchronization process are also studied.

In (Ormberg and Larsen, 1998) in a coupled analysis procedures where floater motions and mooring and riser dynamics are calculated simultaneously, these drawbacks are avoided. Motions and mooring line tensions from model tests and simulations using coupled and separated analysis procedures are compared. Illustrations are given by extensive case studies of a turret-moored ship operating in 150 m, 330 m and 2000 m water depths. The main conclusions are that the traditional separated approach may be severely inaccurate, especially for floating structures operating in deep waters. Coupled analysis should be applied for deep water concepts, at least as a check of important design cases. The agreement between model test results and results from coupled analysis is very good.

In (Liu and Fan, 2008) the leading mode of the ocean-atmosphere coupling that presents the dominate signal of the ocean-atmosphere interaction in global tropical oceans is indentified in this chapter based on the NCEP reanalyzed monthly SST and atmosphere data from January 1948 to December 2005. The influences of the following summer atmosphere circulation in the Leading mode mainly include the impact of Tropical Indian Ocean basin mode on the East Asia monsoon.

(Wang et al., 2008) used simulations of precipitation in 40 years of a regional ocean-atmosphere coupled model, defining extreme precipitation events through the percentile method and analyzing the characteristics of extreme precipitation events simulated by the coupled model in the summer in China. The regional coupled model can basically simulate the correlation among extreme precipitation, total summer precipitation and the count of days of extreme precipitation in high temporal and spatial areas.

(Chen et al., 2005) thinks that the exploration and study of the face of the ancient structure of the different stages of evolution in the Ordos Basin and the environment of the tectonic stress field and its relation to transformation and overlay during the time of key changes will help us have an objective understanding of the unified structure the environment, and its dynamics may be the controlled coupled mineralization effect of a variety of energy resources' coexistence and accumulation.

(Li et al., 2003) combined SVD technology with the phase space and proposed a new SVD phase space analysis method, and then it applied the method to study the main coupling contact between the tropical Pacific SST and the atmospheric circulation in East Asia and deepened the understanding of the interaction between the East Asian winter monsoon and El Nino event, and it finally obtained some valuable results.

(Yue et al., 2004) systematically and comprehensively summed up the application and analysis of the Zebiak-Cane coupled ocean-atmosphere model at home and abroad and pointed out the merits and shortcomings, and it assessed the improvements of pattern and finally preceded a discussion and prospected the direction of development in future.

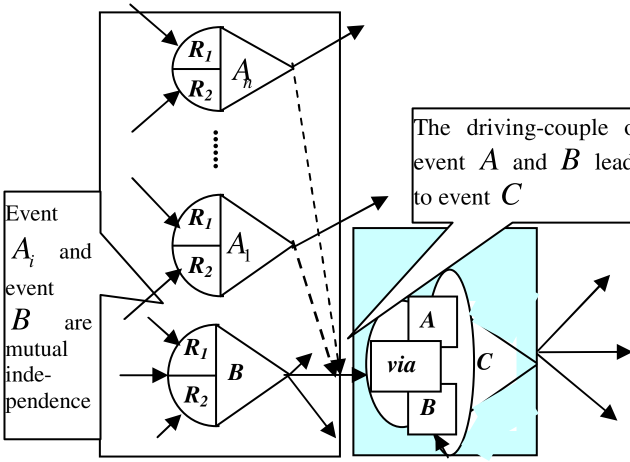
(Peng et al., 2003) pointed out that the ore-forming geological event has a couple of basic features that include a rhythm coupled relationship between different levels of mineralization events and their corresponding geology (tectonic, magmatic, metamorphic, etc.).

In this chapter the node of the driving-couple in the GERTS network is designed to visually represent the driving-coupling event of unconventional incidents in a GERTS network diagram. In addition, the chapter also refers to the idea of the acceleration model in physics to establish the model of driving-couple and uses it to estimate the results of the driving-coupling event. The parameters in the model are mainly determined through the Least-squares method, by obtaining a least-squares parabola approaching a series of historical data points and thus determining the parameters. Finally, taking the example of Daxinganling forest fires, the chapter shows how to apply the least square method to determine the parameters in the model and how to predict and estimate the fire area of forest fires in the future by using the model.

2 Design of the Driving-Coupling Node in the GERTS Network

Definition 2.1. Event B is a induction factor of coupling event C; event A_i (i =1,2, …, n) is not an induction factor of coupling event C, but event A_i (i =1,2, …, n) can affect event C by affecting event B, so we define event C as a driving-couple of event A_i (i =1,2, …, n) and event B. Here we define event A_i (i =1,2, …, n) as a driving factor; event A_i (i =1,2, …, n) can affect the progress of event C by giving a driving effect to event B. For example, in a fire disaster, wind can aggravate the result by affecting the fire. Here we use event *A* to represent the summation of event A_i (i =1,2, …, n), namely $A = \sum_{i=1}^{n} A_i$. In a GERTS network we can construct the node of a driving-couple based on the above idea as follows:

Structure of Node:



The sketch map of driving-coupling event

From the above sketch map we can clearly see the relations between all events: Event B can result in event C, and event A_i (i =1,2, …, n) can affect event C by affecting event B. Essentially, event C is the result of the driving-couple of event A_i (i =1,2, …, n) and event B.

3 Model of Driving-Couple

In physics, there is an accelerative model $s = v_0 t + \frac{1}{2} a t^2$ that vividly describes the relation between an object's distance and time, namely the distance increases accelerately through time. In a driving-couple there is a similarly: the increase of the strength of the driving factor may make the result of the driving-coupling event get serious accelerating. Hence, here we refer to the idea of an acceleration model, and then we have definitions as follows:

Definition 3.1. If B is a induction factor of Z and A_i (i =1,2,…, n) are driving factors and $A = \sum_{i=1}^{n} A_i$, then define T as a driving-coupling algorithm, and there is a model as follows:

$$f\left(Z = A \to B\right) = T\left(A \to B\right) = z_0 + \frac{1}{2} \cdot w_1 \cdot g^2\left(A_1\right) + \frac{1}{2} \cdot w_2 \cdot g^2\left(A_2\right) + \ldots + \frac{1}{2} \cdot w_n \cdot g^2\left(A_n\right) \quad (3.1)$$

Formula (3.1) is the model of a driving-couple, where z_0 represents the result without driving factors and $f\left(Z = A \to B\right)$ represents the result of the driving-coupling event Z, $g\left(A_i\right)$ the strength of driving factors A_i (i=1,2,…,n). For example, if event A_1 represents wind, then $g\left(A_1\right)$ can represent the average speed of wind. The symbols w_i represent the accelerate coefficient of driving-couple of driving factors A_i (i=1,2,…,n). Thus, w_i stand for a key data to measuring the relation between the driving-coupling event Z and driving factors A_i (i = 1, 2, …, n).

Especially when $n = 1$, there is only one driving factor A, and we get a simple model as follows:

$$f\left(Z = A \to B\right) = T\left(A \to B\right) = z_0 + \frac{1}{2} \cdot w \cdot g^2\left(A\right) \tag{3.2}$$

Theorem 3.1. When the strength of driving factors $g\left(A_i\right) = 0$, $f\left(Z = A \to B\right) = z_0$.

Theorem 3.2. In the simple model (3.2), the historical data of the strength of driving factor A and driving-coupling event Z are recorded as $\left(A_1, Z_1\right), \left(A_2, Z_2\right), \ldots, \left(A_N, Z_N\right)$, and then the result without driving factors z_0, and the accelerate coefficient of driving-couple of A can be obtained from the following formula:

$$z_0 = \frac{\left(\sum Z\right)\left(\sum A^4\right) - \left(\sum A^2\right)\left(\sum A^2 Z\right)}{N \sum A^4 - \left(\sum A^2\right)^2} \tag{3.3}$$

$$w = \frac{2\left[N \sum A^2 Z - \left(\sum A^2\right)\left(\sum Z\right)\right]}{N \sum A^4 - \left(\sum A^2\right)^2} \tag{3.4}$$

We prove this theorem as follows:

Suppose that the equation of the Least-squares parabola approaching a series of points $\left(A_1, Z_1\right)$, $\left(A_2, Z_2\right)$, …, $\left(A_N, Z_N\right)$ is:

$$Z = z_0 + \frac{1}{2} \cdot w \cdot A^2 \tag{3.5}$$

Then the Residual sum of squares can be represented as:

$$\text{SSE}=\sum_{i=1}^{N} D_i^2 = \sum_{i=1}^{N}\left(Z_i - z_0 - \frac{1}{2}\cdot w\cdot A_i^2 \right)^2 \tag{3.6}$$

In order to let the SSE be the minimum the Partial derivative of z_0 , w should be 0:

$$\begin{cases} -2\sum\left(Z_i - z_0 - \frac{1}{2}\cdot w\cdot A_i^2 \right) = 0 \\ -\sum\left(Z_i - z_0 - \frac{1}{2} w\cdot A_i^2 \right) A_i^2 = 0 \end{cases} \tag{3.7}$$

Equations (3.7) can be simplified to:

$$\begin{cases} \sum Z = z_0 N + \frac{1}{2}\cdot w\cdot \sum A^2 \\ \sum A^2 Z = z_0 \sum A^2 + \frac{1}{2}\cdot w\cdot \sum A^4 \end{cases} \tag{3.8}$$

By solving equations (3.8), we can obtain z_0 and w:

$$z_0 = \frac{\left(\sum Z\right)\left(\sum A^4\right) - \left(\sum A^2\right)\left(\sum A^2 Z\right)}{N\sum A^4 - \left(\sum A^2\right)^2}$$

$$w = \frac{2\left[N\sum A^2 Z - \left(\sum A^2\right)\left(\sum Z\right)\right]}{N\sum A^4 - \left(\sum A^2\right)^2}$$

Namely, they are formula (3.3) and (3.4).

Notation: In formula (3.3), (3.4) and (3.8) we use simplified marks $\sum Z$, $\sum A^2 Z$, etc. to represent $\sum_1^N Z$, $\sum_1^N A^2 Z$, etc. respectively.

4 Implementation and Results

Since 1950, the quantity of China's average annual forest fires is 13,067, the affected forest area is 653,019 hectares, and tolls are 580 casualties. Forest fires in the country are a natural disaster of strong suddenness and great destruction, and they are difficult to dispose of. They occur mainly due to man-made causes, though lightning and other natural causes may also lead to forest fires. Forest fires have great harms. They will burn a large number of trees and understory plant resources, which will result in a decline in forest cover, and they will directly threaten people's lives and property safety. For example, in May 1987 of the Daxinganling fire—which lasted 28 days and covered 1.01 million hectares, of which forest occupies nearly 70 percent of the area and the forest coverage rate decreased from 76% to 61.5%—more than 50,000 people were affected, with 193 killed and 226 injured. The direct economic losses is about 5 million yuan. In addition, forest fires also cause soil erosion (in severe cases, it even leads to flash floods and landslides), air pollution and environmental problems. In view of the significant dangers of forest fires, effective prevention and reduction of the hazards of forest fires will have great significance.

Through the analysis and transformation of the forest fire and its logic relation, we can describe the evolution of the forest fire based on the GERTS network (figure 4.1). For brevity, here we only consider one driving factor, the wind. In the GERTS network, each event can be described by a number of key parameters, such as the average wind speed, etc., that can be used as a basic description of the wind. Accordingly, we can construct a basic network diagram of the forest fire event and the set of parameters of the main events.

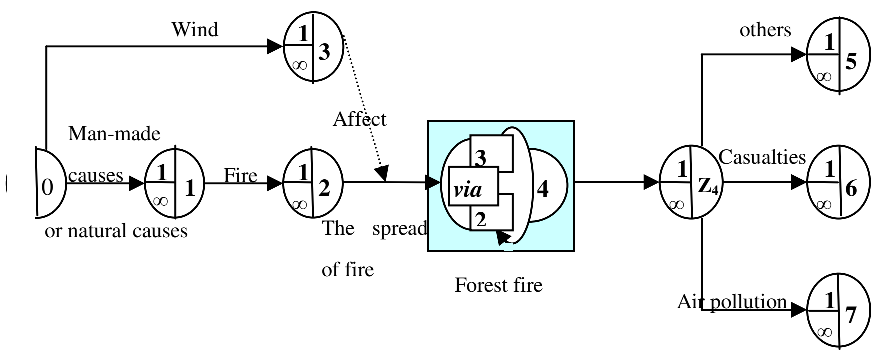


Fig. 4.1 The GERTS network diagram of a forest fire

The parameters set of describing the evolution of a particular case of forest fires in the GERTS network (only consider the parameters of the main events):

(3) The parameters of wind {average speed of wind v }

(4) The parameters of forest fire {fire area s }

The fire area can often be used to measure the extent of the harm caused by forest fires. In the case of no wind, the fire area of the forest fire is recorded as s_0, and in different regions it has different numerical values. Then, through the simple model of driving-couple (3.2), we have:

$$s = s_0 + \frac{1}{2} \cdot w \cdot v^2 \tag{4.1}$$

In formula (4.1), s represents the fire area of the forest fire in the case of wind, s_0 represents the fire area of the forest fire in the case of no wind, and w represents the accelerate coefficient of the wind.

For example, a total of 70 times forest fires occurred in Daxinganling in 2002 and the average fire area is nearly 580 hectares in the year. We randomly select 10 fires and analyze their key data. The specific data can be seen from table 4.1.

Table 4.1 The data of some 10 fires in Daxinganling in 2002

Fire number	Fire area s (hectares)	Average speed of wind v (meters per second)
1	613	6.3
2	437	4.1
3	453	4.3
4	576	5.4
5	380	3.7
6	670	6.4
7	543	5.1
8	597	5.5
9	470	4.4
10	580	5.45

According to the data in Table 4.1 we can find the parameters $s_0 \approx 282$ and $w \approx 19.2$ by using the Least-squares method. So formula (4.1) can be rewritten as:

$$s = 282 + \frac{1}{2} \times 19.2 \cdot v^2 = 282 + 9.6v^2 \tag{4.2}$$

Formula (4.2) is the model of the driving-couple of the forest fire we need. By formula (4.2), we can make a rough prediction and estimates of the fire area of Daxinganling forest fires in case the average speed of wind is known. Here, we use the model to estimate the fire area of a Daxinganling forest fire in July 2003. The average speed of the wind was about 7.2 meters per second at that time. By formula (4.2), we can calculate that $s = 282 + 9.6 \times 7.2^2 = 779$ hectares, and the actual fire area was 860 hectares. The estimated fire area weas 81 hectares less than the actual fire are,a and the error was less than 10%. Thus, the results the model calculated are generally satisfactory.

5 Conclusions

In this chapter, the unconventional driving-coupling node in the GERTS network has been designed, and the GERTS network diagram has also been constructed here to measure the driving-coupling algorithm that has been defined. It effectively resolved the problem of measuring the results of driving-coupling events, and it also provided an effective mathematical tool for the scenario deduction of unconventional incidents. The research in this chapter will have an important practical significance in advancing the scientific of emergency management of unconventional incidents and improving the effectiveness of emergency measures. However, if we want to have a clearer understanding of the coupling rules of unconventional incidents, we should do more research in the future.

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On the Priority Models of the Grey Interval Preference Relation*

Zaiwu Gong, Tianxiang Yao, Jie Cao, and Lianshui Li

The optimal priority method of the grey interval preference relation (GIPR) is proposed. In this chapter, based on the proposed multiplicative consistent conditions of GIPR, we construct three optimal models to get the priority of the GIPR. This method can reduce the information distortion of the operations of grey intervals. It is illustrated by a numerical example to show the feasibility and effectiveness of the proposed method.

1 Introduction

In situations of multiple attribute decision making, decision makers are used to provide their subjective opinions by comparing each pair of alternatives and then constructing the judgment matrices (preference relations) (Saaty, 1980; Wang and Xu, 1990) to order a finite number of alternatives from the best to the worst. Usually, the elements in judgment matrices may take the form of crisp numbers. However, in many practical decision making problems, due to either the uncertainty of objective things or the vague nature of human beings, it is hard for DMs to give a precise judgment. In this sense, they may prefer uncertainty intervals to exact

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* The work is supported by the National Natural Science Foundation of China (No.70901043,No.70873063,No.60804047), Qing Lan Project (No.0911), Humanities and Social Sciences Foundation of Ministry of Education of China, Philosophical and Social Science Foundation of Higher Education of Jiangsu Province of China under Grant (09SJB630043,09SJD630059), Foundation of Nanjing University of Information Science and Technology (SK20080114, 20070122), Research Program of Humanities and Social Sciences at Universities of Anhui Province (2008SK180). Meteorological Soft Science Foundation of China Meteorological Administration (GQR2009023).

numbers. Usually, these intervals are called grey intervals (Liu et al., 2000; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). There are many works on intervals judgment matrices. For example, Sugihara and Tanaka (Sugihara et al., 2004) propose an interval approach for obtaining interval weights of priority from the interval preference relations. In literature (Qin and Lv, 2008), the concepts and properties of weak consistency and consistency in the grey-AHP are presented. However, these papers pay no attention of the uncertainty of grey intervals operations.

In this chapter, in order to reduce the uncertainty of the grey intervals operations, we will propose three optimal models to get the priority of the grey interval preference relations.

2 The Definition of Grey Interval Preference Relation

Some basic operational laws of any two positive grey intervals (Moore, 1966; Dubois and Prade, 1978) are given below.

Let $M_1 = [l_1, u_1]$, $M_2 = [l_2, u_2]$, then

$$[l_1,u_1]+[l_2,u_2]=[l_1+l_2,u_1+u_2];\ [l_1,u_1]-[l_2,u_2]=[l_1-u_2,u_1-l_2];$$

$$[l_1,u_1]\bullet[l_2,u_2]=[l_1l_2,u_1u_2];\ [l_1,u_1]/[l_2,u_2]=[l_1/u_2,u_1/l_2].$$

Any $a \in R$ can be denoted as $A=[a,a]$, and if $[l_1,u_1] \ge a,$ then $l_1 \ge a, u_1 \ge a$.

For simplicity, we denote $N = 1,\cdots,n$, $M = 1,\cdots,m$.

If a preference relation $A=(a_{ij})_{n\times n}$ satisfies $a_{ii}=0.5,$ $a_{ij}+a_{ji}=1,\ a_{ij}>0, i, j \in N$, then A is called a fuzzy preference relation (FPR). A preference relation $A=(a_{ij})_{n\times n}$ is multiplicative consistent if there exists a priority vector $V=(v_1,\cdots,v_n)^T$ such that $a_{ij}=1/(1+v_j/v_i)$ $=v_i/(v_i+v_j), i, j\in N.$

Let $X=\{x_1,\cdots,x_n\}$ be an alternative set. If a preference relation $R=(r_{ij})_{n\times n}$ satisfies $r_{ii}=[0.5,0.5],\ r_{ijl}+r_{jiu} = r_{iju}+r_{jil}=1$, then R is called a grey interval preference relation (GIPR), where $r_{ij}=[r_{ijl}, r_{jiu}]$ denotes the grey preference degree range to which the alternative x_i is preferred to the alternative $x_j, i, j \in N$. If $r_{ii}=[0.5,0.5],$ then there is no difference between x_i and x_j; if $r_{ij}>[0.5,0.5],$ then x_i is preferred to x_j; and if $r_{ij}<[0.5,0.5],$ then x_j is preferred to x_i . A GIPR $R=(r_{ij})_{n\times n}$ is multiplicative consistent (Gong, 2008) if there exists a priority vector $\Omega=(\omega_1,\cdots\omega_n)^T=([\omega_{1l},\omega_{1u}],\cdots[\omega_{nl},\omega_{nu}])^T$ such that $r_{ij}=1/(1+\omega_j/\omega_i)=[\omega_{il}/(\omega_{il}+\omega_{ju}), \quad \omega_{iu}/(\omega_{jl}+\omega_{iu})] \quad \forall i,j\in N.$ where $\omega_i=[\omega_{il},\omega_{iu}]$, $i\in N$.

The GIPR R can be decomposed into the following two matrices:

$$A=\begin{pmatrix} r_{11l} & r_{12l} & \cdots & r_{1nl} \\ r_{21l} & r_{22l} & \cdots & r_{2nl} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1l} & r_{n2l} & \cdots & r_{nnl} \end{pmatrix};\ B=\begin{pmatrix} r_{11u} & r_{12u} & \cdots & r_{1nu} \\ r_{21u} & r_{22u} & \cdots & r_{2nu} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1u} & r_{n2u} & \cdots & r_{nnu} \end{pmatrix}$$

where *A* can be viewed as the least grey preference matrix, and *B* can be viewed as the greatest grey preference matrix.

Definition 1. If GIPR $R=(r_{ij})_{n\times n}$ is multiplicatively consistent, then we call *A* and *B* the consistent sub-matrices of *R*.

3 The Optimal Priority Model of the GIPR

Consider the GIPR $R=(r_{ij})_{n\times n}=([r_{ijl},r_{jiu}])_{n\times n}$ satisfying $r_{ii}=[0.5,0.5]$, $r_{ijl}+r_{jiu}=r_{iju}+r_{jil}=1$. Let $\Omega=(\omega_1,\cdots\omega_n)^T$ = $([\omega_{1l},\omega_{1u}],\cdots[\omega_{nl},\omega_{nu}])^T$ be the priority vector of the multiplicative consistent GIPR R (where we can regard $(\omega_{1l},\cdots\omega_{nl})^T$ and $(\omega_{1u},\cdots\omega_{nu})^T$ as the weight vectors of A and B, respectively), then we have

$$r_{ij}=[r_{ijl},r_{jiu}]=1/(1+\omega_j/\omega_i)= \\ [\omega_{il}/(\omega_{il}+\omega_{ju}),\omega_{iu}/(\omega_{jl}+\omega_{iu})],i,j\in N \tag{3.1}$$

That is,

$$r_{ijl}=\omega_{il}/(\omega_{il}+\omega_{ju}),i,j\in N \tag{3.2}$$

$$r_{jiu}=\omega_{iu}/(\omega_{jl}+\omega_{iu}),i,j\in N \tag{3.3}$$

Let $x_{ij}=1/r_{ijl}-1=\omega_{ju}/\omega_{il}$, $y_{ij}=1/r_{iju}-1=\omega_{jl}/\omega_{iu}$. Then we have two matrices

$$X=(x_{ij})_{n\times n}=\begin{pmatrix}\omega_{1u}/\omega_{1l} & \omega_{2u}/\omega_{1l} & \cdots & \omega_{nu}/\omega_{1l}\\ \omega_{2u}/\omega_{2l} & \omega_{2u}/\omega_{2l} & \cdots & \omega_{nu}/\omega_{2l}\\ \vdots & \vdots & \vdots & \vdots\\ \omega_{1u}/\omega_{nl} & \omega_{nu}/\omega_{nl} & \cdots & \omega_{nu}/\omega_{nl}\end{pmatrix}$$

$$Y=(y_{ij})_{n\times n}=\begin{pmatrix}\omega_{1l}/\omega_{1u} & \omega_{2l}/\omega_{1u} & \cdots & \omega_{nl}/\omega_{1u}\\ \omega_{2l}/\omega_{2u} & \omega_{2l}/\omega_{2u} & \cdots & \omega_{nl}/\omega_{2u}\\ \vdots & \vdots & \vdots & \vdots\\ \omega_{1l}/\omega_{nu} & \omega_{nl}/\omega_{nu} & \cdots & \omega_{nl}/\omega_{nu}\end{pmatrix}$$

Let $\omega_{1u}^2+\cdots+\omega_{nu}^2=k_1^2$, $\omega_{1l}^2+\cdots+\omega_{nl}^2=k_2^2$, and $k_1>0,\ k_2>0$. Obviously, we have $k_1>k_2$. Unitizing each row of vectors of X and Y, respectively, we get two unitized matrices of A and B as follows:

$$\overline{X}=(\overline{x}_{ij})_{n\times n}=\begin{pmatrix}\omega_{1u}/k_1 & \omega_{2u}/k_1 & \cdots & \omega_{nu}/k_1\\ \omega_{2u}/k_1 & \omega_{2u}/k_1 & \cdots & \omega_{nu}/k_1\\ \vdots & \vdots & \vdots & \vdots\\ \omega_{1u}/k_1 & \omega_{nu}/k_1 & \cdots & \omega_{nu}/k_1\end{pmatrix}$$

$$\overline{Y}=(\overline{y}_{ij})_{n\times n}=\begin{pmatrix}\omega_{1l}/\omega_{1u} & \omega_{2l}/\omega_{1u} & \cdots & \omega_{nl}/\omega_{1u}\\ \omega_{2l}/k_2 & \omega_{2l}/k_2 & \cdots & \omega_{nl}/k_2\\ \vdots & \vdots & \vdots & \vdots\\ \omega_{1l}/k_2 & \omega_{nl}/k_2 & \cdots & \omega_{nl}/k_2\end{pmatrix}$$

where $(\omega_{1u}/k_1,\cdots,\omega_{nu}/k_1)^T$ and $(\omega_{1L}/k_2,\cdots,\omega_{nL}/k_2)^T$ can be viewed as the unitized weight of consistent matrices A and B, respectively.

Consider the following matrices:

$$U=\begin{pmatrix}u_{11} & u_{12} & \cdots & u_{1n}\\ u_{21} & u_{22} & \cdots & u_{2n}\\ \vdots & \vdots & \vdots & \vdots\\ u_{n1} & u_{n2} & \cdots & u_{nn}\end{pmatrix},\ P=\begin{pmatrix}p_{11} & p_{12} & \cdots & p_{1n}\\ p_{21} & p_{22} & \cdots & p_{2n}\\ \vdots & \vdots & \vdots & \vdots\\ p_{n1} & p_{n2} & \cdots & p_{nn}\end{pmatrix} \quad (3.4)$$

Where $u_{ij}=(1/r_{ijl}-1)/(\sum_{j=1}^{n}(1/r_{ijl}-1)^2)^{0.5}$, $p_{ij}=(1/r_{iju}-1)/(\sum_{j=1}^{n}(1/r_{iju}-1)^2)^{0.5}$.

(3.5)

As matter of fact, U and P are also the unitized matrices of A and B, respectively. The following lemma is obvious.

Lemma 1. Suppose $\Omega = (\omega_1, \cdots \omega_n)^T$ = $([\omega_{1l}, \omega_{1u}], \cdots \ [\omega_{nl}, \omega_{nu}])^T$ is the priority vector of multiplicative consistent GIPR $R = (r_{ij})_{n\times n} = ([r_{ijl}, r_{jiu}])_{n\times n}$, and suppose $\sum_{i=1}^{n} \omega_{iu}^2 = k_1^2$, $\sum_{i=1}^{n} \omega_{il}^2 = k_2^2$. Then $U = \overline{X}$, $P = \overline{Y}$. That is, $u_{ij} = \omega_{ju} / k_1$, $p_{ij} = \omega_{jl} / k_2$.

Obviously, we have

$$\sum_{i=1}^{n} (\sum_{j=1}^{n} p_{ij} \omega_{jl} / k_2)^2 = n \tag{3.6}$$

$$\sum_{i=1}^{n} (\sum_{j=1}^{n} u_{ij} \omega_{ju} / k_1)^2 = n \tag{3.7}$$

If the GIPR R is multiplicative consistent, then $\sum_{i=1}^{n} (\sum_{j=1}^{n} p_{ij} \omega_{jl} / k_2)^2$ reaches the maximum of n, and $\sum_{i=1}^{n} (\sum_{j=1}^{n} u_{ij} \omega_{ju} / k_1)^2$ reaches the maximum of n. That is, if R is multiplicative consistent, then we have

$$\max \sum_{i=1}^{n} (\sum_{j=1}^{n} p_{ij} \omega_{jl} / k_2)^2 = n \tag{3.8}$$

$$\max \sum_{i=1}^{n} (\sum_{j=1}^{n} u_{ij} \omega_{ju} / k_1)^2 = n \tag{3.9}$$

However, in reality, the multiplicative consistent condition of R may hardly hold. This denotes that $U \neq \overline{X}$, $P \neq \overline{Y}$ and eqs. (3.8) and (3.9) may not hold.

Let $X_i = (x_1, x_2, \cdots, x_n)$, $Y_i = (y_1, y_2, \cdots, y_n)$ satisfying $\sum_{i=1}^{n} x_1^2 = 1$, $\sum_{i=1}^{n} y_1^2 = 1$ denote the unitized weight row vectors of inconsistent matrices A and B, respectively. In order to get the priority vector of the inconsistent GIPR R, we introduce three nonlinear optimal models as follows:

Model (1)

$$\begin{cases} \max\ f(X) = \sum_{i=1}^{n}(\sum_{j=1}^{n} x_j u_{ij})^2 = XU^T U X^T \\ s.t. \sum_{j=1}^{n} x_j^2 = 1 \end{cases} \tag{3.10}$$

Model (2)

$$\begin{cases} \max\ f(Y) = \sum_{i=1}^{n}(\sum_{j=1}^{n} y_j p_{ij})^2 = YP^T P Y^T \\ s.t. \sum_{j=1}^{n} y_j^2 = 1 \end{cases} \tag{3.11}$$

Model (3)

$$\min k_1 + k_2$$
$$s.t. \begin{cases} y_i k_2 \le x_i k_1, i \in N \\ 0 < \delta_1 < k_2 < \delta_2 \le k_1 \end{cases}$$

The solutions to Model (1) and Model (2) are the optimal weight vectors of inconsistent matrices A and B. In Model (3), the meaning of minimizing $k_1 + k_2$ is to make each weight interval $[\omega_{il}, \omega_{iu}]$ as narrow as possible, and $y_i k_2 \le x_i k_1$ denotes that $\omega_{iu} \ge \omega_{il} \forall i \in N$. δ_1 and δ_2 , satisfying $0 < \delta_1 < k_2 < \delta_2 \le k_1$, can be interpreted as two adjustment factors, which ensure $k_2 > 0$ and $k_2 < k_1$. Usually, we set $\delta_1 < 1$ and $\delta_2 = 1$.

Theorem 1. Given the unitized matrix of U with the maximum eigenvalue $\lambda_{\max}$, the maximum value of $f(X) = \sum_{i=1}^{n}(\sum_{j=1}^{n} x_j u_{ij})^2 = XU^T U X^T$ is $\lambda_{\max}$, and the optimal solution vector to Model (1) is the unique positive eigenvector of $U^T U$ corresponding to $\lambda_{\max}$.

Theorem 2. Given the unitized matrix of P with the maximum eigenvalue $\gamma_{\max}$, the maximum value of $f(Y)=\sum_{i=1}^{n}(\sum_{j=1}^{n} y_j p_{ij})^2 = YP^T PY^T$ is $\gamma_{\max}$, and the optimal solution vector to Model (2) is the unique positive eigenvector of $P^T P$ corresponding to $\gamma_{\max}$.

4 The Decision Making Algorithms of the GIPR

Step 1. Decompose the GIPR R into sub-matrices A and B.
Step 2. Construct the unitized matrices U and P by using the equ. (3.4).
Step 3. Solve Model (1-3), getting the optimal priority vectors $([\omega_{1l},\omega_{1u}],\cdots[\omega_{nl},\omega_{nu}])^T$ of the GIPR R.
Step 4. Rank the grey intervals $[\omega_{il},\omega_{iu}], i\in N$ by utilizing the ranking method of intervals (Sugihara et al., 2004). We get the priority chain of the alternatives. (For any two positive intervals [a,b] and [c,d], the degree of preference of [a,b] over [c,d] (or [a,b]>[c,d]) is defined as P([a,b]>[c,d])= {max{0,b-c}-max{0,a-d}}/ [(b-a)+(d-c)]}.

5 Numerical Examples

Example 1. Suppose that the weather bureau invites experts to evaluate the integrated service of its 4 subdivisions, so $S=\{s_1,s_2,s_3,s_4\}$. The GIPR is constructed as follows:

$$\begin{pmatrix} [0.5,0.5] & [0.2,0.4] & [0.3,0.4] & [0.6,0.9] \\ [0.6,0.8] & [0.5,0.5] & [0.6,0.7] & [0.7,0.8] \\ [0.6,0.7] & [0.3,0.4] & [0.5,0.5] & [0.7,0.7] \\ [0.1,0.4] & [0.2,0.3] & [0.3,0.3] & [0.5,0.5] \end{pmatrix}$$

Step 1: Decompose R into the following matrices:

$$A=\begin{pmatrix} 0.5 & 0.2 & 0.3 & 0.6 \\ 0.6 & 0.5 & 0.6 & 0.7 \\ 0.6 & 0.3 & 0.5 & 0.7 \\ 0.1 & 0.2 & 0.3 & 0.5 \end{pmatrix} \quad B=\begin{pmatrix} 0.5 & 0.4 & 0.4 & 0.9 \\ 0.8 & 0.5 & 0.7 & 0.8 \\ 0.7 & 0.4 & 0.5 & 0.7 \\ 0.4 & 0.3 & 0.3 & 0.5 \end{pmatrix}$$

Step 2: Unitize A and B, respectively. We get the unitized matrices U and V as follows:

$$U=\begin{pmatrix}0.2090 & 0.8361 & 0.4877 & 0.1393\\ 0.4631 & 0.6946 & 0.4631 & 0.2977\\ 0.2507 & 0.8774 & 0.3760 & 0.1612\\ 0.8849 & 0.3933 & 0.2294 & 0.0983\end{pmatrix}$$

$$V=\begin{pmatrix}0.6855 & 0.5141 & 0.5141 & 0.0381\\ 0.2185 & 0.8741 & 0.3746 & 0.2185\\ 0.2253 & 0.7887 & 0.5258 & 0.2253\\ 0.3989 & 0.6205 & 0.6205 & 0.2659\end{pmatrix}$$

Step 3: The unique positive eigenvector of U^TU corresponding to maximum eigenvalue 3.5215 is (0.4631 0.7570 0.4205 0.1891)^T; the unique positive eigenvector of V^TV corresponding to maximum eigenvalue 3.7180 is (0.3920 0.7271 0.5283 0.1962)^T.

Step 4: Construct the following optimal model as follows:

$$\min k_1+k_2$$
$$s.t.\begin{cases}0.3920k_2\le 0.4631k_1\\ 0.7271k_2\le 0.7570k_1\\ 0.5283k_2\le 0.4205k_1\\ 0.1962k_2\le 0.1891k_1\\ \delta_1\le k_2<1\le k_1\end{cases}$$

where we set δ_1=0.5, and we can easily get that k_1=1, k_2=0.5.

Step 5: The optimal priority vectors of the GIPR R are as follows:

([0.2316,0.3920], [0.3785,0.7271], [0.2103,0.5283], [0.0946,0.1962])^T .

Step 6: The ranking of the integrated service of weather bureau's 4 subdivisions is as follows:

$$s_2 \underset{77.53\%}{\succ} s_3 \underset{62.02\%}{\succ} s_3 \underset{100\%}{\succ} s_4$$

6 Conclusions and Future Works

As we know, when dealing with operations of grey intervals, the grey degree of the interval may be gradually exaggerated with the increase of the number of computational steps. In this chapter, we construct three optimal models to get the priority of the GIPR. This method can reduce the information distortion of the operations of grey intervals. It is illustrated by a numerical example to show the feasibility and effectiveness of the proposed methods. In this chapter, we only consider the GIPR with one decision maker, so we will focus on the priority research on the collective GIPRs will in future research.

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The Nation-State a Systemic View

Hans Kuijper

The chapter pleads for a new approach in studying nation-states. Having defined the composite and complex notion of 'nation-state', the author groups the main nation-state theories into two categories, and claims that systems science goes far beyond the current attempts to bridge the gap between agency theorists and structuralists.

1 'Nation-State' Defined

A STATE distinguishes itself from other forms of human association, a golf or football club, say. It is a human community with territory and sovereignty. Let us be more specific about these distinctive elements.

A state without territory doesn't exist really. 'Territory' implies borders and/or frontiers, depending on whether the lines of demarcation are drawn by nature or man, grounded in some physical discontinuity/qualitative heterogeneity or not (in the first place). The territory is a state's *cadre de compétence*. Differently put, land lying beyond, or outside, a state's scope of competence does not belong to its territory. Territoriality is a powerful principle. It defines state membership in a way that may not correspond with identity. The borders/frontiers of a state may not at all circumscribe a people, and may in fact encompass several peoples, as national self-determination and irredentist movements make evident. Being member of a family, fraternity/sorority, wandering tribe or religion is disassociated with a particular piece of land or geographic area (country), but being member of a state is not. State membership is defined territorially.

Sovereignty, the other essential element of a state, is a matter of authority. That is to say, the holder of sovereignty does not merely wield coercive power, defined as A's ability to cause B to do what he would otherwise not do. Authority is rather 'the right to command and, correlatively, the right to be obeyed'. Sovereignty, however, is not a matter of mere authority; it is a matter of supreme authority within a territory. The state demands, and usually gets, our highest loyalty. It does not only accompany us to the grave; it can put us there. The rules of the state are laws which, in principle, override all other commitments and allegiances, including the voice of our conscience. There are three dimensions to sovereignty: the holder of it, the

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absolute or non-absolute nature of it, and the relationship between internal and external sovereignty.

A) The character of the holder of supreme authority within a territory is probably the most important dimension. Jean Bodin (1529-1596) thought that sovereignty must reside in a single individual. Both he and Thomas Hobbes (1588-1679), following Niccolò Machiavelli (1469-1527), the 'Florentine secretary' whose masterpiece, *The Prince* (1513) ushered in a new era of political thinking, conceived the sovereign as being above the law. Later thinkers differed, coming to envision a new locus for sovereignty, but remaining committed to the principle. The starting-point of the political philosophy of John Locke (1632-1704) is that by nature human beings are equal and therefore nothing can put anyone under the authority of anybody else except his own consent. He argued that a king had responsibilities to his subjects, and revolt was justified when he failed to protect their rights. Jean-Jacques Rousseau (1712-1778), one of the most profound and complex political thinkers in the West, distinguished between the people as sovereign and the government as agent of the *volonté générale*.

B) Sovereignty can also be absolute or non-absolute. Here, 'absolute' refers not to the extent or character of sovereignty, which must always be supreme, but to the range of matters over which the holder of authority is sovereign. Bodin and Hobbes considered sovereignty as absolute, extending to all matters within a territory, unconditionally. However, it is possible to be sovereign over some matters only. Take the European Union member states; they are sovereign in governing defense, but not in governing the euro.

C) The third dimension of sovereignty concerns different aspect of it. Supreme authority is exercised within borders/frontiers, but a state derives its sovereignty also from being recognized by outsiders. To states, this recognition is what a no-trespassing law is to private property: immunity from interference.

Sovereignty has met with critics. Many of them have regarded any claim to sovereign status as a form of idolatry, sometimes as a carapace behind which cruelties and injustices are carried out free from legitimate outside scrutiny, let alone intervention. Perhaps the two most prominent attacks on sovereignty launched by political philosophers came from Jacques Maritain (1882-1973) and Bertrand de Jouvenel (1903-1987). The set of internally and externally sovereign states is the international system that we euphemistically call the 'United Nations', the word 'nations' being used (*a*) to prevent confusion with the 'United States' (of America) and (*b*) to emphasize the fact that each of the UN member states geographically coincides with a nation – with a culturally and/or ethnically dominant people, that is.

Enthusiasts for globalization apparently believe that the nation-state is fading away, but 'the process whereby the world population is increasingly bonded into a single society' is not neutral; it doesn't just happen. The creation of a 'flat' world, of a global society in which people of all nations and colors are singing of 'perfect harmony' (Coca-Cola) is the project of a hegemonic nation-state, not the undirected, necessary outcome of human actions and interactions. Globalization is to a large extent imposed; it is driven by capitalism, which is not simply a matter of economics separate from politics. "Globalization is best understood as a spatial phenomenon, lying on a continuum with 'the local' at one end and 'the global' at the other," David Held says, but he forgets to tell *how*, in a world divided into some 200 contending countries, we will end up with a single polity (politically organized society), a 'borderless world'. Nation-states matter; they are here to stay, the activities of transnational corporations, and of international bodies such as the United Nations, Interpol, the International Court of Justice, the World Trade Organization, the International Monetary Fund and the World Bank Group, notwithstanding. Playing down the importance of nationalism in pursuit of cosmopolitanism, as Martin Köhler, Daniele Archibugi, Kwame Appiah and Ulrich Beck do, exclusively focusing attention on the 'global network society', as Immanuel Wallerstein, Manuel Castells, Barry Wellman and John Urry do, or advocating a world government system, as Terence Amerasinghe, Richard Falk, Joseph Schwartzberg and Stephen Damours do, makes a dangerous illusion manifest.

2 Theories of the Nation-State

The notion of 'nation-state' emerged in England during the Glorious Revolution (1688), was strongly articulated during the American Revolution (1776) and the French Revolution (1789), and has arguably been the axis of political reflection ever since. It has been elaborated on and restated in various ways. Indeed, it is the warp and woof of social-political thinking. The majority of the nation-state theories can conveniently be grouped into two categories: the individualistic and the collectivistic category.

The individualistic view

The adherents of this view are committed to explaining a nation-state/country in terms of individuals, considering statements about collectives like 'the American people', 'the employers', 'the voters' and 'readership' as shorthand ways of referring to individuals who share certain characteristics. References to groups, or to group behavior, which suggest that these are entities other than individuals having needs, wants, interests and goals are regarded as holistic fallacies. Individualists do not deny that a politically organized society exists, or that people benefit from living in it, but they see a polity as a set of individuals, not as something over and above them. They hold that every person is an end in himself or herself, and that the individual is the unit of achievement. His genius is the wellspring of invention or discovery. While not denying that one person can build on the achievements, or stand on the shoulders, of others, they point out that achievement goes beyond what has already been done; it is something new, created by the individual.

Individualism involves a value system, a theory of human nature, and a general attitude:

1) Its value system may be described in terms of three propositions: (*a*) the individual is of supreme value, society being a means to his/her ends, (*b*) all values are man-centered – that is, they are experienced by human beings, and (*c*) all

individuals are morally equal, meaning, no one should ever be treated as a means to the well-being of another person.

2) Its theory of human nature holds that the interests of the adult are best served by allowing him/her maximum freedom for choosing objectives and the means for obtaining them. This belief is based upon two assumptions: (*a*) each person is the best judge of his/her own interests and, granted educational opportunities, can discover how to advance them, and (*b*) the act of pursuing the chosen objectives contributes to the welfare of the society.

3) As general attitude, individualism subscribes to self-reliance, privacy and the right of the individual to be different from, to compete with and to get ahead of others. Negatively, individualists are opponents of control and interference, particularly when exercised by the government.

Individualism is close to the heart of liberalism, the way of thinking (conserved by the conservatives and radicalized by the radicals) which holds that freedom is everybody's natural condition, and that institutions are to be judged by their success in facilitating it. Individualism, the view that every person is sovereign and has a frontier, is deeply ingrained in the Western tradition. So much so, that it is thought not to be a common characteristic of humanity, indeed almost an eccentricity among cultures. Though the development of individualism/liberalism can be traced back to the Hebrew prophets, the teachings of the pre-Socratic philosophers and the Sermon on the Mount, from all of which there emerged a sense of liberation of the individual from subservience to the (leader of the) group, its prestige rose during the latter part of the eighteenth century, especially after the publication of the ideas of Adam Smith (1723-1790) and Jeremy Bentham (1748-1832). Twentieth century champions of individualism are (amongst many): James Buchanan, Robert Dahl, Ralf Dahrendorf, Hernando de Soto, Milton Friedman, Friedrich Hayek, Robert Nozick, Karl Popper, Ayn Rand, John Rawls, Amartya Sen, and Ludwig von Mises.

The collectivistic view

The adherents of this view regard a polity, ultimate standard of value, as something over and above its members. They do not deny the reality of the individual, but hold that one's identity is essentially made up of relationships and achievement is the product of a group of people sharing values, interests and goals. The individual, who is expected, even required to sacrifice himself or herself for the alleged good of the group, is just a replaceable cog in the machine, an exchangeable piece of equipment. Read Tolstoy's retrospective final chapter of War and Peace and see how he comes to the conclusion that the trends initiated in Europe by the French Revolution would have worked themselves through with or without Napoleon.

Collectivism, which reflects the human instinct to belong to a herd, is close to the heart of socialism, the way of thinking (grown up in opposition to capitalism) which holds that human activities be described in terms of personal, social, economic and/or political relations rather than in terms of individual actions. In the early nineteenth century, when modern socialism made its first appearance (Saint-Simon, Fourier, Owen a.o.), Georg Wilhelm Friedrich Hegel (1770-1831), inspired by the work of Rousseau, argued that the individual realizes his/her true being and freedom only in unqualified submission to the laws and institutions of the nation-state. Karl Marx later provided the most succinct statement of the collectivist view by positing, in the preface to his Contributions to the Critique of Political Economy (1859), the primacy of Produktionsverhältnisse (relations of production). Twentieth century champions of the basic tenets of collectivism are (amongst many): Stephen Bronner, Cornelius Castoriadis, Jürgen Habermas, David Harvey, Robert Heilbronner, Eric Hobsbawm, Alexandre Kojève, Ernesto Laclau, Ernest Mandel, Ralph Miliband, Nicos Poulantzas, and Paul Sweezy.

Individualism/liberalism versus collectivism/socialism – the views seem to be irreconcilable. Individualism is found wanting for making no room for society's peculiar properties, collectivism for losing sight of man's uniqueness. The former is blind to social values, the latter is devoid of respect for the person. Each avoids the other's error by making an opposite mistake of its own. Individualism (politically, economically or sociologically oriented) is inadequate because individuals are interrelated; collectivism (politically, economically or sociologically oriented) is deficient because there are no relations without relata ('things' related). The one underrates the bonds among people, the other plays down individual actions. Individualists tend to overlook the emergence of things with properties that their parts don't have; collectivists are inclined to overlook man's creativity.

Whereas Émile Durkheim (1858-1917), working in the positivist tradition and tending to reification, maintained that the collective possesses a life of its own, external to and coercing its members, Max Weber (1864-1920), working in the anti-positivist tradition and inclined to voluntarism, contended that society is the result of the intentional and meaningful behavior of human beings. After World War II, the 'existentialists' (Jean-Paul Sartre, Maurice Merleau-Ponty, Karl Jaspers, Martin Heidegger, Martin Buber, Gabriel Marcel, Emmanuel Levinas a.o.) were challenged by the 'structuralists' (Claude lévi-Strauss, Edmund Leach, Louis Althusser, Marshall Sahlins, Georges Dumézil, Gilles Deleuze, Tzvetan Todorov a.o.). The former emphasized the idea that man is a being 'for-itself' (as against the being 'in-itself' of mere things), and the related idea that what the individual becomes can only be explained by the choices he/she makes in resolving the 'issue' of his or her life. The latter considered the identification and analysis of underlying, the individual transcending structures to be of paramount importance. In 1966, when somebody had the nerve to write on the Berlin Wall 'Man denkt zu schieben aber man wird geschoben', Michel Foucault thought he could certainly wager that 'man would be erased, like a face drawn in sand at the edge of the sea'.

Various attempts have been made to bridge the gap between the agency theorists ('agency' referring to the capacity of individuals to act independently) and the structuralists, Anthony Giddens, Pierre Bourdieu, Roy Bhaskar, Margaret Archer, and Nicos Mouzelis being the most prominent, ingenious bridge builders. Interesting though their theories are, we venture to say that systemics, or 'systems science', goes far beyond them.

3 The Systemic View

Before we go into the matter of viewing a nation-state/country systemically (as distinct from: systematically), it might be useful to pay some attention to the concept of 'system'.

A system is a special type of set (*Menge*). A set is a well-defined collection, or a grouping into a single entity, of objects. These objects are called the 'elements' or 'members' of the set. The rivers in China, the people living on the earth, the students who are absent from school, the vowels of the alphabet, the solutions of the equation $x^2 - 3x - 2 = 0$, and the numbers 2, 4, 6, 8, … are examples of a set. Set theory, the branch of mathematics that deals with properties of, operations on and relations between sets, aims at a description of the fundamental structure of the mathematical universe. It is a vibrant field of research, with many interrelated subfields. The elements (or parts) of a system are organized, making the system an integrated whole, an object whose parts are held together by bonds of some kind. A system is a set of things and their relations, or in George Klir's formula: S = (T, R). There are numerous kinds of systems that can be studied, qualitatively or quantitatively: physical, geological, mechanical, biological, ecological, social, political, military, medical, educational, legal, economic, financial, managerial, technological, religious, artistic, linguistic, cultural, perceptual and conceptual systems. An atom, the Milky Way, the human brain (containing up to 100 billion interconnected neurons [systems!]), a city and CERN's Large Hadron Collider is a system, but a mathematical model, a computer program, a logic, a scientific discipline, a value configuration, a game, a debate and the Internet is a system too. Other distinctions can be made: there are stable and unstable systems, homo- and heterogeneous systems, animate and inanimate systems, material and immaterial systems, discrete and continuous (and hybrid) systems, causal and anticausal systems, deterministic, probabilistic and grey systems, static and dynamic systems, hard and soft systems, natural and artificial systems, linear and nonlinear systems, autopoietic and allopoietic systems, anticipatory and self-organizing systems, chaotic and solitonic systems, finite-dimensional and infinite-dimensional systems, active and reactive systems, mindless and (uni-or multi)minded systems, 'simple' and 'complex' systems. Usually, a system contains a number of subsystems. Think of a molecule, the human body, a family, an airplane, an airport, a company, an industry, an economy, a university, a library, a medical center, a government, the media, the European Union, the Olympic Games, the animal kingdom, a rainforest, the Blue Planet. So one may wonder whether all these systems have something in common.

Talking about systems, we should bear four points in mind

1) That a system consists of parts seems to be stating what is obvious, if not trivial. Yet the part-whole relation in all domains of reality and conceptualization (differently put: what it means for two or more things to fit together) is the object of a study (mereology) that has a long history (going all the way back to Thales of Miletus [fl. 6th century BC]) and a high degree of sophistication. The word 'part' has many meanings in ordinary language. 'The handle is part of the mug'. 'The cutlery is part of the tableware'. 'The first act was the best part of the play'. 'Sodium is one of the parts of salt'. 'The point is part of the line, which is part of the plane, which is part of the sphere'. Broadly speaking, the word 'part' can be used to indicate any portion, fraction, fragment, share, piece, division, section, sector, compartment, unit, ingredient, constituent, element, member, component,

percentage, particle, branch or bit of a given entity. Mereology (from the Greek *meros*, part) is an attempt to lay down the principles underlying the relationships between an entity and its constituent parts, whatever the nature of the entity. Unlike set theory, mereology is not committed to the existence of *abstracta*: the whole can be as concrete as the parts. But mereology carries no commitment to *concreta* either: the parts can be as abstract as the whole. In other words, mereology is topic-neutral. Areas of space and eras of time stand in part-whole relationship. Likewise, events and actions (not being the same!) may have parts and be parts. Indeed, everything has parts and, simultaneously, is part of something else, the universe and the subatomic constituents of matter (the elementary particles) probably being the exceptions.It was Stanisław Leśniewski (1886-1939), famous member of the Lvóv-Warsaw School of analytical philosophy,[1] who began to codify the formal principles of part/whole theory. For him, the minimal properties of a part/whole relation are that it is asymmetric (if *a* is part of *b*, *b* is not part of *a*), transitive (if *a* is part of *b* and *b* is part of *c*, then *a* is part of *c*), and supplemental (if *a* is part of *b*, then there is a part of *b* having no common part with *a*). Whereas Leśniewski developed the theory of the ‘part of’ relations, assuming that given an object *x*, its parts form a Boolean algebra (classical mereology), Lech Polkowski and Andrzej Skowron, leaving the domain of two-valued logic, and drawing on the pioneering work of Zdzisław Pawlak (1926-2006), introduced the theory of the ‘part of to a degree’ relations (rough mereology).

2) The structure, pattern, architecture, or *Gestalt* of a ‘system’ (from the Greek *sun-histèmi*, com-pose) is an entity of dependencies. It is determined by (*a*) the number, nature and function of its elements/subsystems (modules), (*b*) the number and nature of the relations among these parts, and (*c*) the number and nature of the relations between the system and its surroundings. ‘Relation’, a basic term or category, is difficult to define, for it seems to be impossible to make any statement of what relation is without using the notion of ‘relation’ in doing so, and without acknowledging that a relation cannot exist apart from the ‘things related’. Leaving this maddening fact for another occasion to deal with, we comfort ourselves with the following mathematical definition: a relation R from set A to set B is a subset of the product set $A \times B$, also called the Cartesian product of A and B. Let $A = \{1,2,3\}$ and $B = \{a, b\}$. Then $A \times B = \{(1, a), (1, b), (2, a), (2, b), (3, a), (3, b)\}$, and $R = \{(1, a), (1, b), (3, a)\}$, a relation from A to B. The definition can be extended to more than two sets, and the relations between them can be of many sorts.As ‘structure’ is tied up with ‘system’, the focus of attention is usually on the total of a system’s constituents. However, this total is a ‘whole’ (Gr. *holon*), or *Ganzheit*, rather than merely an ‘aggregate’ (Gr. *pan*), or *Gesamtheit*. Systems are embedded entities the (sometimes ‘identical’) parts of which are organized. A pile of bricks, being an aggregate, is not the system we call ‘building’. By the same token, a succession of sounds is not necessarily a melody. A system, typically, is different from the sum of its parts; it has properties none of its constituents has, much in the same way as the nature of water is irreducible to the attributes of hydrogen and oxygen. Those being in favor of analysis (dividing things up into ever smaller parts for research) should not overlook the subtle difference between *Gesamtheit* and *Ganzheit*. The breaking down (either physically or mentally) of any system, micro or macro, into elements

should not result in losing sight of its supersummative properties and the conditions under which the subsystems operate within the supersystem. It cannot be overstressed: composition is more than, and critically different from, juxtaposition. A good physician and a commander-in-chief are acutely aware of this. If and only if they are organized, entities or modules form a whole, as every architect, *chef de cuisine*, composer, fashion designer, Japanese flower-arranger, even a football-coach can tell. This does not alter the fact that, for a composition to be harmonious, or for a team to be victorious, each of its elements/members needs to be given due care and attention. A chain is only as strong as its weakest link. Setting the whole (group) over against the parts (individuals), as the collectivists/socialists and individualists/liberals persistently do, is misleading, indeed risky. *Tertium datur*: taking both, the whole as well as the parts, into account by focusing on the system-hood (*i.e.* on the T *and* the R in Klir's deceptively simple formula), one discovers that there is a third possibility. There is no primacy or priority to be assigned, because individuals and the group they belong to are mutually implicated, recursively related. The two may be distinguished, but shall never be separated, from each other. A group of individuals is not like a bunch of pencils, nor is the nation-state an aggregate; they are structured, integrated wholes, even if there are internal states of conflict.

3) Everything seems to have a boundary. It makes identification possible. Without boundaries we can neither differentiate nor decide; chaos would prevail. There is a line demarcating the interior of a circle from its exterior. A soccer game begins and ends when the referee blows his whistle. However, the boundary subject is a highly problematic issue.[2] Anaximander, Thales's disciple and successor, contrasted the 'cosmos' (ordered world) with the 'boundless'(*apeiron*), the indefinite and imperceptible from which all distinguishable things come and to which they return 'in accordance with the ordinance of time'. One of the persistent questions concerning infinity (∞) is whether we can know or comprehend it. Another is whether the infinite exists, and if so, to what kind of thing it belongs (to space, time, number?). Limit processes are used throughout analysis, the part (!) of mathematics that studies numbers, or points, and functions (mappings). The conception of these processes is based on the idea of closeness. Augustin-Louis Cauchy (1789-1857), one of the greatest of modern mathematicians, defined a limit (more than 150 years after Newton and, independently, Leibniz had discovered the infinitesimal calculus) as follows: 'When the values successively attributed to the same variable approach indefinitely a fixed value, so as to differ from it as little as one might wish, this latter is called the *limit* of all the others'. So analysis makes approximations into exact quantities, as when the area inside a curved region is defined to be the limit of approximations by rectangles (Archimedes).It may also be observed that ordinary objects, events, and concepts often elude the idealized notion of 'being sharply bounded'. What is the boundary of a cloud, mountain, ecosystem, concept or scientific discipline? Is the killing of humans always wrong? When did the Industrial Revolution begin, and where did it take place? What is the reach of somebody's power or authority? When do we call a man 'bald', 'tall', 'rich', or 'free'? Is our skin the outer envelope of an inner self? When is the beginning and when is the end of man's life? Where is the line demarcating Europe from Asia?

When does a number of rain drops (quantity) start being a shower (quality)? What are the boundaries of love, beauty, experience and creativity? How far radiates a culture or civilization? All these boundaries are unclear, hazy, vague, imprecise and indeterminate. Classical logic/hard computing breaks here down and has to be replaced by fuzzy logic/soft computing, because one of the essential features of the concept of 'set' as Georg Cantor (1845-1918) understood it is conspicuous by its absence, namely, given an object x and a set A, exactly one of the statements 'x is an element of A' (symbolized $x \in A$) and 'x is not an element of A' (symbolized $x \notin A$) is true and the other is false.Physical systems can be 'isolated', 'closed' or 'open', depending on whether matter and/or energy is exchanged with the environment. A casserole being used exemplifies an open physical system; it exchanges both matter (vapour) and energy (heat). Exact calculation of open systems is not possible. One has to put up with approximations by means of models. *Living* systems and (often over time in complexity increasing) *social* systems, which continuously interact with their surroundings, are open systems too, but — distinct from physical systems. Their permeable borders allow matter, energy and information to pass, the openness being a condition for, rather than a guarantee of, their survival. Whether or not the principles of thermodynamics (entropy) also obtain in the world of living and social systems, how information is to be defined and how it relates to knowledge/insight, are intriguing questions we leave to others to answer, but there is one thing we wish to point out, just for the sake of argument: the relation between the concepts of 'openness' and 'boundary/limit' is strained.

4) An important distinction is to be made between two kinds of part-whole relation: composition and extension. The parts of a composition are its components; the identity of a component (what makes it different from the other components) is its *what* or *who*. The parts of an extended whole are its regions/periods; the identity of a region/period (what makes it different from the other regions/periods) is respectively its *where* and *when*. Spatial and temporal parts, irrespective of scale, are no more or less basic than the wholes they compose. Thinking, far from being static, is the constant, imaginary moving backwards and forwards between composition and extension, between installing and de-installing parts. Cognition, allegedly being computational in nature, is conceiving how things actually were, are or will be and, counterfactually, how they would have been or would be in this, that or the next eventuality. It is from the what, the who, the where as well as the when that the *how* and the *why* transpire. The relation between structure/form/being and process/flux/change, another subject that has haunted social scientists, is that between composition and extension. A process takes time and place; it lasts, has duration, continues for a particular length(!) of time (interval, period, or term); it is the concatenation of configurations, the sometimes mathematically tractable sequence of system states; it is a trans-formation involving transient structures, a structure change with structure. The word 'process' refers to the way a system works/operates/functions/behaves, to its 'mechanism', which is frequently coupled to other 'mechanisms', and can be spontaneous or engineered.The subject of change, the fast or slow process of becoming different (we are aware of change only when a different pattern becomes discernible), leads us to the very complicated problem of causality.[3] Dealing with this conundrum adequately would require

writing a book. Suffice it to say that (*a*), besides 'material' causes ('The table is made of wood'), there are 'efficient' causes ('She fell because he pushed her', 'The fire heated the water'), 'formal' causes ('A pianist needs the score to play a concerto', 'The blueprint of a house is necessary for its construction') and 'final' causes ('Shoes are made to protect/embellish feet', 'He moved to the seaside for the sake of his health', 'The monument was built in commemoration of those who died in the war'), and (*b*), in contradistinction to the assumption of reductionist scientists, causality can be and usually is a rather convoluted phenomenon, meaning that in nature and society *non*linear systems (where the whole is *not* equal to the sum of its parts) are far more common than the linear ones.

4 The Systemic View of a Nation-State

A nation-state, or country, is a huge, highly complex, multi-minded/agent-based, evolving, non-equilibrium, rule following, open system. It is a *Ganzheit* in which things hang together, tightly or loosely, but in a way that is distinctive. A nation-state is an intricate network of interfacing networks 'different in extensiveness and intensiveness' (Michael Mann). Its basic units are 'involved in a continuous interplay of complex determinations' (Evelyne Andreewsky). Indeed, a country is a unique *individuum*, something indivisible, a territory-bound and history-moulded organization, a layered, hierarchically ordered, whole that, distinctly interrelated with its parts, constantly changes, sometimes turbulently. Having properties that each of its constituent subsystems lacks, and being a series of complex networks the pattern of which can be analyzed using the tools of graph theory, it is best viewed as an intersection of four fields: the geographic field, the individual-creative field, the socio-cultural field and the historic field: $\mathbf{C} = \mathbf{G} \cap \mathbf{I} \cap \mathbf{S} \cap \mathbf{H}$. Heuristically, the combination of these fields, each of which supposes, and maps onto, the other three (!), can be represented by a tetrahedron, the regular, Plato (and Buckminster Fuller) fascinating polyhedron with four equilateral triangular faces.[4]

The words of John Donne, 'no man is […] entire of it self', are also applicable to a nation-state, because, being part of a 'globalizing' world, it has a number of relations, vital to its development, with its natural and cultural (non-natural) surroundings. It matters a lot whether a country is located in the tropics or in the temperate zone, whether it is land-locked or sea-washed. The nature of the bilateral or multilateral relations with other countries is reflected in its changing balance of international payments, which – it tends to be forgotten – shall not be left only to economists to scrutinize. How, then, is a nation-state to be studied?

Country studies, to which some institutions of tertiary/higher education, such as School of Oriental and African Studies (SOAS) in London and German Institute of Global and Area Studies (GIGA) in Hamburg, are devoted solely, are domains of research not pertaining to a particular aspect of, but – the difference is important – to a particular *region* in the world.[5] Basically, students of a nation-state, irrespective of their view (individualistic or collectivistic), and other than cultural anthropologists (who study a particular *people* or *folk*), can be classified as follows:

1) Students who – without a textbook containing a presentation of the principles and vocabulary of their trade, and unaware of the pitfalls of synopsis – claim to synthesize the results of all kinds of professional study regarding the country of their choice. Having no degree in any of the disciplines concerned, nor having contributed to the development of any of them, they do not shrink from rushing in where angels fear to tread. These jacks-of-all-trades (but masters of none) leave the reader/listener in the dark as to where the parts fit into the whole (the larger scheme), and, conversely, how the whole stands interconnected with the parts, reminding us of the old Chinese proverb *Ben bu guan yu mo yi bu xian yu duo* (the roots are not connected with the twigs; the one is not shown in the many). We are not suggesting that these all-rounders are useless. Certainly not; the (historical or contemporary!) sweep of the country they selected is a broad one, which can be refreshing, when fragmentation of science is rife and nobody seems to know how Humpty is to be put together again. What we do accuse these heroic polymaths of, however, is their refusal to be explicit about the *shallowness* of their knowledge. They shy away from admitting that they are muddle-headed about *their* assumptions, parameters and methodology. They get embarrassed if we ask them to define the theoretical structure of *their* research activities (their unified frame of perception and understanding), to mention *their* discipline's central concept, or to spell out the principles of *their* trade (the study of a *country*), as distinct from the business of, say, political scientists, jurists, military scientists, linguists, literary scientists, and biologists.

2) Students who – having good grounding in the discipline required – attempt to deepen their understanding by exploring, *e.g.*, the flora/fauna, population, language(s), economy, agriculture, religion, mores, education, geological features, public health, or arts of/in a particular country – that is, by applying/testing and, if necessary, adjusting the theories of their textbooks. Scientifically drilled and trained, these students have an in-depth view, which is indispensable for writing authoritatively on subjects within their purview, but — is upheld at the expense of breadth of view. Being professionals (*Fach-Menschen*), they have a tendency towards stove-pipe peering and cylindrical thinking. Enclosed within their universe of concepts (silo) and single-mindedly dedicated to their domain, these Cyclops easily forget that the parts of an aggregate (*Gesamtheit*) can, but the parts of a whole (*Ganzheit*) can *not* be understood in isolation.

This raises the important, all too often neglected, question as to whether, in terms of research and (higher) education, both the Scylla of being mile-wide-but-inch-deep and the Charybdis of being mile-deep-but-inch-wide can be avoided, whether generalization and specialization can be reconciled.

It is our conviction that a safe way between the two monsters can be navigated. That way is the *systemic* way. Only by zooming in and out (as in the film *Powers of Ten*), by paying heed, not only to the system as a whole but also to its constituent parts, by studying a country horizontally as well as vertically (and by addressing the nature of its part structures, not only in their static state but also as a function of time), the strength of group 1 and group 2 (respectively breadth and depth of view) can be obtained. There shall be no looking at the forest without seeing the trees. The two are reciprocally related. To have an eye for the supersystem only, and not for its intimately connected subsystems (and, subsequently, the related parts of these parts), would be foolish. It would betray a leaning towards reification. Neither shall there be looking at the trees without seeing the forest. To cut a country mentally into morsels for single sciences to chew on, would amount to destroying a system (*con*stitution) in order to *com*prehend it. No matter how many aspects of a country can be discerned, they are and will always remain different '*aspects*' (from the Latin *aspectūs*, views) of the same study object. 'Aspect' is not an onto- but epistemological category. Reality does not abide by academic distinctions.

Being a *Gefüge*, a four-dimensional, tetrahedron-like system of systems (of geological, biological, demographic, ecological, political, legal, military, economic, financial, managerial, educational, technological, linguistic, social, religious, artistic or other nature), a nation-state can only be understood interdisciplinarily, through 'comprehensive observation of changes' (*tongbian*). This implies teamwork, scientific collaboration, syntegrity, for no country student can be expected to become a master of all weapons. Should he/she want to be one, he/she would be oblivious to Goethe's famous dictum: '*In der Beschränkung zeigt sich erst der Meister*'. Exploration of the meaning, necessity and possibility of scientific collaboration, about which a heated debate is going on, and which is essentially a matter of *com*position rather than juxtaposition (multidisciplinarity), has to wait for another occasion, but, given the established facts that the best *team* (rather than the *Gesamtheid* of the best players) wins, and collaboration is impossible without communication, three final remarks have to be made.

1) We are on the verge of a new era of computing. E(lectronic)-science (also known as cyberinfrastructure) is making collaborative research of complex systems possible. Its key concept is 'computational grid'. The exciting thing about this system (!) is the combination of vast quantities of digitized data ('digital libraries'), high performance computers (running sophisticated software), and connectivity between computers supported by high-tech telecommunications (Internet technology), all three of which are expanding rapidly. Grid computing will be the new paradigm, allowing users who are distributed throughout the world to share computational resources across the intergradational boundaries between disciplines.

2) Those involved in country studies have a lot to learn from (intelligent) 'service science', a burgeoning branch of knowledge comparable with computer science. The success of the latter is first and foremost in its ability to bring together disciplines in order to solve problems. Service science is, potentially, an interdisciplinary umbrella too. Intimately connected to grid computing, it aims at understanding and innovating service systems, which usually are complex systems – that is to say, systems the parts of which interact nonlinearly. Given the growing importance of service systems, their great diversity, and the extensive range of disciplinary knowledge needed to understand them, effective teamwork is considered necessary. Presently, there are over 130 institutes in the world that are conducting service science programs, and there are worked-out plans to create a 'Service Systems Lab Network' in order to connect the laboratories supporting these programs, and to foster collaboration. Since nobody can hope to become an expert on every subject in the fast expanding field of service science, much value is placed on T-shaped professionals: scientists with profound knowledge in one

particular area of research (discipline), proficiency in communicating with other experts and adeptness in using the tools and techniques of 'visual analytics'– that is to say, scientists keen on interoperability and in search of isomorphic transfer (or mapping) rather than analogy.

3) The objective of *Logic, Epistemology, and the Unity of Science*, the Springer book series that started in 2004, and in which 18 titles have been published so far (July 2009), is to reconsider the question of the unity of science in light of recent developments in logic and theory of knowledge, and 'to provide an integrated picture of the scientific enterprise in all its diversity'. Though no single logical, semantic or methodological framework dominates the philosophy of science, the editors of this series believe that formal techniques like independence friendly logic, dialogical logic, multimodal logic, linear logic and game theoretic semantics 'have the potential to cast new light on basic issues in the discussion of the unity of science' – issues also being a major concern for Diederik Aerts, Editor-in-Chief of the interdisciplinary journal, published since 1995, *Foundations of Science*.

Briefly then, viewing a nation-state/country systemically, or relationally, is the ability to see it as a giant, composite system that, provided the willingness to go wide and deep (collaborate), and to draw upon the theoretical, empirical and methodological advancements in complexity science, could be domesticated (*apprivoisé*) and, provided the harnessing of the power of grid computing, could be correctly represented by a model, which is essentially the artistic product of highlighting what is important and leaving out everything else. Taking our advice ('*Immer strebe zum Ganzen*') seriously, and vigorously implementing the systemics-based research recommendations we have made, in expectation of dogged resistance from certain quarters, may result in more intercultural understanding and better international relations, things that mankind desperately needs.

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Critical Path for a Grey Interval Project Network

Zhongmin Song and Xizu Yan

In systems analysis, uncertainties may exist in model parameters and input data. Those uncertainties can propagate through the analysis and generate uncertainties in systems analysis. Grey systems theory offers a method for incorporating uncertainties into systems analysis. According to grey systems theory and the characteristics of the interval plan network, this paper gives the method of the multiobjective making critical path. Examples are provided at the end to verify the feasibility of this method, which combines subjective factors with objective factors.

1 Introduction

It is well known that the network activity times are uncertain in the network schedule. Therefore, the network activity times should be seen as grey numbers (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006) when making the network schedule. These grey numbers usually have been expressed by certain numbers in the methods of network schedule CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique). A certain number, in fact, can only represent one of the infinite whitening values of a grey number. Therefore, it is incomplete to use a certain number or expectation of the probability distribution to express an uncertain problem. In many cases, we can only obtain their grey intervals (without distribution information).

The critical path technology is a currency technology of the network schedule. It concentrates the decision maker's attention on the critical paths because the activities on the critical path usually are deemed to result in project success or failure. The critical path of the network activity times being grey numbers was researched in (Chanas and Zielinski, 2002; Liu and Chen, 1991). The definition and solution of the interval critical path (ICP) were first given in (Chanas and Zielinski, 2002). On the basis of (Chanas and Zielinski, 2002), the definition and solution of the deadline

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based interval critical path (DBICP) were given in (Liu and Chen, 1991). The interval critical path in (Chanas and Zielinski, 2002) was defined by an objective target. The interval critical path in (Liu and Chen, 1991) was defined by a subjective target. Since the network activity times are uncertain, total duration is also uncertain in the network schedule (total duration is obviously uncertain in fact). The critical path defined by a single objective is obviously inadequate. The critical path being defined by a multiobjective objective is proposed in this paper, and examples are provided at the end to verify the rationality of this method, which combines subjective factors with objective factors.

2 Correlative Concepts and Properties

In this section, we will first introduce some useful definitions.

A. The definition of a grey number

Definition 1. Let x denote a closed and bounded set of real numbers. A grey number $x^{\pm}$ is defined as an interval with known upper and lower bounds but unknown distribution information for x:

$$x^{\pm} = [x^{-}, x^{+}] = [t \in x \mid x^{-} \le t \le x^{+}],$$

where x^{-} and x^{+} are the lower and upper bounds of $x^{\pm}$, respectively. When $x^{-} = x^{+}$, $x^{\pm}$ becomes a deterministic number, i.e. $x^{\pm} = x^{-} = x^{+}$.

Definition 2. The whitening value of a grey number $x^{\pm}$ is defined as a deterministic number with its value lying between the upper and lower bounds of $x^{\pm}$: $x^{-} \le x_{\alpha}^{\pm} \le x^{+}$, where, $x_{\alpha}^{\pm}$ is a whitening value of $x^{\pm}$. This relation can be expressed as $x_{\alpha}^{\pm} = x^{-} + \alpha(x^{+} - x^{-})$, where α is a grey coefficient. When $0 < \alpha < 1$, i.e., $\alpha \in (0,1)$, $x_{\alpha}^{\pm}$ will change between its upper and lower bounds, i.e. $x_{\alpha}^{\pm} \in (x^{-}, x^{+})$; when $\alpha = 0$, $x_{\alpha}^{\pm}$ will reach its lower bound, i.e. $x_{\alpha}^{\pm} = x^{-}$; when $\alpha = 1$, $x_{\alpha}^{\pm}$ will reach its upper bound, i.e. $x_{\alpha}^{\pm} = x^{+}$.

Definition 3. Let λ be a real number and call

$$\lambda x^{\pm} = \begin{cases} [\lambda x^{-}, \lambda x^{+}] & \lambda \ge 0 \\ [\lambda x^{+}, \lambda x^{-}] & \lambda < 0 \end{cases}$$

the product of real and grey numbers.

The operations of grey numbers were shown in (Gou et al., 1995; Okada and Gen, 1994; Wu and Huan, 2004; Liu and Chen, 1991; Liu et al., 1991; Xiao et al., 2005; Chans and Zielinski, 2002).

B. The definition of a certain critical path

In a certain network $G(A,V)$, V is set of nodes and $A=V\times V$ is a set of arcs (arcs express activities). Let 1 denote the start node and n denote the end node. Let $P(n)$ denote the set of paths from 1 to n. For activity $(i,j)\in A$, let $t(i,j)$ denote activity time. For $p\in P(n)$, let $t(p)$ denote length of path p.

Definition 4. The path $p^*\in P(n)$ is a critical path if and only if it is the lengthiest path in network $G(A,V)$, i.e.

$$t(p^*)=\max_{p\in P(n)}\sum_{(i,j)\in p} t(i,j) \tag{2.1}$$

3 The Grey Network and the Critical Path

The grey network $GN(A,V)$ has the same configuration as the certain network $G(A,V)$; the dissimilarity is the network activity times are grey numbers $t^{\pm}(i,j)$. In $GN(A,V)$, since the network activity times are grey numbers, the network total duration is also a grey number. Let $T^{\pm}=[T^-,T^+]$ denote total duration, i.e.

$$T^-=\max_{p\in P(n)}\sum_{(i,j)\in p} t^-(i,j) \tag{3.1}$$

$$T^+=\max_{p\in P(n)}\sum_{(i,j)\in p} t^+(i,j) \tag{3.2}$$

The grey network $GN(A,V)$ has the following properties:

Theorem 1. In grey network $GN(A,V)$, let $T_{\alpha_{ij}}$ be the total duration of the network schedule. When $t(i,j)=t^{\pm}_{\alpha_{ij}}(i,j)$, $T^{\pm}_{\alpha}$ is whitening value of the total duration $T^{\pm}$, then $T_{\alpha_{ij}}\le T^{\pm}_{\alpha}$, where $0<\alpha_{ij}\le\alpha<1$.

Proof. Let $p_{\alpha_{ij}}\in P(n)$ be a critical path when $t(i,j)=t^{\pm}_{\alpha_{ij}}(i,j)$. We have

$$\begin{aligned}
T_{\alpha_{ij}} &= \sum_{(i,j)\in p_{\alpha_{ij}}} t^{\pm}_{\alpha_{ij}}(i,j)=\sum_{(i,j)\in p_{\alpha_{ij}}}\{t^-(i,j)+\alpha_{ij}[t^+(i,j)-t^-(i,j)]\}\\
&\le \sum_{(i,j)\in p_{\alpha_{ij}}}\{t^-(i,j)+\alpha[t^+(i,j)-t^-(i,j)]\}=(1-\alpha)\sum_{(i,j)\in p_{\alpha_{ij}}}t^-(i,j)+\alpha\sum_{(i,j)\in p_{\alpha_{ij}}}t^+(i,j)\\
&\le (1-\alpha)\max_{p\in P(n)}\sum_{(i,j)\in p}t^-(i,j)+\alpha\max_{p\in P(n)}\sum_{(i,j)\in p}t^+(i,j)\\
&=(1-\alpha)T^-+\alpha T^+=T^-+\alpha(T^+-T^-)=T^{\pm}_{\alpha}
\end{aligned}$$

So, we have $T_{\alpha_{ij}}\le T^{\pm}_{\alpha}$.

Theorem 2. In grey network $GN(A,V)$, let T_α be the total duration of the network schedule. When $t(i,j)=t_\alpha^{\pm}(i,j)$, $T_\alpha^{\pm}$ is whitening value of the total duration $T^{\pm}$, then $T_\alpha = T_\alpha^{\pm}$ ($0<\alpha<1$), if and only if the critical path $t(i,j)=t^-(i,j)$ is the same as the critical path $t(i,j)=t^+(i,j)$.

Proof. Let $p_\alpha \in P(n)$ be a critical path. When $t(i,j)=t_\alpha^{\pm}(i,j)$, $T_\alpha = T_\alpha^{\pm}$ ($0<\alpha<1$), we have

$$T_\alpha^{\pm} - T_\alpha = [T^- + \alpha(T^+ - T^-)] - \sum_{(i,j)\in p_\alpha}[t^-(i,j)+\alpha(t^+(i,j)-t^-(i,j))]$$
$$=[(1-\alpha)[T^- - \sum_{(i,j)\in p_\alpha} t^-(i,j)] + \alpha[T^+ - \sum_{(i,j)\in p_\alpha} t^+(i,j)] = 0,$$

From theorem 1, $T^- - \sum_{(i,j)\in p_\alpha} t^-(i,j) \ge 0$, $T^+ - \sum_{(i,j)\in p_\alpha} t^+(i,j) \ge 0$, and $1-\alpha>0, \alpha>0$. Thus $T^- - \sum_{(i,j)\in p_\alpha} t^-(i,j)=0, T^+ - \sum_{(i,j)\in p_\alpha} t^+(i,j)=0$, i.e. $T^- = \sum_{(i,j)\in p_\alpha} t^-(i,j), T^+ = \sum_{(i,j)\in p_\alpha} t^+(i,j)$.

Conversely, let $p_\alpha \in P$ be a critical path when $t(i,j)=t^-(i,j)$ and $t(i,j)=t^+(i,j)$, i.e.

$T^- = \sum_{(i,j)\in p_\alpha} t^-(i,j), T^+ = \sum_{(i,j)\in p_\alpha} t^+(i,j)$. When $0<\alpha<1$, we have

$$T_\alpha^{\pm} = T^- + \alpha(T^+ - T^-) = \sum_{(i,j)\in p_\alpha} t^-(i,j) + \alpha[\sum_{(i,j)\in p_\alpha} t^+(i,j) - \sum_{(i,j)\in p_\alpha} t^-(i,j)]$$
$$= \sum_{(i,j)\in p_\alpha}\{t^-(i,j)+\alpha[t^+(i,j)-t^-(i,j)]\} = \sum_{(i,j)\in p_\alpha} t_\alpha^{\pm}(i,j) \le \max_{p\in P(n)} \sum_{(i,j)\in p} t_\alpha^{\pm}(i,j) = T_\alpha,$$

From theorem 1, $T_\alpha \le T_\alpha^{\pm}$, so that $T_\alpha = T_\alpha^{\pm}$.

Similar to Definition 4, we have the following definitions:

Definition 5. The path $p^* \in P(n)$ is a critical path if and only if it is the lengthiest path in network $GN(A,V)$, i.e.

$$t(p^*) = \max_{p\in P(n)} t(p) = \sum_{(i,j)\in p} t^{\pm}(i,j) \tag{3.3}$$

Computing $\max_{p\in P(n)} \sum_{(i,j)\in p} t^{\pm}(i,j)$ deals with the order of the grey number. At present, the order of the grey number does not have a satisfactory result (Wu and Huan, 2004). People try to solve problems from the other one to avoid complicated order definitions of a grey number. Thus people give the following definitions.

Reference (Chanas and Zielinski, 2002) gives the definition of the critical path as follows.

Definition 6. The path $p^* \in P(n)$ is a critical path if and only if for anyone $t(i,j) \in [t^-(i,j), t^+(i,j)], (i,j) \in A$, when substituting $t(i,j)$ for $t^{\pm}(i,j)$, one has

$$t(p^*) = \max_{p\in P(n)} \sum_{(i,j)\in p} t(i,j) \tag{3.4}$$

Reference (Liu and Chen, 1991) gives a definition of the critical path as follows.

Definition 7. Given a lower control limit t, the probability of $t(p) < t$ is as follows

$$F(p,t) = \begin{cases} 0 & t < t^-(p) \\ \dfrac{t - t^-(p)}{t^+(p) - t^-(p)} & t^-(p) \le t < t^+(p) \\ 1 & t^+(p) \le t \end{cases} \tag{3.5}$$

where $t^-(p) = \sum_{(i,j)\in p} t^-(i,j)$, $t^+(p) = \sum_{(i,j)\in p} t^+(i,j)$.

Definition 8. (Liu and Chen, 1991) Given a lower control limit t, the path $p^* \in P(n)$ is a critical path if and only if

$$F(p^*,t) = \min_{p\in P(n)} F(p,t) \tag{3.6}$$

This critical path has the following properties:

Property 1. $0 \le F(p^*,t) \le 1$.

Property 2. If $\min_{p\in P(n)} t^-(p) > t$, then $t(p^*) = \min_{p\in P(n)} t^-(p)$. Here $F(p,t) < 0 = F(p^*,t)$.

Property 3. If $\min_{p\in P(n)} t^+(p) \le t$, then $t(p^*) = \min_{p\in P(n)} t^+(p)$. Here $F(p^*,t) = 1$.

Property 4. Denote

$$\alpha = \max_{H\in\Gamma(GWG)} \frac{t - t^-(p)}{t^+(p) - t^-(p)} = \frac{t - t^-(p^*)}{t^+(p^*) - t^-(p^*)}$$

then $t(p^*) = \min_{p\in P(n)} t_\alpha^\pm(p)$.

Proof. Denote

$$\beta = \frac{t - t^-(p)}{t^+(p) - t^-(p)},$$

we have $t = t^-(p) + \beta[t^+(p) - t^-(p)]$. From definition of α, we have $t = t^-(p^*) + \alpha[t^+(p^*) - t^-(p^*)]$, thus

$$t = t^-(p) + \beta[t^+(p) - t^-(p)] = t^-(p^*) + \alpha[t^+(p^*) - t^-(p^*)].$$

Because $\alpha \geq \beta$, we have $t^-(p^*) + \alpha[t^+(p^*) - t^-(p^*)] \leq t^-(p) + \alpha[t^+(p) - t^-(p)]$. Therefore $t(p^*) = \min_{p\in P(n)} t_\alpha^\pm(p)$.

Since α is a deterministic number for a given t, from Definition 4, the length of path p^* is a minimum in all the whitening values $t_\alpha^\pm(p)$. Therefore, path p^* is a critical path.

For uncertain problems, if the objective is to solve for the maximum, people's preference in many cases is to follow two aspects. One is the upper objective value, while the other one is lesser uncertainty. They stand for similarly expectation and variance in terms of the concepts of probability theory. Thus we give the following definitions.

Definition 9. For the path $p \in P(n)$, expectation and relative expectation of the path p are as follows:

$$m(p) = \frac{1}{2}[\sum_{(i,j)\in p} t^+(i,j) + \sum_{(i,j)\in p} t^-(i,j)] \tag{3.7}$$

$$\tilde{m}(p) = \frac{m(p)}{\frac{1}{2}[T^+ + T^-]} = \frac{\sum_{(i,j)\in p}[t^+(i,j) + t^-(i,j)]}{T^+ + T^-} \tag{3.8}$$

Definition 10. For the path $p \in P(n)$, variance and relative variance of the path p are defined as follows:

$$d(p) = [\sum_{(i,j)\in p} t^-(i,j) - m(p)]^2 + [\sum_{(i,j)\in p} t^+(i,j) - m(p)]^2 \tag{3.9}$$

$$\tilde{d}(p) = \frac{d(p)}{\frac{1}{2}(T^+ - T^-)^2} = \frac{[\sum_{(i,j)\in p}(t^+(i,j) - t^-(i,j))]^2}{(T^+ - T^-)^2} \tag{3.10}$$

Definition 11. Given a lower control limit t, the path $p^* \in P(n)$ is a critical path if and only if

$$\min_{p\in P(n)}\{-\tilde{m}(p), \tilde{d}(p), F(p,t)\} \tag{3.11}$$

where $\tilde{m}(p)$ denotes the expectation of a decision-maker and $\tilde{d}(p)$ denotes variance of a decision-maker. They reflect objective demands of a decision-maker, and $F(p,t)$ reflects subjective demands of a decision-maker.

There are many methods to solve a multiobjective problem; we adopt the method of weighted average, i.e.

$$\min_{p\in P(n)} -\lambda_1\tilde{m}(p) + \lambda_2\tilde{d}(p) + \lambda_3 F(p,t) \tag{3.12}$$

Here $0 \le \lambda_1 \le 1$, $0 \le \lambda_2 \le 1$, $0 \le \lambda_3 \le 1$, $\lambda_1 + \lambda_2 + \lambda_3 = 1$.

It is obvious that the solution p^* of the above method must be the Pareto effective solution of formula (3.12).

C. Example

Suppose some project was shown in Fig. 3.1 as follows

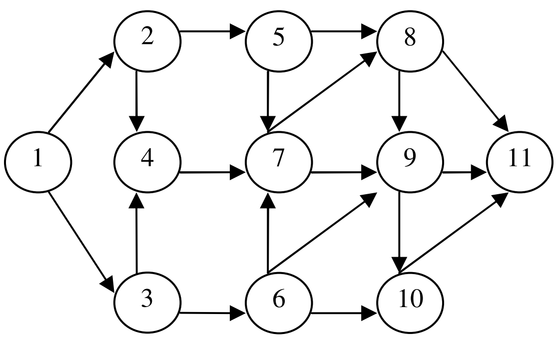

Fig. 3.1

where $t^\pm(1,2) = [4,4]$, $t^\pm(1,3) = [5,6]$, $t^\pm(2,4) = [4,4]$, $t^\pm(2,5) = [7,7]$, $t^\pm(3,4) = [3,4]$, $t^\pm(3,6) = [3,4]$, $t^\pm(4,7) = [7,8]$, $t^\pm(5,7) = [3,5]$, $t^\pm(5,8) = [2,2]$, $t^\pm(6,7) = [7,7]$, $t^\pm(6,9) = [6,15]$, $t^\pm(6,10) = [18,20]$, $t^\pm(7,8) = [2,3]$, $t^\pm(7,9) = [2,12]$,

$t^{\pm}(8,9)=[1,6]$, $t^{\pm}(8,11)=[6,11]$, $t^{\pm}(9,10)=[1,1]$, $t^{\pm}(9,11)=[6,7]$, $t^{\pm}(10,11)=[7,11]$.

We have

$$T^{-} = \max_{p\in P(n)} \sum_{(i,j)\in p} t^{-}(i,j) = 33,$$

$$p^{*} = 1-3-6-10-11.$$

$$T^{+} = \max_{p\in P(n)} \sum_{(i,j)\in p} t^{+}(i,j) = 42,$$

$$p^{*} = 1-3-4-7-9-10-11.$$

$$\tilde{m}(p^{*}) = 0.98667,\ p^{*} = 1-3-6-10-11.$$

$$\tilde{d}(p^{*}) = 0.3086,\ p^{*} = 1-2-5-8-11.$$

The relative expectation and relative variance of the above paths are shown in Table 3.1.

Table 3.1

Efficient solution p^{*}	1–3–4–7–9–10–11	1–3–6–10–11	1–2–5–8–11
$\tilde{m}(p^{*})$	0.893	0.986	0.573
$\tilde{d}(p^{*})$	3.567	0.790	0.308
$F(p^{*},38)$	0.764	0.625	1.000

We can see from data in Table 3.1: The path $p^{*} = 1-3-4-7-9-10-11$ is the critical path in the worst state. If the decision-maker's preference is an expectation, the path $p^{*} = 1-3-6-10-11$ is the critical path. If the decision-maker's preference is variance, the path $p^{*} = 1-2-5-8-11$ is the critical path. If the decision-maker's preference is probability, the path $p^{*} = 1-3-6-10-11$ is the critical path.

For $\min_{p\in P(n)}\{-\tilde{m}(p),\tilde{d}(p),F(p,t)\}$, when $\lambda_2 \geq 0.8$, $\lambda_1+\lambda_3 \leq 0.2$, the path $p^* = 1-2-5-8-11$ is the critical path; when $\lambda_2 < 0.8$, $\lambda_1+\lambda_3 > 0.2$, the path $p^* = 1-3-6-10-11$ is the critical path. Therefore, if decision-maker's preference is variance, the path $p^* = 1-2-5-8-11$ is the critical path, otherwise the path $p^* = 1-3-6-10-11$ is the critical path. It is obvious that the path $p^* = 1-3-6-10-11$ is the critical path. Since this decision balances objectives preferably, it is satisfactory decision.

4 Conclusion

Uncertainty is the main factor restricting a decision-maker's decision-making availability. The traditional single objective study method is too objective or too subjective, especially for unconventional uncertainty problems. The objective factors are important reference factors in the decision-making process and subjective factors are even more. It can enhance decision-making availability to combine subjective factors with objective factors. In this paper, the critical path of the grey interval project network is discussed and the perfect method is given by method of combining subjective factors with objective factors.

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A New Dynamic Clustering Algorithm for an Interval Grey Number*

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In this chapter, the grey dynamic clustering algorithm of an interval grey number is proposed by the joint application of the basic idea of fuzzy equivalent clustering and the method of the grey system theory. Firstly, the similarity coefficient formula of the interval grey number is discussed, and then the clustering of the interval grey number is realized by making use of the transitive closure method. This algorithm combines the grey system theory and the fuzzy set theory, which expands the range of classical equivalent clustering algorithms from the legible number to the interval grey number. Therefore, it's more versatile, and its effectiveness is testified by an example.

1 Introduction

Grey system theory ((Liu and Dang, 2004; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), proposed by Professor Deng Julong in the 80s of the 20th century, is a new, powerful tool that can deal with the uncertainty of information. Grey clustering is a method that divides a number of objects into classes according to the grey incidence matrix or the white whitenization function. The classical decision-making method of grey clustering is established based on the clarity of the definition of the index evaluation, and it cannot deal with the evaluation of the interval grey number. However, with the continuous development of society, people face more and more complex problems, and the uncertainty of the problems and human

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* This work was supported in part by the Planning Project of the National Eleventh-Five Science and Technology (2007BAK34B04), the Chinese National Natural Science Fund (60704042), the Aeronautical Science Foundation (20080768004), the Open Project Program of the Key Lab. of Intelligent Manufacture of Hunan Province (XTU) and the Program of 211 Innovation Engineering on Information in Xiamen University (2009-2011).

thinking have been enhanced. In the actual decision-making process, we often cannot obtain all the decision-making information, but we can usually get decision-making information about the rough scope of the information, the information of the interval grey number. Based on that, the reference (Luo, 2004) has discussed clustering decision-making when the index evaluation of object is an interval grey number, and it also has established the incidence coefficient formula and relative incidence coefficient formulas for the grey interval number. The clustering decision-making method has been proposed based on the grey interval incidence coefficient and a pre-set class number by making use of the grey whitenization function. The above problems have been resolved to some extent by this method. However, firstly, this method should determine the number of classes in advance, and if the number of classes is unknown, the algorithm is not feasible. Secondly, it needs experts to predetermine the whitenization weight function, so the subjective factors of the experts have influence on the classification results. Finally, the calculation process of the algorithm is complex and difficult for decision-making.

Fuzzy mathematics has been developed enormously since Zadeh introduced the concept of fuzzy sets in 1965. With in-depth study, we find that the membership function of fuzzy sets is difficult to be determined in the application, and then the membership degree of interval value is easier to be determined. Moreover, the results of fuzzy reasoning expressed by fuzzy sets for interval value can better reflect the fuzziness of day-to-day reasoning (Wu, 1992). Therefore, the extending form of fuzzy sets, interval-valued fuzzy sets, are more and more common in recent years (Wu, 1992; Zhang and Wang, 1991; Ibuchih and Tanaka, 1993; Mandal, 1997; Fan, 1998). The three FCM clustering algorithm of interval-valued data is given in the reference (Gao et al., 2003; Wu et al., 2005), and they can directly cluster by the classical FCM algorithm with the membership function through pretreatment, but the algorithms cluster by turning the interval grey number into a white number (that is, a definite number), or they cluster by making the use of a simple distance formula. Although the above-mentioned methods can make use of the existing classical FCM algorithm, they reduce the credibility of the results.

In this chapter, the algorithm of interval grey clustering based on the equivalence relation overcomes the above-mentioned shortcomings: Firstly, a similarity coefficient formula for the interval grey number is established by making full use of all information of the interval grey number and on the basis that the interval grey number isn't turned into white number. Secondly, it needn't predetermination of the number of classes that can perform dynamic classification of the transitive closure method by making use of fuzzy equivalence relations. Thirdly, it also needn't subjective determination of the whitenization weight function by experts, so it can increase the objectivity of the algorithm, and it greatly simplifies the process of calculation so that it is easy for decision-making.

2 Basic Concepts

Definition 1. Let $\tilde{a} = [a^L, a^U] = \{x | a^L \le x \le a^U, \ a^L, a^U \in \boldsymbol{R}\}$, so $\tilde{a}$ is an interval grey number. In particular, if $a^L = a^U$, then $\tilde{a}$ degenerates into a real number.

If the relation $\underset{\sim}{R}$ of a domain X meets the conditions:

(1) reflexivity $\mu_{\underset{\sim}{R}}(x, x) = 1$

(2) symmetry $\mu_{\underset{\sim}{R}}(x, y) = \mu_{\underset{\sim}{R}}(y, x)$

(3) transitivity $\boldsymbol{R}^2 \subseteq \boldsymbol{R}$

Fuzzy relation $\underset{\sim}{R}$ is called an Equivalence Relation.

The fussy relation $\underset{\sim}{R}$ that meets the reflexivity and symmetry is called a fuzzy similar relation or fuzzy compatibility relations.

3 The Algorithm for Grey Interval Incidence Clustering Decisions (GICD)

The Method for Grey Interval Incidence Clustering Decisions (GICD) (Luo, 2004) is mainly through the expansion of the grey incidence coefficient formula so that it can also be applied to calculate the interval grey incidence coefficient to achieve the purpose of clustering decision-making.

For a clustering problem, let $X = \{x_1, x_2, \cdots x_n\}$ be the set of all involved objects and $U = \{u_1, u_2, \cdots u_m\}$ be the set of evaluating indicators. The nonnegative interval grey number $\tilde{a}_{ij} = [a_{ij}^L, a_{ij}^U]$ is the effect-evaluating value of object $x_i (1 \le i \le n)$ for indicator u_j $(1 \le j \le m)$. The effect-evaluating vector of object x_i is denoted by $\tilde{a}_i = ([a_{i1}^L, a_{i1}^U], [a_{i2}^L, a_{i2}^U], \cdots, [a_{im}^L, a_{im}^U])$. Try to divide the objects for the decision into p grey classes.

Perform the Grey Extreme Difference Transform on effect-evaluating vectors for the purpose of eliminating dimensions and for better comparability.

For a beneficial type of the target value,

$$\begin{cases} r_{ij}^L = \dfrac{a_{ij}^L - a_{j*}}{a_j^* - a_{j*}} \\[2ex] r_{ij}^U = \dfrac{a_{ij}^U - a_{j*}}{a_j^* - a_{j*}} \end{cases} \tag{3.1}$$

For the cost type of the target value,

$$\begin{cases} r_{ij}^{L} = \dfrac{a_j^{*} - a_{ij}^{U}}{a_j^{*} - a_{j*}} \\ r_{ij}^{U} = \dfrac{a_j^{*} - a_{ij}^{L}}{a_j^{*} - a_{j*}} \end{cases} \tag{3.2}$$

where $a_j^{*} = \max_{1\le i\le n}\{a_{ij}^{U}\}$, $a_{j*} = \min_{1\le i\le n}\{a_{ij}^{L}\}$, $(j = 1,2,\cdots m)$. Then we get a Normalized evaluation vector $\tilde{r}_i = ([r_{i1}^{L}, r_{i1}^{U}],[r_{i2}^{L}, r_{i2}^{U}],\cdots,[r_{im}^{L}, r_{im}^{U}]$.

Definition 2. Suppose that the effect-evaluating vector of every object is denoted by the following: After normalization

$$\tilde{r}_i = ([r_{i1}^{L}, r_{i1}^{U}],[r_{i2}^{L}, r_{i2}^{U}],\cdots,[r_{im}^{L}, r_{im}^{U}]$$

where $[r_{ij}^{L}, r_{ij}^{U}]$ is a nonnegative interval grey number within [0,1]. Let

$$r_j^{L+} = \max_{1\le i\le n}\{r_{ij}^{L}\},\ r_j^{U+} = \max_{1\le i\le n}\{r_{ij}^{U}\},\ (j = 1,2,\cdots m) \tag{3.3}$$

Then, the m-dimensional vector of nonnegative interval grey number

$$\tilde{r}^{+} = ([r_1^{L+}, r_1^{U+}],[r_2^{L+}, r_2^{U+}],\cdots[r_m^{L+}, r_m^{U+}]) \tag{3.4}$$

is called the ideal effect-evaluating vector of the evaluated objects.

Definition 3. Suppose that the effect-evaluating vector and the ideal effect-evaluating vector of objects are defined as formula (3.3), respectively, in Definition 2, then

$$\gamma_{ij}^{+} = \frac{1}{2}\left(\frac{\min\limits_{1\le i\le n}\min\limits_{1\le j\le m}\left|r_j^{L+} - r_{ij}^{L}\right| + \lambda \max\limits_{1\le i\le n}\max\limits_{1\le j\le m}\left|r_j^{L+} - r_{ij}^{L}\right|}{\left|x_j^{L+} - x_{ij}^{L}\right| + \lambda \max\limits_{1\le i\le n}\max\limits_{1\le j\le m}\left|x_j^{L+} - x_{ij}^{L}\right|} + \frac{\min\limits_{1\le i\le n}\min\limits_{1\le j\le m}\left|x_j^{U+} - x_{ij}^{U}\right| + \lambda \max\limits_{1\le i\le n}\max\limits_{1\le j\le m}\left|x_j^{U+} - x_{ij}^{U}\right|}{\left|x_j^{U+} - x_{ij}^{U}\right| + \lambda \max\limits_{1\le i\le n}\max\limits_{1\le j\le m}\left|x_j^{U+} - x_{ij}^{U}\right|} \right) \tag{3.5}$$

is called the grey interval incidence coefficient of sub-factor $[r_{ij}^{L}, r_{ij}^{U}]$ to the ideal factor $[r_j^{L+}, r_j^{U+}]$ $(i = 1,2,\cdots,n,\ j = 1,2,\cdots,m)$, where $\lambda \in [0,1]$ is the recognition coefficient (or call it the relative factor adjusted to the environment).

The GICD arithmetic steps are as follows:

Step 1: Normalize the effect-evaluating vectors (the evaluating vector for a non-negative grey number) by formula (3.1) or (3.2) (the grey extreme difference transform), and the normalization is shown as $\tilde{r}_i = ([r_{i1}^L, r_{i1}^U],$ $[r_{i2}^L, r_{i2}^U], \cdots, [r_{im}^L, r_{im}^U])$; then, we can get the ideal effect-evaluating vector of object by Definition 2, as shown in formula (3.4).

Step 2: For all objects, calculate their grey incidence coefficient vectors, which are $\gamma_i^+ = (\gamma_{i1}^+, \gamma_{i2}^+, \cdots, \gamma_{im}^+)$, $(i = 1, 2, \cdots, n)$ by the grey interval incidence coefficient formula (3.5).

Step 3: To decide the number of grey classes p according to the decision problem, divide the range of the grey interval incidence coefficient of the object, related to the ideal object for indicator u_j $(j = 1, 2, \cdots, m)$, into p smaller intervals.

Step 4: By practical application or the qualitative research of experts, we can get the whitenization weight function $f_j^k(x)$ $(j = 1, 2, \cdots, m;\ k = 1, 2, \cdots, p)$ of grey class k for indicator u_j if the weight vector $\eta = (\eta_1, \eta_2, \cdots, \eta_m)$ of the indicator is unknown, then it may be calculated by the formula

$$\eta_j = \left\{ \sum_{k=1}^{m} \left[\sum_{i=1}^{n} (1 - \gamma_{ij}^+)^2 \Big/ \sum_{i=1}^{n} (1 - \gamma_{ik}^+)^2 \right] \right\}^{-1}, \ (j = 1, 2, \cdots, m).$$

Step 5: For object x_i $(i = 1, 2, \cdots, n)$, belonging to grey class k $(k = 1, 2, \cdots, p)$, calculate the synthetic clustering coefficient σ_i^k $(i = 1, 2, \cdots, n;\ k = 1, 2, \cdots, p)$ as $\sigma_i^k = \sum_{j=1}^{m} f_j^k(\gamma_{ij}^+) \cdot \eta_j^k$. Calculate the grey class to which object x_i belongs by using the formula $\max_{1 \le k \le p} \left\{ \sigma_i^k \right\} = \sigma_i^{k^*}$. Then, in the same grey class, rank the order of the objects for the decision by their clustering coefficients.

4 The Interval Grey Number Dynamic Clustering Algorithm Based on the Equivalence Relations

In order to quantify the classification, we must first determine some number indicators of the classifications. The number index denotes the degree of similarity between samples (or variables), known as the clustering statistics. Clustering statistics can be divided into two categories, similarity and distance. By comparing a variety of the similarity formula (Wu et al., 2005), the author proposes a similarity coefficient formula between the interval grey number vectors as follows:

Definition 4. Let interval grey number vectors

$$\tilde{\boldsymbol{a}} = ([a_1^L, a_1^U],[a_2^L, a_2^U],\cdots[a_m^L, a_m^U]),$$

$$\tilde{\boldsymbol{b}} = ([b_1^L, b_1^U],[b_2^L, b_2^U],\cdots[b_m^L, b_m^U]).$$

The definition of the max-min similarity coefficient between the interval grey numbers is as follows:

$$n(\tilde{\boldsymbol{a}},\tilde{\boldsymbol{b}}) = \frac{\sum_{j=1}^{m}[\min(a_j^L, b_j^L) + \min(a_j^U, b_j^U)]}{\sum_{j=1}^{m}[\max(a_j^L, b_j^L) + \max(a_j^U, b_j^U)]} \tag{4.1}$$

Easily proved:

(1) Reflexivity: $n(\tilde{\boldsymbol{a}},\tilde{\boldsymbol{a}}) = 1$,

(2) Symmetry: $n(\tilde{\boldsymbol{a}},\tilde{\boldsymbol{b}}) = n(\tilde{\boldsymbol{b}},\tilde{\boldsymbol{a}})$.

In addition, if $a_i^L = a_i^U, b_i^L = b_i^U, (i = 1,2\cdots,m)$ so that the interval grey number degenerates into a clear number, formula (4.1) degenerates into

$$n(\boldsymbol{a},\boldsymbol{b}) = \frac{\sum_{j=1}^{m}\min(a_j, b_j)}{\sum_{j=1}^{m}\max(a_j, b_j)} \tag{4.2}$$

Formula (4.2) is the max-min similarity coefficient formula in the classical fuzzy clustering algorithm (Wu et al., 2005). It can be seen that (4.2) is the special condition of (4.1), and the interval grey number equivalent cluster contains the classical fuzzy equivalent clustering. Formula (4.1) established a bridge between the grey system and the fuzzy theory, which has a more extensive application value.

In accordance with the formula (4.1) and normalized matrix $\tilde{\boldsymbol{R}} = (\tilde{r}_{ij})_{n\times m}$, whose row vector is the normalized one,

$$\tilde{r}_i = ([r_{i1}^L, r_{i1}^U],[r_{i2}^L, r_{i2}^U],\cdots,[r_{im}^L, r_{im}^U]), (i = 1,2,\cdots,n).$$

The similarity coefficient n_{ij} that is characterized by the similar degree of classified objects can be calculated, and then the fuzzy similarity relation matrix $\boldsymbol{N} = (n_{ij})_{n\times m}$ can be established. It is clear that it only satisfies the reflexivity and symmetry, but it does not satisfy transitivity. So it is not a fuzzy equivalence relation, and it should be transformed into a fuzzy equivalence relation. Here $\boldsymbol{N}^*$ is different from $\boldsymbol{N}$, but $\boldsymbol{N}^*$ is the smallest transitive closure containing $\boldsymbol{N}$.

The transitive closure of the similar matrix $\boldsymbol{N}$ can be obtained by the square method:

$$\mathrm{N} \to \mathrm{N}^2 \to \mathrm{N}^4 \to \cdots \mathrm{N}^{2k} = \mathrm{N}^*,\ 2^{k-1} < n \le 2^k;\ \text{that is, } k-1 < \log_2^n \le k .$$

Using the above method, a maximum of only $[\log_2^n + 1]$ steps will be needed to find N^*. Here $[x]$ is the greatest integer containing x.

In fact, N^* is the smallest equivalent matrix that contains N. We set to do the following transformation of the elements in matrix N^* for arbitrary $\lambda \in [0,1]$:

$$n_{ij}^* = \begin{cases} 1, if \ \ n_{ij}^* \ge \lambda \\ 0, if \ \ n_{ij}^* \le \lambda \end{cases}$$

After the above transformation, we can get an ordinary equivalence relation, that is the λ level matrix N_λ^* of N^*, thus determining a classification. When λ changes, the classification also changes, so it is a dynamic clustering method. There is no need to determine the classification number ahead, but in accordance with specific issues to select the appropriate λ level, it can be classified accordingly.

5 Clustering Algorithm

Based on the above definition, the interval grey number dynamic clustering algorithm based on the equivalence relations is proposed. Concrete steps are as follows:

Step 1: For a clustering problem, let $X = \{x_1, x_2, \ \cdots x_n\}$ be the set of all involved objects, and $U = \{u_1, u_2, \cdots u_m\}$ is the set of evaluating indicators. The nonnegative interval grey number $\tilde{a}_{ij} = [a_{ij}^L, a_{ij}^U]$ is the effect-evaluating value of object $x_i (1 \le i \le n)$ for indicator $u_j (1 \le j \le m)$. Then, the sample data matrix $\tilde{\boldsymbol{A}} = (\tilde{a}_{ij})_{n \times m}$ is obtained. Perform the grey extreme difference transform on $\tilde{a}_{ij}$ by formula (3.1) and (3.2), so normalized matrix $\tilde{\boldsymbol{R}} = (\tilde{r}_{ij})_{n \times m}$ is obtained.

Step 2: Calculate the fuzzy similarity matrix of $\tilde{\boldsymbol{R}}$ by formula (4.1).

Step 3: Obtain the smallest transitive closure N^* of $\boldsymbol{N}$.

Step 4: In accordance with the specific issues, select the appropriate λ level, get the λ level matrix N_{λ}^{*} of N^{*}, and then get the dynamic cluster.

6 An Example

To increase the comparability to reference (Luo, 2004), do some slight modifications to the example of reference (Luo, 2004).

The decision problem is on housing investment (i.e. buying uptowns): There are 5 kinds of investable uptowns (objects), which are denoted by x_1, x_2, x_3, x_4 and x_5, respectively. Suppose that an investor considers 5 indicators in housing investment, i.e. u_1 (m^2)-area of the house, u_2 (level)-equipment, u_3 (level)-environment, u_4 (yuan/m2)-price and u_5 (km)-distance to work place. Among the 5 indicators, u_1, u_2 and u_3 are the benefit type of indicators; u_4 and u_5 are the cost type of indicators. For these four kinds of uptowns, their evaluating value of indicators is shown in Table 6.1 (without considering other factors, such as endurable price of investors, etc.). Make a decision on the objects worthy of investment and do a cluster analysis on these 5 investable uptowns.

Solve this problem using the clustering algorithm above.

Step 1: Perform the grey extreme difference transform on $\tilde{a}_{ij}$ in Table 6.1 by formula (3.1) and (3.2), so the normalized result is obtained as shown in Table 6.2.

Normalized matrix $\tilde{\boldsymbol{R}} = (\tilde{r}_{ij})_{n\times m}$ is obtained by Table 6.2.

$$\tilde{\boldsymbol{R}}=\begin{pmatrix} [0.\ 57143, 1] & [1,1] & [0.25,0.5] & [0.75,1] & [0.83333,0.83333] \\ [0.28571,0.71429] & [0,0] & [0,0.25] & [0.625,0.875] & [1,1] \\ [0,0.28571] & [0.5,0.5] & [0.875,1] & [0,0.25] & [0,0] \\ [0.14286,0.42857] & [0.5,0.5] & [0.5,0.625] & [0.625,0.875] & [0.66667,0.66667] \\ [0.57143, 1] & [1, 1], & [0.875, 1] & [0.75, 1] & [1, 1] \end{pmatrix}$$

Table 6.1

EVALUATING VALUE OF INDICATORS FOR FIVE KINDS OF UPTOWNS

objects	u_1	u_2	u_3	u_4	u_5
x_1	[90,120]	[7, 7]	[6, 8]	[2900,3100]	[10, 10]
x_2	[70,100]	[3, 3]	[4, 6]	[3000,3200]	[8, 8]
x_3	[50, 70]	[5, 5]	[11, 12]	[3500,3700]	[20, 20]
x_4	[60, 80]	[5, 5]	[8, 9]	[3000,3200]	[12, 12]
x_5	[90,120]	[7, 7]	[11, 12]	[3500,3700]	[20, 20]

Table 6.2

NORMALIZED EVALUATING VALUE OF OBJECTS FOR FIVE INDICATORS

objects	u_1	u_2	u_3	u_4	u_5
x_1	[0. 57143, 1]	[1,1]	[0.25,0.5]	[0.75,1]	[0.83333,0.83333]
x_2	[0.28571,0.71429]	[0,0]	[0,0.25]	[0.625,0.875]	[1,1]
x_3	[0,0.28571]	[0.5,0.5]	[0.875,1]	[0,0.25]	[0,0]
x_4	[0.14286,0.42857]	[0.5,0.5]	[0.5,0.625]	[0.625,0.875]	[0.66667,0.66667]
x_5	[0.57143, 1]	[1,1]	[0.875,1]	[0.75,1]	[1, 1]

Step 2: Calculate fuzzy similarity matrix of $\tilde{\boldsymbol{R}}$ by formula (4.1). That is,

$$n(x_1, x_2) = \frac{4.41666}{8.07143} = 0.54720 \approx 0.55$$

The detailed calculations are omitted. Lastly we get the similarity coefficient matrix:

$$\boldsymbol{N} = \begin{pmatrix} 1 & 0.55 & 0.26 & 0.64 & 0.95 \\ 0.55 & 1 & 0.11 & 0.55 & 0.52 \\ 0.26 & 0.11 & 1 & 0.42 & 0.37 \\ 0.64 & 0.55 & 0.42 & 1 & 0.60 \\ 0.95 & 0.52 & 0.37 & 0.6 & 1 \end{pmatrix}$$

For the calculation here, the author would like to point out that the normalized vector $\boldsymbol{r}_5 = ([0.57143,\ 1],[1,\ 1],[0.875,\ 1],[0.75,\ 1],[1,\ 1])$ of sample x_5 in this case is the same as the ideal effect-evaluating vector in the example in reference (Luo, 2004). According to the meaning of the similarity coefficient, such a conclusion can be drawn by the last row $\boldsymbol{n}_5 = (0.95, 0.52, 0.37, 0.6, 1)$ in matrix $\boldsymbol{N}$: The close degree of samples x_1, x_2, x_3, x_4 to the ideal object x_5 is 0.95, 0.52, 0.37, 0.61 so that we can easily come to the conclusion in the example in reference (Luo, 2004) that the order of uptowns is $x_1 \succ x_4 \succ x_2 \succ x_3$. However, this method greatly simplifies the cumbersome decision-making process of the GICD method, so that the process of decision-making steps and the calculation are simpler. If there are more options, this new Algorithm is still easy to use to carry out the decision-making. At the same time, this method avoids determining the subjective whitenization weight function, so that the decision-making is more objective and therefore more reliable.

In addition, we may now divide the objects into 3 grey classes, like the result in reference (Luo, 2004): h_1 (the grey class worthy of investment), h_2 (the grey class backup), and h_3 (the grey class not suitable for investment). For $\boldsymbol{n}_5 = (0.95, 0.52, 0.37, 0.6, 1)$, if setting $\lambda = 0.6$, the λ level matrix is

$(1,0,0,1,1)$, so we get the result that $h_3 = \{x_2, x_3\}$. For the same reason, if setting $\lambda = 0.6$, we get $h_1 = \{x_1\}$. If setting $\lambda = 0.6$ and weeding out the best x_1, we can get $h_2 = \{x_4\}$. It can be seen that the conclusion by the GICD method is the conclusion that makes x_5 the sole standard of a "classification". It is not a true cluster analysis.

Step 3: Obtain the smallest transitive closure N^* of $\boldsymbol{N}$.

$$\boldsymbol{N}^2 = \begin{pmatrix} 1 & 0.55 & 0.42 & 0.64 & 0.95 \\ 0.55 & 1 & 0.42 & 0.55 & 0.55 \\ 0.42 & 0.42 & 1 & 0.42 & 0.42 \\ 0.64 & 0.55 & 0.42 & 1 & 0.64 \\ 0.95 & 0.55 & 0.42 & 0.64 & 1 \end{pmatrix} = \boldsymbol{N}^4 = N^*$$

Step 4: Get the λ level matrix N^*_λ of N^*, then obtain the dynamic cluster.

If setting $\lambda = 0.55$, the λ level matrix of N^* is the following:

$$N^*_{0.55} = \begin{pmatrix} 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 \end{pmatrix}$$

It is easily seen from N^* that 5 uptowns can be divided into 2 classes: x_1, x_2, x_4, x_5 are in a class , and x_3 is another class.

If setting $\lambda = 0.64$, the λ level matrix of N^* is the following:

$$N^*_{0.55} = \begin{pmatrix} 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 \end{pmatrix}$$

So they can be divided into 3 classes: x_1, x_4, x_5 are in a class, and x_2, x_3 are 2 other classes.

If setting $\lambda = 1$ or $\lambda = 0.42$, then $N^*_1 = \boldsymbol{I}, N^*_{0.42} = \boldsymbol{E}$. The former one divides these five uptowns into their respective categories for classes of 5, but the latter one merges these 5 uptowns into a class.

From the above classification process, it's not difficult to see that the class result is relevant to λ values. The greater λ is, the more classes there are. When λ is low to a value, all samples are classified as a class. Therefore, we can adjust the value of λ to obtain the appropriate classes, according to the needs of practical problems, without setting the number of classes first.

7 Conclusion

In this chapter, the following work is summarized:

1. The similarity coefficient formula of a interval grey number is established, which lays the foundation for the grey dynamic cluster.
2. The grey dynamic cluster algorithm of the interval grey number is proposed to overcome the limitation that fuzzy equivalent clustering cannot apply to the interval grey number.
3. The subjectivity and limitations of the GICD method is analyzed and simplified, and the decision-making of the interval grey number is made easier.
4. An example is given to illustrate the rationality of the grey dynamic cluster algorithm of an interval grey number and the validity of the relational arithmetic.

In short, this chapter presents a new algorithm to analyze the clustering of the interval grey number based on the idea of the grey system theory, and the establishment of the similarity coefficient formula of the interval grey number, which combines with the use of the fuzzy equivalent clustering to achieve the clustering of the interval grey number, and it expands the range of the classical equivalent clustering algorithms from the legible number to the interval grey number.

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Research on the New Algorithms of Simple Grey Numbers, Complex Grey Numbers and Multiple Grey Numbers*

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Although the grey systems theory has been successfully utilized in many fields and demonstrates promising results, literature shows that its performance still could be improved. Remarks on grey numbers and algorithms of grey numbers need to be farther discussed. The grey number is the basic element of the grey systems theory. The algorithms of grey numbers are the foundation of grey mathematics. This chapter modifies the definition of a grey number and discusses several remarks on grey numbers. We propose a method for abstracting the information of a grey number covered set. And, we propose the algorithms of simple grey numbers, complex grey numbers and multiple grey numbers. All these works are meaningful to bringing grey mathematics to perfection, and they propose more grey applying models.

1 Introduction

Based on widespread divisions in activities of scientific research, a highly synthetic tendency has brought forward many cross-disciplinary theories. Systems science has revealed more profoundly and essentially some important internal relations among the subjects, which deeply promoted the integrative progress of modern science and technology, see (Liu and Lin, 2006; Lin et al., 2004). With the help of these new theories, many complicated or unsolvable problems can now be resolved successfully. These theories include systems theory, information theory, cybernetics, synergetic theory and general systems theory. Because the information people obtain is always uncertain and limited, a variety of uncertainty theories emerged. Young R.C. and Moore R E. proposed the interval number (see (Young, 1931;

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* The work is partially supported by the Research Fund for the Doctoral Program of National Ministry of Education though Grant NO. 200802870020. At the same time the authors would like to acknowledge the philosophy and social science research fund of NUAA via Grant V0865-091.

Moore, 1979; Ishihuchi and Tanaka, 1990), L.A. Zadeh proposed fuzzy mathematics and Z. Pawlark proposed the rough sets theory (Pawlak, 1982; Pawlak et al., 1995; Zadeh, 1965). In the meantime, because of limited information and knowledge, only part of system structure could be fully realized. To overcome this problem, Deng J.L. proposed the grey systems theory (Deng, 1982; Deng, 1988a; 1988b; 1992; 1993a; 1993b; 1995a; 1995b; 1995c; 1999a). The grey systems theory has been successfully utilized in many fields and has demonstrated promising results (Zhang et al., 2003; Wu and Chang, 2003; 2004; Shen Victor et al., 2005; Li et al., 2006). Deng compared the difference among the grey systems theory, probability theory and fuzzy theory (Deng, 1995d). A grey number is used to describe the problems with small samples of poor information, and it has been applied in systematic analysis, forecasting, control and decision-making. Although grey systems have been widely used, there are many problems that need to be solved. The algorithms of the numbers are the most important problem. We can analyze the problem using the following example.

Example 1.1. For grey numbers $\otimes_1 \in [2,3]$, $\otimes_2 \in [4,6]$, if

$$\otimes_3 = \otimes_1 + \otimes_2 , \otimes_4 = \otimes_1 \times \otimes_2 ,$$

then

$$\otimes_3 = \otimes_1 + \otimes_2 \in [2,3] + [4,6] = [6,9],$$

$$\otimes_4 = \otimes_1 \times \otimes_2 \in [2,3] \times [4,6] = [8,18]$$

But

$$\otimes_3 - \otimes_1 \in [6,9] - [2,3] = [3,7] \neq \otimes_2$$

and

$$\otimes_4 \div \otimes_1 \in [8,18] \div [2,3] = [2.667,9] \neq \otimes_2 .$$

From example 1.1, we know that the operations $+$ and $-$ are not invertible operations and that the operations $\times$ and $\div$ are not invertible operations in existing algorithms of grey numbers. Therefore, we need to establish new algorithms. Presently, there are many difficulties in the grey systems theory. Grey numbers and their algorithm are the essential problems. Literature is misconceived or incorrectly expressed on grey numbers and their algorithm (Deng, 1999b; 2002; Li and Liu, 2007)). The paper (Deng, 1999b) proposed the grey number and several simple algorithms. The paper (Deng, 2002) showed the concrete algorithm, which is analogous with the algorithm of interval numbers. The paper (Li and Liu, 2007) farther discussed the algorithm of grey numbers. More algorithms were proposed and suited for discrete grey numbers, continuous grey numbers and mixed grey numbers. All the literature could not solve the invertible operations problems. For these reasons, grey mathematics has not been correctly established. In this chapter, in order to promote the grey systems theory and establish grey mathematics, we will modify some remarks on the grey number and propose new algorithms.

The remaining chapter is organized as follows: In section 2, we modify the definition of the grey number, and some remarks on the grey number are discussed. We also propose a method of abstracting information of grey numbers. In section 3, the algorithms of grey numbers are discussed. Finally, section 4 comes to the conclusions of this chapter.

2 Definitions and Information on the Abstracting Method of Grey Numbers

A. Definition and some remarks of grey numbers

Definition 2.1. A proposition is a sentence that includes an object and some characters of the object. We marked the proposition as $\mathscr{P}$.

Definition 2.2. The whole character information of an object is called the proposition-information field or the information background of the proposition, which is marked as $\mathscr{P}(\theta)$.

Definition 2.3. Due to some proposition $\mathscr{P}$, $\mathscr{P}(\theta)$ is the proposition-information field. Since the proposition is expressed incompletely and since it is difficult to catch all the information of the proposition, we can only know the probable range of the proposition's value or a set, including several values. The set is marked as D. So, the proposition can be expressed as an uncertain number $\otimes$ under the $\mathscr{P}(\theta)$. d^* is the true value of the proposition. Then, we call

(1) $\otimes$ is a grey number under the proposition $\mathscr{P}$.
(2) D is the value-covered set of $\otimes$.
(3) $\mathscr{P}(\theta)$ is the information background of grey number $\otimes$.
(4) d^* is the true value of grey number $\otimes$.

Generally, we mark the grey number as $\forall \otimes \Rightarrow d^* \in D$.

From definitions 2.1-3, we can farther comprehend the meaning of a grey number.

Remark 2.1. Grey number $\otimes$ is a real number, but its certain value is unknown. $\otimes$ is not isolated but exists with a proposition $\mathscr{P}$. There is no concrete proposition, and the grey number is meaningless.

Remark 2.2. Value-covered D is a real number set, including the true value d^*. It is the extension of proposition $\mathscr{P}$ under the information background $\mathscr{P}(\theta)$. The value-covered D depends on the information background $\mathscr{P}(\theta)$. With the information increasing continually, the range of value-covered D becomes less. When all the information is obtained, the grey number becomes a real number. So, the value-covered D embodies dynamic and evolutive properties.

Remark 2.3. True value d^* is a real number. It is the connotation of the proposition $\mathscr{P}$ and the grey number $\otimes$. We know the value d^* exists in the value-covered set D, but we don't know the certain value.

Remark 2.4. The true value d^* is unknown. When we do the operations of grey numbers, no information of the grey number can be decreased arbitrarily, i.e. all the values in value-covered D are needed to do the operations or we could lost the true value d^*.

Remark 2.5. When the grey number $\otimes$ is defined, the value-covered set D and the true value d^* are defined accordingly.

Example 2.1. The stature of an adult is a grey number. Suppose the value is estimated to be 1.8 to 1.9 meters before measuring. Then, $D=[1.8,1.9]$ is the value-covered set of the stature. If we measured the value of the stature to be 1.86 meter, $d^*=1.86$ is the true value of the stature.

The grey number is a real number under a given information background, and we merely know the range of the grey number but don't know the certain value of it. As a real number, it can't be differentiated as continuous or discrete. But as a value-covered set D, it can be differentiated as continuous or discrete. According to the different form of the value-covered set, we can propose the concept of the continuous grey number, discrete grey number and mixed grey number.

Definition 2.4. Let D be a value-covered set of grey number $\otimes$, if

(1) D is a continuous set, i.e. an interval number, we call D the continuous covered set of grey number $\otimes$ and $\otimes$ as a continuous grey number. It is marked as $\forall\otimes \Rightarrow d^* \in D, D=[a,b]$ or $\otimes=[a,b]$.

(2) D is a discrete set, and we call D as the discrete covered set of grey number $\otimes$ and $\otimes$ as a discrete grey number. It is marked as $\forall\otimes \Rightarrow d^* \in D, D=\{d_1,d_2,\cdots,d_n\}$ or $\otimes=\{d_1,d_2,\cdots,d_n\}$.

(3) D is a union set of continuous sets and discrete sets, and we call D the mixed covered set of grey number $\otimes$, and the grey number $\otimes$ is called a mixed grey number. $\otimes$ is marked as $\forall\otimes \Rightarrow d^* \in D, D=[a,b]\bigcup\{d_1,d_2,\cdots,d_n\}$ or $\otimes=[a,b]\bigcup\{d_1,d_2,\cdots,d_n\}$.

Example 2.2. (1) Suppose someone's age is probably 18, 19, 20 or 21. Then the age is a discrete grey number, marked as $\otimes=\{18,19,20,21\}$.

(2) Suppose someone's avoirdupois is between 70 and 75 kg. Then the avoirdupois is a continuous grey number, marked as $\otimes=[70,75]$.

(3) Suppose a company needs to add investment. There are two channels of adding investment; one channel is when stockholders add 3000, 4000 or 5000 dollars. The other channel is when the employees collect 2000 to 4000 thousands dollars. So, the total investment is a mixed grey number, marked as $\otimes=[2000,4000]\bigcup\{3000,4000,5000\}$.

B. Information abstracting method of grey numbers

Definition 2.5. Suppose D_1 and D_2 are the value-covered set of grey number $\otimes$. If $D_1 \subset D_2$, then we call D_1 the relative superior value-covered set of $\otimes$ and D_2 the relative inferior value-covered set of it.

Due to the same grey number, we can abstract valid information from the uncertain information, and the grey number will become a real number when we abstract all the valid information. We can abstract information from the operations of grey number-covered sets.

Theorem 2.1. Suppose $D_1, D_2, \cdots, D_n$ are the n different value-covered sets of grey number $\otimes$. Then we can get $\forall \otimes \Rightarrow d^* \in D, D = \bigcap_{k=1}^{n} D_k$ or abbreviated as $\otimes = \bigcap_{k=1}^{n} \otimes_k$.

Proof: We prove the conclusion with the continuous value-covered sets of grey number $\otimes$. The discrete or mixed value-covered sets can be proved analogously.

Due to a grey number $\otimes$, we have n different value-covered sets:

$$\otimes_1 = [a_1, b_1], \otimes_2 = [a_2, b_2], \cdots, \otimes_n = [a_n, b_n]$$

then

$$d^* \in [a_1, b_1], d^* \in [a_2, b_2], \cdots, d^* \in [a_n, b_n]$$

so

$$a_1 \le d^* \le b_1, a_2 \le d^* \le b_2, \cdots, a_n \le d^* \le b_n$$

Let

$$a = \max\{a_1, a_2, \cdots, a_n\}, b = \min\{b_1, b_2, \cdots, b_n\}$$

and we can get

$$d^* \in [a, b]$$

but

$$[a, b] = \bigcap_{k=1}^{n} [a_k, b_k]$$

Therefore, $d^* \in \bigcap_{k=1}^{n} [a_k, b_k]$, i.e. $\otimes = \bigcap_{k=1}^{n} \otimes_k$.

Example 2.3. Suppose grey number $\otimes$ has the value-covered sets

$$\otimes_1 = [0.5, 1.3], \otimes_2 = [0.4, 1.2],$$

$$\otimes_2 = [0.6, 1.5], \otimes_4 = [0.55, 1.35]$$

Then we know

$$\otimes = [0.5,1.3] \cap [0.4,1.2] \cap [0.6,1.5] \cap [0.55,1.35] \\ = [0.6,1.2]$$

3 The Algorithms of Grey Numbers

Definition 3.1. If and only if the grey number $\otimes$ can be linearly expressed by an exclusive proposition-information field, then the grey number is called a simple grey number.

Definition 3.2. If the grey number $\otimes$ can be expressed by a linear combination of two or more proposition-information fields, then the grey number is called a complex grey number.

Definition 3.3. Let D_i and d_i^* be the value-covered set and true value of grey number $\otimes_i$. Let D_j and d_j^* be the value-covered set and true value of grey number $\otimes_j$. $\circ$ is an operation. Let $\otimes_{ij}$ be the result of $\otimes_i$ and $\otimes_j$ for the $\circ$ operation. Let D_{ij} be the value-covered set of the grey number $\otimes_{ij}$. Then we have the general $\circ$ operation formula:

$$\otimes_i \circ \otimes_j = \otimes_{ij} \Leftrightarrow \\ \left\{ \forall d_i^* \in D_i, d_j^* \in D_j, \exists d_{ij}^* \in D_{ij} \Rightarrow d_i^* \circ d_j^* = d_{ij}^*, D_i \circ D_j = D_{ij} \right\}$$

abbreviated as $\otimes_i \circ \otimes_j = \otimes_{ij}$.

Due to the grey numbers $\otimes_i$ and $\otimes_j$, their true values d_i^* and d_j^* are unknown. So, the most important operation is the operation of D_i and D_j in the general $\circ$ operation formula.

C. Self-minus and self-divide of a grey number

Theorem 3.1. The result of the self-minus of a grey number is zero. That is, $\otimes - \otimes = 0$.

Proof: d^* is the true value of $\otimes$. So $d^* \in \otimes$, for d^* is a real number. For the real number, we have $d^* - d^* = 0$. Therefore, $\otimes - \otimes = 0$.

Theorem 3.2. The result of the self-divide of a grey number is 1. That is, $\frac{\otimes}{\otimes} = 1$.

Proof: d^* is the true value of $\otimes$. So, $d^* \in \otimes$, for d^* is a real number. For the real number, when $d^* \neq 0$, we have $\frac{d^*}{d^*} = 1$. Therefore, $\frac{\otimes}{\otimes} = 1$. It is marked as $\otimes^k = \underbrace{\otimes \times \otimes \times \cdots \times \otimes}_{k}$, $k\otimes = \underbrace{\otimes + \otimes + \cdots + \otimes}_{k}$, where k is the amount of $\otimes$.

Theorem 3.3. For the discretional grey number $\otimes$, we have $\otimes^k - \otimes^k = 0$ and $k\otimes - k\otimes = 0$. When 0 is not the true value of $\otimes$, we have $\otimes^k \div \otimes^k = 1$ and $(k\otimes) \div (k\otimes) = 1$.

D. Covered operation of a simple grey number

When $\otimes_i$ and $\otimes_j$ are simple grey numbers, we can define the covered operation of a simple grey number with the idiographic value-covered sets as D_i and D_j.

Definition 3.4. Suppose the grey numbers $\otimes_i$ and $\otimes_j$ have the corresponding discrete value-covered sets $D_i = \{d_{ik} \,|\, k = 1, 2, \cdots, n\}$ and $D_j = \{d_{jl} \,|\, l = 1, 2, \cdots, m\}$. If $\otimes_i \circ \otimes_j = \otimes_{ij}$, $\circ \in \{+, -, \times, \div\}$, then $D_i \circ D_j = D_{ij}$. So, the value-covered set D_{ij} of complex grey number $\otimes_{ij}$ is

(1) $D_{ij} = D_i + D_j = \{d_{ik} + d_{jl} \,|\, k = 1, 2, \cdots, n; l = 1, 2, \cdots, m\}$

(2) $D_{ij} = D_i - D_j = \{d_{ik} - d_{jl} \,|\, k = 1, 2, \cdots, n; l = 1, 2, \cdots, m\}$

(3) $D_{ij} = D_i \times D_j = \{d_{ik} \times d_{jl} \,|\, k = 1, 2, \cdots, n; l = 1, 2, \cdots, m\}$

(4) $D_{ij} = D_i \div D_j = \{d_{ik} \div d_{jl} \,|\, k = 1, 2, \cdots, n; l = 1, 2, \cdots, m\}$, where $0 \notin D_j$.

Example 3.1. $\otimes_1 = \{3, 4, 5\}$, $\otimes_2 = \{2, 4\}$. Calculate the value-covered sets of $\otimes_1 + \otimes_2$, $\otimes_1 - \otimes_2$, $\otimes_1 \times \otimes_2$ and $\otimes_1 \div \otimes_2$.

According to Definition 3.4, we get the results $\otimes_1 + \otimes_2 = \{5, 6, 7, 8, 9\}$, $\otimes_1 - \otimes_2 = \{-1, 0, 1, 2, 3\}$,

$$\otimes_1 \times \otimes_2 = \{6, 8, 10, 12, 16, 20\}$$

and

$$\otimes_1 \div \otimes_2 = \{0.75, 1, 1.25, 1.5, 2, 2.5\}.$$

Definition 3.5. Suppose the grey numbers $\otimes_i$ and $\otimes_j$ have the corresponding continuous value-covered sets $D_i = [a_i, b_i]$ and $D_j = [a_j, b_j]$. If $\otimes_i \circ \otimes_j = \otimes_{ij}$, $\circ \in \{+, -, \times, \div\}$, then $D_i \circ D_j = D_{ij}$. So, the value-covered set D_{ij} of complex grey number $\otimes_{ij}$ is

(1) $D_{ij} = D_i + D_j = [a_i + a_j, b_i + b_j]$

(2) $D_{ij} = D_i - D_j = [a_i - b_j, b_i - a_j]$

(3) $$D_{ij} = D_i \times D_j = [\min\{a_i a_j, a_i b_j, b_i a_j, b_i b_j\}, \max\{a_i a_j, a_i b_j, b_i a_j, b_i b_j\}]$$

(4) $$D_{ij} = D_i \div D_j = [\min\{\frac{a_i}{a_j}, \frac{a_i}{b_j}, \frac{b_i}{a_j}, \frac{b_i}{b_j}\}, \max\{\frac{a_i}{a_j}, \frac{a_i}{b_j}, \frac{b_i}{a_j}, \frac{b_i}{b_j}\}]$$, where $0 \notin D_j$

Example 3.2. $\otimes_1 = [3,5]$, $\otimes_2 = [2,4]$. Calculate the value-covered sets of $\otimes_1 + \otimes_2$, $\otimes_1 - \otimes_2$, $\otimes_1 \times \otimes_2$ and $\otimes_1 \div \otimes_2$.

According to Definition 3.5, we get the results $\otimes_1 + \otimes_2 = [5,9]$, $\otimes_1 - \otimes_2 = [-1,3]$, $\otimes_1 \times \otimes_2 = [6,20]$ and $\otimes_1 \div \otimes_2 = [0.75, 2.5]$.

Definition 3.6. Suppose the grey number $\otimes_i$ has the corresponding discrete value-covered set $D_i = \{d_{ik} | k = 1, 2, \cdots, n\}$, and $\otimes_j$ has the corresponding continuous value-covered set $D_j = [a_j, b_j]$. If $\otimes_i \circ \otimes_j = \otimes_{ij}$, $\circ \in \{+, -, \times, \div\}$, then $D_i \circ D_j = D_{ij}$. So, the value-covered set D_{ij} of the complex grey number $\otimes_{ij}$ (or the value-covered set D_{ji} of the complex grey number $\otimes_{ji}$) is

(1) $D_{ij} = D_i + D_j = \bigcup_{k=1}^{n} [d_{ik} + a_j, d_{ik} + b_j]$

(2) $D_{ij} = D_i - D_j = \bigcup_{k=1}^{n} [d_{ik} - b_j, d_{ik} - a_j]$ or

$D_{ji} = D_j - D_i = \bigcup_{k=1}^{n} [a_j - d_{ik}, b_j - d_{ik}]$

(3) $D_{ij} = D_i \times D_j = \bigcup_{k=1}^{n} [\min\{d_{ik} a_j, d_{ik} b_j\}, \max\{d_{ik} a_j, d_{ik} b_j\}]$

(4) $$D_{ij} = D_i \div D_j = \bigcup_{k=1}^{n} [\min\{d_{ik}/a_j, d_{ik}/b_j\}, \max\{d_{ik}/a_j, d_{ik}/b_j\}]$$, where $0 \notin D_j$

(5) $\begin{aligned} D_{ji} &= D_j \div D_i \\ &= \bigcup_{k=1}^{n}[\min\{a_j/d_{ik}, b_j/d_{ik}\}, \max\{a_j/d_{ik}, b_j/d_{ik}\}] \end{aligned}$, where $0 \notin D_i$

Example 3.3. $\otimes_1 = \{3,6\}$, $\otimes_2 = [2,4]$. Calculate the value-covered sets of $\otimes_1 + \otimes_2$, $\otimes_1 - \otimes_2$, $\otimes_1 \times \otimes_2$ and $\otimes_1 \div \otimes_2$.

According to Definition 3.6, we get the results:

$$\otimes_1 + \otimes_2 = [5,7] \cup [8,10], \otimes_1 - \otimes_2 = [-1,1] \cup [2,4], \otimes_1 \times \otimes_2 = [6,12] \cup [12,24] = [6,24],$$

$$\otimes_2 \div \otimes_1 = [\frac{1}{3}, \frac{2}{3}] \cup [\frac{2}{3}, \frac{4}{3}] = [\frac{1}{3}, \frac{4}{3}]$$

$$\otimes_1 \div \otimes_2 = [0.75, 1.5] \cup [1.5, 3] = [0.75, 3].$$

E. Covered operation of a complex grey number

Suppose $\otimes_i$ is the linear combination of n grey numbers, and $\otimes_{i1}, \otimes_{i2}, \cdots, \otimes_{in}$, $\otimes_j$ is the linear combination of m grey numbers $\otimes_{j1}, \otimes_{j2}, \cdots, \otimes_{jm}$. If any element of $\otimes_{i1}, \otimes_{i2}, \cdots, \otimes_{in}$ is independent of any element of $\otimes_{j1}, \otimes_{j2}, \cdots, \otimes_{jm}$, then we call $\otimes_i$ independent of $\otimes_j$, or we call $\otimes_i$ dependent on $\otimes_j$.

Definition 3.12. Due to the complex grey number $\otimes_{ij}$ and the simple grey number $\otimes_j$, D_{ij} and D_j are the corresponding value-covered sets of $\otimes_{ij}$ and $\otimes_j$. If $\otimes_{ij}$ is the calculated result of $\otimes_j$ and another grey number $\otimes_i$ under the $\circ$ operation, where $\circ \in \{+, -, \times, \div\}$, then we can calculate the value-covered set D_i of grey number $\otimes_i$ with the invertible operation of $\circ$ operation. If $\otimes_i \circ \otimes_j = \otimes_{ij}$, then $D_i = D_{ij} * D_j$, $* \in \{-, +, \div, \times\}$. The value-covered set D_i of the grey number $\otimes_i$ is

(1) if $D_{ij} = D_i + D_j$, then $D_i = D_{ij} - D_j$.

(2) if $D_{ij} = D_i - D_j$, then $D_i = D_{ij} + D_j$.

(3) if $D_{ij} = D_i \times D_j$, then $D_i = D_{ij} \div D_j$, where $0 \notin D_j$.

(4) if $D_{ij} = D_i \div D_j$, then $D_i = D_{ij} \times D_j$, where $0 \notin D_j$.

F. Covered operation of a multiple grey number

Definition 3.13. Suppose grey numbers $\otimes_1, \otimes_2, \cdots, \otimes_n$ have the corresponding discrete covered sets $D_i = \left\{ d_{ik_i} \middle| k_i = 1, 2, \cdots, m_i \right\}$. If $\otimes = f(\otimes_1, \otimes_2, \cdots, \otimes_n, \circ)$ is the result of two or more $\circ$ operations, where $\circ \in \{+, -, \times, \div\}$, then we have the corresponding value-covered set $D = f(D_1, D_2, \cdots, D_n, \circ)$ of the complex number $\otimes$. The set is

$$D = f(D_1, D_2, \cdots, D_n, \circ) = \left\{ f(d_{1k_1}, d_{2k_2}, \cdots, d_{nk_n}, \circ) \right\}$$
$$k_1 = 1, 2, \cdots, m_1; k_2 = 1, 2, \cdots, m_2; \cdots; k_n = 1, 2, \cdots, m_n$$

Example 3.4. Suppose $\otimes_1 = \{3, 4, 5\}$, $\otimes_2 = \{2, 4\}$ and $\otimes_3 = \{1, 4\}$. Calculate the value-covered set of $\otimes_1 \otimes_3 + \otimes_2$, $\otimes_1^2 - \otimes_2$ and $(\otimes_1 + \otimes_3) \div \otimes_2$.

According to Definition 3.13, we can get the results:

$\otimes_1 \otimes_3 + \otimes_2 = \{5, 6, 7, 8, 9, 14, 16, 18, 20, 22, 24\}$, $\otimes_1^2 - \otimes_2 = \{5, 7, 12, 14, 21, 23\}$,

$$(\otimes_1 + \otimes_3) \div \otimes_2 = \{1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 3, 3.5, 4, 4.5\}$$

Definition 3.14. Suppose the grey numbers $\otimes_1, \otimes_2, \cdots, \otimes_n$ have the corresponding continuous covered sets $D_i = [a_i, b_i]$. If $\otimes = f(\otimes_1, \otimes_2, \cdots, \otimes_n, \circ)$ is the result of two or more $\circ$ operations, where $\circ \in \{+, -, \times, \div\}$, then the corresponding value-covered set $D = f(D_1, D_2, \cdots, D_n, \circ)$ of complex number $\otimes$ can be calculated by the two optimized models:

$$\min f(x_1, x_2, \cdots, x_n, \circ)$$
$$s.t \begin{cases} a_1 \le x_1 \le b_1 \\ a_2 \le x_2 \le b_2 \\ \vdots \\ a_n \le x_n \le b_n \end{cases}$$

and

$$\max f(x_1, x_2, \cdots, x_n, \circ)$$
$$s.t \begin{cases} a_1 \le x_1 \le b_1 \\ a_2 \le x_2 \le b_2 \\ \vdots \\ a_n \le x_n \le b_n \end{cases}$$

Let $a = \min f(x_1, x_2, \cdots, x_n, \circ)$, $b = \max f(x_1, x_2, \cdots, x_n, \circ)$. Then, the corresponding value-covered set $D = f(D_1, D_2, \cdots, D_n, \circ) = [a, b]$.

Example 3.5. Suppose $\otimes_1 = [1,2]$, $\otimes_2 = [3,5]$ and $\otimes_3 = [2,4]$. Calculate the value-covered set of $\otimes_1 \otimes_2 + \otimes_3^2$, $\otimes_1^2 - \otimes_2 + \otimes_3 \otimes_2$ and $(\otimes_1 + \otimes_3) \div \otimes_2$.

According to Definition 3.14, we can get the results:

$$\otimes_1 \otimes_2 + \otimes_3^2 = [3,10] + [4,16] = [7,26],$$

$$\otimes_1^2 - \otimes_2 + \otimes_3 \otimes_2 = [1,4] + [3,15] = [4,19], (\otimes_1 + \otimes_3) \div \otimes_2 = [0.6, 2]$$

Definition 3.15. Suppose the grey numbers $\otimes_1, \otimes_2, \cdots, \otimes_n$ are composed of two parts, $\otimes_1, \otimes_2, \cdots, \otimes_s$ and $\otimes_{s+1}, \otimes_{s+2}, \cdots, \otimes_n$. $\otimes_1, \otimes_2, \cdots, \otimes_s$ have the corresponding discrete covered sets $D_i = \left\{ d_{ik_i} \middle| k_i = 1, 2, \cdots, m_i \right\}$ and $\otimes_{s+1}, \otimes_{s+2}, \cdots, \otimes_n$ have the corresponding continuous covered sets $D_i = [a_i, b_i]$. If $\otimes = f(\otimes_1, \otimes_2, \cdots, \otimes_n, \circ)$ is the result of two or more $\circ$ operations, where $\circ \in \{+, -, \times, \div\}$, then the corresponding value-covered set $D = f(D_1, D_2, \cdots, D_n, \circ)$ of complex number $\otimes$ can be calculated by the two optimized models:

$$\min f(d_{1k_1}, d_{2k_2}, \cdots, d_{sk_s}, x_{s+1}, x_{s+2}, \cdots, x_n, \circ)$$

$$s.t \begin{cases} a_{s+1} \le x_{s+1} \le b_{s+1} \\ a_{s+2} \le x_{s+2} \le b_{s+2} \\ \vdots \\ a_n \le x_n \le b_n \end{cases}$$

and

$$\max f(d_{1k_1}, d_{2k_2}, \cdots, d_{sk_s}, x_{s+1}, x_{s+2}, \cdots, x_n, \circ)$$

$$s.t \begin{cases} a_{s+1} \le x_{s+1} \le b_{s+1} \\ a_{s+2} \le x_{s+2} \le b_{s+2} \\ \vdots \\ a_n \le x_n \le b_n \end{cases}$$

Let

$$\begin{aligned} & a(d_{1k_1}, d_{2k_2}, \cdots, d_{sk_s}) \\ & = \min f(d_{1k_1}, d_{2k_2}, \cdots, d_{sk_s}, x_{s+1}, x_{s+2}, \cdots, x_n, \circ) \end{aligned},$$

$$b(d_{1k_1}, d_{2k_2}, \cdots, d_{sk_s})$$
$$= \max f(d_{1k_1}, d_{2k_2}, \cdots, d_{sk_s}, x_{s+1}, x_{s+2}, \cdots, x_n, \circ)$$

Then, the corresponding value-covered set

$$D = f(D_1, D_2, \cdots, D_n, \circ)$$
$$= \bigcup_{k_i=1,2,\cdots,m_i; i=1,2,\cdots,s} [a(d_{1k_1}, d_{2k_2}, \cdots, d_{sk_s}), b(d_{1k_1}, d_{2k_2}, \cdots, d_{sk_s})].$$

4 Conclusion

It is meaningful to comprehend correctly the connotation and the algorithm of grey numbers. In this chapter, we discussed two important aspects, the connotation and the value-covered set operation algorithm of grey numbers. We defined the grey number value-covered set with a proposition-information field and put forth several remarks on the definition of a grey number. We proposed a method for abstracting the information of a grey number covered set. According to the different forms of grey numbers, we proposed three kinds of different and associated algorithms, including simple grey numbers, complex grey numbers and multiple grey numbers. In fact, the algorithm of simple grey numbers is the basic form that is suited for the covered set operations of simple grey numbers or independent grey numbers. The algorithm of complex grey numbers is suited for the dependent grey numbers. The covered algorithms of simple grey numbers and complex grey numbers are both dualistic operations, i.e. there are two grey numbers in an equation. The covered algorithm of multiple grey numbers is suited for the covered set operations of more grey numbers. The simple algorithm and the complex algorithm are both particular forms of the multiple algorithm. All these works are meaningful to bringing grey mathematics closer to perfection, and they propose more grey applying models.

Grey systems theory is a young subject of systematical methods. Although we have made some progress in algorithms of grey numbers in this chapter, there are many problems that still need to be researched. These include how to combine the algorithm with the function and matrix; how to combine the algorithm with the existed grey applying model; how to combine the algorithm with other subject, such as decision-making, input-output analysis, management and economics, etc. These may be our upcoming works.

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Extended Grey Numbers

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Combining both intervals and discrete sets of numbers, this paper presents a definition for an extended grey number model representing both continuous and discrete grey numbers. Based on the new definition, the operation properties and degree of greyness are investigated and a new formula for arithmetic operations of grey numbers is derived.

1 Introduction

Grey numbers are usually represented as closed intervals, and hence its calculus (Liu et al., 2000; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006) is very similar to interval calculus (Alefeld and Herzberger, 1983). However, grey numbers can also be discrete in nature, and the continuous intervals can not fully reveal the available information in a discrete grey number. For instance, we may know that a grey number g can only select one value from 12, 15 and 18. The probability for each number to be the white number is 0.3333. If we write it as $g = [12, 18]$, then the probability of each number being the white number is close to 0. Obviously, the continuous grey numbers can not express this situation. In fact, discrete grey numbers are part of grey numbers in grey systems, although their use has not gained as much attention as continuous grey numbers. In this paper, we extend a grey number to a combination of both continuous and discrete representation, and investigate various operations.

In order to do this, this paper is structured as follows. In the next section a brief overview of grey systems and grey numbers is provided. Section 3 defines extended grey numbers. Section 4 discusses various operations of grey numbers and gives some examples of the operation of grey numbers. Finally, in section 5 we draw out the conclusions.

2 Grey Systems and Grey Numbers

Grey systems were proposed by Professor Julong Deng in 1982 (Deng, 1982). In this system, the information is classified into three categories: white with

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completely certain information, grey with insufficient information, and black with totally unknown information. Grey systems are concerned with, in particular, the information belonging to the grey category. Because of insufficient information, most of the statistical characteristics of the system may not be clearly identified. However, the data available may reveal the range of infor-mation. We now provide a number of definitions.

Definition 1. Grey numbers (Liu et al., 2000). *A grey number is a num-ber with clear upper and lower boundaries but which has an unknown position within the boundaries.*

A grey number for the system is expressed mathematically as (Cheng et al., 2002)

$$a^{\pm} = [a^{-}, a^{+}] = \{t \in a^{\pm} \mid a^{-} < t < a^{+}\} \tag{1}$$

where $a^{\pm}$ is a grey number, t is information, a^{-} and a^{+} are the upper and lower limits of the information. Clearly, a grey number represents the range of the possible variance of the underlying number. In this sense, it is the same as an interval value with the same upper and lower limit (Alefeld and Herzberger, 1983). In fact, the arithmetic of grey numbers is very similar to interval values (Liu et al., 2000). The operation on a grey number is defined as

$$a^{\pm} \otimes b^{\pm} = [f^{-}(a^{+}, b^{+}, a^{-}, b^{-}), f^{+}(a^{+}, b^{+}, a^{-}, b^{-})] \tag{2}$$

where $\otimes$ is an operator, f^{+} and f^{-} are the functions for minimum and maximum values. The +, −, × and ÷ operations are as follows:

$$a^{\pm} + b^{\pm} = [a^{-} + b^{-}, a^{+} + b^{+}] \tag{3}$$

$$a^{\pm} - b^{\pm} = [a^{-} - b^{+}, a^{+} - b^{-}] \tag{4}$$

$$a^{\pm} \times b^{\pm} = [\min\{a^{-}b^{-}, a^{+}b^{+}, a^{-}b^{+}, a^{+}b^{-}\}, \max\{a^{-}b^{-}, a^{+}b^{+}, a^{-}b^{+}, a^{+}b^{-}\}] \tag{5}$$

$$\frac{a^{\pm}}{b^{\pm}} = [\min\{\frac{a^{-}}{b^{-}}, \frac{a^{+}}{b^{+}}, \frac{a^{-}}{b^{+}}, \frac{a^{+}}{b^{-}}\}, \max\{\frac{a^{-}}{b^{-}}, \frac{a^{+}}{b^{+}}, \frac{a^{-}}{b^{+}}, \frac{a^{+}}{b^{-}}\}] \tag{6}$$

$$b^{\pm^{-1}} = [\frac{1}{b^{+}}, \frac{1}{b^{-}}] \tag{7}$$

Here, we assume $a^{-} \le a^{+}$ and $b^{-} \le b^{+}$. For Equation (6) and (7), we assume $b^{-} \neq 0$ and $b^{+} \neq 0$.

However, compared with interval values, a grey number en-riches its uncertainty representation with the degree of greyness and whitenisation function.

Definition 2. Degree of greyness for grey numbers (Liu et al., 2000). *The significance of the unknown interval to the white number represented by a grey number is called as degree of greyness.*

It is a function of the interval and the underlying white number. Because that the underlying white number is un-known, the degree of greyness is expressed as a function of two boundaries of a grey number: $g^{\circ}(a^{\pm}) = f(a^{-}, a^{+})$. Ob-viously, the interval between a^{+} and a^{-} has direct influence on the degree of greyness.

For grey systems, the operation is not limited to the oper-ation of interval values, it considers also the whitenisation of its output interval values. Regardless of the interval of a grey number, its real value could only be one value within this scope. The technique to transfer a grey number into a white number is called whitenisation. There is a weight function

$W(a^{\pm})$ for whitenisation: $a = W(a^{\pm})$. Here a is the white number after the whitenisation, which is the number with the highest possibility to be the real value.

However, the present arithmetic operation for grey num-bers does not fully reflect the information contained in dis-crete grey numbers. According to definition 1, each number inside $a^{\pm}$'s boundary $[a^{-}, a^{+}]$ would be an eligible candidate for the underlying white number. Therefore, the probability for a number $a^{-} \le b_i \le a^{+}$ to be the underlying white number is: $P(b_i) = \frac{1}{\infty} \to 0$. If we know the underlying white number can only be one of limited candidates $\{b_1, b_2, \ldots, b_n\}$ ($n<\infty$). The real probability should be:

$$P(b_i) = \frac{1}{n}$$

This situation is exactly due to grey information, and we do not know which candidate is the right one but we do know it is within a finite set. Obviously, the interval based representation of grey numbers can not deal with this situation, and it is necessary to extend it to include discrete numbers. We have defined grey number sets in our previous paper (Yang and John, 2003). Here, we will extend the grey number definition to combine both continuous and discrete grey numbers into one model.

3 Extended Grey Numbers

From Equation (1), we may get conclusions that a grey number has to have two boundaries and it is continuous. However, this is not true. In Liu's book, he had pointed out that there can be discrete grey numbers as well as continuous grey numbers (Liu et al., 2000). However, most research efforts focus on continuous grey numbers. The operations for discrete grey numbers are totally different from those for continuous grey numbers, and then can not be derived directly from interval calculus. Here, we give a new definition of grey numbers to consider both continuous and discrete grey numbers.

Definition 3. Grey numbers Let $g \in R$ be a real number and $g^{\pm}$ be a union set of closed or open intervals

$$g^{\pm} = \bigcup_{i=1}^{n} [a_i^{-}, a_i^{+}] \tag{8}$$

Here i= 1, 2,…, n_+, n is an integer and $0 < n < \infty, a_i^-, a_i^+ \in R$ and $a_{i-1}^+ \le a_i^- \le a_i^+ \le a_{i+1}^+$. For any interval $[a^-_i, a^+_i]$, p_i is the probability for $g \in [a^-_i, a^+_i]$. If the following conditions hold for

- $p_i > 0$ iff $[a_i^-, a_i^+] \in g^\pm$
- $\sum_{i=1}^{n} p_i = 1$

then we call g a grey number represented by $g^\pm$. $g^- = \inf_{a_i^- \in g^\pm} a_i^-$ and $g^+ = \sup f_{a_i^+ \in g^\pm} a_i^+$ are called as the lower and upper limits of $g^\pm$.

Here, it should be noted that the intervals involved in grey numbers do not need to be closed although our expression uses the closed representation. Obviously, definition 3 is much more general than Equation (1). It removes the limitation for open sets and discrete sets to represent a grey number. From definition 3, it is also clear that a grey number $g^\pm$ is different from the set $g^\pm$. The grey number $g^\pm$ represents only one number which is not clearly identified among the elements in set $g^\pm$. Before we discuss further the properties of grey numbers, we define two special cases for grey numbers.

Definition 4. White numbers *For any grey number* $g^\pm \in R$, *if* $|g^+ - g^-| = 0$, *then this* $g^\pm$ *is called a white number.*

Definition 5. Black numbers *For any grey number* $g^\pm \in R$, *if* $|g^+ - g^-| = \infty$, *then this* $g^\pm$ *is called a black number.*

Here, we discuss a black number defined in the whole R^+ or $R^+ \cap \{0\}$, and the $|g^+ - g^-|$ of a black number could be a finite value when $g^\pm$ is defined in a measurable subset of R. Clearly, a white number is a normal crisp number where everything is clearly known, and a black number is a number with nothing known. Therefore, we can further classify grey numbers into different categories according to theorem 1.

Theorem 1. $g^\pm$ is a grey number defined by definition 3. The following properties hold for $g^\pm$:

- $g^\pm$ is a continuous grey number $g^\pm = [a^-_1, a^+_n]$ iff $a^-_i = a^+_{i-1}$ ($\forall i > 1$) or $n = 1$
- $g^\pm$ is a discrete grey number $g^\pm = \{a_1, a_2, \ldots, a_n\}$ iff $a_i = a^-_i = a^+_i$
- $g^\pm$ is a mixed grey number iff only part of its intervals shrink to crisp numbers and others keep as intervals.

***Proof*:** According to definition 3, we have

$$g^\pm = \bigcup_{i=1}^{n} [a_i^-, a_i^+]$$

if $a_i^- = a_i^+$, each interval will be connected in their boundaries, hence

$$g^\pm = [a^-_1, a_1]\ U\ [a_1, a_2]\ U\ [a_2, a_3]\ U \ldots U\ [a_n, a^+_n] = [a^-_1, a^+_n]$$

If n = 1, obviously

$$g^{\pm} = [a^{-}_{1}, a^{+}_{1}]$$

On the contrary, if $g^{\pm} = [a^{-}_{1}, a^{+}_{n}]$, then

$$\bigcup_{i=1}^{n} [a_i^-, a_i^+] = [a_1^-, a_n^+]$$

If at least for $i=j$ we have $a^{+}_{j-1} < a^{-}_{j}$ and $n > 1$, then

$$\bigcup_{i=1}^{n} [a_i^-, a_i^+] = \{a_1^-, a_{j-1}^+) \bigcup (a_j^-, a_i^+] \neq [a_1^-, a_n^+]$$

It conflicts with our assumption, thus we have

$$a^{+}_{i-1} \geq a^{-}_{i} \text{ or } n = 1$$

however

$$a^{+}_{i-1} \leq a^{-}_{i}$$

Therefore, we have

$$a^{-}_{i} = a^{+}_{i-1} \text{ or } n = 1$$

Now we prove the second rule. *If* $a_i = a^{-}_{i} = a^{+}_{i}$, it is obvious that each interval shrinks to a crisp number.

Therefore, we have

$$g^{\pm} = \bigcup_{i=1}^{n} [a_i^-, a_i^+] = \bigcup_{i=1}^{n} a_i = \{a_1, a_2, ..., a_n\}$$

If $g^{\pm} = \{a_1, a_2, \ldots, a_n\}$, then

$$[a^{-}_{i}, a^{+}_{i}] = [a_i, a_i]$$

hence

$$a^{-}_{i} = a^{+}_{i} = a_i$$

The proof of the third rule is straightforward. ■

As aforementioned, the degree of greyness is very important to grey numbers, hence we need a formal definition with respect our definition for grey numbers in definition 3.

Definition 6. Degree of greyness of a grey number

For any grey number $g^{\pm}$, g^{-}, $g^{+} \in R$ are its lower and upper limits. The degree of greyness of $g^{\pm}$ is a function

$g^{\circ} = f(g^{-}, g^{+})$ *satisfying the following conditions*

- $g^{\circ} \geq 0$
- $g^{\circ} = 0$ *iff* $g^{-} = g^{+}$

There are many functions satisfying these conditions, and hence there may be many different valid functions for degree of greyness of grey numbers. For example, we can adopt the following simple equations.

If we consider grey numbers in the positive $R^+ \, U \, \{0\}$, we can define it as

$$g^{\circ} = \frac{g^{+} - g^{-}}{g^{+} + g^{-}} \tag{9}$$

From equation (9), $g^{\circ} = 1$ when $g^{-} = 0$. Under this situation, $g^{\pm}$ is a black number.

It is obvious that Equation (9) satisfies all properties in definition 6. From definition 6 and Equation (9) we can also see that the degree of greyness of a grey number depends only on the two limits of a grey number and has nothing to do with the cardinality of its candidate set. For example, both $g_1^{\pm} = [40, 60]$ and $g_2^{\pm} = \{40, 60\}$ have the same degree of greyness using Equation (9)

$$g_1^{\circ} = g_2^{\circ} = \frac{60 - 40}{60 + 40} = 0.2$$

but their cardinalities are completely different

$$\text{Card}(g_1^{\pm}) = \infty, \qquad \text{Card}(g_2^{\pm}) = 2$$

This indicates that the degree of greyness is a parameter for the grey number rather than any candidate in its candidate set. This is different from the probability for each number in its candidate set to be the underlying white number.

4 Operations on Grey Numbers

For any two numbers $a^{\pm} = \bigcup_{i=1}^{m} [a_i^{-}, a_i^{+}]$ and $b^{\pm} = \bigcup_{i=1}^{n} [b_i^{-}, b_i^{+}]$ defined by definition 3, their arithmetic operations follow the same rules as in Equation (2). However, because of the involvement of discrete grey numbers and mixed grey numbers, the operation has to consider those separate intervals or numbers. Therefore, Equation (2) has to be modified to consider these new parameters.

$$a^{\pm} \otimes b^{\pm} = \bigcup_{i=1}^{m} \bigcup_{j=1`}^{n} [f^{-}(a_i^{+}, b_j^{+}, a_i^{-}, b_j^{-}), f^{+}(a_i^{+}, b_j^{+}, a_i^{-}, b_j^{-})] \tag{10}$$

Obviously, Equation (2) is a special case of Equation (10) when m=n=1. From this, we can derive the corresponding operations for addition, subtract, times and division operations.

According to Equation (3)–(7), the +, −, × and ÷ opera-tions can be derived from Equation (10) as follows:

$$a^{\pm} + b^{\pm} = \bigcup_{i=1}^{m} \bigcup_{j=1}^{n} [a_i^{-} + b_j^{-}, a_i^{+} + b_j^{+}] \tag{11}$$

$$a^{\pm} - b^{\pm} = \bigcup_{i=1}^{m} \bigcup_{j=1}^{n} [a_i^{-} - b_j^{+}, a_i^{+} - b_j^{-}] \tag{12}$$

$$a^{\pm} \times b^{\pm} = \bigcup_{i=1}^{m} \bigcup_{j=1`}^{n} [\min\{a_i^{-} b_j^{-}, a_i^{+} b_j^{+}, a_i^{-} b_j^{+}, a_i^{+} b_j^{-}\}, \max\{a_i^{-} b_j^{-}, a_i^{+} b_j^{+}, a_i^{-} b_j^{+}, a_i^{+} b_j^{-}\}] \tag{13}$$

$$\frac{a^{\pm}}{b^{\pm}}=\bigcup_{i=1}^{m}\bigcup_{j=1}^{n}[\min\{\frac{a_i^-}{b_j^-},\frac{a_i^+}{b_j^+},\frac{a_i^-}{b_j^+},\frac{a_i^+}{b_j^-}\},\max\{\frac{a_i^-}{b_j^-},\frac{a_i^+}{b_j^+},\frac{a_i^-}{b_j^+},\frac{a_i^+}{b_j^-}\}] \tag{14}$$

$$b^{\pm^{-1}}=\bigcup_{j=1}^{n}[\frac{1}{b_j^+},\frac{1}{b_j^-}] \tag{15}$$

Here, we assume $a^-_i \le a^+_i$ and $b^-_j \le b^+_j$. For Equation (14) and (15), we assume $b^-_j \neq 0$ and $b^+_j \neq 0$.

In addition to these operations, we define two other opera-tions which are useful in applying grey numbers: conjunction and disjunction operations.

Definition 7. For any two grey numbers $a^{\pm}=\bigcup_{i=1}^{m}[a_i^-,a_i^+]$ and $b^{\pm}=\bigcup_{i=1}^{n}[b_i^-,b_i^+]$ defined by definition 3, their conjunction $a^{\pm}\vee\ b^{\pm}$ and disjunction $a^{\pm}\wedge b^{\pm}$ are defined as following:

$$a^{\pm}\vee b^{\pm}=\bigcup_{i=1}^{m}\bigcup_{j=1}^{n}[a_i^-\vee b_j^-,a_i^+\vee b_j^+] \tag{16}$$

$$a^{\pm}\wedge b^{\pm}=\bigcup_{i=1}^{m}\bigcup_{j=1}^{n}[a_i^-\wedge b_j^-,a_i^+\wedge b_j^+] \tag{17}$$

As shown by definition 3, a grey number is in fact represented by a set, hence it is natural to consider set operations between grey numbers.

Definition 8. For any two grey numbers $a^{\pm}=\bigcup_{i=1}^{m}[a_i^-,a_i^+]$ and $b^{\pm}=\bigcup_{i=1}^{n}[b_i^-,b_i^+]$ defined by definition 3, their union $a^{\pm}\bigcup b^{\pm}$, intersection $a^{\pm}\bigcap b^{\pm}$ and complement of $a^{\pm}$ are defined as following

$$a^{\pm}\bigcup b^{\pm}=\bigcup_{i=1}^{m}\bigcup_{j=1}^{n}\{[a_i^-,a_i^+]\bigcup[b_j^-,b_j^+]\} \tag{18}$$

$$a^{\pm}\bigcap b^{\pm}=\bigcup_{i=1}^{m}\bigcup_{j=1}^{n}\{[a_i^-,a_i^+]\bigcap[b_j^-,b_j^+]\} \tag{19}$$

$$\neg a^{\pm}=\bigcap_{i=1}^{m}\{[-\infty,a_i^-]\bigcup[a_j^+,+\infty]\} \tag{20}$$

Obviously, Equation (10) has shown that the results of these arithmetic operations in Equation (11)–(20) are still grey numbers. Therefore, they have their associated degree of greyness as well. Their degree of greyness can be calculated according to the following theorem.

Theorem 2. For any two grey $a^{\pm}=\bigcup_{i=1}^{m}[a_i^-,a_i^+]$ and $b^{\pm}=\bigcup_{i=1}^{n}[b_i^-,b_i^+]$ defined by definition 3, their arithmetic operation defined by Equation (11)–(20) produces another grey number $c^{\pm}$. Adopting the equation (9), its degree of greyness satisfies one of the following equations:

$$c^{\circ} = \frac{a_m^+ + b_n^+ - a_1^- - b_1^-}{|a_m^+ + b_n^+| + |a_1^- + b_1^-|}, \text{ if } c^{\pm} = a^{\pm} + b^{\pm} \tag{21}$$

$$c^{\circ} = \frac{a_m^+ - b_n^- - a_1^- + b_1^+}{|a_m^+ - b_n^-| + |a_1^- - b_1^+|}, \text{ if } c^{\pm} = a^{\pm} - b^{\pm} \tag{22}$$

$$c^{\circ} = \frac{s_1 - s_2}{|s_1| + |s_2|}, \text{ if } c^{\pm} = a^{\pm} \times b^{\pm} \tag{23}$$

$$c^{\circ} = \frac{t_1 - t_2}{|t_1| + |t_2|}, \text{ if } c^{\pm} = \frac{\mathrm{a}^{\pm}}{\mathrm{b}^{\pm}} \tag{24}$$

$$c^{\circ} = b^{\circ}, \text{ if } c^{\pm} = b^{\pm^{-1}} \tag{25}$$

$$c^{\circ} = \frac{a_m^+ \vee b_n^+ - a_1^- \vee b_1^-}{|a_m^+ \vee b_n^+| + |a_1^- \vee b_1^-|}, \text{ if } c^{\pm} = a^{\pm} \vee b^{\pm} \tag{26}$$

$$c^{\circ} = \frac{a_m^+ \wedge b_n^+ - a_1^- \wedge b_1^-}{|a_m^+ \wedge b_n^+| + |a_1^- \wedge b_1^-|}, \text{ if } c^{\pm} = a^{\pm} \wedge b^{\pm} \tag{27}$$

$$c^{\circ} = \frac{a_m^+ \vee b_n^+ - a_1^- \wedge b_1^-}{|a_m^+ \vee b_n^+| + |a_1^- \wedge b_1^-|}, \text{ if } c^{\pm} = a^{\pm} \bigcup b^{\pm} \tag{28}$$

$$c^{\circ} = \frac{a_{k_2}^+ \wedge b_{l_2}^+ - a_{k_1}^- \vee b_{l_1}^-}{|a_{k_2}^+ \wedge b_{l_2}^+| + |a_{k_1}^- \vee b_{l_{11}}^-|}, \text{ if } c^{\pm} = a^{\pm} \bigcap b^{\pm} \tag{29}$$

$$c^{\circ} = \begin{cases} 0 \;\; if \;\; c = \neg a^{\pm} \;\; and \;\; a^{\circ} = 1 \\ 1 \;\; if \;\; c = \neg a^{\pm} \;\; and \;\; a^{\circ} < 1 \end{cases} \tag{30}$$

Here, for $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$, we assume $a^-_i \leq a^+_i$ and $b^-_j \leq b^+_j$. We define the degree of greyness of empty set as $\emptyset^{\circ} = 0$. For Equation (24) and (25), we assume $b^-_j \neq 0$ and $b^+_j \neq 0$. For s_1, s_2, t_1, t_2, k_1, k_2, l_1 and l_2 in Equation (23), (24) and (29), we have

$$s_1 = \sup_{i=1}^{m} \sup_{j=1}^{n} \{a_i^- b_j^-, a_i^+ b_j^+, a_i^- b_j^+, a_i^+ b_j^-\}$$

$$s_2 = \inf_{i=1}^{m} \inf_{j=1}^{n} \{a_i^- b_j^-, a_i^+ b_j^+, a_i^- b_j^+, a_i^+ b_j^-\}$$

$$t_1 = \sup_{i=1}^{m} \sup_{j=1}^{n} \{\frac{a_i^-}{b_j^-}, \frac{a_i^+}{b_j^+}, \frac{a_i^-}{b_j^+}, \frac{a_i^+}{b_j^-}\}$$

$$t_2 = \inf_{i=1}^{m} \inf_{j=1}^{n} \{\frac{a_i^-}{b_j^-}, \frac{a_i^+}{b_j^+}, \frac{a_i^-}{b_j^+}, \frac{a_i^+}{b_j^-}\}$$

$$k_1 = \min\{i : [a_i^-, a_i^+] \wedge [b_j^-, b_j^+] \neq \phi\}$$

$$k_2 = \max\{i : [a_i^-, a_i^+] \wedge [b_j^-, b_j^+] \neq \phi\}$$

$l_1 = \min\{j : [a_i^-, a_i^+] \wedge [b_j^-, b_j^+] \neq \phi\}$
$l_2 = \max\{j : [a_i^-, a_i^+] \wedge [b_j^-, b_j^+] \neq \phi\}$

***Proof*:** According to Equation (10), we have

$$a^{\pm} \otimes b^{\pm} = \bigcup_{i=1}^{m} \bigcup_{j=1}^{n} [f^-(a_i^+, b_j^+, a_i^-, b_j^-), f^+(a_i^+, b_j^+, a_i^-, b_j^-)]$$

and for intervals $[a^-_k, a^+_k] \in a^{\pm}$ and $[b^-_l, b^+_l] \in b^{\pm}$, we have

$$p_k > 0 \text{ and } p_l > 0 \qquad 1 \le k \le m \text{ and } 1 \le l \le n$$

The interval produced by $[a^-_k, a^+_k]$ and $[b^-_l, b^+_l]$ is

$$[f^-(a^+_k, b^+_l, a^-_k, b^-_l), f^+(a^+_k, b^+_l, a^-_k, b^-_l)] \in a^{\pm} \otimes b^{\pm}$$

we have

$$p_{(k,l)} = p_k \times p_l > 0 \qquad 1 \le k \le m \text{ and } 1 \le l \le n$$

If an interval $[a_j^-, a_j^+] \notin a^{\pm}$ and $[a_j^-, a_j^+] \notin b^{\pm}$, then

$$p_{(j,l)} = 0 \times p_l = 0$$

Similarly, we can prove that an interval produced by two intervals outside $a^{\pm}$ and $b^{\pm}$ has 0 as its probability to contain the number represented by Equation (10). In addition to this, we have

$$\sum_{i=1}^{m} \sum_{l=1}^{n} p_{a_k} p_{b_l} = \sum_{k=1}^{m} p_{a_k} \sum_{l=1}^{n} p_{b_l} = 1$$

Thus $a^{\pm} \otimes b^{\pm}$ is a grey number.

For Equation (21)–(30), we prove only Equation (21) here, Equation (22)–(30) can be proved in a similar way.

According to Equation (11), we have

$$c^{\pm} = a^{\pm} + b^{\pm} = \bigcup_{i=1}^{m} \bigcup_{j=1}^{n} [a_i^- + b_j^-, a_i^+ + b_j^+]$$

According to definition 3, we know $a_1^- \le a_1^+ \le a_2^- \le a_2^+ ... \le a_m^+$ and $b_1^- \le b_1^+ \le b_2^- \le b_2^+ ... \le b_n^+$. Thus, we have $a_1^- + b_1^- \le a_i^- + b_j^-$ and $a_i^+ + b_j^+ \le a_m^+ + b_n^+$ for any $i=1,2,\ldots,m$ and $j=1,2,\ldots,n$. Then we get

$$c^- = a_1^- + b_1^- \text{ and } c^+ = a_m^+ + b_n^+$$

Hence

$$c^{\circ} = \frac{c^+ - c^-}{c^+ + c^-} = \frac{a_m^+ + b_n^+ - a_1^- - b_1^-}{a_m^+ + b_n^+ + a_1^- + b_1^-} \qquad \blacksquare$$

Example. $A^{\pm}$,$B^{\pm}$ and $C^{\pm}$ are three different grey numbers $A^{\pm}$ = [70, 100], $B^{\pm}$ = {70, 80, 90} and $C^{\pm}$ ={[60, 75], 80, 100}. According to Equation (11)–(20), we have

$$A^{\pm}+B^{\pm} = [140,170]\cup[150,180]\cup[160,190] = [140,190]$$

$$B^{\pm}+C^{\pm} = [130,145]\cup\{150\}\cup\{170]\}\cup[140,155]\cup\{160\}\cup\{180\}\cup[150,165]\cup\{170\}\cup\{190\} = \{[130,165],170,180,190\}$$

$$A^{\pm}+C^{\pm} = [130,175]\cup[150,180]\cup[170,200] = [130,200]$$

$$A^{\pm}-B^{\pm} = [0,30]\cup[-10,20]\cup[-20,10] = [-20,30]$$

$$B^{\pm}-C^{\pm} = [-5,10]\cup\{-10\}\cup\{-30]\}\cup[5,20]\cup\{-20\}\cup[15,30]\cup\{10\}\cup\{-10\} = \{-30,-20,-10,[-5,30]\}$$

$$A^{\pm}-C^{\pm} = [10,25]\cup[-10,20]\cup[-30,0] = [-30,25]$$

$$A^{\pm}\times B^{\pm} = [4900,7000]\cup[-5600,8000]\cup[-6300,9000] = [-4900,9000]$$

$$B^{\pm}\times C^{\pm} = [4200,5250]\cup\{5600\}\cup\{7000\}\cup[4800,6000]\cup\{6400\}\cup\{8000\}\cup[5400,6750]\cup\{7200\}\cup\{9000\} = \{[4200,6750],7000,7200,8000,9000\}$$

$$A^{\pm}\times C^{\pm} = [4200,7500]\cup[5600,8000]\cup[7000,10000] = [4200,10000]$$

$$\frac{A^{\pm}}{B^{\pm}} = [1,\frac{10}{7}]\cup[\frac{7}{8},\frac{5}{4}]\cup[\frac{7}{9},\frac{10}{9}] = [\frac{7}{9},\frac{10}{7}]$$

$$\frac{B^{\pm}}{C^{\pm}} = [\frac{14}{15},\frac{7}{6}]\cup\{\frac{7}{8}\}\cup\{\frac{5}{10}\}\cup[\frac{16}{15},\frac{4}{3}]\cup\{1\}\{\frac{4}{5}\}\cup[\frac{18}{15},\frac{3}{2}]\cup\{\frac{9}{8}\}\cup\{\frac{9}{10}\} = \{\frac{7}{10},\frac{4}{5},\frac{9}{10},[\frac{14}{15},\frac{3}{2}]\}$$

$$\frac{A^{\pm}}{C^{\pm}} = [\frac{14}{15},\frac{5}{3}]\cup[\frac{7}{8},\frac{5}{4}]\cup[\frac{7}{9},1] = [\frac{7}{10},\frac{5}{3}]$$

$$A^{\pm^{-1}} = [\frac{1}{100},\frac{1}{70}]$$

$$B^{\pm^{-1}} = \{\frac{1}{70}\}\cup\{\frac{1}{80}\}\cup\{\frac{1}{90}\} = \{\frac{1}{90},\frac{1}{80},\frac{1}{70}\}$$

$$C^{\pm^{-1}} = [\frac{1}{75},\frac{1}{60}]\bigcup\{\frac{1}{80}\}\bigcup\{\frac{1}{100}\} = \{\frac{1}{100},\frac{1}{80},[\frac{1}{75},\frac{1}{60}]\}$$

$$A^{\pm} \vee B^{\pm} = [70,100]\bigcup[80,100]\bigcup[90,100] = [70,100]$$

$$B^{\pm} \vee C^{\pm} = [70,75]\bigcup\{80\}\bigcup\{100\}\bigcup[80,80]\bigcup\{80\}\bigcup\{100\}\bigcup[90,90]\bigcup\{90\}\bigcup\{100\} = \{[70,75],80,90,100\}$$

$$A^{\pm} \vee C^{\pm} = [70,100]\bigcup[80,100]\bigcup[100,100] = [70,100]$$

$$A^{\pm} \wedge B^{\pm} = [70,70]\bigcup[70,80]\bigcup[70,90] = [70,90]$$

$$B^{\pm} \wedge C^{\pm} = [60,70]\bigcup\{70\}\bigcup\{70\}\bigcup[60,75]\bigcup\{80\}\bigcup\{80\}\bigcup[60,75]\bigcup\{80\}\bigcup\{90\} = \{[60,75],80,90\}$$

$$A^{\pm} \wedge C^{\pm} = [60,75]\bigcup[70,80]\bigcup[70,100] = [60,100]$$

$$A^{\pm} \bigcup B^{\pm} = [70,100]\bigcup[70,100]\bigcup[70,100] = [70,100]$$

$$B^{\pm} \bigcup C^{\pm} = [60,75]\bigcup\{70,80\}\bigcup\{70,100\}\bigcup\{[60,75],80\}\bigcup\{80\}\bigcup\{80,100\}\bigcup\{[60,75],90\}\bigcup\{80,90\}\bigcup\{90,100\} = \{[60,75],80,90,100\}$$

$$A^{\pm} \bigcup C^{\pm} = [60,100]\bigcup[70,100]\bigcup[70,100] = [60,100]$$

$$A^{\pm} \bigcap B^{\pm} = \{70\}\bigcup\{80\}\bigcup\{90\} = \{70,80,90\}$$

$$B^{\pm} \bigcap C^{\pm} = \{70\}\bigcup\{80\} = \{70,80\}$$

$$A^{\pm} \bigcap C^{\pm} = [70,75]\}\bigcup\{80\}\bigcup\{100\} = \{[70,75\},80,100\}$$

$$\neg A^{\pm} = \{[-\infty,70)\bigcup(100,+\infty]\} = \{[-\infty,70),(100,+\infty]\}$$

$$\neg B^{\pm} = [-\infty,70)\bigcup(70,+\infty]\bigcup[-\infty,80)\bigcup(80,+\infty]\bigcup[-\infty,90)\bigcup(90,+\infty] = \{[-\infty,60),(70,80),(80,90),(90,+\infty]\}$$

$$\neg C^{\pm} = [-\infty,60)\bigcup(75,+\infty]\bigcup[-\infty,80)\bigcup(80,+\infty]\bigcup[-\infty,100)\bigcup(100,+\infty] = \{[-\infty,60),(75,80),(80,100),(100,+\infty]\}$$

Their degree of greyness can be calculated according to Equation (9) or Equation (21)-(30).

$$(A^{\pm})^{\circ}=\frac{100-70}{100+70}=\frac{3}{17},\ (B^{\pm})^{\circ}=\frac{90-70}{90+70}=\frac{1}{8},\ (C^{\pm})^{\circ}=\frac{100-60}{100+60}=\frac{1}{4}$$

$$(A^{\pm}+B^{\pm})^{\circ}=\frac{100+90-70-70}{100+90+70+70}=\frac{5}{33},\ (B^{\pm}+C^{\pm})^{\circ}=\frac{90+100-70-60}{90+100+70+60}=\frac{3}{16},$$

$$(A^{\pm}+C^{\pm})^{\circ}=\frac{100+100-70-60}{100+100+70+60}=\frac{7}{33}$$

$$(A^{\pm}-B^{\pm})^{\circ}=\frac{100-70-70+90}{|100-70|+|70-90|}=1,\ (B^{\pm}-C^{\pm})^{\circ}=\frac{90-60-70+100}{|90-60|+|70-100|}=1,$$

$$(A^{\pm}-C^{\pm})^{\circ}=\frac{100-60-70+100}{|100-60|+|70-100|}=1$$

$$(A^{\pm}\times B^{\pm})^{\circ}=\frac{9000-4900}{9000+4900}=\frac{41}{139},\qquad (B^{\pm}\times C^{\pm})^{\circ}=\frac{9000-4200}{9000+4200}=\frac{12}{33},$$

$$(A^{\pm}\times C^{\pm})^{\circ}=\frac{10000-4200}{10000+4200}=\frac{29}{71}$$

$$\left(\frac{A^{\pm}}{B^{\pm}}\right)^{\circ}=\frac{\frac{100}{70}-\frac{70}{90}}{\frac{100}{70}+\frac{70}{90}}=\frac{41}{139},\ \left(\frac{B^{\pm}}{C^{\pm}}\right)^{\circ}=\frac{\frac{90}{60}-\frac{70}{100}}{\frac{90}{60}+\frac{70}{100}}=\frac{4}{11},\ \left(\frac{A^{\pm}}{C^{\pm}}\right)^{\circ}=\frac{\frac{100}{60}-\frac{70}{100}}{\frac{100}{60}+\frac{70}{100}}=\frac{29}{71}$$

$$(A^{\pm}\vee B^{\pm})^{\circ}=\frac{100-70}{100+70}=\frac{3}{17},\ (B^{\pm}\vee C^{\pm})^{\circ}=\frac{100-70}{100+70}=\frac{3}{17},\ (A^{\pm}\vee C^{\pm})^{\circ}=\frac{100-70}{100+70}=\frac{3}{17}$$

$$(A^{\pm}\wedge B^{\pm})^{\circ}=\frac{90-70}{90+70}=\frac{1}{8},\ (B^{\pm}\wedge C^{\pm})^{\circ}=\frac{90-60}{90+60}=\frac{1}{5},\ (A^{\pm}\wedge C^{\pm})^{\circ}=\frac{100-60}{100+60}=\frac{1}{4}$$

$$(A^{\pm}\bigcup B^{\pm})^{\circ}=\frac{100-70}{100+70}=\frac{3}{17},\ (B^{\pm}\bigcup C^{\pm})^{\circ}=\frac{100-60}{100+60}=\frac{1}{4},\ (A^{\pm}\bigcup C^{\pm})^{\circ}=\frac{100-60}{100+60}=\frac{1}{4}$$

$$(A^{\pm}\bigcap B^{\pm})^{\circ}=\frac{90-70}{90+70}=\frac{1}{8},\ (B^{\pm}\bigcap C^{\pm})^{\circ}=\frac{80-70}{80+70}=\frac{1}{15},\ (A^{\pm}\bigcap C^{\pm})^{\circ}=\frac{100-70}{100+70}=\frac{3}{17}$$

$$(\neg A^{\pm})^{\circ}=(\neg B^{\pm})^{\circ}=(\neg C^{\pm})^{\circ}=1$$

Obviously, the extended grey numbers can combine both continuous and discrete grey numbers together in a seamless model. Our results in the example show that both representations can be treated in the same way in the proposed model without losing any information of the involved discrete grey numbers.

5 Conclusion

One of the advantages of grey numbers over intervals is its capability in expressing discrete numbers as well as continuous numbers. This is not shown by the present application of grey numbers. Considering this problem, we defined a new definition of grey numbers which integrates both continuous grey numbers and discrete grey numbers. Because of the involvement of discrete grey numbers and its mixture with continuous grey numbers, their arithmetic operations are different from single intervals. Based on the analysis of the properties of new grey numbers, we discussed their degree of greyness and derived their arithmetic operations and relevant degree of greyness. Our results show that grey numbers are different from intervals and have more powerful capability in expressing uncertainty caused by missing information.

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Industrial Restructuring of Jiangsu Based on the Grey Linear Programming Model Considering Energy-Saving*

Chaoqing Yuan and Sifeng Liu

It was found that the change of industrial structure increased energy intensity from 2000 to 2007 in Jiangsu. The reason is that the second industry grew very rapidly, and the proportion of the second industry increased. A grey linear programming model was created to find an ideal industry structure to decrease energy consumption. It was concluded that the energy intensity of Jiangsu will decline by the industrial restructuring from 2007 to 2010.

1 Introduction

Since 2000, the economy has grown rapidly in Jiangsu province; meanwhile, the energy consumption has grown along with economy. Economy growth depends on the growth of secondary industry in Jiangsu, but the secondary industry consumes more energy, so the industrial structure has a great effect on energy consumption in Jiangsu. Many researchers have studied the energy-saving effect of the industrial structure. The energy intensity in China has declined, and efficiency effects contributed the majority while structure effects contributed less (X. Lin, 1995; Hua Liao, 1997). It is similar in Chinese industrial sectors (Stinton, 1994; Zhong, 2003). With the exception of few years, industry restructuring even has had a negative effect on energy efficiency (Wu Qiaosheng, 2006). The secondary industry is predominantly a driving force to reducing comprehensive energy intensity, while tertiary industry development will also lead the energy intensity ascending in Shanghai (Lin Yanjun, 2006). The efficiency share is a major factor affecting energy consumption intensity, and the structure share is playing a negative role in the decrease of energy consumption intensity. Moreover, the impact of efficiency

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* This work was supported in part by the United Nations Development Programme (UNDP) Tender Project (00035738C27), Jiangsu Social Science Fund (07EYA017), and Social Project of the Ministry of Education (07JC630064).

shares on energy consumption intensity is consistent, while the impact of structure shares on energy consumption seems to be inconsistent because of the impact of macroeconomic policy at the same time (LIU Feng-chao, 2007). This chapter will study the effect of industrial structure but also research how to decrease energy intensity by industry restructuring.

2 The Energy-Saving Effect of Industry Structure in Jiangsu

A. Decomposition of energy intensity

Energy intensity indicates energy consumption per GDP; that is,

$$e = E / Y$$

where E refers to energy consumption, and Y refers to GDP.

Energy consumption and GDP are decomposed according to the three industries as follows:

$$E = \sum_{i=1}^{3} E_i = E_1 + E_2 + E_3 \tag{1}$$

$$Y = \sum_{i=1}^{3} Y_i = Y_1 + Y_2 + Y_3 \tag{2}$$

So energy intensity can be decomposed as follows:

$$e = \frac{E}{Y} = \frac{\sum_{i=1}^{3} E_i}{\sum_{i=1}^{3} Y_i} = \frac{\sum_{i=1}^{3} e_i Y_i}{\sum_{i=1}^{3} Y_i} = \sum_{i=1}^{3} e_i y_i \tag{3}$$

Where e_i: Energy intensity of each industry, y_i: the proportion of each industry.

Assume that $e^n (n = 1,2,\cdots,N)$ indicates the energy intensity of period n and e^0 indicates the energy intensity of the base period, then

$$e^n = \sum_{i=1}^{3} e_i^n y_i^n \text{ , } e^0 = \sum_{i=1}^{3} e_i^0 y_i^0$$

And e^n can be decomposed as follows:

$$e^n = \sum_{i=1}^{3} e_i^n y_i^n = \sum_{i=1}^{3} e_i^0 y_i^0 + \sum_{i=1}^{3} e_i^0 (y_i^n - y_i^0) + \sum_{i=1}^{3} y_i^n (e_i^n - e_i^0) \tag{4}$$

The change of energy intensity can be decomposed as follows:

$$\Delta e = e^n - e^0 = \sum_{i=1}^{3} e_i^0 (y_i^n - y_i^0) + \sum_{i=1}^{3} y_i^n (e_i^n - e_i^0) = \Delta e_s + \Delta e_e \qquad (5)$$

where $\Delta e_s = \sum_{i=1}^{3} e_i^0 (y_i^n - y_i^0)$ indicates the change of energy intensity caused by industrial structure; $\Delta e_e = \sum_{i=1}^{3} y_i^n (e_i^n - e_i^0)$ indicates the change of energy intensity caused by energy efficiency.

B. The change of energy intensity caused by industrial structure in Jiangsu

From industrial structure of Jiangsu, as shown in table I, the proportions of secondary industry and tertiary industry increased from 2000 to 2007.

Table I Industrial Structure of Jiangsu (%)

Year	Primary industry	Secondary Industry	TERTIARY INDUSTRY
2000	12.2	51.9	35.9
2007	7.0	55.6	37.4

Resource: Statistical Yearbook of Jiangsu 2008.

From the energy intensity of each industry in Jiangsu, as shown in table II, the energy usage efficiency of primary industry and secondary industry improved from 2000 to 2007, but energy usage efficiency of tertiary industry dropped slightly.

Table II Energy intenstiy of each industy in jiangsu (%)

YEAR	PRIMARY INDUSTRY	SECONDARY INDUSTRY	TERTIARY INDUSTRY
2000	0.315591	1.315753	0.207038
2007	0.208768	1.239479	0.208854

According to Equation (5), the change of energy intensity can be calculated as:

$\Delta e =$ -0.01383 tce per 10^4 RMB;

The change of energy intensity caused by industry structuring can be calculated as:

$\Delta e_s = 0.035378$ tce per 10^4 RMB;

The change of energy intensity caused by energy efficiency can be calculated:

$\Delta e_e =$ -0.04921 tce per 10^4 RMB.

The improvement of energy efficiency decreased energy intensity 0.04921 tce per 104 RMB, but industrial structure increased energy intensity 0.035378 tce per 104 RMB, so energy intensity decreased 0.01383 tce per 104 RMB. The growth of the proportion of secondary industry increased the energy intensity from 2000 to 2007. Jiangsu has a large proportion of secondary industry, so industrial restructuring is very important to save energy.

3 Industrial Restructuring to Save Energy

A. Model

In this chapter, a grey linear programming model (Lin and Liu, 1999) is created to study how to decrease energy intensity by industrial restructuring, considering fixed assets, labor, water resource constraints, as well as the characteristics of regional economic growth.

Table III Value added of secondary industry and tertiary industry (100 million yuan)

Year	Secondary industry	Tertiary Industry
1992	1664.17	1235.333
1993	2052.606	1545.868
1994	2519.692	1721.936
1995	2926.665	1977.836
1996	3288.103	2261.523
1997	3703.228	2580.025
1998	4152.445	2913.057
1999	4621.258	3205.202
2000	5156.966	3563.766
2001	5721.246	3971.866
2002	6503.31	4432.34
2003	7623.117	4980.003
2004	8927.957	5647.072
2005	10355.04	6489.14
2006	12011.85	7494.957
2007	13877.93	8708.081

Resource: Statistical Yearbook of Jiangsu2008.

The development of tertiary industry is closely related to that of the secondary industry in Jiangsu Province, as shown in table III. A linear regression model is set up in which the Value Added of secondary industry is an independent variable and the Value Added of tertiary industry is a dependent variable. The parameters of the model are estimated, and the linear regression equation is shown as follows. The R2=0.998 that shows the regression model is good.

$$\widehat{Y}_3 = 0.604Y_2 + 329.983 \tag{6}$$

By studying the real values and simulated values of the regression model, as shown in table IV, we find the following features:

$$0.9Y_3 < \widehat{Y}_3 < 1.1Y_3 \tag{7}$$

Equation (7) shows the relation between secondary industry and tertiary industry, which should be considered in regional industrial restructuring in Jiangsu. Two constraints can be generated from equation (7).

$$1.1Y_3 - 0.604Y_2 > 329.983 \tag{8}$$

$$0.9Y_3 - 0.604Y_2 < 329.983 \tag{9}$$

Table IV Relative error of the Linear Regression Model

YEAR	RELATIVE ERROR $(\widehat{Y}_3 - Y_3)/Y_3$	REAL VALUES Y_3	SIMULATED VALUES $\widehat{Y}_3$
1992	1235.333	1335.142	7.48%
1993	1545.868	1569.757	1.52%
1994	1721.936	1851.877	7.02%
1995	1977.836	2097.689	5.71%
1996	2261.523	2315.997	2.35%
1997	2580.025	2566.733	-0.52%
1998	2913.057	2838.06	-2.64%
1999	3205.202	3121.223	-2.69%
2000	3563.766	3444.79	-3.45%
2001	3971.866	3785.615	-4.92%
2002	4432.34	4257.982	-4.09%
2003	4980.003	4934.346	-0.93%
2004	5647.072	5722.469	1.32%
2005	6489.14	6584.427	1.45%
2006	7494.957	7585.138	1.19%
2007	8708.081	8712.25	0.05%

So, a linear programming model can be set up as follows:

$$\min \quad e_1Y_1 + e_2Y_2 + e_3Y_3$$
$$\begin{cases} a_{11}Y_1 + a_{12}Y_2 + a_{13}Y_3 \le b_1 \\ a_{21}Y_1 + a_{22}Y_2 + a_{23}Y_3 \le b_2 \\ a_{31}Y_1 + a_{32}Y_2 + a_{33}Y_3 \le b_3 \\ Y_1 + Y_2 + Y_3 \ge Y_A \\ 1.1Y_3 - 0.604Y_2 > 329.983 \\ 0.9Y_3 - 0.604Y_2 < 329.983 \\ Y_1 > 0 \\ Y_2 > 0 \\ Y_3 > 0 \end{cases} \tag{10}$$

where e_1, e_2, e_3: Energy intensity of each industry; Y_1, Y_2, Y_3: Value Added of each industry; $a_{1j}, j = 1,2,3$: Fixed assets per Value Added of each industry, which indicates necessary fixed assets of the unit Value Added, $a_{2j}, j = 1,2,3$: Labor per Value Added of each industry, which indicates necessary labor of the unit Value Added, $a_{3j}, j = 1,2,3$: Water resource per Value Added of each industry, which indicates water consumption of the Unit Value Added, b_1: Fixed assets; b_2: Labor; b_3 :Water resource; Y_A :the objective of the regional economic growth. a_{ij} indicates kinds of resource consumption of the unit Value Added of each industry, and it is called the resource consumption coefficient. a_{ij} and b_i ($j = 1,2,3$) are predicted by GM(1,1), so equation (10) is a grey linear programming model.

B. The objectives of industrial structuring of Jiangsu in 2010

In order to adjust the industrial structure in 2010, GM (1, 1) (Liu Sifeng, 2004; Sydow, et al., 2001; Lin and Liu, 2000) is applied to predict the resource consumption coefficients and resources, as shown in table V and table VI.

Table V The predicted values of resource consumption coefficients in 2010

	PRIMARY INDUSTRY	SECONDARY INDUSTRY	TERTIARY INDUSTRY
a_{1j}	0.035258	0.591764	0.666996
a_{2j}	0.381073	0.061943	0.121078
a_{3j}	0.174942	0.014495	0.000669

Table VI The predicted values of resources of Jiangsu in 2010

YEAR	FIXED ASSETS (100 MILLION RMB)	LABOR (10000 PERSON)	WATER (100 MILLION CUBIC METERS)
2010	27606.01	4613.216	545.0447

The goal of economic growth of Jiangsu in Eleventh Five-Year Planning is that the GDP will reach 29000 × 100 Million RMB, so $Y_A = 29000$. Then, a grey linear programming model can be established according to equation (10).

$$Min \quad 0.22003Y_1 + 1.34747Y_2 + 0.403861Y_3$$

$$\begin{cases} 0.035258Y_1 + 0.591764Y_2 + 0.666996Y_3 \le 27606.01 \\ 0.381073Y_1 + 0.061943Y_2 + 0.121078Y_3 \le 4613.216 \\ 0.174942Y_1 + 0.014495Y_2 + 0.000669Y_3 \le 545.044665 \\ Y_1 + Y_2 + Y_3 \ge 29000 \\ 1.1Y_3 - 0.604Y_2 > 329.983 \\ 0.9Y_3 - 0.604Y_2 < 329.983 \\ Y_1 > 0 \\ Y_2 > 0 \\ Y_3 > 0 \end{cases} \tag{11}$$

This model is resolved, and the results are shown as below.

$$Y_1 = 1757.229492\ ;\ Y_2 = 15869.088867\ ;\ Y_3 = 11373.681641.$$

And the objectives of industrial structuring of Jiangsu in 2010 are calculated, as shown in table VII.

Table VII The Goal industrial structure of Jiangsu in 2010

Industry	Primary Industry	Secondary Industry	Tertiary Industry
Proportion	6.06%	54.72%	39.22%

In the Eleventh Five-Year Planning, the proportion of tertiary industry will reach 40%. It is consistent with the result of this chapter. So, the result of this chapter is reasonable to a certain extent.

According to equation (5), if the goal industrial structure is achieved, industrial restructuring will decrease the energy intensity of Jiangsu 0.009069 tce per 104 RMB from 2007 to 2010.

4 Conclusion

From 2000 to 2007, industrial structuring increased the energy intensity of Jiangsu. This chapter shows that energy intensity will decline slightly from 2007 to 2010 through the adjustment of the industrial structure. Industrial restructuring of Jiangsu is a difficult task. Secondary industry grows rapidly and promotes the development of Jiangsu. North of Jiangsu is a new and important growth pole of Jiangsu. Industrializing north of Jiangsu will accelerate the development of secondary industry in Jiangsu. The south of Jiangsu has entered an advanced stage of industrialization, with a foundation for the development of tertiary industry. Because the GDP of south of Jiangsu is much more than that of the north, the development of the tertiary industry of the south of Jiangsu is related to the overall optimization of industrial structure in Jiangsu. So, some industries should be focused in Nanjing, Suzhou, Wuxi and Changzhou, such as the modern logistics industry, the software industry, financial services, business and technology services, cultural industries, tourism and so on.

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Location of Logistics Distribution Centers with Grey Production Capacity Based on Hybrid PSO*

Qishan Zhang and Hong Liu

At the location of logistics distribution centers, there are a lot of grey information, which are helpful to the location of logistics distribution centers. The principal purpose of this chapter is to develop a method for dealing with the grey production capacity at the location of logistics distribution centers. A grey programming model of the distribution center location with the grey production capacity was proposed, and its grey chance-constrained programming and the algorithm based on hybrid particle swarm optimization were obtained. The results of an example show that the model and algorithm are effective for dealing with the grey production capacity at the location of logistics distribution centers.

1 Introduction

The logistics distribution network is an important component of the logistics system. Recently, uncertain network optimization has become a hot field in logistics research. Location optimization is an important problem of distribution network optimization, in which there are fuzzy information, stochastic information, grey information and mixed information, and so on. If the uncertain information can be dealt with effectively, the practicability of location optimization results can be improved. At present, the distribution location of fuzzy or stochastic information has been extensively studied (Hua and Sheu, 2003; Yang et al., 2007; Chen, 2001; Sheu, 2007; Yang et al., 2002; Li et al., 2000), while the optimization problem of distribution location with grey information has not been covered. In this chapter, grey chance-constrained programming and particle swarm optimization (PSO) are combined to study the problem of distribution location with grey production capacity, and an effective approach is proposed to resolve it. For more details on grey information and related methodology, please consult with (Liu and Lin 2006; Lin et al., 2004; Lin and Liu, 2006).

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* This work is supported by Natural Science Foundation of China under the project of 70871024.

2 The Optimization Models

A. Mathematical model

Suppose there is a manufacturer whose production capacity is *P*. It must be decided to establish *m* distribution centers from *M* distribution nodes and *n* sales centers from *N* sales points, which produces the minimum total cost of logistics under the conditions satisfied with the demands and constraints.

Parameter symbols are expressed as follows.

W_i : fixed fee that distribution center *i* selected to be established.
Q_i : capacity of distribution center *i*.
C_i : freight by factory into logistics center *i*.
F_i : unit processing cost of distribution center *i*.
C_{ij}: freight by distribution center *i* into sales center *j*.
W_j: fixed fee that sales center *j* selected to be established.
F_i : unit processing cost of sales center *j*.
d_j: distance between factory and distribution center *i*.
d_{ij}: distance between distribution center *i* and sales center *j*.
I : the set of distribution centers.
J : the set of sales centers.
$\otimes P$: a grey quantity throughput of the factory.

Decision-making variables are as follows:

$X_i = (0,1)$, 1 denotes that distribution center *i* is selected, 0 is that it's not.
$Y_j = (0,1)$, 1 denotes that sales center *j* is selected, 0 is that it's not.
q_i : flux by factory into distribution center *i*.
f_{ij} : flux by distribution center *i* into sales center *j*.

Model I, the mathematical model of logistics distribution location, is described as follows:

$$\min f = \sum_{i=1}^{m} X_i W_i + \sum_{j=1}^{n} Y_j W_j + \sum_{i=1}^{m} X_i F_i + \sum_{j=1}^{n} Y_j F_j + \sum_{i=1}^{m} q_i C_i d_i + \sum_{i=1}^{m}\sum_{j=1}^{n} f_{ij} C_{ij} d_{ij} \quad (1)$$

s.t.

$$\sum_{i=1}^{m} q_i \le \otimes P \quad (2)$$

$$q_i \le X_i Q_i \quad (3)$$

$$\sum_{j=1}^{n} f_{ij} = q_i, \forall i \in I \quad (4)$$

$$\sum_{i=1}^{m} X_i = m, \sum_{j=1}^{n} Y_j = n, m \geq 1, n \geq 1, \quad \forall i \in I, \forall j \in J \tag{5}$$

where objective function (1) minimizes the total cost, function (2) guarantees that the total flux is less than or equal to the grey throughput of the factory, function (3) expresses that the flux of every distribution center is less than their maximum capacity, respectively, function (4) shows that the outflow from every distribution center is equal to the inflow, function (5) denotes the number of distribution centers and sales centers selected to be established.

B. Transferred grey chance-constrained model

Chance-constrained programming (CCP) was proposed by Charnes and Cooper (Charnes and Cooper, 1959), and it can deal with stochastic variables in a constraint condition. Similarly, if the constraint contains grey information, it is grey chance-constrained programming model (GCCP) (Deng, 1988; Liu and Guo, 1999; Zhang, 2002; Liu and Wang, 2003; Zhang and Wang, 2009; Liu and Zhang, 2007; Zhang and Chen, 2007), which can be expressed as follows:

$$\begin{cases} \min \bar{f} \\ s.t. \Pr\{f(x,\otimes) \geq \bar{f}\} \geq \beta \\ \quad \Pr\{g_k(x,\otimes) \leq 0\}, k = 1,2,\cdots,p\} \geq \alpha \end{cases} \tag{6}$$

where $\Pr\{\cdot\}$ is the possibility of event $\{\cdot\}$, α is the confidence level of constraints, and β is the confidence level of the objective function, which are pre-given.

A point is feasible if and only if the possibility of event $\{g_k(x,\otimes) \leq 0\}, k = 1,2,\cdots,p\}$ is not less than α, viz. the possibility of violation of constraints is less than $(1-\alpha)$. $\bar{f}$ is the optimal objective value when the objective function ensures the confidence level is at least β, $\otimes$ is a grey parameter whose bound and whitenization weight function $\varphi(x)$ are known.

For any given decision variable x, grey simulation is used to test whether the chance-constrained is satisfactory or not. The test method is as follows:

Step 1: Generate N random values, which are in [0,1] and uniformly distributed, then calculate the whiten values $\overline{\otimes}_1, \overline{\otimes}_2, \cdots \overline{\otimes}_N$ by the whitening weight function $\varphi(x)$.

Step 2: Accumulate the number N' when $g_k(x,\overline{\otimes}_l) \leq 0, k = 1,2,\cdots,p, l = 1,2,\cdots,N$ is satisfactory. Then, by the law of large numbers, the test condition is transformed as if and only if $N'/N \geq \alpha$.

Then, Model I can be transformed into the chance-constrained Model II as follows:

$$\begin{cases} x = [X, Y, q_i, f_{ij}] \\ \min \bar{f} \\ s.t. \Pr\{f(x, \otimes P) \geq \bar{f}\} \geq \beta \\ \quad \Pr\{g_k(x, \otimes P) \leq 0\}, k = 1, 2, \cdots, p\} \geq \alpha \end{cases} \tag{7}$$

3 The Algorithm

Model II needs to confirm the location of the distribution centers and sales centers, and it needs to determine the distribution route. It is a NP hard problem. The PSO algorithm has the advantages of fast convergence and intelligence (Kennedy and Eberhart, 1995; Eberhart and Kennedy, 1995; Liu and Zhang, 2007), and it is suitable for solving the problem. In this chapter, a hybrid PSO is proposed to resolve model II, and the implementation method is as follows:

Step 1: Set the parameters of the PSO.
Step 2: Initialize the particle x.

$x = [X \ Y \ q_i \ f_{ij}]$, where

$X = (X_1, X_2, \cdots, X_M)$ is the M-dimensional binary vector,

$Y = (Y_1, Y_2, \cdots, Y_N)$ is the N-dimensional binary vector,

$q_i = (q_{i1}, q_{i2}, \cdots, q_{iM})$ is the M-dimensional decimal vector, and

$f_{ij} = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1N} \\ f_{21} & f_{22} & \cdots & f_{21} \\ \vdots & \vdots & \vdots & \vdots \\ f_{N1} & f_{N2} & \cdots & f_{NM} \end{bmatrix}$ is the $N \times M$ decimal matrix.

Step 3: Take f as the fitness function.

Step 4: Updating: calculate the new velocity and position of every particle according to formula (8), where ω is inertia weight, c_1 and c_2 are positive constants and are called the acceleration coefficient; $r_1, r_2 \in [0,1]$ are random numbers, p_{id} is the best position of each particle, and p_{gd} is the global best particle.

$$\begin{cases} v_{id} = \omega v_{id} + c_1 r_1 (p_{id} - x_{id}) + c_1 r_1 (p_{gd} - x_{id}) \\ x_{id} = x_{id} + v_{id} \end{cases} \tag{8}$$

Step 5: Stop rule: when the iterative number attains the maximum generation, or the optimal solution remains unchanged after several iterations. Otherwise, return to step 3 and go on searching.

4 Example

Suppose a manufacturer wants to choose m $(m < M)$ distribution centers and n $(n < N)$ sales centers.

Taking into account the current and future business development needs of the manufacturer, its production capacity P is a grey variable, and it then has $\otimes P$, and its whitening weight function is expressed as follows:

$$\varphi(x) = 1/(0.001(x-8000)^2 + 1) \tag{9}$$

Other parameters are shown in table 1-5. The parameters of the PSO are defined as: population size = 10, c_1=c_2=2, ω=0.2, maximum iteration number=30, the threshold number of the same result=10, and $\alpha = \beta$ =0.9. Based on the hybrid PSO, the experiment simulation result is shown in table 6.

Table 1 Freight by factory into distribution centers. (yuan/t)

No.	1	2	3	4	5	6
C_i	9	4	7	5	8	6

Table 2 Coordinates of all nodes

Node	Coordinate (x, y)		
Factory	1	34.84	48.41
Candidate logistics centers	1	22.48	42.56
	2	43.60	40.90
	3	20.82	18.82
	4	58.78	31.62
	5	31.38	65.52
	6	65.78	70.43
Candidate sales centers	1	55.21	62.20
	2	12.81	24.96
	3	52.47	42.56
	4	16.28	71.28
	5	36.03	31.31
	6	27.42	32.97
	7	41.42	57.61
	8	51.56	12.71
	9	18.18	45.89
	10	65.95	69.37

Table 3 Fixed fee, capacity and unit processing cost of distribution centers

No.	W_i (Million)	Q_i (t)	F_i (yuan)
1	1	4000	5000
2	2	5000	5000
3	2	4800	6000
4	0.6	3000	2000
5	1.5	4500	3000
6	1.6	4300	3000

Table 4 Freight by distribution center i into sales center j (yuan/t.km)

C_{ij}	1	2	3	4	5	6
1	5	6.5	4	11	7.5	11
2	10	7	9	11	4	12
3	5	9	5	11	13.5	5
4	9	9	11	12.5	12	9
5	12	9	12.5	5.5	6.5	12
6	11	12	12.5	7	12.5	12.5
7	6.5	9	9	7.5	7	10
8	6	9	10	13	5	12
9	8	5.5	10	12.5	12	10
10	10	10	7	12	7.5	6.5

Table 5 Fixed fee and unit processing cost of sales centers

No.	W_j (yuan)	F_j (yuan)
1	3000	1000
2	4000	950
3	4500	900
4	5500	900
5	3600	1000
6	3200	1000
7	3800	1000
8	4200	950
9	4100	950
10	4600	900

Table 6 The experiment simulation results

experiment number		10
successful number		10
average time (s)		35.0310
Best fitness value: the total cost (million)	minimum	58.4072
	maximum	103.3880
	average	79.7850

Where the minimum total cost is 58.4072 million and the best solution is as follows: X = (0 1 0 0 0 0), viz. the second distribution center is selected; Y=(1 0 1 0 1 0 0 0 0 1), viz. the first, third, fifth, tenth sales center are selected; q_i=(0 2500 0 0 0 0), viz. q_2=2500; $f_{2\text{-}1}$=45, $f_{2\text{-}3}$=930, $f_{2\text{-}5}$=835, $f_{2\text{-}10}$=690.

5 Conclusion

The location of logistics distribution centers contains various types of grey information, including production capacity, time windows, customer demand quantity, costs and prices and so on. The chapter discusses only the grey production capacity at the location of logistics distribution centers. The optimization model with the grey production capacity is a grey hybrid model of integer programming and linear programming with grey parameters. This model may be transformed into corresponding grey chance-constrained programming and solved by using hybrid particle swarm optimization.

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Part II
Grey Incidence Analysis and Application

The Diagnosis of Firm's "Diseases" Using the Grey Systems Theory Methods*

Camelia Delcea and Emil Scarlat

The core of our proposal is the determination of a "matrix of symptoms", based on grey systems theory. The symptoms of a firm can be represented by economic-financial ratios, usually used by analysts to make predictions and suggestions. The ability to create such a matrix of symptoms implies that given level of symptom's intensity, we can determinate if the analyzed firm presents some "diseases". By diseases we understand the causes which generate anomalies at the firm. With the utilization of such a matrix, the activity of the analyst can be really improved.

1 Introduction

Prediction of firm's "diseases" is a relatively new field in the economic and financial analysis. The economic context in which firms carry out their activities is dynamic and constantly changing. Creditors, auditors, stockholders and senior management all have a vasted interest in utilizing and developing a methodology or model that will allow them to monitor and regulate the financial performance of a firm via accounting ratios. By identifying changes and anticipating them, firms can take decisions to compensate or eliminate any negative effects and leverage the positive effects, thus facilitating the achievement of the firm's goals.

In this study, we propose to construct a matrix of symptoms, as this is the main element on which the diagnosis of the situation of the firm will be based. The symptoms of a firm can be represented by ratios, which are the indicators the analysts look at to make their predictions and suggestions. The occurrence of symptoms, which are objectively measurable, allows certain methods to be used to construct membership functions for symptoms, related to the idea of relative

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* This work was supported in part by the European Structural Founds under project nr. 7832, "Doctoral Research and PhD students in Education- Research- Innovation, DOC- ECI".

frequency. That is why the field is suitable for tools taken from grey systems theory, which allow us to properly model the variables taken into consideration.

2 Evolution of Models and Methods for Diagnosis and Prediction of Diseases of Firms

The starting point in making a prediction on the firm's evolution was the desire to early understand the precursor signals of a disaster and to take action that would try to improve the financial situation of a firm, even avoid its bankruptcy.

The assumption on which such predictions are based was that certain preliminary aspects regarding the insolvency of a firm can be seen by studying the dynamics of growth rates for a set of indicators derived from the financial accounting.

The first papers belonged to Fitz Patrick (FitzPatrick, 1932), who considered a set of 19 bankrupt firms and another set of 19 non-bankrupt firms. Following the research, it was found that 3 years before bankruptcy, the financial ratios were significantly changed. Another study is that made by Winakor and Smith (Winakor and Smith, 1935), who conducted research for a period of ten years before the bankruptcy establish, noting that the financial ratios deteriorate as firms were directed towards bankruptcy. Mervin (1942) reached similar conclusions.

However, the scientific concerns in this area began in 1967 with the research made by Beaver (1967). His research is intended to a benchmark for future research in purpose of finding alternatives for bankruptcy prediction using the financial ratios of a firm. Beaver developed a univariate discriminant analysis model, taking into account two sets of firms, bankrupt and non-bankrupt, and different ratios of them on a period equal to one year before the bankruptcy established. Those ratios have been selected following a dichotomous classification test. These models are now part of the classical models of bankruptcy prediction.

1966 is the year of birth of the risk index models. In these models, to each analyzed firm is assigned a number of points between 0 and 100, according to the rates involved in the model, so that the higher points indicate a better financial situation. Points are allocated so that the most important rates to get a higher weight. However, the allocation of weights is subjective (Balcaen and Ooghe, 2006). These models were introduced by Tamari (1966) and later extended by Moses and Liao (1987).

An important moment in the development of bankruptcy prediction models was the one in which Altman (1968) introduced a statistical multivariate analysis technique called multiple discriminant analysis to the problem of firm failure prediction and estimated a Z-score model. His model was used to discriminate between abnormal and healthy firms, using a statistical function.

After 1968, there have been an enormous number of studies based on Altman's Z-score model. Many of these hane focused on verification and assessment of the results obtained by the mentioned model (Altman et al., 1977; Deakin, 1972; Edminster, 1972; Taffler, 1982).

Fuzzy logic (Zadeh, 1965) was also widely used in firms' bankruptcy prediction. Thus, Siegel, Korvin and Omer (1995) argue that quantitative models based on fuzzy systems theory can solve this problem. It goes to a new approach to problem that may occur at firm level, both from the view point of quantitative variables, but especially in the qualitative variables, related to the subjectivity of decisions taken therein.

In 1982, Professor Deng Ju-Long published "Problems of Grey Control Systems", which proposed a new theory: the grey systems theory which managed to develop and mature rapidly, and even to impose. In practice, grey systems theory has been widely applied in analysis, modeling, prediction, control, decision making, in almost all areas: social, economic, mechanical and technical science, agriculture, industry, transport, petrology, meteorological, ecological, hydrological, geological, financial, medical, military, and others (Liu and Lin, 2005). Its main characteristic is that it manages to achieve good performance in analysis conducted on a small range of data and on a large number of variables.

3 Methods of Grey System Theory and Their Application in Diagnosis

Grey systems theory, unlike other interdisciplinary theories, has found and has managed to retain a place within them, especially because its success in real systems applications. This theory exceeds the drawbacks encountered in the use of probability theory and statistical methods (the need of reasonable size samples and determination of certain distributions to make inferences) and those of fuzzy mathematics (which deals with the study of problems with cognitive uncertainty phenomena, using so-called "membership functions", based on experience).

A. Methods of Grey Numbers' Generation Based on Average

A frequently problem encountered in any economic analysis is the lack of data. There are many cases where the collected data set of an observed economic system is incomplete, and thus, the researcher faces some difficulties in the undertaken analysis. Also, on the collected data, it may happened that in the initial data set, some values to be abnormal, much higher or much lower than the other values of the series, and, an analysis based on such a data set is leading to erroneous results. For the existence of some abnormal values, a possibility can be to identify and to exclude them from the data set, but the problem cannot be considered resolved either in this case, because it returns to the case where we have "gaps" in the data set. Grey system theory gives us, however, a method to solve this problem, namely to generate new values for filling empty spaces in data sequence.

We consider therefore that the data sequence analyzed contains"empty" information, which we note with $\phi(k)$, where k stands for the position in the data sequence. In this case, the data sequence X shows as follows:

$$X = (x(1), x(2), ..., x(k-1), \phi(k), x(k+1), ..., x(n))$$

The number value $\phi(k)$ is in the range delimited by $x(k-1)$ and $x(k+1)$, and the two values represents the lower and the upper limit of the unknown value.

Based on the series presented above we define the following value:

$$x^*(k) = 0.5x(k-1) + 0.5x(k+1)$$

As being a generated average value based on two non-consecutive neighborhood values.

The sequence obtained from using this method is called a generated sequence of non-consecutive neighbors (Liu and Lin, 2005).

We can generate sequences based on consecutive neighbors, in this way:

We consider the following data sequence: $X = (x(1), x(2), ..., x(k-1), x(k), x(k+1), ..., x(n))$ and the relation:

$$x^*(k) = 0.5x(k-1) + 0.5x(k)$$

It can be obtained the sequence:

$$X^* = (x^*(2), x^*(3), ..., x^*(n))$$

One of the most popular models of grey system theory is the GM model ("mean generation"), which is based on this method of generating average using the consecutive neighbor. This method is mainly used to emphasize a particular trend, if any.

In the firm analysis, the method of generating numbers based on average may be used if the purpose of the research is to observe the evolution in time of a specific variable, and for certain periods of time, for various reasons, those are unknown to the researcher.

For example, we consider the following sequence, which represents the quantity of products sold by the firm F (expressed in pieces) during an year, with monthly sales record:

$$\begin{aligned} C &= (c(1), c(2), c(4), c(5), c(9), c(11), c(12)) \\ &= (470, 690, 520, 440, 480, 710, 710) \end{aligned}$$

As can be seen, from a total of 12 months, we know only the quantities sold in 7 months, and for the other months, we can calculate the quantities by using the method of generating numbers based on average:

$$c(3) = \frac{1}{2}[c(2) + c(4)] = \frac{1}{2}(690 + 520) = 605$$

$$c(6) = \frac{1}{2}[c(5) + c(7)] = \frac{1}{2}(440 + 460) = 450$$

$$c(7) = \frac{1}{2}[c(5) + c(9)] = \frac{1}{2}(440 + 480) = 460$$

$$c(8) = \frac{1}{2}[c(7) + c(9)] = \frac{1}{2}(460 + 480) = 470$$

$$c(10) = \frac{1}{2}[c(9) + c(11)] = \frac{1}{2}(480 + 710) = 595$$

We obtained the series:

$$C = (c(1), c(2), c(3), c(4), c(5), c(6), c(7), c(8), c(9), c(10), c(11), c(12)) =$$
$$= (470,690,605,520,440,450,460,470,480,595,710,710)$$

B. Methods of Grey Clusters Theory

Grey data analysis is the base of many applications, such as economic applications and diagnosis and prediction of diseases of firms' applications. Data representation techniques are various, and different characteristics that data might have are causing difficulties in accurate classification of the object.

As we all know, classification can be of two types: unsupervised classification, when we speak about clustering, and supervised classification, namely discriminated analysis.

Through clustering it is trying to skip some of the variables of the analyzed system without this operation to affect the fundamental characteristics of the system.

Grey clustering is a method, based on matrices of grey incidence or whitenization weight functions of grey numbers, to classify observation indices or observational objects into definable classes (Liu and Lin, 2005). Regarding grey clustering based on grey incidence matrix, we test the connections among the analyzed factors so that we can make use of one of these factors to represent its group of factors, in a way that doesn't affect the available information. The second method, which refers to the cluster of whitenization weight functions of grey classes, it is applied to check whether a specified object belongs to a certain predefined class.

Next, we present clusters of grey incidences. We consider a set of n observational objects and m characteristic data values for each of these n objects. In terms of grey system theory, we have the following representation (Liu and Lin, 2005):

$$X_i = (x_i(1), x_i(2), ..., x_i(n)), i = 1,2,...,m$$

We note the absolute degree of incidence of X_i and X_j with ε_{ij}, calculated as it follows:

$$\varepsilon_{ij} = \frac{1 + |s_i| + |s_j|}{1 + |s_i| + |s_j| + |s_i - s_j|}$$

Where s_i : $s_i = \int_1^n (X_i - x_i(1))dt$

We obtain a triangular matrix A, called the incidence matrix of the characteristic variables:

$$A = \begin{pmatrix} \varepsilon_{11} & \varepsilon_{12} & ... & \varepsilon_{1m} \\ & \varepsilon_{22} & ... & \varepsilon_{2m} \\ & & ... & ... \\ & & & \varepsilon_{mm} \end{pmatrix}, \ \varepsilon_{ii} = 1$$

Taken a fixed critical value $r \in [0,1]$, for any value $\varepsilon_{ij} \geq r,\ i \neq j$, the variables X_i and X_j are treated as those of the same characteristics. Depending on the value chosen for the r parameter, the number of variables included in a certain class can be higher or less.

In practical analyses, it is quite difficult or impossible sometimes to classify each firm into groups of firms where, theoretically, it would be possible that some "diseases" to display. This is the reason why the classical method of forming classes of firms based on different ratios, so used in practice, haven't obtain the expected results and many opportunities have been lost.

Before extending on a large scale the information regarding on the set of firms taken under consideration, we can try another approach in order to reduce the cost of the research, with the method of clusters of grey incidences. In this way, we obtain a reduction of the considerate variables. The manner of applying the method of clustering based on grey incidence matrix has been exposed in the previous paragraph.

An important element is even the manner in which we choose the critical value *r*, because it depends on the number of variables included in each class. So, taken under consideration the purpose of the research, different values of *r* in [0, 1] can be chosen. If the number of variables in each class is desired to be as small as possible, then we choose a critical value *r* as close as 1, and, in contrary, as close as 0.

C. Methods of Grey Incidence Analysis

Solving the problem of diagnosis of "diseases" that can appear at firm level depends on the identified symptoms. We won't discuss in this case about how we choose the firms that analyzed or about the way we establish the set of symptoms that we use, because in many cases symptoms are represented by the financial ratios and indicators of a firm, which have a quantitative dimension that can be easily measured.

Most of the models used in diagnosis are based on a set of data collected at firm level (sometimes processed data), in a given period of time. Usually, we consider the values of symptoms at the level of year *t*, in most of the cases this is the year before bankruptcy, without attempting to link these values with the changes that have occurred in the indicator over a greater period, for example 3-5 years.

To have an overview of how the symptoms are evolving, until the moment they actually get to determine the bankruptcy of a firm, we propose a 5 years analysis and we use a matrix of symptoms expressed for each firm. If data are partially missing, these can be calculated using the grey method shown in paragraph 3.A.

We propose to determine which one of the considered symptoms manifest the biggest influence in each firm and to establish a hierarchy of then, in order to build a matrix of symptoms at the level of all the firms considered.

4 Firm Analysis

We note the set of symptoms S_j, with j = 1... n.

The correlation matrix between the level of each symptom of a firm and the corresponding year, for a universe of time equal to 5 years, is noted as follows:

$$X = \begin{pmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ .. & \dots & \dots & \dots \\ x_{51} & x_{52} & \dots & x_{5n} \end{pmatrix}$$

We will try to build an incidence level matrix of each symptom at the firms:

$$\gamma_{ij} = \begin{pmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1n} \\ .. & \dots & \dots & \dots \\ \gamma_{51} & \gamma_{52} & \cdots & \gamma_{5n} \end{pmatrix},$$

Where γ_{ij} is the grey incidence degree of symptom *j* on the considerate firm, in *i* year, with $i = 1,...,5$

To this purpose, we calculate the absolute degree of grey incidence, the relative degree of grey incidence, and by combining the two, the synthetic degree of grey incidence, which will help us in taking the decision.

D. Absolute Degree of Grey Incidence

We calculate the next sequence (Liu and Lin, 2005):

$$X_j^0 = (x_{1j} - x_{1j}, x_{2j} - x_{1j}, x_{3j} - x_{1j}, \ldots, x_{5j} - x_{1j}) \quad \text{with} \quad j = 1, \ldots, n.$$

For the first set of symptoms, we have a sequence as shown:

$$X_1^0 = (x_{11} - x_{11}, x_{21} - x_{11}, x_{31} - x_{11}, \ldots, x_{51} - x_{11})$$
$$= (x_{11}^0, x_{21}^0, x_{31}^0, x_{41}^0, x_{51}^0)$$

Next, we apply the formula of the absolute degree of grey incidence of the first year's symptom on the others:

$$\varepsilon_{1j} = \frac{1 + |s_1| + |s_j|}{1 + |s_1| + |s_j| + |s_1 - s_j|}$$

where $|s_1|, |s_2|, |s_3|, |s_4|, \ldots, |s_n|$ are calculated as follows:

$$|s_j| = \left| \sum_{k=2}^{4} x_{kj}^0 + \frac{1}{2} x_{5j}^0 \right|$$

We obtain the absolute degree of grey incidence: $\varepsilon_{12}, \varepsilon_{13}, \varepsilon_{14}, \ldots, \varepsilon_{1n}$

E. Relative Degree of Grey Incidence

The relative degree of grey incidence is obtained using the following relations:

$$r_{1j} = \frac{1+\left|s_1^{'}\right|+\left|s^{'}_j\right|}{1+\left|s_1^{'}\right|+\left|s_j^{'}\right|+\left|s^{'}_1 - s_j^{'}\right|}$$

$$\left|s^{'}_j\right| = \left|\sum_{k=2}^{4} x_{kj}^{0\,'} + \frac{1}{2} x_{5j}^{0\,'}\right|$$

We calculate the initial values of X_j as:

$X_j^{'} = (\frac{x_{1j}}{x_{1j}}, \frac{x_{2j}}{x_{1j}}, \frac{x_{3j}}{x_{1j}}, \frac{x_{4j}}{x_{1j}}, \frac{x_{5j}}{x_{1j}}) = (x_{1j}^{'}, x_{2j}^{'}, x_{3j}^{'}, x_{4j}^{'}, x_{5j}^{'})$, and the images of zero-start point:

$$X_j^{0'} = (x^{'}_{1j} - x^{'}_{1j}\ , x^{'}_{2j} - x^{'}_{1j}, x^{'}_{3j} - x^{'}_{1j}, \ldots, x^{'}_{5j} - x^{'}_{1j})$$
$$= (x_{11}^{'0}, x_{21}^{'0}, x_{31}^{'0}, x_{41}^{'0}, x_{51}^{'0})$$

F. Synthetic Degree of Grey Incidence

The synthetic degree of grey incidence is based on the absolute and relative degrees of grey incidence obtained earlier: $\rho_{1j} = \theta\varepsilon_{1j} + (1-\theta) r_{1j}$, with j= 2... n, $\theta \in [0,1]$ and $0 < \rho_{1j} \le 1$.

The size of synthetic degree of grey incidence obtained: $\rho_{12}, \rho_{13}, \ldots, \rho_{1n,}$ determine the degree in which each symptom influence the firm and conduct it to a bankrupt one. As the synthetic degree of grey incidence is higher, its corresponding symptom is more important. We classify these symptoms and we assign weights depending on the degree of grey incidence, and on the "sign" of symptoms. About a symptom *i* we are saying that it has a positive sign (greater is better) as it takes a higher value, the analyzed firm presents a better financial situation. Otherwise, the sign is negative (less is better).

The analysis was conducted at a single firm level. We will proceed the same with each of the F firms taken into analysis, and we will establish intensity levels for each of them.

By aggregation, we obtain a matrix of intensity level for each symptom and firms, in the form:

$Q = \begin{pmatrix} q_{11} & \cdots & q_{1N} \\ \cdots & \ddots & \cdots \\ q_{F1} & \cdots & q_{FN} \end{pmatrix}$, N= the total number of symptoms manifested at the level of considered firms, and F= the total number of firms

For example, we assume that a symptom is positive. In this case we attribute an intensity level *q,* equal to 1, to the highest synthetic degree of grey incidence placed on its column, and to the next ones, in order, the values: 0.96, 0.92, 0.88, 0.84, 0.8, …, 0.12, 0.08, respectively 0.04. If negative symptom, the award will be in reverse order.

G. *Numerical Example*

In order to better understand the proposed model, we develop a numerical example below. We assume that we analyze a set of F = 25 firms, for five years. In the analysis we assume the existence of nine symptoms as it follows:

S1: Solvability (positive symptom - it shows the capacity of a firm to pay its debt within the time prescribed – as the firm is solvent, its financial situation is better)
S2: Quick ratio (positive symptom)
S3: Working capital (positive symptom)
S4: EBIT-Yield (positive symptom)
S5: Interest cover ratio (positive symptom)
S6: Profit margin (positive symptom)
S7: Return on equity (positive symptom)
S8: Return on total assets (positive symptom)
S9: Gearing (negative symptom)

The values of symptoms considered for each firm are presented in Annex 1.

By using an excel worksheet we obtain the matrix of synthetic degree of grey incidence:

$$\rho_{ik} = \begin{pmatrix}
0.887341 & 0.876991 & 0.875939 & 0.651581 & 0.895744 & 0.830686 & 0.827280 & 0.626469 \\
0.766126 & 0.795103 & 0.737944 & 0.699424 & 0.779402 & 0.757995 & 0.932435 & 0.898971 \\
0.851452 & 0.957812 & 0.642783 & 0.863177 & 0.647200 & 0.709993 & 0.727306 & 0.678526 \\
0.901182 & 0.839176 & 0.751931 & 0.554213 & 0.595070 & 0.602805 & 0.597186 & 0.639696 \\
0.949399 & 0.714805 & 0.871436 & 0.539693 & 0.652070 & 0.719640 & 0.785739 & 0.526487 \\
0.881983 & 0.787871 & 0.639409 & 0.795913 & 0.684849 & 0.824054 & 0.837393 & 0.534686 \\
0.973359 & 0.922897 & 0.912397 & 0.794473 & 0.775744 & 0.721895 & 0.748727 & 0.578740 \\
0.686949 & 0.677308 & 0.625095 & 0.673399 & 0.752315 & 0.842776 & 0.846529 & 0.527720 \\
0.57465 & 0.656739 & 0.602016 & 0.576723 & 0.655381 & 0.649648 & 0.651813 & 0.525137 \\
0.573329 & 0.681707 & 0.593964 & 0.636264 & 0.658196 & 0.594806 & 0.593578 & 0.525030 \\
0.747175 & 0.771079 & 0.676675 & 0.610125 & 0.758700 & 0.733834 & 0.779607 & 0.601087 \\
0.711217 & 0.691509 & 0.690427 & 0.623779 & 0.712253 & 0.756064 & 0.732938 & 0.625905 \\
0.775325 & 0.791534 & 0.607540 & 0.732379 & 0.668310 & 0.617410 & 0.612120 & 0.552817 \\
0.776114 & 0.773256 & 0.729776 & 0.645365 & 0.757723 & 0.680138 & 0.676349 & 0.549616 \\
0.951504 & 0.898468 & 0.787265 & 0.724015 & 0.913351 & 0.732820 & 0.755040 & 0.791502 \\
0.933983 & 0.864013 & 0.838849 & 0.812009 & 0.810252 & 0.790350 & 0.734719 & 0.622797 \\
0.937254 & 0.965991 & 0.910852 & 0.652863 & 0.740105 & 0.710346 & 0.744192 & 0.773253 \\
0.845119 & 0.763306 & 0.730960 & 0.822574 & 0.683908 & 0.660631 & 0.668776 & 0.811928 \\
0.917541 & 0.85056 & 0.925802 & 0.643510 & 0.85752 & 0.745343 & 0.738978 & 0.598324 \\
0.833665 & 0.806711 & 0.677603 & 0.595395 & 0.762178 & 0.715017 & 0.774925 & 0.586901 \\
0.628765 & 0.612268 & 0.602451 & 0.733050 & 0.666656 & 0.684552 & 0.648732 & 0.527718 \\
0.687085 & 0.663076 & 0.850618 & 0.583431 & 0.749814 & 0.740637 & 0.725492 & 0.571525 \\
0.841232 & 0.911332 & 0.741743 & 0.575240 & 0.705195 & 0.645229 & 0.650691 & 0.540271 \\
0.769588 & 0.640484 & 0.635679 & 0.677745 & 0.632736 & 0.618638 & 0.619333 & 0.532207 \\
0.687317 & 0.741415 & 0.85480 & 0.706960 & 0.900873 & 0.898963 & 0.850566 & 0.601901
\end{pmatrix}$$

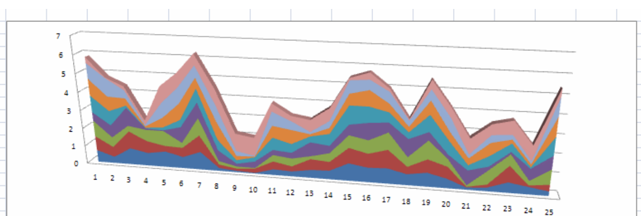
We obtain matrix Q:

$$
Q = \begin{pmatrix}
0.68 & 0.80 & 0.88 & 0.48 & 0.92 & 0.92 & 0.84 & 0.32 \\
0.36 & 0.56 & 0.56 & 0.68 & 0.80 & 0.80 & 1.00 & 0.04 \\
0.92 & 0.96 & 0.32 & 1.00 & 0.12 & 0.40 & 0.44 & 0.20 \\
0.72 & 0.68 & 0.64 & 0.08 & 0.04 & 0.08 & 0.08 & 0.24 \\
0.88 & 0.32 & 0.84 & 0.04 & 0.16 & 0.52 & 0.80 & 0.92 \\
0.64 & 0.52 & 0.28 & 0.88 & 0.40 & 0.88 & 0.88 & 0.76 \\
1.00 & 0.92 & 0.96 & 0.84 & 0.76 & 0.56 & 0.64 & 0.60 \\
0.16 & 0.20 & 0.20 & 0.60 & 0.60 & 0.96 & 0.92 & 0.88 \\
0.08 & 0.12 & 0.12 & 0.16 & 0.20 & 0.24 & 0.28 & 0.96 \\
0.04 & 0.24 & 0.04 & 0.36 & 0.24 & 0.04 & 0.04 & 1.00 \\
0.32 & 0.44 & 0.36 & 0.28 & 0.68 & 0.64 & 0.76 & 0.44 \\
0.28 & 0.28 & 0.44 & 0.32 & 0.48 & 0.76 & 0.48 & 0.28 \\
0.44 & 0.60 & 0.16 & 0.76 & 0.32 & 0.12 & 0.12 & 0.64 \\
0.48 & 0.48 & 0.48 & 0.40 & 0.64 & 0.32 & 0.36 & 0.68 \\
0.96 & 0.84 & 0.68 & 0.56 & 1.00 & 0.60 & 0.68 & 0.12 \\
0.80 & 0.76 & 0.72 & 0.92 & 0.84 & 0.84 & 0.52 & 0.36 \\
0.84 & 1.00 & 0.92 & 0.52 & 0.52 & 0.44 & 0.60 & 0.16 \\
0.60 & 0.40 & 0.52 & 0.96 & 0.36 & 0.28 & 0.32 & 0.08 \\
0.76 & 0.72 & 1.00 & 0.44 & 0.88 & 0.72 & 0.56 & 0.48 \\
0.52 & 0.64 & 0.40 & 0.24 & 0.72 & 0.48 & 0.72 & 0.52 \\
0.12 & 0.04 & 0.08 & 0.80 & 0.28 & 0.36 & 0.2 & 0.84 \\
0.20 & 0.16 & 0.76 & 0.20 & 0.56 & 0.68 & 0.40 & 0.56 \\
0.56 & 0.88 & 0.60 & 0.12 & 0.44 & 0.20 & 0.24 & 0.72 \\
0.40 & 0.08 & 0.24 & 0.64 & 0.08 & 0.16 & 0.16 & 0.80 \\
0.24 & 0.36 & 0.80 & 0.72 & 0.96 & 1.00 & 0.96 & 0.40
\end{pmatrix}
$$

The elements of the matrix Q are suggestive and show us which of the symptoms of a possible "disease" is more intense in every firm. On the other hand, based on this matrix, by aggregating it with a matrix of economic causes, we can determinate the matrix of economic-financial knowledge. We should note that when we will want to achieve a matrix of economic causes, we should take in consideration the fact that its elements can have both quantitative and qualitative nature.

On our numerical example we can say that the smaller the level of intensity, the more likely is that the firm to become bankrupt. Among the considered firms, we can easily see that the firm nr.10 records low level of intensity for most of the symptoms, while firm nr. 7 presents the best from this regard.

This can also be observed by making a sum of the intensity levels, as we can see from the chart:



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Series8	0,32	0,04	0,2	0,24	0,92	0,76	0,6	0,88	0,96	1	0,44	0,28	0,64	0,68	0,12	0,36	0,16	0,08	0,48	0,52	0,84	0,56	0,72	0,8	0,4
Series7	0,84	1	0,44	0,08	0,8	0,88	0,64	0,92	0,28	0,04	0,76	0,48	0,12	0,36	0,68	0,52	0,6	0,32	0,56	0,72	0,2	0,4	0,24	0,16	0,96
Series6	0,92	0,8	0,4	0,08	0,52	0,88	0,56	0,96	0,24	0,04	0,64	0,76	0,12	0,32	0,6	0,84	0,44	0,28	0,72	0,48	0,36	0,68	0,2	0,16	1
Series5	0,92	0,8	0,12	0,04	0,16	0,4	0,76	0,6	0,2	0,24	0,68	0,48	0,32	0,64	1	0,84	0,52	0,36	0,88	0,72	0,28	0,56	0,44	0,08	0,96
Series4	0,48	0,68	1	0,08	0,04	0,88	0,84	0,6	0,16	0,36	0,28	0,32	0,76	0,4	0,56	0,92	0,52	0,96	0,44	0,24	0,8	0,2	0,12	0,64	0,72
Series3	0,88	0,56	0,32	0,64	0,84	0,28	0,96	0,2	0,12	0,04	0,36	0,44	0,16	0,48	0,68	0,72	0,92	0,52	1	0,4	0,08	0,76	0,6	0,24	0,8
Series2	0,8	0,56	0,96	0,68	0,32	0,52	0,92	0,2	0,12	0,24	0,44	0,28	0,6	0,48	0,84	0,76	1	0,4	0,72	0,64	0,04	0,16	0,88	0,08	0,36
Series1	0,68	0,36	0,92	0,72	0,88	0,64	1	0,16	0,08	0,04	0,32	0,28	0,44	0,48	0,96	0,8	0,84	0,6	0,76	0,52	0,12	0,2	0,56	0,4	0,24

Fig. 1 Sum of the registered intensity levels calculated based on matrix Q

5 Conclusions

Determination of "diseases" of firms is an actual field in economic analysis, and the papers that deal with this problem are numerous. Theories that have grown since the research begun in this field are many and their purpose is the same: to find a way by which a possible "disease" or bankruptcy can be anticipated, to find a way to highlight the occurrence of such a phenomena.

In prediction of "diseases" of firms, particularly in the stage of diagnosis, a great attention must be given to symptoms manifested by the firms under analysis and to their quantification.

The method of constructing symptoms' matrix is based on facilities offered by the grey systems theory and it tries to find a way of determining the rank to which individual symptoms affect the final status of a firm or of a group of firms.

This method can be applied even to determine the matrix of economic causes that generate these symptoms, with the only difference that when we talk about causes, it should be taken into account that the non-quantitative aspect may be an issue. This implies certain conditions, so that the qualitative causes to be transformed in quantitative causes.

The research can be extended to determine a matrix of economic-financial knowledge, by aggregating the matrix of symptoms and causes, both using all methods of grey systems theory, but also by using hybrid methods. An example of a hybrid model that can be created by combining the methods of grey systems theory with the benefits of CBR (Case Based Reasoning) methods, so that after we obtain the matrix of economic-financial knowledge, we can attribute it the ability to learn from experience. But, such an approach will be the subject of future research.

Annex 1

Firm 1	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,47	0,57	0,63	0,15	1,97	0,15	0,27	0,33	1,67
Year II	0,22	0,22	0,28	0,07	1,93	0,1	0,22	0,28	1,72
Year III	0,25	0,37	0,39	0,1	2,21	0,07	0,18	0,22	1,88
Year IV	0,32	0,17	0,18	0,13	2	0,08	0,19	0,26	1,87
Year V	0,28	0,19	0,21	0,04	1,8	0,08	0,21	0,23	1,76

Firm 2	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,33	0,46	0,49	0,07	1,22	0,08	0,37	0,43	1,87
Year II	0,35	0,27	0,30	0,07	1,26	0,10	0,28	0,41	1,73
Year III	0,27	0,31	0,39	0,09	1,21	0,07	0,24	0,32	1,68
Year IV	0,29	0,32	0,37	0,11	1,57	0,09	0,19	0,26	1,87
Year V	0,31	0,40	0,43	0,15	1,72	0,15	0,21	0,93	1,96

Firm 3	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,41	0,46	0,47	0,02	2,2	-0,03	0,22	0,26	3,3
Year II	0,37	0,45	0,44	0,1	2,1	0,04	0,24	0,29	2,7
Year III	0,31	0,31	0,32	0,13	1,87	0,06	0,18	0,21	2,1
Year IV	0,36	0,37	0,4	0,07	2,3	0,06	0,36	0,37	1,8
Year V	0,38	0,4	0,42	0,01	2,6	0,08	0,34	0,37	1,5

Firm 4	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,21	0,26	0,31	0,03	2,1	0,14	0,31	0,36	1,1
Year II	0,47	0,46	0,48	0,16	1,3	0,03	0,22	0,26	4,32
Year III	0,53	0,55	0,57	0,14	1,1	0,02	0,21	0,23	4,21
Year IV	0,36	0,38	0,41	0,12	1,5	0,06	0,24	0,24	3,87
Year V	0,34	0,36	0,37	0,08	1,6	0,08	0,25	0,27	3,33

Firm 5	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,43	0,42	0,36	0,16	0,9	-0,05	0,16	0,19	0,45
Year II	0,22	0,24	0,27	0,08	2,4	0,02	0,1	0,13	2,33
Year III	0,35	0,32	0,38	0,06	2,7	0,11	0,18	0,16	2,54
Year IV	0,32	0,36	0,41	0,05	2,1	0,03	0,22	0,23	1,98
Year V	0,49	0,51	0,53	0,09	1,8	-0,01	0,18	0,21	1,56

Firm 6	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0.24	0.32	0.42	0.01	2.5	-0.11	0.35	0.37	1.4
Year II	0.27	0.28	0.31	0.16	1.79	-0.06	0.17	0.23	3.26
Year III	0.22	0.29	0.34	0.12	1.54	0.04	0.32	0.33	3.74
Year IV	0.19	0.24	0.27	0.03	2.65	0.02	0.29	0.31	4.2
Year V	0.17	0.21	0.24	0.14	3.2	-0.03	0.27	0.26	2.91

Firm 7	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0.26	0.28	0.29	0.09	2.31	-0.08	0.32	0.34	3.72
Year II	0.23	0.24	0.33	0.05	2.72	-0.06	0.17	0.26	2.94
Year III	0.36	0.37	0.35	0.11	4.03	-0.03	0.36	0.37	2.71
Year IV	0.42	0.45	0.47	0.15	2.19	0.01	0.31	0.34	2.13
Year V	0.21	0.22	0.35	0.12	2.53	0.04	0.29	0.32	1.24

Firm 8	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0.44	0.21	0.21	0.02	0.76	-0.11	0.42	0.47	0.42
Year II	0.27	0.23	0.22	0.04	0.98	-0.04	0.32	0.41	1.16
Year III	0.23	0.19	0.18	0.02	0.41	-0.09	0.27	0.34	2.22
Year IV	0.31	0.21	0.24	0.07	1.2	0.03	0.43	0.42	1.93
Year V	0.34	0.22	0.27	0.09	0.34	-0.06	0.36	0.36	3.2

Firm 9	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0.09	0.43	0.17	0.12	0.76	-0.11	0.32	0.36	4.22
Year II	0.16	0.13	0.12	0.04	0.98	-0.14	0.32	0.41	1.16
Year III	0.23	0.19	0.18	0.02	0.41	-0.09	0.27	0.34	2.22
Year IV	0.41	0.21	0.24	0.07	0.26	0.03	0.43	0.42	0.93
Year V	0.34	0.22	0.27	0.09	0.34	-0.06	0.36	0.36	3.2

Firm 10	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0.11	0.43	0.17	0.12	0.76	-0.11	0.42	0.47	4.22
Year II	0.37	0.23	0.22	0.04	0.98	-0.04	0.32	0.41	1.16
Year III	0.23	0.19	0.18	0.02	0.41	-0.09	0.27	0.34	2.22
Year IV	0.41	0.21	0.24	0.07	1.2	0.03	0.43	0.42	0.93
Year V	0.34	0.22	0.27	0.09	0.34	-0.06	0.36	0.36	3.2

Firm 11		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,28	0,35	0,37	0,18	2,06	0,11	0,34	0,35	2,22
	Year II	0,42	0,29	0,31	0,14	1,58	0,07	0,32	0,31	2,16
	Year III	0,23	0,31	0,33	0,06	1,36	0,09	0,29	0,34	1,82
	Year IV	0,31	0,33	0,44	0,07	1,12	0,13	0,23	0,32	0,97
	Year V	0,34	0,32	0,27	0,11	2,34	0,08	0,36	0,39	0,92

Firm 12		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,32	0,44	0,47	0,17	2,06	0,15	0,34	0,39	2,14
	Year II	0,47	0,36	0,35	0,12	1,61	0,07	0,28	0,31	2,26
	Year III	0,33	0,31	0,34	0,07	1,14	0,06	0,29	0,31	1,71
	Year IV	0,24	0,37	0,33	0,05	1,32	0,11	0,26	0,3	0,94
	Year V	0,27	0,21	0,26	0,06	2,22	0,09	0,28	0,29	1,12

Firm 13		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,14	0,26	0,27	0,15	2,06	0,09	0,24	0,29	2,17
	Year II	0,37	0,39	0,41	0,11	2,58	0,11	0,18	0,2	2,21
	Year III	0,31	0,33	0,34	0,08	2,14	0,08	0,22	0,23	1,63
	Year IV	0,38	0,41	0,46	0,11	1,92	0,13	0,24	0,31	0,84
	Year V	0,32	0,38	0,39	0,11	2,11	0,12	0,27	0,29	1,04

Firm 14		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,13	0,21	0,24	0,08	2,02	-0,04	0,22	0,25	2,42
	Year II	0,22	0,23	0,24	0,09	1,88	0,03	0,19	0,21	1,21
	Year III	0,27	0,28	0,34	0,12	1,94	0,08	0,24	0,25	1,03
	Year IV	0,19	0,21	0,24	0,07	1,92	0,07	0,19	0,22	0,84
	Year V	0,22	0,28	0,3	0,06	2,01	0,05	0,21	0,26	2,04

Firm 15		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,33	0,34	0,34	0,14	2,02	0,14	0,32	0,33	0,73
	Year II	0,28	0,31	0,32	0,12	2,88	0,13	0,27	0,3	0,67
	Year III	0,42	0,44	0,45	0,16	2,56	0,16	0,26	0,28	0,43
	Year IV	0,39	0,41	0,44	0,11	2,42	0,15	0,25	0,27	0,81
	Year V	0,36	0,38	0,4	0,09	1,91	0,15	0,25	0,29	1,04

Firm 16		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,26	0,27	0,27	0,1	2,22	0,12	0,29	0,34	0,21
	Year II	0,29	0,31	0,32	0,09	2,45	0,1	0,31	0,31	0,47
	Year III	0,34	0,36	0,4	0,13	2,37	0,13	0,32	0,34	0,33
	Year IV	0,32	0,36	0,39	0,11	2,32	0,14	0,27	0,29	0,89
	Year V	0,31	0,37	0,42	0,09	2,46	0,13	0,25	0,28	1,24

Firm 17		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,14	0,17	0,18	0,08	1,57	-0,02	0,16	0,17	1,27
	Year II	0,22	0,23	0,26	0,11	1,46	0,05	0,14	0,16	1,04
	Year III	0,16	0,2	0,21	0,13	1,34	-0,01	0,18	0,22	2,11
	Year IV	0,28	0,29	0,33	0,12	1,59	0,07	0,16	0,16	3,13
	Year V	0,21	0,24	0,29	0,09	1,42	0,07	0,15	0,18	2,26

Firm 18		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,23	0,32	0,38	0,12	2,23	0,14	0,33	0,37	0,44
	Year II	0,42	0,47	0,48	0,16	2,46	0,15	0,24	0,3	1,09
	Year III	0,36	0,41	0,44	0,13	2,14	0,12	0,31	0,32	0,71
	Year IV	0,27	0,31	0,33	0,1	2,51	0,13	0,28	0,35	0,33
	Year V	0,31	0,34	0,4	0,12	2,17	0,11	0,29	0,38	1,16

Firm 19		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,17	0,22	0,27	0,06	1,98	0,05	0,29	0,33	2,36
	Year II	0,23	0,27	0,31	0,08	1,77	0,09	0,27	0,28	2,14
	Year III	0,26	0,31	0,35	0,11	1,84	0,11	0,3	0,31	1,91
	Year IV	0,19	0,21	0,23	0,07	1,61	0,09	0,28	0,36	1,42
	Year V	0,19	0,24	0,29	0,06	1,83	0,06	0,24	0,28	1,56

Firm 20		S1	S2	S3	S4	S5	S6	S7	S8	S9
	Year I	0,27	0,34	0,37	0,18	2,24	0,11	0,35	0,33	2,21
	Year II	0,41	0,39	0,41	0,16	1,58	0,08	0,32	0,31	2,24
	Year III	0,24	0,34	0,35	0,06	1,37	0,11	0,31	0,34	1,42
	Year IV	0,32	0,33	0,44	0,09	1,32	0,13	0,23	0,29	0,92
	Year V	0,33	0,36	0,237	0,11	2,34	0,08	0,36	0,39	0,76

Firm 21	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,1	0,23	0,27	0,15	0,46	-0,09	0,27	0,32	3,72
Year II	0,13	0,17	0,17	0,04	0,98	-0,1	0,32	0,39	1,36
Year III	0,24	0,29	0,18	0,05	0,56	-0,08	0,27	0,34	1,22
Year IV	0,41	0,21	0,27	0,07	0,23	0,07	0,32	0,26	0,74
Year V	0,36	0,22	0,27	0,11	0,34	-0,06	0,36	0,36	3,1

Firm 22	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,41	0,21	0,21	0,12	0,46	-0,08	0,32	0,36	1,42
Year II	0,28	0,25	0,29	0,04	0,96	-0,04	0,32	0,41	1,16
Year III	0,33	0,29	0,28	0,02	0,71	-0,09	0,25	0,33	2,92
Year IV	0,31	0,21	0,24	0,05	1,2	0,05	0,43	0,42	1,73
Year V	0,36	0,28	0,37	0,09	0,34	-0,06	0,26	0,31	4,02

Firm 23	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,17	0,26	0,27	0,02	2,1	-0,06	0,23	0,26	3,1
Year II	0,32	0,34	0,48	0,11	1,3	0,03	0,22	0,29	2,32
Year III	0,46	0,52	0,55	0,09	2,1	0,09	0,27	0,29	1,09
Year IV	0,36	0,38	0,41	0,12	1,9	0,06	0,24	0,24	1,81
Year V	0,3	0,34	0,37	0,08	1,6	0,08	0,21	0,27	1,23

Firm 24	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,12	0,23	0,37	0,12	0,76	0,11	0,42	0,47	3,12
Year II	0,24	0,29	0,32	0,04	0,98	0,04	0,34	0,41	1,26
Year III	0,23	0,31	0,38	0,15	0,41	0,09	0,25	0,37	1,02
Year IV	0,31	0,31	0,34	0,11	1,2	0,13	0,43	0,42	0,73
Year V	0,34	0,32	0,41	0,09	0,34	0,06	0,36	0,36	1,2

Firm 25	S1	S2	S3	S4	S5	S6	S7	S8	S9
Year I	0,31	0,24	0,31	0,14	2,02	0,14	0,27	0,33	0,73
Year II	0,22	0,31	0,32	0,09	2,82	0,13	0,22	0,31	1,62
Year III	0,27	0,34	0,41	0,15	2,16	0,15	0,26	0,28	1,23
Year IV	0,39	0,41	0,42	0,11	2,12	0,15	0,24	0,25	0,81
Year V	0,34	0,37	0,4	0,09	1,71	0,15	0,25	0,29	1,04

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Apply GRA in CSL Communication Topics Selection*

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This chapter is to utilize grey incidence analysis to calibrate and analyze the priorities of communication topics for learning Chinese as second language (CSL) learners based on their interests. Presently there are no appropriate studies discussed regard how to measure CSL learners' interests and categorization of their interests in prioritized format. This is the first development through survey approach for this category of study. There are 84 questionnaire data of kindergarten level used in this chapter collected by the Overseas Compatriot Affairs Commission (OCAC) during teaching material development research project conducted in USA in 2008. The result of this chapter will provide further reference for OCAC and other relative CSL editing and publishing industries uses.

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* This work was supported in part by both the National Science Council under Grant NSC 97-2631-S-003-002 and the Overseas Compatriot Affairs Commission.

1 Introduction

Learning Chinese as second language (CSL) has become popular recently due to the economic boost in China. From the present languages practice in the world today, Chinese has become the second major language used in comparison with English. Majority of CSL learner includes Chinese born overseas and foreigners whom are also interest to learn Chinese. With the increase of demand on learning CSL which bring about the essentiality of quality improvement on the teaching materials contents.

A successful CSL teaching material contents design has a direct motivation to CSL learners and the impact on their learning effectiveness. It is a great importance to focus on the interest of CSL learner when editing the contents of CSL teaching materials in order to fulfill their needs and increase their learning effectiveness. Currently there are no such appropriate studies discussed regards how to measure CSL learners' interests and categorization of their interests in prioritized format.

There are numbers of directions to evaluate teaching CSL in overseas such as referring to the heritage programs; teachers' professional development, teachers' role in multilingual children's English and French language development, and children's discursive practices (Curdt-Christiansen, 2006). Some of the articles focus on the learning characteristics (Lijing, 2006) of Chinese students, or the activities used inside classroom to discuss the CSL contents (Huang, 2003; Kumamoto-Healey, 2000). There was one article discuss how to select situation content for US kindergarten and elementary (Tsai, 2008). However, the information on the discussion of what CSL communication content taught is very insufficient.

We assume data was approximately normally distributed and collected as many data as possible to minimize random errors during data analysis via statistical methods. According to an experimental study from Chang, there are no significant differences in the methods used between AHP, ELECTRE, TOPSIS and GRA when data approximately normally distributed (Chang, 2001). Contrary to this point of view, it is not appropriate to assume data we collected from survey hold the property of normal distribution. To address this problem, GRA can effectively discriminate the differences between subjects for fewer amounts of data or with uncertain data distribution (Deng and Guo, 1996). Other than this, data calibration is easily calculated and convenient and accurately locates the key factors or indicators selection. These are the major issues making of GRA so popular for data analysis (Lin, 2004). It is not surprise that we can find a lot of articles or papers applying GRA as the major method for data analysis. For example, Guo and Huang utilize GRA to prioritize factors from 25 steal companies' performance appraisal and review system (Guo and Huang, 2007). Wang used GRA to select evaluating indicators during Taiwan shipping container company performance review (Wang, 2006). Applying GRA on the performance review can often been utilized in hospital industry (Sun, 1999). In addition, GRA also used during decision making procedures such as finding key factor for investment strategy (Lin, and Yang, 1999), unemployment rate forecasting (Hu et al., 2008), etc. Many researchers integrate GRA with other methods for data analysis. For example, integrate GRA with Fuzzy measurement (Zhao and Mei, 1999), or with DEA (Guo and Huang, 2007), or with Neural Network, or with Case-based Reasoning (Tong and Shi, 2001).

The CSL teaching material topics we had listed in our survey were implemented by Functionalist Approach in Europe. There are total of 90 different topics in 6 different categories (Tsai, 2009). It is not appropriate to include all 90 topics in one CSL teaching material even though we had utilized GRA to prioritize the topics. It is necessary to make decision on which topics should include and which one should not.

This chapter applied GRA as the major method for CSL teaching material topic selection. The total of 84 questionnaire data of kindergarten level used in this chapter were collected from the Overseas Compatriot Affairs Commission (OCAC) during teaching material development research project conducted in USA 2008. All of them represented their students' interested topics in the kindergarten classes in USA. The data was in ordinal ratings. The result of this chapter will provide further reference for OCAC and other relative CSL editing and publishing industries uses.

2 Methods

The validity of traditional statistical analysis techniques is based on assumptions such as normal distribution as well as large sample size. However, it is not realistic to make decisions under those assumptions. Deng argued that making decisions under uncertainty and with insufficient or limited data available for analysis is actually a norm for managers in either public or private sectors (Deng, 1989). To address this problem, grey relational analysis, which first proposed by Deng in 1982 (Deng, 1982), is one of the most important and well-known methods to analyze uncertain and insufficient data in various fields. The procedures applying GRA used in this article consist of the following steps.

A. Generate comparison vector

The data we had collected came from 6 different categories. Each category consists of different numbers of teaching material topics in ordinal rating scale format. Total of 30 out of 90 CSL teaching material topics from 6 different categories were selected from each participant. There are 5 topics selected from first category and 3, 10, 8, 2 and 2 topics separately selected for 2nd, 3rd, 4th, 5th, and 6th category (Overseas Compatriot Affairs Commission, 2008) respectively. The reason of using proportion of total topics to standardized data before generating comparison data was due to its attribute of trend of original data. For example, there were 5 out of 12 topics selected in prioritize format of 1st category. The first priority topic in the 1st category is defined as $\frac{12}{90}$ and the fifth priority in the 1st category is defined as $\frac{8}{90}$. For those unselected topics in each category were all defined as $\frac{1}{90}$. Let

$$x_i = \left(x_{i1}, x_{i2}, \cdots, x_{in}\right)^T \tag{1}$$

where $i = 1, \cdots, 90; n = 1, \cdots, 71$; $x_i(k)$ represent the rating scale of the i^{th} teaching material topic from the k^{th} CSL teacher.

B. Generate matrix of the difference

There are two major GRA, localized and globalized, used in grey theory (Masatake and Yamaguchi, 2004; Wen et al., 2006). The difference between these two is that localized GRA is through comparison of difference between each vector and the reference vector, and globalize GRA is through comparison of difference between vectors. In addition, Nagai-Yamaguchi's globalized GRA holds the property of normality, isolation, coincidence, and symmetry (Yamaguchi et al., 2006) and it is effectively distinguish the difference between each subjects compared with Deng's, Wong's, Wu's, Wen's, Hsia's and Liu's GRA (Yamaguchi, 2006). There is no CSL standard of CSL teaching material topics available for reference. Therefore, this article apply Nagai-Yamaguchi globalize GRA as its major methodology during data analysis. Let

$$\Delta_{ij}(k) = \left\| x_i(k) - x_j(k) \right\|_{\xi} = \left[\sum_{k=1}^{n} \left| x_{ik} - x_{jk} \right|^{\xi} \right]^{\frac{1}{\xi}} \tag{2}$$

where $\Delta_{ij}(k)$ represented the difference of the rating value between i^{th} and j^{th} teaching material topic from the k^{th} CSL teacher.

$1 \leq \xi \leq \infty$, when $\xi = 1$ represent the city block distance, $\xi = 2$ represent the Euclidian distance. This article applied Euclidian distance during its data analysis.

C. Find the global maximum value Δ_{max}

Define Δ_{max} as follow in (3):

$$\Delta_{max} = \max_{\forall j} \max_{\forall j} \left\| x_i(k) - x_j(k) \right\|_{\xi} \tag{3}$$

D. Calibrate globalize grey incidence coefficient.

Let

$$\gamma\left(x_i(k), x_j(k)\right) = 1 - \frac{\Delta_{ij}}{\Delta_{max}} \tag{4}$$

where $\gamma\left(x_i(k), x_j(k)\right)$ represents the grey relational coefficient of the difference between i^{th} and j^{th} CSL teaching material topic from the k^{th} CSL teacher.

$$
\begin{bmatrix} x_1 = (x_{11}, x_{12}, \cdots, x_{1n})^T \\ x_2 = (x_{21}, x_{22}, \cdots, x_{2n})^T \\ \vdots \\ x_m = (x_{m1}, x_{m2}, \cdots, x_{mn})^T \end{bmatrix} \xrightarrow{\text{LP norm}} \begin{bmatrix} \Delta_{11} & \Delta_{12} & \cdots & \Delta_{1n} \\ \Delta_{21} & \Delta_{22} & \cdots & \Delta_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \Delta_{m1} & \Delta_{m2} & \cdots & \Delta_{mn} \end{bmatrix}
$$

$$
\downarrow 1 - \frac{\Delta_{ij}}{\Delta_{max}}
$$

$$
\begin{bmatrix} \gamma(x_1, x_1) & \gamma(x_1, x_2) & \cdots & \gamma(x_1, x_n) \\ \gamma(x_2, x_1) & \gamma(x_2, x_2) & \cdots & \gamma(x_2, x_n) \\ \vdots & \vdots & \ddots & \vdots \\ \gamma(x_m, x_1) & \gamma(x_m, x_2) & \cdots & \gamma(x_m, x_n) \end{bmatrix}
$$

Fig. 1 Nagai-Yamaguchi grey relational matrix cited from Yamaguchi

E. Compute grey incidence matrix

Let $\Gamma(x_i, x_j)$ represent the grey relational matrix. Figure 1 (Yamaguchi, 2006) indicates the procedure of grey relational matrix generating. The magnitude of $\Gamma(x_i, x_j)$ reflects the overall degree of standardized deviance of i^{th} from j^{th} CSL teaching material topic.

In general, a vector with high eigenvalue indicates that this vector has a higher degree of favored consensus. This data reported here were analyzed using globalized GRA model via a MATLAB program implemented by (Wen et al., 2006).

3 Analysis and Results

There were 13 questionnaires omitted due to the missing value in category. The reason of not applying any statistical missing value technique was due to the GRA assumption of uncertain and insufficient data available in realistic of data collected.

F. Eigenvalue and Eigenvector from grey relational matrix

The maximum eigenvalue corresponding eigenvector is calibrated. Sort this vector into increasing order to rank the CSL teaching material topics on the based of CSL teachers' interests. Those 90 CSL teaching material topics can be prioritize into total of 63 different groups. In other words, there are 46 topics, approximately more than 51%, remained indiscriminate.

This ranking result of the CSL teaching material topics also shows a lot different compared with methods of Friedman Analysis of Variance by Ranks (Chao and Tsai, 2009). Please see figure 2 for the example in 1st category.

G. Weight on each categories

There are 6 categories in the survey questionnaire. We defined the weights on each category according to their importance to the students in kindergarten. The weights were advised by CSL expertise from Teaching Chinese as Second Language Dept. in National Taiwan Normal University. The distribution of the weight are as follows; weighted 35% for 1st category, 10% for 2nd category, 20% for each 3rd and 4th category, 10% for 5th category and 5% for 6th category.

Let

$$\begin{bmatrix} x_1 = (x_{11}, x_{12}, \cdots, x_{1n})^T \\ x_2 = (x_{21}, x_{22}, \cdots, x_{2n})^T \\ \vdots \\ x_m = (x_{m1}, x_{m2}, \cdots, x_{mn})^T \end{bmatrix} \Rightarrow \begin{bmatrix} \begin{bmatrix} x_{11} \\ x_{21} \\ \vdots \\ x_{m1} \end{bmatrix} \begin{bmatrix} x_{12} \\ x_{22} \\ \vdots \\ x_{m2} \end{bmatrix} \cdots \begin{bmatrix} x_{1n} \\ x_{2n} \\ \vdots \\ x_{mn} \end{bmatrix} \end{bmatrix} \Rightarrow [M_1, M_2, \cdots, M_6] \tag{5}$$

$$[M_1, M_2, \cdots, M_6] \times \begin{bmatrix} [W_1] & & & \\ & [W_2] & & \\ & & \ddots & \\ & & & [W_6] \end{bmatrix} = [S]_{k \times n}$$

where $[W_i]_{\substack{n \times n \\ \forall i}}$ represented the weight matrix for i^{th} category and $[S]_{k \times n}$ represented a $k \times n$ matrix of the weighted standardized data on each category before globalized GRA.

Table I the comparision between Friedman, Weighted and Un-weighted priority for 1st category.

Friedman	Weight	Un-weight
Q3101	Q3101	Q3101
Q3102	Q3102	Q3102
Q3105	Q3105	Q3104
Q3104	Q3104	Q3103
Q3103	Q3103	Q3105
Q3106	Q3110	Q3109
Q3110	Q3106	Q3110
Q3111	Q3111	Q3106
Q3109	Q3109	Q3107
Q3107	Q3107	Q3108
Q3108	Q3108	Q3111
Q3112	Q3112	Q3112

After globalized GRA calibrating, the maximum eigenvalue, 59.4524, corresponding eigenvector is observed. Sort this vector into increasing order to rank the CSL teaching material topics on the based of CSL teachers' interests. This weighted priority result of the CSL teaching material topics (Table I) shows no significant difference compared with methods of Friedman Analysis.

4 Conclusions

Those weighted 90 CSL teaching material topics can be discriminate into 79 different groups of topic compared with 63 groups without weighted. This result indicated that weighted data can be easily distinguishing the distance between each topic compared with un-weighted data.

Under Friedman Analysis of Variance by Ranks, grouping of 1st category can only be discriminated into 3 significant groups compared with weighted GRA which are able to discriminate topics in 1st category into 12 groups. Practically weighted GRA are more appropriate used for CSL text book design.

The comparison of the effectiveness between the weighted and un-weight data is another major issue need to focus on. This result of the priority with weighted CSL teaching material topics shows no significant different compared with the result utilized methods of Friedman analysis of variance by rank.

After plotting these ranking data into the figure indicated as figure 2 below, there are 7 CSL teaching material topics apparently are not correlated to the others 83 topics. Therefore, we recommended not to including those 7 topics during kindergarten textbook design. Appendix indicated the finial rank of CSL teaching material topics.

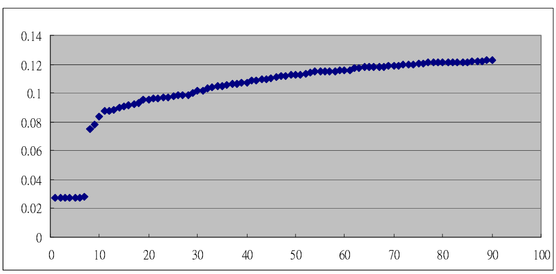

Fig. 2 CSL teaching topic ranking structure

Item	Name	grey relational coefficient	Rank
Q3301	expressing agreement or disagreement with a statement	0.0754	1
Q3309	stating whether one knows thing or facts	0.0779	2
Q3401	stating whether one like / dislike	0.0835	3
Q3319	offering / accepting an apology	0.0875	4
Q3302	expressing degree of certainty / uncertainty	0.0879	5
Q3325	expressing concern over something	0.088	6
Q3403	expressing degree of willingness / unwillingness	0.0903	7
Q3315	expressing approval	0.0908	8
Q3402	expressing pleasure and happiness / unhappiness	0.0918	9
Q3407	expressing gratitude	0.0921	10
Q3312	accepting	0.0932	11
Q3327	supporting	0.0951	12
Q3101	greeting people	0.0954	13
Q3409	expressing hope	0.0961	14
Q3304	expressing believe of something / disbelieve of something	0.0962	15
Q3324	expressing sympathy	0.0968	16
Q3308	expressing something possible / something impossible	0.097	17
Q3303	denying statements	0.0979	18
Q3408	expressing affection / compassion	0.0983	19
Q3307	expressing ability/ inability to do something	0.0984	20
Q3323	expressing comfort to someone	0.0984	20
Q3102	when meeting a friend or acquaintance	0.0998	22
Q3321	expressing obedience	0.1016	23
Q3310	expressing obligation	0.102	24
Q3412	expressing fear	0.1034	25
Q3313	expressing rejection	0.1041	26
Q3404	expressing satisfaction / dissatisfaction	0.1047	27
Q3326	offering understanding of certain things	0.105	28
Q3105	expressing gratitude	0.1053	29
Q3317	expressing decision on something	0.1062	30
Q3306	stating confession	0.1066	31
Q3104	introducing someone to someone else	0.1069	32
Q3416	expressing surprise	0.1072	33
Q3320	expressing forbearance	0.1087	34
Q3330	offering advisory	0.109	35
Q3424	expressing of heartbreaking	0.1093	36
Q3314	expressing planning of something	0.1094	37
Q3413	expressing annoyance	0.1099	38
Q3318	expressing that something that is permissible	0.1107	39
Q3420	making an assumption	0.112	40
Q3411	expressing anxiety over something	0.1122	41
Q3305	expressing suspicion over something	0.1124	42

Item	Name	grey relational coefficient	Rank
Q3103	When been introduced to someone or someone is introduced to you.	0.1127	43
Q3415	expressing luck	0.1128	44
Q3423	expressing urgency over something	0.1134	45
Q3110	offering greeting	0.1144	46
Q3106	taking leave	0.1149	47
Q3328	expressing disapproval	0.1152	48
Q3111	inviting someone to do something	0.1153	49
Q3406	expressing regret	0.1153	49
Q3419	expressing uncertainty / confusion	0.1153	49
Q3410	expressing disappointment	0.1155	52
Q3109	congratulation someone	0.1157	53
Q3421	expressing feeling of relief	0.1157	53
Q3316	expressing an opinion	0.1176	55
Q3329	expressing a mutual statement	0.1177	56
Q3405	expressing feeling of displeased	0.1178	57
Q3107	making departure	0.1179	58
Q3425	offering condolences	0.118	59
Q3418	expressing someone liable for something	0.1182	60
Q3322	making oneself responsible	0.1183	61
Q3108	Sending-off someone	0.1185	62
Q3417	Feeling of inferiority of oneself	0.1186	63
Q3414	making complain over something	0.1191	64
Q3422	expressing feeling of no alternative	0.1194	65
Q3311	expressing denying necessity	0.1196	66
Q3112	accepting an offer or invitation	0.1198	67
Q3605	asking someone to change the theme	0.1205	68
Q3607	closing a conversation	0.1206	69
Q3604	encourage someone to join the conversation	0.1209	70
Q3505	instructing or directing someone to do something	0.121	71
Q3504	warning	0.1212	72
Q3602	attracting attention	0.1212	72
Q3603	asking if you have been understood	0.1212	72
Q3606	joining a conversation	0.1212	72
Q3506	requesting for something	0.1214	76
Q3507	prohibiting	0.1214	76
Q3503	reminding	0.1215	78
Q3601	opening a conversation	0.1218	79
Q3502	proposing / suggesting	0.1219	80
Q3209	asking	0.1221	81
Q3201	narrating	0.1225	82
Q3501	asking for a request	0.1229	83

Appendix

Those 83 CSL teaching material topics can be rank into total of 76 different groups. In other words, there are approximately more than 91.5% of the topics can be discriminated. This result is more satisfied to us compared with un-weighted GRA and Friedman Analysis.

As the result mentioned above, it is comfortable for us to referral this weighted result and provide further reference for OCAC and other relative CSL editing and publishing industries uses. However, 83 CSL teaching material topics are still too many for the CSL kindergarten learners even thought they are in prioritize format. Therefore, to utilize GMD, grey making decision, on the CSL teaching material topic recommendation in the implementation of the textbook of CSL kindergarten learners is vital for the future study.

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The Model of New Grey Incidence and Its Application*

Lizhi Cui and Sifeng Liu

Grey incidence is an important part of grey system theory on the basis of grey decision-making and grey cluster. Analyzing departed grey incidence models, this chapter constructed a new grey incidence model by gradual tempo difference between reference sequence and relevant sequence. Meanwhile, the new model has some characters. A real example shows its simplification and practicability.

1 Introduction

Grey incidence analysis is an important part of grey system theory and the foundation of grey system analysis, grey decision-making and grey cluster. It's a model of studying relationship degree among factors in system. Since Professor Deng created Grey system theory in 1982, more and more scholars have taken part in research of grey system theory (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). Grey incidence analysis can be applied to cases of various sample sizes and distributions with a relatively small amount of computation. And, in general, each application of grey incidence analysis does not result in situations of disagreement between quantitative analysis and qualitative analysis. When analyzing an abstract system or a phenomenon, what's most important is to choose the right sequence of characteristic data to describe the system's behavior. The sequence of data is called a mapping quantity of the special system's behavior. The fundamental idea of grey incidence analysis is that the closeness of a relationship is judged based on the similarity level of the geometric patterns of sequence curves. The more similar the curves are, the higher the degree of incidence between sequence, and vice versa. A lot of grey incidence models have been put forward, for example, Deng's degree of grey incidence (Deng, 2002), absolute degree of grey incidence (Mei, 1992)[1], relative degree of grey incidence (Liu et al., 2004), grey incidence of B-model (Wang, 1989), grey incidence of C-model (Wang and Zhao, 1999), grey incidence of

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* This work is supported by the National Science Foundation of China (No.70701017) and Ministry of Education, research of grey prediction model (200802870020).

T-model (Tang, 1995), grey incidence of entropy (Zhang and Guo, 1996), degree of grey Euclid incidence (Zhao et al., 1998), degree of grey slope incidence (Dang and Liu, 2004), and some improvement model afterwards (Cui, 2008; Tang et al., 2008; Sun and Dang, 2008; Shi et al., 2008; Cao, 2008). Some properties have been discussed in the literature (Xiao, 1997; Lv et al., 2000; Xie and Liu, 2007). These scholars have researched grey incidence models from different aspects, and have obtained some application effect. However the relationship of closeness between sequences is considered in most of the literature. There are some defects in some literature: (1) Degree value of grey incidence is not unique. Degree of grey incidence is influenced by many factors, for instance data conversion way between reference sequence and comparative sequence, different value of distinguishing coefficient ξ , etc. (2) Commonly distinguishing coefficient $\xi = 0.5$, then degree of grey incidence $\gamma_i > 0.333$. (3) Degree of grey incidence is mostly not symmetry, so grey incidence theory is not perfect. It is necessary in constructing a new grey incidence model. Under the professor Deng's grey incidence thought, we put forward a grey similarity incidence model on the base of gradual tempo and to get some basic properties. A real example shows its simplification and practicability.

2 A New Grey Incidence Model

If each factor in a space of grey incidence factors is seen as a point in the space without size and volume, and each data value of the factor, observed at a different time moment, different index, or different object, is seen as the coordinate of the point, then we will be able to study the relationship between factors or between factors and the system's characteristics in a special n-dimensional space. In this way, the relevant degree of grey incidence can be defined by using the distance function in the n-dimensional space. If growth trend of two factors is consistent, i.e. the synchronized change degree is high, we think that degree of grey incidence is big, otherwise then low. Time series exist in the social economy. Gradual tempo is one of the important characteristics in time series, so correlative degree of two time series is very important. We may study degree of grey incidence by using of development level, and may also consider from gradual tempo. If the gradual tempo between reference sequence and relevant sequence is consistent, we may think the degree of grey incidence is very big. It is our thought.

In systems analysis, after the mapping quantities which describe system's behaviors well, have been chosen, thus we need to clarify all the factors that effectively affect the systems' behaviors. The space, consisting of system factors, forms a base for grey incidence analysis. On such a base, comparisons and evaluations can be done in order to study system's behaviors of factors. If each factor in a space of grey incidence factors is seen as a point in the space without size and volume, and each data value of the factor, observed at a different time moment, different index, or different object, is seen as the coordinate of the point, then we will be able to study the relationship between factors or between factors and the system's characteristics in a special n-dimensional space. In this way, degree of grey incidence can be defined by using the gradual tempo in the space.

In systems analysis, after the mapping quantities, which describe systems' behaviors well, have been chosen, we need to clarify all the factors that effectively affect the systems' behaviors. If quantitative analysis is needed, then it is necessary to process the mapping quantities so that these quantities and factors might become non-dimensional with similar behaviors for negatively correlated factors and positively correlated factors.

Definition 1. (Liu et al., 2004) Assume that X_i is a systems' factor with the k th observation value being $x_i(k)$, $k = 1, 2, \cdots, n$. Then

$$X_i = (x_i(1), x_i(2), \cdots, x_i(n)) \tag{1}$$

is called a behavioral sequence of the factor X_i .

1. If k stands for time, then $x_i(k)$ represents an observation of the factor X_i at the time moment k , and

$$X_i = (x_i(1), x_i(2), \cdots, x_i(n)) \tag{2}$$

is called a behavioral time sequence of the factor X_i .

2. If k is an ordinarily of some criteria and $x_i(k)$ is the observation of the factor X_i at the criterion k , then

$$X_i = (x_i(1), x_i(2), \cdots, x_i(n)) \tag{3}$$

is called a behavioral criterion sequence of the factor X_i .and

3. If k is the ordinal number of the object observed and $x_i(k)$ stands for the observation value of the factor X_i at the time moment k , then the sequence

$$X_i = (x_i(1), x_i(2), \cdots, x_i(n)) \tag{4}$$

is called a behavioral horizontal sequence of the factor X_i .

For example, when X_i represents some economic factor, k stands for time, and $x_i(k)$ the observation value of the factor X_i at the moment k , the sequence

$$X_i = (x_i(1), x_i(2), \cdots, x_i(n)) \tag{5}$$

is an economic behavioral time sequence. If k is the ordinality of a criterion, assuming that the set of all criteria applied is ordered, and then the sequence $X_i = (x_i(1), x_i(2), \cdots, x_i(n))$ is an economic behavioral criterion sequence. If k stands for the ordinality of different economic districts, assuming that the set of all economic districts studies have been ordered, then the sequence $X_i = (x_i(1), x_i(2), \cdots, x_i(n))$ is an economic behavioral horizontal sequence.

No matter which sequence we have, being time, or criterion, or horizontal, we can always conduct the needed incidence analysis.

Definition 2. Assume that

$$X_0 = (x_0(1), x_0(2), \cdots, x_0(n)) \tag{6}$$

is a sequence of data representing a system's characteristics, and

$$X_i = (x_i(1), x_i(2), \cdots x_i(n)), i = 1, 2, \cdots n \tag{7}$$

are sequences of relevant factors. For a given real number $\gamma_{0i}(k)$, if the real number

$$\gamma_{0i}(k) = \frac{1}{1 + |d_i(k) - d_0(k)|} \tag{8}$$

and $d_0(k) = x_0(k) / x_0(k-1), d_i(k) = x_i(k) / x_i(k-1)$,

$$\gamma_{0i} = \frac{1}{n-1} \sum_{k=2}^{m} \gamma_{0i}(k) \tag{9}$$

Then γ_{0i} is called the degree of grey incidence of X_i with respect to X_0, and $\gamma_{0i}(k)$ the incidence coefficient of X_i with respect to X_0 at point k.

The concept of the degree of grey incidence of sequence X_0 and X_i is a quantitative representation of the development rate of X_0 and X_i relative to their last time points. The closer the rates of development of X_0 and X_i are, the greater γ_{0i} is, and vice versa.

Proposition 1. γ_{0i} satisfies

1. The property of normality.

$0 < \gamma_{0i} \le 1, i \in \{1, 2, \cdots m\}$ and $\gamma_{0i} = 1 \Leftrightarrow \forall k \in \{1, 2, \cdots m\}, d_i(k) = d_0(k)$.

2. The property of symmetry.

For $X_i, X_j \in X$ then $\gamma_{ij} = \gamma_{ji}$.

3. The property of closeness .The smaller $|d_i(k) - d_0(k)|$ is the larger γ_{0i}.

Proof 1. If $d_i(k) = d_0(k)$, then $\gamma_{0i}(k) = 1$

If $d_i(k) \ne d_0(k)$, then $|d_i(k) - d_0(k)| > 0$ .Therefore, $1 < 1 + |d_i(k) - d_0(k)|$. So $\gamma_{0i}(k) < 1$. It is obvious that for any k, $\gamma_{0i}(k) > 0$. Hence, $0 < \gamma_{0i} \le 1$.

2. For any k, $\left|d_i(k)-d_j(k)\right|=\left|d_j(k)-d_i(k)\right|$, then $\gamma_{ij}(k)=\gamma_{ji}(k)$, so $\gamma_{ij}=\gamma_{ji}$.Degree of the new grey incidence satisfies the property of symmetry.

3. The property of closeness. It is obvious. The closer gradual tempo between reference sequence and relevant sequence is, the greater degree of grey incidence is.

Proposition 2. Assume that X_0 and X_i are two sequences of the same length with non-zero values. If $X_i=cX_0$, where $c>0$ is a constant, then $\gamma_{0i}=1$.

Proof 2. Assume that $X_0=\left(x_0(1),x_0(2),\cdots,x_0(n)\right)$

Then

$$\begin{aligned}X_i&=(x_i(1),x_i(2),\cdots,x_i(n))\\&=(cx_0(1),cx_0(2),\cdots,cx_0(n))\end{aligned}\tag{10}$$

And

$$\begin{aligned}d_i(k)&={x_i(k)}\big/{x_i(k-1)}={cx_0(k)}\big/{cx_0(k-1)}\\&={x_0(k)}\big/{x_0(k-1)}=d_0(k)\end{aligned}\tag{11}$$

So $\gamma_{0i}=1$.

Proposition 3. Assume that X_0 and X_i are sequences of the same length with non-zero values, a and b non-zero constants, and the degree of grey incidence of aX_0 and bX_i is γ'_{0i}. Then $\gamma'_{0i}=\gamma_{0i}$. In other words, scalar multiplication does not change the degree of grey incidence.

Proof 3. Assume that

$$X_0=\left(x_0(1),x_0(2),\cdots,x_0(n)\right)\tag{12}$$

$$X_i=(x_i(1),x_i(2),\cdots,x_i(n))\tag{13}$$

Then

$$aX_0=\left(ax_0(1),ax_0(2),\cdots,ax_0(n)\right)\tag{14}$$

$$bX_i=(bx_i(1),bx_i(2),\cdots,bx_i(n))\tag{15}$$

And

$$d'_0(k)={ax_0(k)}\big/{ax_0(k-1)}={x_0(k)}\big/{x_0(k-1)}=d_0(k)\tag{16}$$

$$d_i'(k) = \frac{bx_i(k)}{bx_i(k-1)} = \frac{x_i(k)}{x_i(k-1)} = d_i(k) \tag{17}$$

For any k , then $\gamma'_{0i}(k) = \gamma_{0i}(k)$. So $\gamma'_{0i} = \gamma_{0i}$.

In fact, the gradual tempos of aX_0 and bX_i is respectively equal to those of X_0 and X_i .So, scalar multiplication does not act in any way .Hence, $\gamma_{0i}' = \gamma_{0i}$.

3 Practical Application

In national economy system, the level of development on tertiary industry not only affects tertiary industry, but also influences employment situation. Tertiary industry will be main industry department in China, which can absorb labors and alleviate employment pressure very much. Therefore, it is necessary to analyze the main influencing factors of tertiary industry of China, in order to take some corresponding measurements to enhance employment level and promote industry structure. Per person GDP, level of urbanization, industrial added values etc. are introduced in this article. Then the relation between these indexes with employment of tertiary industry is studied. Some mutual reactions among these factors determine the development situation and tendency of the systems. We want to know: which factors among the many are more important? Which factors have more effects on the future development of the systems than others? Which factors actually cause desirable changes in the systems so that these factors need to be strengthened?

Table 1 Recorded values of variables for the years 1995 to 2007

index	X_0 (employment of tertiary)	X_1(per person GDP)	X_2 (urbanization)	X_3 (industrial added value)
1995	16880	5046	29.04	24718
1996	17927	5846	30.48	28580
1997	18432	6420	31.91	31752
1998	18860	6796	33.35	33541
1999	19205	7159	34.78	35357
2000	19823	7858	36.22	39570
2001	20228	8622	37.66	42607
2002	21090	9398	39.09	45935
2003	21809	10542	40.53	53612
2004	23011	12336	41.76	62815
2005	23771	14053	42.99	76190
2006	24614	16165	43.9	90351
2007	24917	18934	44.94	107367

Which factors hinder desirable development of the systems so that they need to be controlled? The data for the years 1995 to 2007 originates from Chinese Statistics Yearbook and statistical bulletin, which are selected.

Now we make some explanation to these indexes. Economic level of growth is expressed by the index of per person GDP. There is a close relation between economical growth and employment. According to the law of economist Oakum, economic growth rate exceeds potential rate of 2.5% to 3%, and the unemployment rate reduces 1%. In brief, economy grows quickly, and employment opportunity is big. There is an inverse correlation relation between economic growth and unemployment. As result of increase of per person GDP, the city and countryside inhabitant consumption pattern has changed inevitably. Education, leisure entertainment and other professional service demand increase continually. The tertiary industry obtains large development and provides much employment opportunity.

Urbanization level weighs the scale of tertiary industry. The domestic and foreign massive facts prove that city is the main development platform of tertiary industry. It is determinative that the tertiary industry provides product characteristic and service is provided by the tertiary industry. We cannot store service, also we must produce and consume service simultaneously. These decide that tertiary industry must rely on city. When population concentration arrives at the certain scale, there is some profit in the tertiary industry. So the tertiary industry can develop quickly.

Industrial added value expresses industrialization level. The industrialization is a stage of economy development and social progress necessity. It is symbol that social productive force reaches a certain stage and the technology advancement is direct power of industrialization. Advanced technology level must have advanced education, thus the industrialization inevitably impels tertiary industry to develop.

Taking employment of tertiary industry as reference sequence, we use the new grey incidence model to analyze. The result is as following.

Table 2 degree of new grey incidence and order

index	Employment of tertiary industry	Per person GDP	Urbanization	Industrial added value
degree of grey incidence	1.000	0.923	0.986	0.912

According to table 2, per person GDP, urbanization and industrial added value all are important to employment of tertiary industry. From $\gamma_{02} > \gamma_{01} > \gamma_{03}$, it can be known that $X_2 \succ X_1 \succ X_3$ with X_2 being the most favorable factor, X_1 the second favorable, and X_3 the last. That is to say, urbanization has the greatest effect on the employment of tertiary industry, per person GDP has second greatest effect, and industrial added value has the least effect on the employment of tertiary industry. This result agrees very well with the actual situation in China. Urbanization can promote development of tertiary industry, which can introduce some new industries in tertiary industry. Population clustering in urbanization accelerates service industry development. The level of per person GDP shows the degree of economic growth to some extent. The economy level of development is high, and people have large service demands. Additionally, the industry development inevitably impels tertiary industry, especially finance, insurance, leisure entertainment and so on. So degree of grey incidence between employment of tertiary industry and industrial added value is 0.912.

4 Conclusion

According to the idea of grey incidence theory, a new grey incidence model is constructed by gradual tempo difference of reference sequence and relevant sequence. Meanwhile, the model has properties of normality, symmetry closeness. Scalar multiplication does not change the degree of grey incidence. Finally, a practical example shows its simplification and practicability.

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The Analysis of China's Macro-economy with Grey Dynamic Model in 30 Years of Reform and Opening up

Juan Du and Xuemeng Wang

Macro-economic system is a multi-factor, multi-level, multi-aim typical grey system possessed of indefinite. Its running process is a grey dynamic one composed with many relations of many complex structures and interlaced functions. By using the grey systematic theory model, this chapter studies two major problems in China's macro-economic system during the reform and opening up. First, it obtains the incidence degree between the gross domestic product (GDP) and the three industries (primary industry, secondary industry and tertiary industry), the productive values of the three industries and their internal industries according to the grey dynamic relation analysis. It also builds the industrial related trees of China's macro-economy in each "Five-Year Plan" period. Second, it analyzes the economic cycle of China since 1990s and forecasts the economic scale for the next cycle through GM (1, 1) model and the analysis of the residual error. Moreover, it analyzes the dynamic change of China's macro-economy, the development state and existing problems, meanwhile, counter-measures and suggestions are put forward to provide a scientific basis for China's macro-economic adjustment and the further economic growth.

1 Introduction

Ever since the reform and opening up, China's economic construction has made remarkable achievements. The total value of economy maintains a growing trend and the industrial structure is more practical. However, in the process of rapid industrialization, resource and environmental restrains loom gradually and become more and more serious in restricting the strength of economic development and there exists the periodic variation in the process of development. These require us to positively promote the fundamental change of economic growth mode, optimize the

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industrial structure, coordinate the industrial development, recognize and master the inner periodic principles in the economic development, thus achieve sustainable, rapid and healthy economic development. Therefore it is supposed to have a dynamic analysis of the impact of all the industries within ever-changing overall economic system and have a correct understanding of the relational grade between the progress of industries with overall economic growth and a scientific forecast of future tendency of economic development after mastering the periodic principles in the past.

Macro-economic system is a multi-factor, multi-level, multi-aim complex, with complex structure and function (Yu, 1997). Grey system theory believes that macro-economic system is a typical grey system and all the factors in the system jointly act on the entire system (Liu and Lin, 2006; Lin et al., 2004; Lin et al., 2006). Meanwhile, these factors also interact and they themselves have dynamic changes over time. The industrial structure is the changing grey volume of each factor in correspondence with certain period in this system, and the process of changing can be studied by using the grey relational analysis method. Meanwhile, the exact process path of time series which reflects the dynamic characteristic of macro-economy is a sum of vector composed by three separated parts, that is, long-term trend, periodic variation, and random fluctuation These three parts embody the dynamic characteristics in system. Grey system model is a differential equation describing the dynamic variation. We obtain the long-term trend of economic development and periodic variation by using GM (1, 1) model, predict the future economic development of China, analyze and understand the dynamic development process of macro-economy in a higher level, which may provide a scientific basis for economic structure adjustment and economic development.

2 The Basic Principles of the Grey System Model

A. The Model of the Grey Dynamic Relation Analysis (Deng, 1992)

The essence of grey relational analysis is to make a geometric comparison in the data series which are responded to the changing characteristics of all the factors. The closer the curves are, the greater the relational grade of the corresponding series is, and vice versa. It analyzes the close level between the characteristic behavior of grey system and relevant factors to determine which is primary and which is secondary, and which has small impact and which has great impact.

Macro-economy is a system with continuous dynamic change, and the relational grade of factors within the system is that in the process of development it changes over time series. With the use of dynamic relation analysis, we could further understand the trend that relevant factors in the system change and develop over time. If such change makes the relational grade of behavior series of relevant factors increase, it shows that the correlation of the factors will develop in a closer direction; on the contrary, their correlations are weakening.

The use of the grey relation analysis can definite the changing trend of all factors in this system and find out the main factors which affect the further development of the system so as to grasp the main features of things and the principal contradiction, promote and guide the system to rapid, healthy and efficient development.

B. GM (1, 1) Model of the Economic Cycle (Wang and Luo, 1993)

Economic growth and periodic variation are interdependent. The delineation of the economic cycle is relevant to not only the alternation of the economic growth rate, but also the economic level which has achieved. Therefore, when we analyze the economic cycle, we should identify the trends of economic development and measure the level of economic development in different periods first, then we can determine the direction and magnitude of fluctuation. When the actual statistical value is higher than the trend value, the positive fluctuation quantity indicates that the economy system is in an extension state; on the contrary, it is in a convergent state. When we use the grey dynamic model to analyze the economic cycle, we also analyze the long-term trend of economic development first. Through the analysis of the residual error of the model, we can determine the state of economic system during different periods respectively. The economy is in an extended phase when the residual error is positive, and the economy is in a convergent phase when the residual error is negative

GM (1, 1) model is a differential equation describing the dynamic relationship between the speed of economic development and its economic gross. We can obtain a smooth curve by GM (1, 1) model, which reflects the developing trend of the economic system. However, the original curve keeps regular cyclical swing around the trend curve, indicating the regularity of periodic variation. We can obtain modified quantity of residual error in different periods by periodical analysis of residual error series of GM (1, 1) model and simulation of residual error series according to corresponding cycle length and sine (or cosine) curve of amplitude. Formula can be expressed as the following equation:

$$\hat{E}(t_i) = A_i \sin \frac{2\pi t_i}{T_i} \tag{1}$$

$\hat{E}(t_i)$ represents simulated data of residual error at time t in cycle i, A_i represents the biggest amplitude of cycle i, T_i represents length of cycle i. We can identify the length of each cycle by the sign of residual error series.

We can obtain modified quantity of economic cycle by combining modified quantity of residual error with trend value that has been computed by GM (1, 1) model at the same time. Modified quantity of economic cycle can be expressed as the following equation:

$$\tilde{x}^{(0)}(t) = \hat{x}^{(0)}(t) + \hat{E}(t) \tag{2}$$

$\tilde{x}^{(0)}(t)$ represents modified quantity of economic at time t, $\hat{x}^{(0)}(t)$ represents trend value computed by GM (1,1) model at time t.

This will not only decreases the residual error generally, but also makes the predictive value fluctuate, since the trend curve is closer to the original curve, and the accuracy of the model can be improved. In the course of forecast, the cycle of future series can refer to the variation trend of residual error cycle of known series; the amplitude can be selected and controlled reasonably according to range allowed by system and is likely changed. Then we can forecast after determining the cycle and amplitude of future.

The process of economic development often shows the random fluctuation which can be decided by many unpredictable natural and human factors. Due to the unpredictability, it is difficult to study the random fluctuation by quantity and model.

3 Grey Dynamic Relation Analysis between China's Economy and Its Industrial Structure

The chapter divides the structure of China's economic system into three levels (Fig. 1), making the relation analysis of each level regarded as one collectivity. The figures of GDP of China, the productive values of three industries, and the productive values of three industrial internal industries from 1978 to 2006 are obtained from the China Statistical Yearbook (National Bureau of Statistics of China). For the convenience of consistency with the "Five-Year Plan" while analyzing and discussing, the six dynamic periods of 1978-2006, 1981-2006, 1986-2006, 1991-2006, 1996-2006, 2001-2006 are picked to calculate the relational grade of GDP and three industries, three industries and internal industries, and three typical periods. Among them are chosen to form the related trees between China's economy and industry (Fig. 2-Fig. 4). Line the correlation sequence based on the relational grade, then score for the correlation sequence of all relevant factors in the rules as follows: the factor at first has N points, then the one followed by has N-1 points. The factor in the N place gets 1 point, then sum up the points of each factors in each period of time. Finally, we get the total points of all the factors (Hao et al., 2004) on the basis of which to have a comprehensive assessment of all the industries' position in macro-economy. The results are shown in table I and II.

1) The Grey Relation Analysis of GDP and the Three Industries: As is seen from the figures and tables, in GDP, the secondary industry has the greatest relational grade with GDP, then followed by the tertiary, and the primary has the least impact, i.e., the total productive value of the secondary industry has the greatest impact on GDP. From the dynamic point of view, the relational grade of the secondary was the first before 2001, while was lower than the primary before 1986. In 1986, the tertiary started to exceed the primary coming to the second place. In 1978, the proportions of the productive value of the primary, the secondary and the tertiary in GDP respectively are 28.19%, 47.88% and 23.94% respectively. In 2006, the results are 11.73%, 48.92%and 39.36% respectively. Since the reform and opening up policy, industrial structure had been adjusted constantly, from "secondary > primary > tertiary" to "tertiary > secondary > primary", which is more reasonable and high-grade, but still at a low level, mainly, manifesting that the proportions of the primary and secondary industries were too high while that of tertiary industry ware

too low. At present, for the developed countries which have completed the process of industrialization as well as the newly industrialized countries, the proportions of primary industry is generally below 5%, the secondary below 30% and the tertiary remains about 70%.

This difference is a structural difference and also the difference of quality and level between China and the above two kinds of countries in economy (Chen, 2007). Because of the large population, limit resource and poor environment, we should endeavor to optimize the inner structure of the secondary industry, then lower the percentage gradually and focus more on the tertiary industry which can use less resource, have stronger ability for employment.

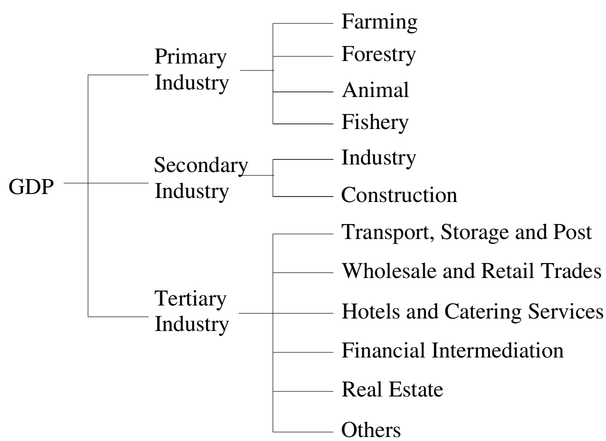

Fig. 1 Structure of economic system

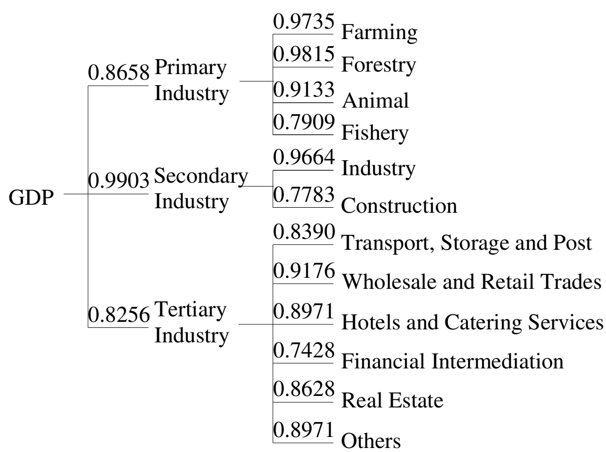

Fig. 2 The relative tree of China's economy and industries (1981-2006).

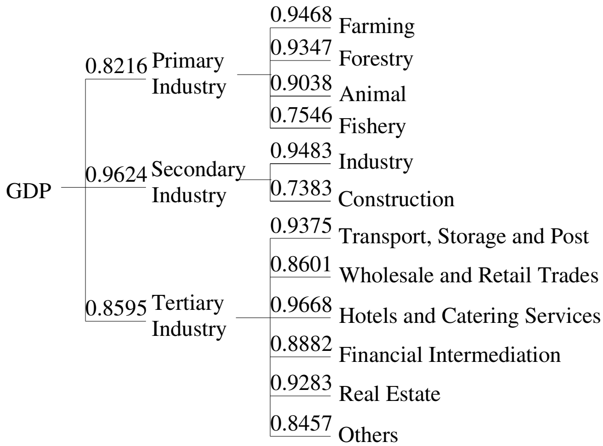

Fig. 3 The relative tree of China's economy and industries (1986-2006)

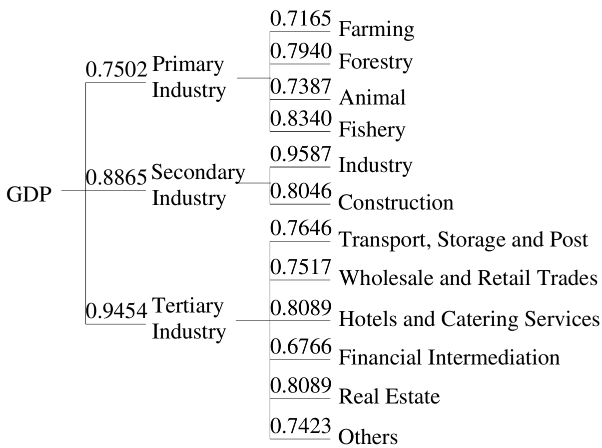

Fig. 4 The relative tree of China's economy and industries (2001-2006).

2) The Grey Relation Analysis of the Primary Industry and All Its Internal Industries: As is demonstrated in the charts, among the relevant factors that affect the primary industry, forestry has the greatest relational grade with the primary. Forestry is closely relational to agricultural production and the development of forestry is one of the key points of agricultural work, but the output value of China's forestry and its proportion in the total productive value of the primary are both low. In 2006, the total output value of forestry is 160.2 billion Yuan, which is merely 3.78% of that of the agriculture. Being the second one, farming is still the backbone project of agriculture and is the basis of all agricultural work. The third and fourth are, respectively, animal and fishery, such relational grade is contradictory to China's large population but limit land, the adjustment of food structure to high-grade and

Table I The relative sequence of China's economy and industries

	Primary Industry	Secondary Industry	Tertiary Industry
1978-2006	2	1	3
1981-2006	2	1	3
1986-2006	3	1	2
1991-2006	3	1	2
1996-2006	3	1	2
2001-2006	3	2	1
Score	8	17	11

Table II The relative sequence of three industries and their internal industries

	Primary Industry				Secondary Industry	
	Farming	Forestry	Animal	Fishery	Industry	Construction
1978-2006	2	1	3	4	1	2
1981-2006	2	1	3	4	1	2
1986-2006	1	2	3	4	1	2
1991-2006	1	3	2	4	1	2
1996-2006	2	1	4	3	1	2
2001-2006	4	2	3	1	1	2
Score	18	20	12	10	12	6
	Tertiary Industry					
	Transport, Storage and Post	Wholesale and Retail Trades	Hotels and Catering Services	Financial Interme-diation	Real Estate	Others
1978-2006	5	3	1	6	2	4
1981-2006	5	1	2	6	4	3
1986-2006	2	5	1	4	3	6
1991-2006	4	3	1	5	2	6
1996-2006	3	4	1	5	2	6
2001-2006	3	4	2	6	1	5
Score	20	22	34	10	28	12

the increasing demand for animal food. Animal production maintains a good momentum of development, but its contribution to agriculture is not very positive and has a comparatively less investment than forestry and farming industry. Among our land resource 13.5% is plantation, 41.7% is ley which can be used, and 16.5% is forestland. Land which can be used for forestry and stockbreeding is vast. According to the producing rate, forestry is 1/16 of farming, and animal is just 1/5 of farming (He and Liao, 2005). The improvement of forestry and animal is an important way to develop our primary industry. For our country, forestry is not only an economic industry, but also an important part to protect and improve the environment and maintain our ecologic balance. The trend of development of stockbreeding is to promote the industry which is in need of large labor but independent on the plantation and its deep processed industries.

3) The Grey Relation Analysis of the Secondary Industry and All Its Internal Industries: As is shown in the figures and tables, for quite a long time, among the relevant factors which affect the secondary industry. Industry has the greatest correlation with the secondary, followed by construction. Industry is an important basis and leading force of national economic development, but the contradictions of the industrial structure in China are conspicuous, which restrains the better economic development. One problem is that the proportion of heavy industry is too high which reached to 70% in 2006. Another problem is that the general industrial products with a serious oversupply of the process capacity coexist with the lack of high value-added and hi-tech products. In 2006, the productive value of hi-tech industries was 4199.6 billion Yuan, which is simply 13.27% of that of all industries. This industrial structure has a tremendous pressure on China's already-strained resources and poor ecologic environment, resulting in lower economic efficiency. We must control low-level redundant construction and restrain total amount of promotion in the secondary industry especially industry development. We should mainly depend on the high technology to optimize the industrial structure and enhance the quality and efficiency of economy. For one thing, the advanced and appropriate high technology should be used to transform traditional industries and to promote the upgrade of industry, and for another, we should develop knowledge-intensive industries such as communications, electronics, bio-pharmacy etc. Through these industries, we can develop with the application of high technology and the technological innovation so that we can get more benefit (Jing and Shen, 2005).

4) The Grey Relation Analysis of the Tertiary Industry and All Its Interment Industries: As is illustrated in the charts, hotels and catering services has the greatest correlation. Those ranking from the second to sixth are: real estate, wholesale and retail trades, transport, storage and post, others and financial intermediation. It suggests that these traditional industries such as catering services, business, transportation, post and telecommunications have a greater correlation with tertiary industry while finance and insurance, tourism, information, consultation, technology services, education, culture and other emerging industries have a relatively smaller correlation, implying that the internal structural level of tertiary industry in China is still low and has much room to upgrade. Since the reform and opening up, the implementation of the compensation for the use of land,

monetization of housing distribution and commercialized reform in housing consumption have made the real estate experience a great development, a rapid growth in investment and a marked increase in the amount of real estate transactions, which play an obvious role in developing the tertiary industry, even the overall national economy. Nevertheless, the lack of a sound operational mechanism, and the inefficiency of macro-regulation have put the development of the industry into a false inflation and in a condition of confusion. It has excessively negative effects on development of the tertiary industry and the national economy.

During the development process of world economy, newly emerging service industry gives impetus to the development of world economy; they are characterized to be clean, have low level of consumption and high benefit. It is so prosperous that it becomes the symbol of modern economy. But traditional ones still stay in leading position in our service industry, while newly emerging types of knowledge-intensive stay lower. We should highlight on science and technology, strengthen competing ability of knowledge and technology, and develop the high-leveled service industries such as culture, consultation, management, technique patent, finance and communications etc (Dong, 2007).

4 Analysis and Forecast of the Economy of China

The weak economic base in early period of reform and opening up made little increase in value, though the speed of economy was not slow and the trend was upward between 1978 to 1990; with the great success of reform and opening up and the increase speed of economic development, the periodic variation in economy varies gradually from hidden invisible variation to obvious periodic variation. So, we adopt the GDP of China in 1991-2007 as original data of grey dynamic model to analyze the economic cycle of China and forecast the economic scale for the next cycle.

C. Analysis on the Economic Cycle of China

We use GDP data in 1991-2007 to establish GM (1, 1) model for the expected a=-0.1243476; u=31893.39 through calculation and further get GM (1,1) model, that is $x^{(1)}(t+1) = 278266.7e^{-0.1243476}t - 256485.7$; then obtain simulated data of GDP of every year through inverse accumulated generating operation. We use the absolute average value of residual error as amplitude, that is A=5499.063; calculate correction quantity of every point, form correctional curve by combining correction quantity with trend curve. The stimulant situation of trend curve of GM (1, 1) with correction curve and original curve are shown in figure 5, and curves of residual error series are shown in fig 6.

In Fig. 6, the cycle of residual error series can be divided into two periods: 1991-1993 is the first period that is a remnant period of last cycle; 1994-2005 is the second period that is an entire cycle, the economic cycle is twelve years (T1=12), which is a medium-and-long period. During the second period the economy system was extended in the states of 1994-1999, while was convergent in 2000-2005. This shows that the economic growth cycle has good comparability between China and world. This cycle can be ideographically divided into four phases: 1994-1996 was the increasing phase, 1997-1999 was the descending phase, 2000-2003 was the recessionary phase, and 2004-2005 was the reviving phase. The course of this change is in accordance with the actual process of China's economic development. Rectification through a three-year period, socialist market economic was established formally in China in 1992. After that China's economy maintained the overheated trend, so Chinese government adopted the policy of fiscal and monetary restraint in 1994-1996 and implemented “soft landing “successfully in 1996. The premature formation of a buyer's market and the Asian financial crisis led to deficiency of total demand, and this was the cause of the economic downturn in 1997. From 1997 to 2002, the national economy development had been in the adjustment stage, the solution of expanding social needs was the implementation of expansionary policies. Since 2003, the main problems of Chinese economy were overheated investment, structure contradiction of consumption, insufficient of effective demand.

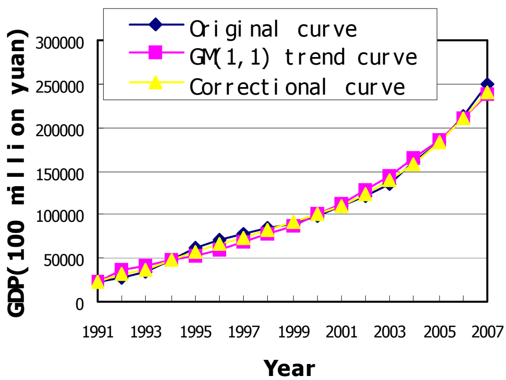

Fig. 5 Trend curve of China's economy and its correctional curve

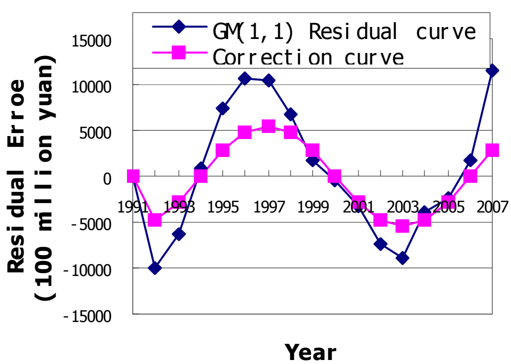

Fig. 6 Residual error curve of grey model of China's economy

Many reasons led to this periodic variation, including the transformation of ownership structure, imbalance of aggregate social supply, demand and adjustment of economic structure (structure of industry, consumption, income distribution and region), reform of the pricing system, and change of the means of macro-regulation and extending the opening (Huang, 2008).

D. Forecast of Economy of China

According to the variable trend of economic development, we forecast the amount of GDP of China in 2006-2017 with T=12. The results are shown in TABLE III.

According to TABLE III, the economy of China will increase with fluctuation during 2006-2017. The economic system will extend in the period of 2006-2011(during which, it will be relative increasing phase in the period of 2006-2008 and relative descending phase in the period of 2009-2011), and will converge in the period of 2012-2017. The subprime mortgage crisis broke out in America in 2007 and the financial crises which were throughout the world in 2008, and then the real economy had an immense downward momentum. The economic growth rate of China slowed down obviously because the global economic crisis had a great impact on the economy of China. The GDP of 2008 grew by 9.0 percent, which is the lowest during the past seven years. It indicates that the economic system entered a convergent state advance.

Table III Forecast of GDP of China

Year	Trend value	Periodic variation	Forecast
2006	210101.1	0	210101.1
2007	237921.1	2750	240671.1
2008	269423.9	4763.14	274187.04
2009	305098.5	5500	310598.5
2010	345495.5	4763.141	350258.64
2011	391243	2750.002	393993
2012	443047.8	0	443047.8
2013	501710.3	-2750	498960.3
2014	568141.8	-4763.193	563378.61
2015	643369	-5500	637869
2016	728560	-4763.141	723796.86
2017	825026	-2750.001	822276

5 Conclusion

The analysis of China's macro-economy by the theory and method of grey system is unique. By using grey dynamic model, the chapter studies China's macro-economy after reform and opening up, and draws a conclusion that the problems China's economy faced are the result of own structural adjustment, business fluctuation and international financial crisis. China's economy has to undergo a period of painful adjustment, which may last two or three years or even longer, and it is an inevitable process.

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Piecewise Analysis and Prediction of Spring Flow Based ON GM(1,1) Model*

Yonghong Hao, Lixia Zhang, Ting Wei, and Xuemeng Wang

One of the largest springs in North China, the Liulin Karst Springs, has been decaying since 1950s. We introduced the piecewise analytical concept to GM (1, 1) model focusing on analysis and prediction of Liulin Karst Springs discharge. We divided the spring discharge processes into two phases: pre-1973 and post-1973. In the first phase (i.e. 1957-1974) the spring discharge was affected by climate change and in the second phase (i.e.1973-2007) the spring discharge was influenced by both climate change and anthropogenic activities. In the first phase, spring flow was simulated by the grey system GM (1, 1) decomposition model, then the effects of climate change were modeled. By extrapolating the model, we acquired a calculation of the spring discharge in the second phase solely under the effects of climate change. Based on water balance analysis, we conclude that the contribution of climate change to depletion of Liulin Springs is 0.18-0.34 m^3/s from 1974-2007. However, the contribution of anthropogenic activities to depletion of spring flow is

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* This work was supported in part by the National Natural Science Foundation of China NSFC-40572150, the Scientific and Technological Development Planning Project of Tianjin 06YFSZSF05100, the Start-up Fund of Tianjin Normal University 5RL070, the Planning Project for Tianjin New Coastal Region of Tianjin Normal University 52LE24, and Open Fund of State Key Laboratory of Environmental Geochemistry of China.

2.55-2.70 m^3/s in 2007. The contribution of climate change only accounts for 10% of human activities, therefore human activities have large contribution to Linlin Spring depletion. Regarding to the contribution of human activity effects on spring discharge decline, groundwater pumping only account for 20%-35% of the spring flow depletion; 65%-80% of the depletion are likely to be caused by other human activities including dam-building, dewatering during coal mining, and deforestation.

1 Introduction

HYDROLOGICAL processes with natural or artificially created inconsistency and nonhomogeneity can be segmented into parts with different statistical characteristics. It is known that water resources systems are influenced by climate change and anthropogenic activities, but the large scale water resources developments were the events in recent five decades. So, hydrological processes can be divided into two phases: pre-development and post-development. During the first phase (i.e. pre-development), hydrological processes are affected by climate change, while during the second phase (i.e. post-development), the hydrological processes are dominated by climate change and human activities. In this chapter, we introduced the piecewise analytical concept to GM (1, 1) model focusing on analysis and prediction of Liulin Karst Springs discharge in China. This allows us to obtain a better understanding of karst hydrological processes and sustainable development in karst systems by differentiating the contribution of climate change from anthropogenic impacts on the decline of Liulin Springs.

Karst formations often constitute significant aquifers. It is estimated that 25% of the global population is supplied largely or entirely by groundwater from karst aquifers (Jaquet et al., 2004; Ford and Williams, 1989). However, karst aquifers are generally considered to be particularly vulnerable to climate change and anthropogenic impacts (Leibundgut, 1998). Climate change influences hydrological processes and alters the recharge and discharge of karst aquifers. There are many human activities that, intentionally or not, produce severe impacts in karst, and often with irreparable damage (Parise and Gunn, 2007). Large withdrawals of water in karst areas for municipal, agricultural, and industrial use may affect the water supply in surrounding areas (Parise et al., 2004). Karst groundwater has become an important indicator to assess climate change and anthropogenic effects on hydrological processes (Taminskas and Marcinkevicius, 2002; Guo et al., 2005). Based on the projected climate change scenarios using general circulation models, Loáiciga et al. (2000) simulated the potential impacts on groundwater in the Edwards Balcones Fault Zone (BFZ) karst aquifer in Texas, USA (Loáiciga et al., 2000). The results showed that the Edwards BFZ aquifer could be severely impacted under a warmer climate. Viles (2003) analyzed the impacts of climate change on karst geomorphology in the UK and Ireland using a conceptual model (Viles, 2003). The author reached some general conclusions over the magnitude and nature of impacts of climate change on karst hydrology, dissolution rates and mass movements, but none of these impacts of climatic change are likely to be as serious as some of the local human impacts such as quarrying and pollution. Nkhuwa

(2003) found that impacts of urbanization on groundwater quality are a consequence of human activities on a very fragile and vulnerable geologic environment according to chemical and bacteriological analyses in Lusaka karst aquifer (Nkhuwa, 2003). Li et al. (2008) gained a better understanding of natural and anthropogenic influences on water quality based on carbon isotope studies and water chemistry in Southwest China (Li et al., 2008). The results show that local rain events in summer and a longer water residence time in winter play an important role in groundwater carbon evolution in karst flow systems of Southwest China. And they also indicate that urban anthropogenic activities have an effect on the carbon evolution of groundwater and might threaten water quality. Hao et al. (2006; 2007) introduced grey system theory to simulation of karst springs flow and proposed GM (1, 2) model with time-lags and GM (1, 1) decomposition model (Hao et al., 2006; Hao et al., 2007). Then the models were used to study the relations between precipitation and Liulin Springs flow in China. The results showed that the influence of climate change on spring discharge at Liulin Springs is long-term and evident. But these models mainly studied the combined effects of both climate change and human activities on spring flow. Few of these studies differentiate the contribution of climate change from those of anthropogenic effects on karst spring flow processes. However, for further sustainable development of karst groundwater, it is essential to discern the contribution of climate change from anthropogenic effects on karst spring flows. The purpose of this chapter is to investigate the depletion of Liulin Springs in North China by differentiating the respective effects of climate change and anthropogenic activities.

China has some of the largest karst terrains in the world. One-quarter of the world's carbonate rock occurs in China. Carbonate rock outcrops cover 1.3 million km^2 or one-seventh of China's area. If more deeply covered and buried karsts are included, up to one-third of the country can be classified as karst, which is 3,463,000 km^2 (Sweeting, 1995). Karst terrain of China is concentrated in two regions: an area located in a semiarid climate zone in the northern part of China, and a humid climate zone in the southwest part of China (He et al., 1997; Yuan, 1994). Karstification is highly influenced by precipitation and topography, which can cause large differences in karst aquifers between different regions. In the northern part of China, annual precipitation is less than 800 mm, and most carbonate aquifers are overlain by thick Permian carboniferous-sandstone and shale, and Quaternary sediments. Karstification in these areas is generally not very developed, in contrast to the karst systems in humid, southwest China, where well-developed caves and highly-connected ground flow channels are abundant (Hao et al., 2007). However, large karst basins provide an inflow of more than 1 m^3/s to many big karst springs in the northern part of China.

The Liulin Spring complex is one of the biggest in the north part of China. They are located in the Sanchuan River Valley in the west of Shanxi Province. Groundwater from the middle Ordovician karst aquifer has been one of the most important sources of water supply in Liulin Springs Basin. The Liulin Spings flow has been declining since the 1950s, especially after the early 1970s when the groundwater resources of the basin begin to be developed for industrial, municipal, and irrigation uses. In this project, we concentrated on investigating the depletion of the Liulin Springs in order to understand karst hydrological processes, and to improve our approaches to sustainable development planning in karst areas of North China.

2 The Hydrogeological Setting of the Liulin Springs Basin

The spring complex consists of about 100 springs that are distributed along 2 km of the Sanchuan River bed. Between 1957 and 2007, the average spring discharge of the complex was 3.04 m^3/s, and the average precipitation over the complex was 497 mm (Fig. 1). During this 48 year span, approximately 65% of the annual precipitation occurred during July, August, and September (Han et al., 1993).

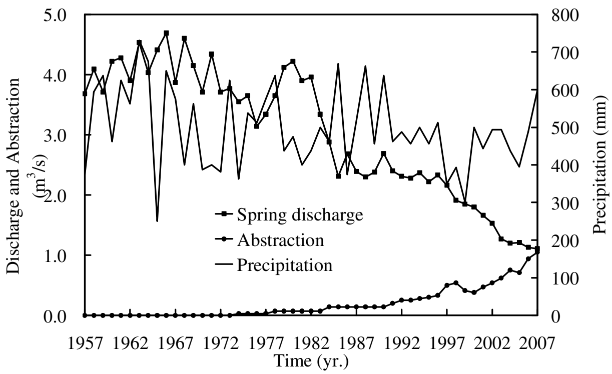

Fig. 1 Precipitation, spring discharge, and abstraction in Liulin Springs Basin

The Liulin Springs Basin covers an area of 5,100 km^2, ranging from 660 to 1,200 m above sea level with the lowest elevation in the west. The main outcropping strata in Liulin Springs Basin are Archean metamorphic rocks, Ordovician carbonate rocks, Carboniferous and Permian coal seams, Triassic detrital formations, and Quaternary deposits. Generally, there are five kinds of karst groundwater natural boundaries regarded as: (a) groundwater divide; (b) surface water divide; (c) tectonic divide; (d) impermeable bed boundary; and (e) impermeable fault boundary (Han et al., 2006). The perimeter of Liulin Springs Basin is defined by three of these five boundary types. The northern and eastern boundaries of the basin are surface water divide, which are composed of Archaean metamorphic mountains; while the southern boundary is groundwater divide, and western boundary is impermeable bed boundary, which consists of Carboniferous-Permian coal-bearing sandstone and shale. The main aquifer in this region is comprised of the middle Ordovician carbonates, including limestone, dolomite, and marl mingled with gypsum. Its total thickness exceeds 500m. Precipitation is the primary source of recharge to the aquifer. Groundwater recharge occurs mainly from infiltration of precipitation into outcropping limestone areas. In the Liulin Springs Basin, groundwater moves toward the west and encounters a low-permeable formation along the west boundary.

Eventually the groundwater perches to surface in Sanchuan River Valley and creates Linlin Springs.

3 Methods

A. Grey system GM (1, 1) decomposition model

Karst aquifers are highly heterogeneous in nature. They are dominated by secondary or tertiary porosity (i.e., fractures or conduits, respectively) and may exhibit hierarchical permeability structures or flow paths (Cao and Fang, 1982). In karst systems, precipitation and runoff reach the subsurface water through infiltrating, and subsequently, groundwater propagates and emerges as springs. Based upon the grey system theory, karst system by their nature is a grey system (Liu and Lin, 2006; Lee and Wang, 1998; Lin et al., 2004), thus we simulate karst hydrological processes by using grey system decomposition model (Hao et al., 2007). Examining the karst spring discharge data over different time scales, we found that it has different trends. The time series of spring flow $Q(t)$, generally includes three specific components at different time scales: (1) the long-term trend, $\hat{x}^{(0)}(t)$; (2) periodic variation, $S(t_i)$; and (3) random fluctuation $R(t)$. Based on this conceptualization, spring discharge can thus be expressed as

$$Q(t) = \hat{x}^{(0)}(t) + S(t_i) + R(t) \tag{1}$$

where $Q(t)$ is defined as the spring discharge, $\hat{x}^{(0)}(t)$ is the long-term trend of the spring flow, $S(t_i)$ is the periodic variation, and $R(t)$ is the random fluctuation .

We use a gray system GM (1, 1) model to simulate the long-term trend. By analyzing the residuals of the long-term trend, we obtain periodic variation, and random fluctuation components (Hao et al., 2007).

B. Simulation of the long-term trend using the GM (1,1) model

GM (1, 1) is set up by using a time series of raw data $x^{(0)}(t)$ to form an accumulating generation $x^{(1)}(t)$. The first order differential equation is given by

$$\frac{dx^{(1)}(t)}{dt} + ax^{(1)}(t) = u \tag{2}$$

Where $x^{(0)}(t)$ is called the spring discharge of year t, $x^{(1)}(t)$ the accumulating generation, a the development coefficient and u the grey action quantity.

The approximate time response sequences of the GM (1, 1) grey differential system are set up as

$$x^{(1)}(t+1) = (x^{(1)}(0) - \frac{u}{a})e^{-at} + \frac{u}{a} \tag{3}$$

and by restoring accumulation generation, we can express the restored values of $\hat{x}^{(0)}(t)$ as

$$\hat{x}^{(0)}(t) = \hat{x}^{(1)}(t+1) - \hat{x}^{(1)}(t) \tag{4}$$

Eq. (3) and Eq. (4) are grey predicted equations of GM (1, 1) model. $\hat{x}^{(0)}(t)$ is tendency of spring discharge.

C. Simulation of periodic variation

The periodic variation is acquired by analyzing the residuals of long-term trend, then fitting the residuals sinusoidal and obtaining the periodic variation,

$$S(t_i) = A_i \sin \frac{2\pi t_i}{T_i} \tag{5}$$

Where $S(t_i)$ is the simulation of the residuals in period i in year t, A_i considered as the amplitude of period *i*, and T_i is the length of period *i*. The period could be defined by residual series and the period of the suitable sinusoid is the fluctuant period of spring discharge.

When combining the long-term $x^{(0)}(t)$ and the period variation $S(t_i)$, we get the long-term and periodic trend of spring discharge $TS(t)$:

$$TS(t) = \hat{x}^{(0)}(t) + S(t) \tag{6}$$

D. The calculation of random fluctuation

The random fluctuation was calculated as follows:

$$R(t) = x^{(0)}(t) - TS(t) \tag{7}$$

Because of the unpredictability of the random factor, we use the mean absolute value of the random fluctuations, $\overline{|R(t)|}$, instead of $R(t)$, so we have

$$Q(t) = \hat{x}^{(0)}(t) + S(t_i) \pm \overline{|R(t)|} \tag{8}$$

Where $Q(t)$ is the simulated spring discharge.

E. Water balance

In generally, the karst hydrological processes can be divided into two phases on time. The first phase is karst system under the sole impact of climate change, which is corresponding to the periods when anthropogenic impacts are scarce. The second phase is under impacts of both climate change and human activities. In order to differentiate the respective effects of climate change and human activities on depletion of spring flow, we calculate the water balance for second phase.

Using spring flow data of the first phase, we can set up grey system GM (1, 1) decomposition model. By extrapolating the model, we acquired the spring discharge $Q(t)$ for the second phase, which describes the spring discharge under the sole impact of climate change. Accordingly we setup the water balance equation for karstic groundwater in the second phase,

$$Q_{c\lim ate}(t) = Q_{human}(t) + Q_{obsevation}(t) \tag{9}$$

Where $Q_{c\lim ate}(t)$ denotes spring discharge under the impact of climate change; $Q_{human}(t)$ denotes the spring flow depletion by human activities; $Q_{observation}(t)$ denotes the observed spring discharge.

$$Q_{human}(t) = Q_{c\lim ate}(t) - Q_{obsevation}(t) \tag{10}$$

4 Simulation of Liulin Springs Discharge

Because of the limitation in economics and technology, karst groundwater development began at 1973 (Fig. 1). Thus we divide the spring flow sequence into two phases: pre-1973 and post-1973. In the first phase (i.e. 1957-1973) the Liulin Springs discharge was affected solely by climate change (i.e. precipitation) and in the second phase (i.e.1974-2007) the springs discharge was influenced by both climate change and human activities. Using the springs discharge data in the first phase, we set up a GM (1, 1) decomposition model. The system parameters are expressed as $\binom{a}{u} = \binom{0.002}{4.183}$. The predicted model is $x^{(1)}(t+1) = \text{-}2422.7\mathrm{e}^{-0.002t} + 2426.5$. Fig. 2 shows the long-term trend curve of the Liulin Springs discharge from 1957-1973. The curve accurately reflects the general trend of the Liulin Springs discharge over time, but does not correspond with its periodic fluctuation. In this curve, the average value of absolute residual error is $\overline{|\varepsilon(t)|}$=0.14, and the mean relative error is $\overline{|q(t)|}$=3.76%.

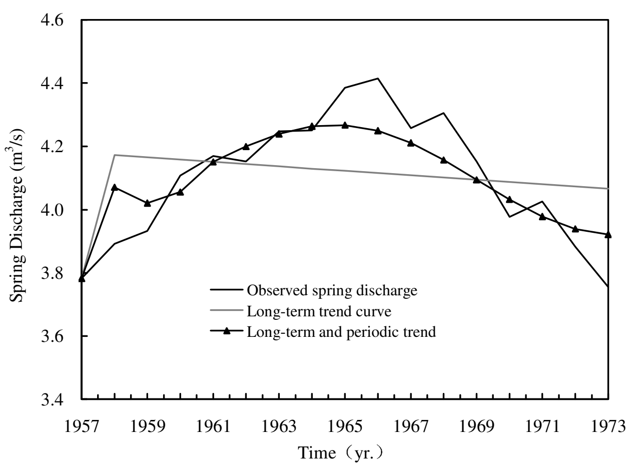

Fig. 2 Grey system GM (1, 1) model simulation curves for the Liulin Springs

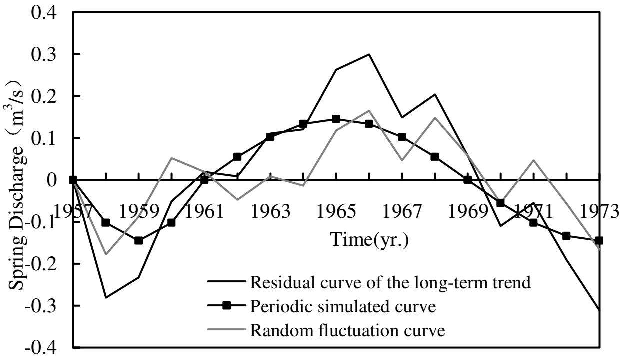

Fig. 3 Period variation and random fluctuation curves for the Liulin Springs

In order to determine the periodic variation, $S(t_i)$, of the Liulin Springs, we fit the residual curve of the long-term trend sinusoidally (Fig. 3). The amplitude of the sinusoid is estimated by the mean absolute value $\overline{|\varepsilon_i(t)|}$: $S(t_i) = \overline{|\varepsilon_i(t)|}\sin\dfrac{2\pi t_i}{T_i}$.

Fig. 3 reflects that fluctuation of residual curves can be divided into two stages. In stage 1 (before 1961), period T_1=8 years, amplitude $A_1 = \overline{|\varepsilon_1(t)|}$ =0.15m^3/s; in stage 2 (after 1961), period T_1=16 years, amplitude $A_2 = \overline{|\varepsilon_2(t)|}$=0.14m^3/s. The long-term and periodic trend, *TS(t)*, is obtained by combining the long-term trend, $\hat{x}^{(0)}(t)$, and the periodic variation, $S(t_i)$. The *TS(t)* curve is displayed in Fig. 2, which shows that the curve fits the discharge with a higher accuracy than the long-term trend curve. In the *TS(t)* curve, the average absolute value of residual error is $\overline{|\varepsilon'(t)|}$=0.08 m^3/s, and the mean relative error is $\overline{|q'(t)|}$ =1.93%.

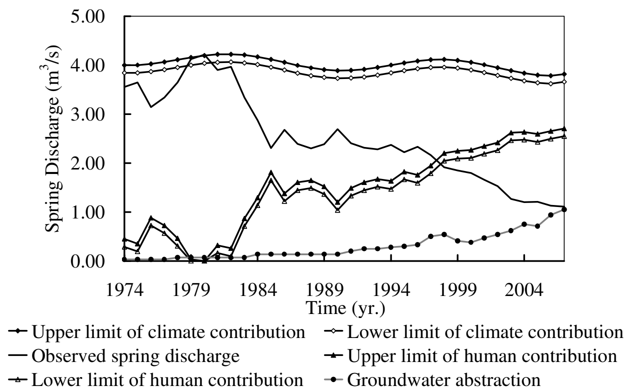

Fig. 4 Hydrological processes of the Liulin Springs under effects of climate change and anthropogenic activities

The random fluctuation curve $R(t)$ is acquired on the basis of Equation 7, and the curve is shown in Fig. 3. The average value of random fluctuation $\overline{|R(t)|}$ =0.079 m^3/s.

According to Equation (8), GM (1, 1) decomposed model of the Liulin Springs from 1957-1973 was obtained. Running the model, we acquired the spring flow under sole impact of climate change in second phase (i.e.1974-2007). Then through water balance equations (9) and (10), we differentiate the respective effects of climate change and human activities on depletion of spring discharges. Results show in Fig. 4.

5 Results and Discussion

Fig. 4 shows that the spring discharge decreased during the years from 1974 to 2007 under effects of climate change. The average annual spring discharge was 3.84-4.00 m^3/s in 1974 and 3.66-3.81 m^3/s in 2007. Therefore, the contribution of climate change effects on depletion of the Liulin Springs is 0.18-0.34 m^3/s from 1974-2007. However, the contribution of anthropogenic activities effects on depletion of spring flow is 2.55 -2.70 m^3/s in 2007. Therefore, human activities have large contribution to Linlin Spring depletion.

Regarding to the contribution of human activity effects on spring discharge decline, groundwater pumping only account for 20%-35% of the declines; 65%-80% of the declines are likely to be caused by other human activities (Fig. 4).

Following important human activities are supposed to have the important contribution to change the regional hydrological processes. Dam-building causes the recharge decline from river bed. Three larger reservoirs were constructed on branches of the Sanchuan River. Wucheng Reservoir that lies on Dongchuan River constructed in 1957 with the storage of 12.44 million m^3; Chenjiawan Reservoir that lies on Nanchuan River constructed in 1967 with the capacity of 10 millin m^3 and Hengquan Reservoir that lies on Beichuan River that being under construction with the storage of 85.6 million m^3. These reservoirs changed the regional hydrological processes, causing the decline of surface water recharge to karst groundwater. In the Liulin Springs Basin, the annual recharge capacity from river bed reduced from 38.6 million m^3 in 1956 to 18 million m^3 in 2000.

Coal mining is one of the main industries in the Liulin Springs Basin. There are a total of 74 coal mines throughout the Liulin Springs Basin and the annual coal output reached to 13.4 million tons in the 2006. The estimated annual dewatering from coal mining is 12.7 million m^3. Because Carboniferous-Permian coal-bearing formations are above Ordovician karst aquifer in elevation in Liulin Springs Basin, dewatering from coal mining artificially decreases the recharge of precipitation to karst aquifer. Therefore, dewatering from coal mining is one of the important artificial activities causes the depletion of Liulin Springs flow.

Deforestation changed the underlying surface and the hydrological processes of the Liulin Springs Basin. Percentage of forest cover reduced from 36% in 1980s to 24% in beginning of 21 century. Consequently, the infiltration of precipitation to karst aquifer is decreased. It is likely to be one of the main reasons that cause the spring flow depletion.

6 Conclusions

One of the largest springs in North China, the Liulin Karst Springs, is vulnerable to anthropogenic impacts and regional climate change and has declined since 1950s. This chapter discussed the response of Liulin Springs discharge to climate change and human activities by introducing the piecewise analytical concept to GM (1, 1) model. In Liulin Springs Basin, the development of karst groundwater began in 1973. Accordingly, the spring discharge data were divided into two phases: pre-1973 and post-1973. In the first phase (i.e. 1957-1973) the spring discharge was affected by climate change, and in the second phase (i.e.1974-2007) the spring discharge was influenced by both climate change and human activities. In the first phase, spring flow was simulated by the grey system GM (1, 1) decomposition model. Then the effects of climate change were modeled. By extrapolating the model, we acquired a calculation of the spring discharge in the second phase sole under the effects of climate change. Based on water balance analysis, we conclude that the contribution of climate change to depletion of Liulin Springs is 0.18-0.34 m^3/s from 1974-2007. However, the contribution of anthropogenic activities to depletion of spring flow is 2.55 -2.70 m^3/s in 2007. The contribution of climate change only accounts for 10% of contribution of human activities. Therefore, human activities have large contribution to Linlin Spring depletion.

Regarding to the contribution of human activity effects on spring discharge decline, groundwater pumping only account for 20%-35% of the spring flow depletion; 65%-80% of the depletions are likely to be caused by other human activities. Firstly dam-building caused the recharge capacity from river bed to karst aquifer decline from 38.6 million m^3 in 1956 to 18 million m^3 in 2000. Secondly dewatering from coal mining artificially decreases the recharge of precipitation to karst aquifer and the estimated annual dewatering from coal mining is 12.7 million m^3 in 2006. Finally deforestation changed the underlying surface and hydrological processes. Percentage of forest cover reduced from 36% in 1980s to 24% in beginning of 21 century. Consequently, the infiltration of precipitation to karst aquifer is decreased, which caused the spring flow decline. Therefore, it is unreasonable only considering groundwater pumping as human activity while ignoring the contributions of other human activities.

As a representative of karst springs in North China, the Liulin Springs reflect varieties of karst spring discharge and exploitation processes of groundwater for recent 50 years. Before the 1970s, karst groundwater is mainly on natural circulation. After that time, human exploitation increased and spring discharge decreased. In the 21st century, karst groundwater exploitation and economic activities disturbed groundwater circulation that have exceeded natural supplement.

Grey system model successfully simulated effects of climate change and human activities on spring discharge. It investigated the response of spring discharge to climate change and human activities. The GM (1, 1) model is a useful tool in regional groundwater plan and sustainable development.

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Relational Analysis between Technological Progress and Economic Growth: An Empirical Study in Counties from Jiangsu Province

Ning Luo, Weijun Zhong, and Shu'e Mei

Based on the improved grey T's correlation degree, the chapter employs data of 50 counties in Jiangsu Province that participated in the nationwide technological progress assessment from 2003 to 2006, and takes an empirical analysis on the relation between technical input-output indicators and gross domestic product (GDP). This chapter also proposes the identity and difference of how technological progress advances economy in southern, middle and northern Jiangsu from the perspective of the whole province and each of the three regions.

1 Introduction

Technological progress is the primary impetus that improves local productivity and comprehensive competence for a region. A great number of studies have shown that inputs in science and technology (S&T) especially research and development (R&D) expenditures, exert a significant and far-reaching influence on economic development and productivity growth. Griliches and Lichtenberg (1984) modeled the relation between growth of total factor productivity (TFP) and R&D stocks based on Cobb-Douglas production function at the industry level, and concluded that there appeared a rather strong relationship between the intensity of private (but not federal) R&D expenditures and subsequent growth in productivity (Griliches, 1984). Becker and Murphy (1992) conducted a study on the ratio of R&D expenditure to gross domestic product (GDP) in OECD countries, and concluded that nation wealth had certain affinity with investment in R&D (Becker and Murphy, 1992). The study of Galor and Tsiddon (1997) analyzed the interaction between

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technological progress, economic growth and earning equality, revealing that the reduction in concentration of ability in technologically advanced sectors and convenient access to technology as well slowed future economic growth (Tsiddon, 1997). Guellec and Bruno (2001) employed data from 16 OECD countries during the period between 1980 and 1998, and utilized panel data to analyze how different types of R&D expenditures affected multi-factor productivity in the long term (Guellec and de la Potterie, 2001). Bronzini and Piselli (2009) estimated the long-run relationship between total factor productivity (TPF) and R&D stock as one of the three capitals between 1980 and 2001 across Italian regions, and found that regional productivity was positively affected by R&D activity and R&D stock was the bi-directional causality found through Granger-causality tests (Bronzini and Piselli, 2009). In Coccia's research (2009), a regression analysis based on quadratic function and mathematical optimization methods was applied to find the optimal range of domestic expenditure on R&D expressed as percentage of GDP (GERD), which was concluded between 2.3 percent and 2.6 percent (Mi et al., 2004).

Compared with econometric methods, grey incidence analysis (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006) that could be easily implemented on the computer has few specific limitations on the quantity as well as the distribution of samples. It also has been widely used in studies of the correlation between technological progress and economic development. Mi and Liu (2004) calculated grey relative relational grade between technology input and economic increase in Jiangsu province, confirming that both R&D expenditure and input in technical human resources positively affected on economy, while the influence of the latter one was more significant (Hu and Gao, 2004); Data from five provinces in Middle China were used in Hu and Gao's research (2004) and their conclusion was similar to the study of Mi and Liu (Tang and Liu, 2006); Tang and Liu (2006) took into account hysteresis effect of input in S&T on economic growth in their grey T's incidence degree analysis between distinct types of R&D expenditures and economic development (Deng, 1989).

However, current studies are mostly concentrated on technical inputs, especially investments in R&D and the input of technical talents. Few research concerns about the correlation between technical outputs and economic outputs. However, technical achievements, as a matter of fact, might not be certainly transferred into economic benefits. As a result, this chapter brings technical outputs into technological progress system.

The chapter is organized as follows. In the second part, indicators and data are described and the necessary descriptive statistical analysis is presented. The methodology of grey T's correlation degree analysis and the application in this empirical study are illustrated in the third section. The fourth section presents analysis of results in the third part, which summarized the identity and difference of correlation between economic growth and technological progress in counties in three regions in Jiangsu province. The fifth section concludes and proposes several policy suggestions.

2 Data Collection and Description

In this chapter we utilize data from 50 counties in Jiangsu Province, the primary source of which is the database of nationwide technological progress assessment.

Data are obtained from the survey constantly conducted by Ministry of Science and Technology of the People's Republic of China. All sample counties participated in the nationwide technological progress assessment from 2003 to 2006. In this technological progress system, both inputs and outputs in S&T in a region are included, based on which how each indicator in this system influences economic development in a county is discussed.

The selected attribute variable of economic growth is GDP of one county (in billion RMB), with the variable symbol definition as X0. Five indicators are included in regional inputs and outputs in S&T, respectively. The variable symbol definitions and abbreviations of each indicator are illustrated in Table I.

Table I Abbrivation And Notation Of Variables

Indicator (Variable)	Abbreviation	Symbol
Regional Input In S&T		
Local special project funds for S&T(in ten thousand RMB)	S&TF	X_1
Percentage of special project funds for S&T in local final accounts (%)	PS&TF	X_2
Population of professional and technical personnel per ten thousand people	PTP	X_3
R&D expenditure from industrial enterprises above designed size (in ten thousand RMB)	R&DE	X_4
Percentage of R&D expenditure in sales revenue from industrial enterprises above designed size (%)	PR&DE	X_5
Regional Output In S&T		
Number of patent applications per ten thousand people	PA	X_6
Number of patent grants per ten thousand people	PG	X_7
High-tech industrial added value (in ten thousand RMB)	H-TIAD	X_8
Percentage of high-tech industrial added value in industrial added value (%)	PH-TIAD	X_9
Turnover of technology contracts per year (in thousand RMB)	TTC	X_{10}

3 Computation of Grey Relational Grade between Technological Progress and Economic Development in Counties of Jiangsu Province

A. Methodology

The Grey Relational Analysis (GRA) is to explore the similarity and dissimilarity among factors in developing dynamic process (Deng, 1989). It uses the grey relational grade to measure the relational degree of factors. In this chapter, the method of improved grey T's degree is utilized in order to accurately reflect the positive and negative correlation between technological progress and economic development. The related method is described as follows:

The original series are:

$$X_i = \{x_i(t_1), x_i(t_2)..., x_i(t_n)\}$$

Where $i = 0, 1, 2, .., p \in N$, $n = 1, 2, \dots, q \in N$.

For $i = 0$, $X_0 = \{x_0(t_1), x_0(t_2), ...x_0(t_n)\}$ is a reference sequence, and for $i \neq 0$, $X_i = \{x_i(t_1), x_i(t_2), ...x_i(t_n)\}$ is a comparative sequence.

For each original sequence, each term in the corresponding increment sequence is (Tang, 1995):

$$\Delta x_i(t_k) = x_i(t_k) - x_i(t_{k-1}) \tag{1}$$

Where $i = 0, 1, 2, \dots, p \in N$, $k = 2, 3, \dots, q \in N$. Equation (1) denotes the increment of the sequence X_i from the time-point t_{k-1} to t_k.. Then

$$D_i = \frac{\sum_{k=2}^{n} |\Delta x_i(t_k)|}{n-1} \tag{2}$$

Where $i = 0, 1, 2, .., p \in N$. Equation (2) denotes the mean value of absolute value of increment for the sequence X_i from the time-point t_{k-1} to t_k.. And then

$$z_i(t_k) = \frac{\Delta x_i(t_k)}{D_i} \tag{3}$$

Where $i = 0, 1, 2, .., p \in N$, $k = 2, 3, \dots, q \in N$. Equation (3) denotes the non-dimensionailzation of the increment of the sequence X_i from the time-point t_{k-1} to t_k..

Then grey relational coefficient could be computed as follows (Sun and Dang, 2008):

If $z_0(t_k) \neq 0,\ or\ z_i(t_k) \neq 0$ where $i = 0, 1, 2, .., p \in N$, $k = 2, 3, \dots, q \in N$, the grey relational coefficient would be calculated in (4):

$$\xi(\Delta x_0, \Delta x_i) = \mathrm{sgn}(z_0(t_k) \cdot z_i(t_k)) \cdot \frac{1}{1 + 0.5\left\| z_0(t_k) \right| - \left| z_i(t_k) \right\| + 0.5\left(1 - \frac{\min\left(\left|z_0(t_k)\right|, \left|z_i(t_k)\right|\right)}{\max\left(\left|z_0(t_k)\right|, \left|z_i(t_k)\right|\right)}\right)} \tag{4}$$

In (4), $\mathrm{sgn}(z_0(t_k) \cdot z_i(t_k))$ reflects positive or negative correlation of the two sequences; in other words, $\xi(\Delta x_0, \Delta x_i) > 0$ when $z_0(t_k) \cdot z_i(t_k) \geq 0$, and $\xi(\Delta x_0, \Delta x_i) < 0$ when $z_0(t_k) \cdot z_i(t_k) < 0$.

Otherwise, if $z_0(t_k)=0, and\ z_i(t_k)=0$, where i = 0, 1, 2, .., $p \in N$, k = 2, 3, …, $q \in N$, the grey relational coefficient is shown in (5)

$$\xi(y_0, y_i)=1 \tag{5}$$

Grey relational grade could be calculated as follows:

For two time sequences X_0, X_i on $\left[t(1), t(n)\right]$, the grey relational grade could be gained in (6):

$$r(X_0, X_i)=\frac{1}{t(n)-t(1)}\sum_{k=2}^{n}\Delta t_k \cdot \xi(t_k) \tag{6}$$

When $-1 \le r < 0$, sequence X_0 is negatively correlated with sequence X_i; when $0 < r \le 1$, sequence X_0 is negatively related with sequence X_i. The larger the value of $|r|$ is, the stronger the correlation between two sequences. When $r=0$, the two sequences are not relevant.

B. Application

Taking data into Equation (1) to (6), we could acquire grey relational grades between individual indicator in the technological progress system and economic growth in each sample county of Jiangsu Province from 2003 to 2006. The result is shown in Appendix A and B.

4 Relational Analysis between Technological Progress and Economic Development in Counties

C. Difference of correlations between technological progress and economic growth in counties for each indicator: a perspective from the province as a whole

On the whole, the effect of the inputs and outputs in S&T on economic dimension in Jiangsu Province is positive, that is, technological progress could advance local economic development.

From the standpoint of the influence of each indicator on economy, high-tech industrial added value has the greatest influence on gross domestic product (GDP) in counties. Other indicators, in terms of average relational grades between each indicator and GDP, could be arranged from the second highest to the lowest as local special project funds for S&T, R&D expenditure from industrial enterprises above designed size; the number of patent applications per ten thousand people, population of professional and technical personnel per ten thousand people, turnover of technology contracts per year, the percentage of high-tech industrial added value in industrial added value, the number of patent grants per ten thousand people, percentage of R&D expenditure in sales revenue from industrial enterprises above designed size, percentage of special project funds for S&T in local final accounts.

From variations of correlation between each index and economic development, the impact on GDP of percentage of R&D expenditure in sales revenue from industrial enterprises above designed size province sharply vary in 50 counties in Jiangsu (with a variance that equals 0.125). Other indicators, in terms of variance of relational grades between each indicator and GDP in 50 counties, could be arranged from the second largest to the smallest as the number of patent grants per ten thousand people, percentage of high-tech industrial added value in industrial added value, population of professional and technical personnel per ten thousand people, percentage of special project funds for S&T in local final accounts, turnover of technology contracts per year, the number of patent applications per ten thousand people, R&D expenditure from industrial enterprises above designed size, high-tech industrial added value, local special project funds for S&T.

D. Difference of correlations between technological progress and economic development for each region in Jiangsu Province: A perspective from southern, middle and northern Jiangsu

As is shown in Table II, each indicator of input and output in S&T affects economic development differently in southern, middle and northern Jiangsu.

In southern Jiangsu, factors in technological progress system owning relatively great effects on county economy (indices with the average relational grades larger than 0.5) include R&D expenditure from industrial enterprises above designed size, the number of patent applications per ten thousand people, population of professional and technical personnel in ten thousand people, high-tech industrial added value, local special project funds for S&T, the number of patent grants per ten thousand people, indicators above ordered from the strongest correlation to the weakest one with GDP. Specifically, the population of professional and technical personnel has a universal far-reaching influence on economic growth in southern Jiangsu. In other words, social and economic conditions that have been rapidly developed in this region could effectively attract and encourage technical talents, who in return propel local economy forward through their technology-intensive work; therefore, it is regarded as a virtuous circle in which economic development appeals to talents while input in human resource contributes to the constant growth in GDP. On the other hand, impetuses local special project funds for S&T and high-tech industrial added value give to GDP in counties in this region are not as distinctive as that in the average degree of the whole province. Thus, more governmental attention is requested in southern Jiangsu to the input-output efficiency of technical resources, and the industrial structure should also be further improved and optimized.

Among the three regions, influence of technological progress on economic dimension is the most significant in middle Jiangsu; such a fact also illustrates that the rapid development of this region during recent years, to certain degree, has benefited from the technological advance. Factors in input and output in S&T that positively affect economy of these counties (indices with the average relational grades larger than 0.5) include high-tech industrial added value, R&D expenditure from industrial enterprises above designed size, local special project funds for S&T, the number of patent applications per ten thousand people, the percentage of high-tech industrial added value in industrial added value, population of professional and technical personnel per ten thousand people, turnover of technology contracts per year, indicators above arranged from the most distinct correlation to the least one. Specifically, high-tech industrial added value makes a remarkable contribution to local GDP in counties in middle Jiangsu with indistinctive variations, the result illuminate that the development of technology-intensive industry generally impels county economy in middle Jiangsu.

Table II Relational Grade between Technological Progress and Gdp in Jiangsu Province

Economic growth		Technology Input					Technology Outcome				
Relational grade with GDP (X_0)		S&TF	PS&TF	PTP	R&DE	PR&DE	PA	PG	H-TIAD	PH-TIAD	TTC
All counties	Mean value	0.666	0.365	0.500	0.663	0.375	0.600	0.430	0.672	0.445	0.472
	Variance	0.034	0.097	0.099	0.057	0.125	0.071	0.109	0.040	0.104	0.083
Southern Jiangsu	Mean value	0.626	0.367	0.631	0.692	0.378	0.655	0.606	0.629	0.434	0.372
	Variance	0.046	0.125	0.047	0.056	0.135	0.027	0.059	0.048	0.154	0.106
Middle Jiangsu	Mean value	0.725	0.417	0.580	0.729	0.454	0.677	0.373	0.813	0.613	0.569
	Variance	0.035	0.081	0.061	0.040	0.079	0.047	0.097	0.003	0.056	0.075
Northern Jiangsu	Mean value	0.653	0.321	0.309	0.582	0.306	0.484	0.311	0.595	0.313	0.485
	Variance	0.020	0.091	0.128	0.068	0.159	0.117	0.130	0.043	0.066	0.057

For counties in northern Jiangsu, effect of technological progressive factors on economic development is of much smaller magnitude than that in southern and middle Jiangsu. It also reveals the reason for which local development in society and economy in this region lags behind the whole province; one of the possible explanations might be the relative tardiness of its technological progress in this region, compared with that in southern and middle Jiangsu, as well as barriers to the transfer from technical achievements to economic benefits. Technological progressive factors with significant influences on economy in northern Jiangsu (indices with the average correlation degrees larger than 0.5) include local special project funds for S&T, high-tech industrial added value, R&D expenditure from industrial enterprises above designed size, and indicators above arranged from the most distinct correlation to the least one. Nevertheless, effects of these three indicators on county economic dimension still seem to be comparatively insufficient. Meanwhile, although R&D expenditure from enterprises is evidently higher than that from government in northern Jiangsu, the influence of fiscal investment in technology on GDP is more significant. Consequently, it is concerned that enterprises in this region have started to play the principal part in regional innovation system, yet their input in R&D cannot be effectively transferred into social and economic values. In addition, the correlation between turnover of technology contracts per year and GDP in this region, which is lower than 0.5 but higher than that in southern Jiangsu and the mean value of the province, has a comparatively constant and potent effect on economic development; specifically, this index is closely related with economic growth in 9 counties, the number as half of sample counties in northern Jiangsu. As a result, how turnover of technology contracts per year would affect future county development in this region is worthy of further concern. Furthermore, what should be pointed out is that although the quantity of professional and technical personnel could hardly be viewed as a major impetus to economic increase in this region, in certain exceptional districts (such as Sheyang County, Yancheng City) it is the primary factor that contributes to local economic development.

5 Conclusion and Policy Suggestion

E. Conclusions

This chapter utilizes the methodology of grey relational analysis and employs data from 50 counties in Jiangsu Province to discern primary factors in technological progress system which exert the significant influence on local economic growth from 2003 to 2006 in each county in Jiangsu Province. Results in the study are described as follows:

1) From perspective of correlations between technological progress and county economy in the whole province, effects of those absolute value indicators on economic dimension, such as local special project funds for S&T and R&D expenditure from industrial enterprises above designed size in technical input and high-tech industrial added value in technical output, are more remarkable and less variant than corresponding relative value indicators. The fact that the quantity of patent applications in a district has a greater impact on GDP than that of patent grants, it illustrates that the will of innovation in a region exerts a positive effect on economic advancement in counties.

2) Generally, counties in middle Jiangsu possess the closest correlation between technological progress and GDP in these three regions, while the relational grade in northern Jiangsu is the lowest one. Additionally, counties where technological progress indicators significantly propel regional economy are concentrated in southern and middle Jiangsu.

3) For counties in southern Jiangsu, enterprises play a consequential role in the procedure of impelling economy through technological progress, and the input of technical talents in this region is closely correlated with economic growth. In middle Jiangsu, most technological progress indicators are relevant to GDP in counties within this region, and the variances of relational grades between input-out in S&T and economic growth are comparatively small. Taken northern Jiangsu as a whole, the effects of technological progress on GDP is not sufficient enough that it could rarely be the major driving force to economic development; however, in certain indicators and counties' potential influence of technological advance on economic might be exploited and released.

F. Policy Suggestion

Based on the analysis above, policy suggestions are made as follows:

1) From the perspective of the whole province, county governments should increase fiscal investment in science and technology. Also, corresponding policies could be taken to encourage R&D activities in enterprises. Furthermore, supports should be provided to high-tech industries that help the transfer from technical achievements to production value. The series of measures would have a universal positive effect on economic development in counties from Jiangsu province.

2) For county governments in southern Jiangsu, it is necessary to establish and complete the incentive mechanism for technical talents and to concentrate on the quantity as well as the quality of innovation. It is also concerned that the industrial structure should be adjusted to improve the status of high-tech industry and technology-intensive corporations.

3) For county governments in middle Jiangsu, the next step on concern is to further encourage the industrialization of technique innovation, and to ameliorate the outside in which high-tech industry develops. Specifically, it is of necessity to provide corresponding fiscal and financial policies in support of the development of small and middle-sized high-tech enterprises under the condition of global financial crisis and economic recession.

4) For county governments in northern Jiangsu, policies that foster the development of technology transaction market would be helpful because through technique transaction and technology introduction counties in northern Jiangsu could improve their regional innovation capabilities and lay a foundation for driving economic growth from technological progress.

5) Based on the recognition of how regional technological progress influences economic growth, each county should adjust its policies and measures in accordance with local conditions. To counties where scientific and technological strength lags behind and technological progress is relatively tardy, it is essential for county governments to discern the primary factors in technological progress system that have the most significant effects on economy, to increase inputs of these indicators and to promote corresponding outputs, all measures were taken with an orientation and target that technological advance would effectively serve the development of economy and society.

Appendix A Correlation between technical Inputs and economic Growth

City	County	S&TF	PS&TF	PTP	R&DE	PR&D.
Chang-zhou	Jintan	0.700	0.646	0.845	0.712	0.686
	Liyang	0.742	0.695	0.630	0.647	0.339
	Wujin	0.611	0.515	0.664	0.387	0.065
Wuxi	Huishan	0.674	0.430	0.652	0.709	0.671
	Jiangyin	0.851	0.181	0.317	0.274	-0.054
	Xishan	0.653	0.746	0.504	0.607	0.494
	Yixin	0.680	0.427	0.445	0.720	0.724
Suzhou	Kunshan	0.731	0.548	0.832	0.733	0.223
	Taicang	0.690	0.393	0.733	0.096	-0.002
	Wujiang	0.038	-0.130	0.424	0.598	0.409
	Zhangjia-gang	0.814	0.781	0.758	0.738	-0.103
Nanjing	Gaochun	0.075	-0.040	0.576	0.338	0.132
	Jiangning	0.595	0.131	0.673	0.639	0.517
	Lishui	0.275	0.316	0.776	0.673	0.592
Zhen-jiang	Dantu	0.381	0.062	0.173	0.533	0.133
	Danyang	0.691	0.144	0.529	0.640	0.506
	Yangzhong	0.638	0.159	0.459	0.727	0.695
Yang-zhou	Gaoyou	0.765	0.429	0.597	0.710	0.636
	Jiangdu	0.707	0.548	0.759	0.370	-0.097
	Yizheng	0.733	0.323	0.368	0.705	0.348
Taizhou	Gaogang	0.132	0.173	0.114	0.349	0.179
	Hailing	0.434	0.098	0.402	0.394	0.080
	Jiangyan	0.765	0.686	0.763	0.241	-0.012
	Jingjiang	0.668	0.538	0.245	0.485	0.223
	Taixin	0.729	0.593	0.640	0.715	0.657
	Xinghua	0.670	0.266	0.719	0.704	0.742
Nantong	Hai'an	0.721	0.583	0.705	0.637	0.623
	Haimen	0.441	0.357	0.389	0.671	0.443
	Qidong	0.769	0.516	0.418	0.717	0.696
	Rudong	0.511	0.164	0.713	0.413	0.526
	Rugao	0.679	-0.079	0.705	0.487	0.491
	Tongzhou	0.532	0.427	0.365	0.475	0.344
Huai'an	Chuzhou	0.328	0.039	-0.029	0.101	0.154
	Huaiyin	0.401	0.149	0.384	0.397	0.366
	Lianshui	0.438	0.048	0.259	0.327	0.425
	Xuyu	0.292	-0.119	0.431	0.469	0.167
Lianyun-gang	Donghai	0.462	0.222	0.676	0.515	0.570
	Ganyu	0.705	0.352	-0.311	0.209	-0.536
Suqian	Shuyang	0.497	0.184	0.177	0.590	0.602
Xuzhou	Feng	0.124	-0.080	0.103	0.382	0.419
	Pei	0.722	0.459	0.432	0.660	0.593
	Pizhou	0.797	0.099	0.075	0.686	0.616
	Suining	0.645	0.579	0.509	0.620	0.283
	Tongshan	0.432	0.154	0.394	0.672	0.310
Yan-cheng	Binhai	0.497	0.008	0.536	0.726	0.256
	Dafeng	0.647	0.325	0.348	0.669	0.581
	Dongtai	0.445	0.152	0.347	0.632	0.399
	Funing	0.332	0.287	0.098	0.064	0.123
	Sheyang	0.810	0.066	0.397	0.393	0.166
	Xiangshui	0.635	0.261	0.068	0.666	-0.007

Appendix b Correlation between Technical Outputs and Economic Growth

City	County	PA	$\overline{PG}$	H-TIAD	$\overline{H\text{-}TIAD}$	TTC
Chang-zhou	Jintan	0.692	0.711	0.356	0.357	0.395
	Liyang	0.779	0.435	0.558	0.369	0.390
	Wujin	0.706	0.519	0.591	0.702	0.346
Wuxi	Huishan	0.803	0.425	0.593	0.162	0.340
	Jiangyin	0.672	0.450	0.776	0.304	0.390
	Xishan	0.633	0.425	0.660	0.337	0.588
	Yixin	0.665	0.014	0.796	0.769	0.725
Suzhou	Kunshan	0.263	0.459	0.352	0.395	0.378
	Taicang	0.253	0.608	0.464	0.233	0.287
	Wujiang	0.447	0.189	0.768	0.391	0.628
	Zhangjia-gang	0.557	0.508	0.419	0.048	0.322
Nanjing	Gaochun	0.666	0.630	0.307	-0.643	0.393
	Jiangning	0.833	0.719	0.809	0.490	0.078
	Lishui	0.657	0.460	0.724	0.458	0.451
Zhen-jiang	Dantu	0.518	0.367	0.621	0.641	0.057
	Danyang	0.737	0.468	0.619	0.710	0.134
	Yangzhong	0.771	0.481	0.672	0.616	0.295
Yang-zhou	Gaoyou	0.714	0.697	0.785	0.546	0.730
	Jiangdu	0.609	0.469	0.750	0.378	0.784
	Yizheng	0.479	0.435	0.785	0.408	0.259
Taizhou	Gaogang	0.340	0.727	0.756	0.585	0.725
	Hailing	0.629	0.102	0.655	0.462	0.420
	Jiangyan	0.773	0.337	0.742	0.264	0.350
	Jingjiang	0.437	0.088	0.828	0.501	0.239
	Taixin	0.763	-0.177	0.753	0.705	0.719
	Xinghua	0.777	0.320	0.850	0.546	0.102
Nantong	Hai'an	0.794	0.375	0.713	0.600	0.769
	Haimen	0.666	0.344	0.383	0.100	0.746
	Qidong	0.771	0.403	0.786	0.690	0.570
	Rudong	0.727	0.425	0.725	0.459	0.473
	Rugao	0.741	0.299	0.441	0.484	0.688
	Tongzhou	0.530	0.471	0.666	0.489	0.406
Huai'an	Chuzhou	0.701	0.313	0.416	0.304	0.149
	Huaiyin	0.382	0.392	0.317	0.280	0.383
	Lianshui	0.379	0.131	0.352	0.647	0.485
	Xuyu	0.382	0.170	0.560	0.168	0.547
Lianyun-gang	Donghai	0.081	0.453	0.368	0.299	-0.230
	Ganyu	0.109	-0.401	0.407	0.088	0.003
Suqian	Shuyang	-0.066	0.117	0.441	0.019	0.740
Xuzhou	Feng	-0.120	-0.189	0.449	0.426	0.526
	Pei	0.520	0.416	0.406	0.072	0.058
	Pizhou	0.464	0.192	0.771	0.076	0.329
	Suining	0.436	0.048	0.275	0.261	0.107
	Tongshan	0.412	0.392	0.506	0.331	0.366
Yan-cheng	Binhai	0.748	0.696	0.603	0.363	0.706
	Dafeng	0.517	-0.261	0.442	0.554	0.310
	Dongtai	0.633	0.396	0.384	0.136	0.801
	Funing	0.581	0.060	0.344	-0.074	0.435
	Sheyang	0.439	-0.210	0.651	0.577	-0.026
	Xiangshui	0.378	0.206	0.623	0.110	0.289

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Optimization Method of Grey Relation Analysis Based on the Minimum Sensitivity of Attribute Weights

Xinping Xiao and Huan Guo

Changes of attribute weights directly affect the results of grey incidence analysis for advancing the stability of results on grey relation decision-making. This chapter proposes an optimization method of grey relation analysis based on the minimum sensitivity of attribute weights. The main idea is as follows: First, we certify that sensitivity satisfies the properties of outer measure, explains that it is reasonable to use the sensitivity to measure the stability of grey relation analysis. Then the conditions and properties are given when the changes of attribute weights in grey relation analysis are effective. On the purpose of getting the minimum sensitivity we construct a multi-objective quadratic programming model based on objective weighting method and the partial preference information of the decision maker. The particle swarm optimization (PSO) algorithm is used to solve the model, and then we get grey relation analysis based on the weight. Finally, this method is used to evaluate R&D human resources.

1 Introduction

Grey incidence analysis is to serialize and patternize grey relation order, whose operating mechanism and physical principle are not clear, or those lack of physical prototype fundamentally, and then build grey relation analysis model, so as to make the grey relation quantitative, ordering and visible. It can also provide important means of technical analysis for complex systems' modeling (Deng, 2000). Grey relation analysis is an important part of grey system theory (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), which is the cornerstone of grey system's analysis, modeling, prediction and decision-making. It has wide application in various areas, such as investment decision-making, project evaluation, program optimization, plant siting, resource allocation, industrial sector developing sorting, tender bidding and economic benefits' comprehensive evaluation (Wen, 2004; Xie and Hu, 2005; Song et al., 2005; Chen et al., 2006; Lee et al., 2006).

However, the data's uncertainty and variability are often extremely difficult for decision makers. In order to obtain reasonable and stable grey relation analysis,

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decision maker need to analyze the sensitivity of results, so it is significant to do sensitivity analysis of grey relation decision-making method. Usually we take two aspects of sensitivity analysis into account, attribute value and attribute weight. Jeffrey and Ringuest did sensitivity analysis of multi-attribute decision-making attribute value, using L_p -metric optimization method (Ringuest, 1997). S. L. Liu and W. H. Qiu analyzed the sensitivity of generalized dual-point method and obtained the variation range of attribute value on condition that the position of program sorting is constant (Liu and Qiu, 1998). X.P. Xiao and W.Z. Li did sensitivity analysis of grey relation analysis for multi-attribute decision making with time series (Xiao and Lee, 1995). Some scholars indirectly took into account of decision making's rationality and stability by given weight. Common weighting methods are objective weighting, subjective weighting and integrative weighting. Subjective weighting contains expert survey method, two coefficient method, hierarchy analysis method, importance sort method, and so on (Mu and Zhang, 2008). Objective weighting contains principal component analysis, entropy technology, and maximum deviation, etc (Zhang et al., 2008). The integrative weighting is the proper combination of objective weighting and subjective weighting (Niu and Zhang, 2007). What's more, W.M. Tang built a new multilevel comprehensive evaluation model based on grey relation analysis, using grey relation degree to determine index weight (Tang, 2006). But different weighting method does not correspond to identical weight as to the same issue, and the attribute weight's changes directly influence the result of grey relation decision-making. So it is necessary to study attribute weights that can make results of decision-making reasonable and stable. In order to enhance the stability of grey relation decision-making's results; the chapter presents a new method of grey relation analysis based on sensitivity analysis.

2 Basic Theorem of Grey Relation Analysis

Suppose there are only one decision-maker, a determined project set $S=\{S_1,S_2,...,S_m\}$ and a determined index set $P=\{P_1,P_2,...,P_n\}$ during the process of grey relation analysis. We can define a decision matrix with $m\times n$, $M=(a_{ij})_{m\times n}$, $i\in I=\{1,2,...,m\}$, $j\in J=\{1,2,...,n\}$. The decision matrix should be standardized because the attribute values are generally not in the same degree. The common standardized method is as follows:

$$a'_{ij}=\begin{cases}\dfrac{M_j-a_{ij}}{M_j-m_j} & \text{while } P_j \text{ is ascribed to benefit type}\\[2ex] \dfrac{a_{ij}-m_j}{M_j-m_j} & \text{while } P_j \text{ is ascribed to cost type}\end{cases}$$

where $M_j=\max\limits_{1\le i\le m}a_{ij}$, $m_j=\min\limits_{1\le i\le m}a_{ij}$, $j\in J$.

Suppose the matrix $M = (a_{ij})_{m\times n}$ has been standardized, in which the element a_{ij} stands for the value of i th project S_i under the j th attribute P_j. As for the above standardized method, we can confirm attribute value of ideal project as $(1,1,\cdots,1)$ .Then we calculate relation coefficient,

$$r_{ij} = \frac{\min_i \min_j \Delta_{ij} + \xi \max_i \max_j \Delta_{ij}}{\Delta_{ij} + \xi \max_i \max_j \Delta_{ij}}$$

Where $\Delta_{ij} = 1 - a_{ij}$. For the character of decision matrix M , we know that $\min_i \min_j \Delta_{ij} = 0$, $\max_i \max_j \Delta_{ij} = 1$, so $r_{ij} = \frac{\xi}{\Delta_{ij} + \xi}$. Then we can get relation coefficient matrix $r = (r_{ij})_{m\times n}$ and relation degree $R_i = \sum_{j=1}^{n} w_j r_{ij}$, therefore, $R = \{R_1, R_2, ..., R_m\}$ corresponding to S , which is a vector composed by relation degree between decision-making project and ideal project.

3 The Definition and Theorem Related to Sensitivity Analysis

Based on the definition proposed by Traintaphyllou and Sabchez (2007), we can define sensitivity as follows:

Definition 1. For two arbitrary projects S_i, S_k in S , if their existing relation order is changed following by changing current weight of a certain attribute P_j, then the change of the attribution weight is effective. Otherwise, it is ineffective.

Definition 2. For two projects S_i, S_k in S , if the change of P_j is effective, and the relation order of S_i, S_k is changed when w_j is changed to $w'_j = w_j + \varepsilon_{ikj}$, and then ε_{ikj} is called the smallest change of P_j.

Definition 3. For all the $j \in J$, $D_j = \min_{i \neq k \in I} \{|\varepsilon_{ikj}|\}$ is the threshold value of P_j, and $\mathrm{Sens}(P_j) = \frac{1}{D_j}$ is the sensitivity of P_j. Especially, $\mathrm{Sens}(P_j) = 0$ when all the changes of P_j are ineffective.

According to Definition 1-3, there is the following conclusion: the larger sensitivity of attribute and the more impact on the result of its change. On the contrary, the smaller sensitivity of attribute, the less impact on the result. Based on the above definitions, we can certify sensitivity is submitted to the characters of outer measure (Cheng and Zhang, 2005). Then we know that it is reasonable by using sensitivity to analyze the stability of decision making, thus explaining that it is feasible to avoid the sensitivity of decision, and further propose an optimization method.

Theorem 1. Sensitivity of attribute P is submitted to the characters of outer measure:

1.1) $\mathrm{Sens}(P_j) \geq 0$, $\mathrm{Sens}(P_j) = 0$, if and only if the change of P_j is inexistence ;

1.2) If $A_j \subset A_l$, then $\mathrm{Sens}(P_j) \leq \mathrm{Sens}(P_l)$, (while A_j, A_l are the sets which were respectively consisted of the smallest change of P_j, P_l);

1.3) $\mathrm{Sens}(\bigcup_{j=1}^{n} P_j) \leq \sum_{j=1}^{n} \mathrm{Sens}(P_j)$.

Proof. Generally, we obtain attribute sensitivity via discussing the vector W of attribute weight (that is to say, considering the change of w_j, $j \in J$). According to definition 3, when resolving $\mathrm{Sens}(P_j)$ we need consider all the smallest change ε_{ikj} of attribute weight w_j, let all the smallest change ε_{ikj} ($i,k \in I$) note as a set A_j which is on the behalf of the attribute P_j, then we think over $\mathrm{Sens}(P_j)$.

1.1) According to the definition of sensitivity, it is obviously that $\mathrm{Sens}(P_j) \geq 0$. Especially, $\mathrm{Sens}(P_j) = 0$ when the smallest change of P_j is inexistence, that is, the change of the attribution weight is ineffective.

1.2) Let A_j and A_l as the sets of all the smallest change of P_j and P_l. Suppose $A_j \subset A_l$, $\varepsilon_j = \min_{i,k \in I} \left\{ \varepsilon_{ikj} \,\middle|\, \varepsilon_{ikj} \in A_j \right\}$ and $\varepsilon_l = \min_{i,k \in I} \left\{ \varepsilon_{ikl} \,\middle|\, \varepsilon_{ikl} \in A_l \right\}$, we know $\varepsilon_j > \varepsilon_l$ by set properties. Then according to sensitivity formula we can obtain $\mathrm{Sens}(P_j) \leq \mathrm{Sens}(P_l)$.

1.3) Let $\{P_1, P_2, \cdots, P_n\}$ be attribute set, $\{A_1, A_2, \cdots, A_n\}$ be the vector sets where A_j composed of the smallest change of attribute P_j , and $\varepsilon_j = \min_{i,k \in I} \left\{ \varepsilon_{ikj} \,\middle|\, \varepsilon_{ikj} \in A_j \right\}$, then we know that $\mathrm{Sens}(\bigcup_{j=1}^{n} P_j) = \dfrac{1}{\min_j \{\varepsilon_j\}}$, where $\bigcup_{j=1}^{n} P_j$ be the union of all the smallest change set of attribute weight, whereas $\sum_{j=1}^{n} \text{Sens}(P_j) = \sum_{j=1}^{n} \frac{1}{\varepsilon_j}$, obviously $\text{Sens}(\bigcup_{j=1}^{n} P_j) \le \sum_{j=1}^{n} \text{Sens}(P_j)$.

Through the above proof, Theorem 1.1 shows that sensitivity is non-negative. Sensitivity of the attribute is zero if and only if the change of attribute is ineffective, in other words, the attribute which is not sensitive is correspondingly stable; Theorem 1.2 affords a method of comparing the attribute sensitivity, that is to say, if the smallest change set of a attribute is included in the other one, then the sensitivity of the included one is no larger than the other's; Theorem 1.3 shows that it is possible to lower the sensitivity by considering all the attributes, so we always look for the most insensitive weight. Based on the characters of sensitivity, we propose an optimization method of grey relation analysis aiming at the smallest sensitivity.

4 Quadratic Programming Model Based on Sensitivity Analysis and Its Algorithm

4.1 The Property of Sensitivity Analysis Based on Preference Information

In relation coefficient matrix $(r_{ij})_{m\times n}$, R_i, R_k are the relation degree between S_i, S_k and ideal project respectively, $W = (w_1, w_2, ..., w_n)^T$ is the weight vector of P which satisfies $\sum_{j\in J} w_j = 1, w_j \ge 0$, $j \in J$.

Theorem 2. Suppose $S_i \succ S_k$ $(i, k \in I)$, then

2.1) If $r_{ij} = r_{kj}$, then the weight change of S_i, S_k in P_j is ineffective;

2.2) If $(R_i - R_k)(r_{ij} - r_{kj}) > 0$ and $\sum_{l=1, l\ne j}^{n} w_l (r_{il} - r_{kl}) > 0$, then the weight change of S_i, S_k in P_j is ineffective;

2.3) If $(R_i - R_k)(r_{ij} - r_{kj}) < 0$, then the weight change of S_i, S_k in P_j is effective.

Proof. 2.1) it is obvious.

2.2) R_i, R_k are the relation degree between S_i, S_k and ideal project respectively, by the preference information $R_i > R_k$, and $(R_i - R_k)(r_{ij} - r_{kj}) > 0$, it is easy to say that $r_{ij} > r_{kj}$. Suppose the weight change of S_i, S_k in P_j $(j \in J)$ is effective, then there exists ε_{ikj},

$$w'_j = \frac{w_j - \varepsilon_{ikj}}{1-\varepsilon_{ikj}} \geq 0 \ (j \in J),\ w'_l = \frac{w_l}{1-\varepsilon_{ikj}} \geq 0 \ (l \neq j \in J)$$

$W' = (w'_1, w'_2, ..., w'_n)^T$ is the vector of changed weight.

R'_i, R'_k are the changed relation degree between S_i, S_k and ideal project respectively, then $R'_i < R'_k$, thus

$$\frac{\sum_{j=1}^{n} w_j r_{ij} - \varepsilon_{ikj} r_{ij}}{1-\varepsilon_{ikj}} < \frac{\sum_{j=1}^{n} w_j r_{kj} - \varepsilon_{ikj} r_{kj}}{1-\varepsilon_{ikj}}$$

By

$$R_i = \sum_{j=1}^{n} w_j r_{ij}\ , R_k = \sum_{j=1}^{n} w_j r_{kj}\ , r_{ij} > r_{kj}$$

Then

$$R_i - \varepsilon_{ikj} r_{ij} < R_k - \varepsilon_{ikj} r_{kj} \tag{1}$$

$$\varepsilon_{ikj} > \frac{R_i - R_k}{r_{ij} - r_{kj}} \tag{2}$$

Because of

$$\sum_{\substack{l=1 \\ l \neq j}}^{n} w_l (r_{il} - r_{kl}) > 0$$

we have

$$R_i - R_k > w_j (r_{ij} - r_{kj})$$

$$w_j < \frac{R_i - R_k}{r_{ij} - r_{kj}} \tag{3}$$

According to (2) and (3), we know $w_j < \varepsilon_{ikj}$, then $w'_j = \dfrac{w_j - \varepsilon_{ikj}}{1-\varepsilon_{ikj}} \geq 0$ which is not reasonable, so we can certify the hypothesis is wrong, therefore, the weight change of S_i, S_k in P_j is ineffective.

2.3) By $(R_i - R_k)(r_{ij} - r_{kj}) < 0$ and $R_i > R_k$, then $r_{ij} < r_{kj}$.
According to (1), we get

$$\varepsilon_{ikj}(r_{kj} - r_{ij}) < R_k - R_i$$

$$\varepsilon_{ikj} < \frac{R_k - R_i}{r_{kj} - r_{ij}} < 0 \le w_j$$

Then we can obtain

$$w_j' = \frac{w_j - \varepsilon_{ikj}}{1 - \varepsilon_{ikj}} \ge 0$$

When w_j is changed into w_j', the relation order of S_i and S_j is changing, hence the weight change of P_j is effective.

Theorem 3. Suppose $S_i \succ S_k$ and the weight changes of P_j and P_l are effective, If $r_{ij} - r_{kj} > r_{il} - r_{kl}$ $(i, k \in I; j, l \in J)$, then $\mathrm{Sens}(P_j) > \mathrm{Sens}(P_l)$.

Proof. As $S_i \succ S_k$ and P_j is effective, by (1)

$\varepsilon_{ikj}(r_{kj} - r_{ij}) < R_k - R_i$ (Obtain $R_i > R_k$)

If $r_{kj} - r_{ij} > 0$, then $\varepsilon_{ikj} < \dfrac{R_i - R_k}{r_{ij} - r_{kj}} < 0$; If $r_{kj} - r_{ij} < 0$, then $\varepsilon_{ikj} > \dfrac{R_i - R_k}{r_{ij} - r_{kj}} > 0$, therefore

$$\left|\varepsilon_{ikj}\right| > \left|\frac{R_k - R_i}{r_{kj} - r_{ij}}\right|$$

By

$$r_{ij} - r_{kj} > r_{il} - r_{kl}$$

We have

$$\left|\frac{R_k - R_i}{r_{kj} - r_{ij}}\right| < \left|\frac{R_k - R_i}{r_{kl} - r_{il}}\right|$$

$$\left|\varepsilon_{ikj}\right| < \left|\varepsilon_{ikl}\right| \quad D_j < D_l$$

Therefore

$$\mathrm{Sens}(P_j) > \mathrm{Sens}(P_l).$$

Based on the preference information $S_i \succ S_k$, Theorem 2 demonstrates that if $r_{ij} \neq r_{kj}$, the necessary and sufficient condition for weight change of P_j being ineffective is that $(R_i - R_k)(r_{ij} - r_{kj}) > 0$ and $\sum_{\substack{l=1 \\ l\neq j}}^{n} w_l (r_{il} - r_{kl}) > 0$;Theorem 3 demonstrates when the weight change of P_j is effective, the larger D_j is, the smaller impact on the result.

4.2 The Multi-Objective Programming Model for Getting the Weight and Its Algorithm

Considering the partial preference information of the decision-maker, we denote

$$\Lambda = \left\{ (i,k) \middle| \text{all the known preference } S_i \succ S_k \;\; i,k \in \mathrm{I} \right\}$$
$$M = \left\{ j \in J \middle| \; (R_i - R_k)(r_{ij} - r_{kj}) > 0 \right\}$$
$$\bar{M} = \left\{ j \in J \middle| (R_i - R_k)(r_{ij} - r_{kj}) < 0 \right\}$$
$$N = \left\{ j \in M \middle| \left| r_{ij} - r_{kj} \right| = \max_{l\in M} \left\{ \left| r_{il} - r_{kl} \right| \right\} \;\; (i,k) \in \Lambda \right\}$$
$$\bar{N} = \left\{ j \in \bar{M} \middle| \left| r_{ij} - r_{kj} \right| = \max_{l\in \bar{M}} \left\{ \left| r_{il} - r_{kl} \right| \right\} \;\; (i,k) \in \Lambda \right\}$$

For getting the smallest sensitivity of grey relation analysis, we can construct the single-objective programming□based on the Theorem 2 and 3, as follows:

$$\textit{Goal}: \quad \max \left\{ \sum_{j\in \bar{N}} \frac{\left| R_i - R_k \right|^2}{\left| r_{ij} - r_{kj} \right|^2} \right\} = W^T Q W$$

$$\textit{Subject to}: \; \sum_{\substack{l=1 \\ l\neq j}}^{n} w_l (r_{il} - r_{kl}) > 0 \quad \underset{(i,k)\in\Lambda}{j \in N};$$

$$e^T W = 1; \; W \geq 0$$

Where the elements of Q are following:

$$q_{ll} = \sum_{j\in \bar{N}} \left(\frac{r_{il} - r_{kl}}{r_{ij} - r_{kj}} \right)^2 \quad l \in J;$$

$$q_{pl} = \sum_{j\in \bar{N}} \frac{(r_{ip} - r_{kp})(r_{il} - r_{kl})}{(r_{ij} - r_{kj})^2} \quad p \neq l \in J; e = (1,1,\ldots,1)^T.$$

For getting the reasonable weight, we obtain the single-objective programming II using the objective weight method

Goal: $\min\left\{\sum_{j=1}^{n} g_j\right\} = W^T HW$

Subject to: $\sum_{\substack{l=1 \\ l\neq j}}^{n} w_l (r_{il} - r_{kl}) > 0 \quad j\in N_{(i,k)\in\Lambda}$;

$e^T W = 1$; $W \geq 0$

H is a diagonal matrix whose elements are as follows:

$$h_{jj} = \sum_{i=1}^{m} \frac{(r_j - r_{ij})^2}{(r_j - r'_j)^2}$$

Where $r_j = \max\{r_{1j}, r_{2j}, ..., r_{mj}\}$ and $r'_j = \min\{r_{1j}, r_{2j}, ..., r_{mj}\}$, $j\in J$.

Combining Programming I and II, we can get multi-objective programming III

Goal: $\min\left\{-W^T QW, W^T HW\right\}$

Subject to: $\sum_{\substack{l=1 \\ l\neq j}}^{n} w_l (r_{il} - r_{kl}) > 0 \quad j\in N_{(i,k)\in\Lambda}$;

$e^T W = 1$; $W \geq 0$

Program III is a multi-objective quadratic programming model, whose solution is an optimal weight value. Here we use PSO algorithm to solve the problem (Zeng and Jie, 2004). PSO algorithm firstly initializes a group of random solutions of objective function and each individual is called particle. According to the objective function, every particle can get a fitness value. In iteration process, each particle is updated with two "best" values. One "best" value is the best solution the particle currently searched. It is named as individual extreme value "*pbest*". Another "best" value is the best solution all particles currently search. It is the global best value and called "*gbest*". Each particle modified its position and velocity according to the following formulas:

$$v_{ij}^{k+1} = v_{ij}^{k} + c_1 rand()(pbest_{ij}^{k} - x_{ij}^{k}) + c_2 Rand()(gbest_{j}^{k} - x_{ij}^{k}) \quad (4)$$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1} \quad (5)$$

In a *d*-dimensions search space, $V_i^k = (v_{i1}^k, v_{i2}^k, v_{i3}^k, \cdots, v_{id}^k)$ is the velocity vector of the i th particle in the k th step; $X_i^k = (x_{i1}^k, x_{i2}^k, x_{i3}^k, \cdots, x_{id}^k)$ is the position of the i th particle in the k th step; $pbest_i^k$ is the best position of the i th particle until k th step; $gbest^k$ is the best position in the swarm until k th step;

c_1 and c_2 are constants known as acceleration coefficients and usually $c_1 = c_2 = 2$; $rand()$ and $Rand()$ are two separately random functions in the range [0,1].

The calculation procedure of PSO is shown as bellow:

1) Initialize particle population in the feasible region, set the size as *Pnum* ,and initialize the particle velocity;
2) According to formulas (4) and (5), calculate each particle's fitness value, then choose global extreme value and individual extreme value;
3) If requirement is met (up to a certain accuracy or up to the maximum cycle number), go to step (5), or else go to step (4);
4) Update particles' velocity and position according to above formulas, then go to step (2);
5) Get out global extreme value and corresponding solution, exit the loop.

5 Application Analyses

In order to evaluate the level of an industry's R&D human resource in Wuhan, expert analyzed four large-scale enterprises S_i $(i = 1, 2, ..., 4)$ in this industry. There are five attributes P_j $(j = 1, 2, ..., 5)$ for evaluating the level, such as knowledge quantity, innovation ability, communion ability, health condition, heart bearing capacity, which are all belonging to benefit type. Expert marks the enterprises aiming at the five attributes, whose values range from 1 to 10, and then gets the decision matrix:

$$A = \begin{bmatrix} 5 & 8 & 8 & 6 & 9 \\ 8 & 6 & 10 & 8 & 8 \\ 6 & 9 & 7 & 10 & 7 \\ 9 & 7 & 9 & 8 & 6 \end{bmatrix}$$

Using the above standardization method to deal with A, then we get

$$A' = \begin{bmatrix} 0 & 0.67 & 0.33 & 0 & 1 \\ 0.75 & 0 & 1 & 0.5 & 0.67 \\ 0.25 & 1 & 0 & 1 & 0.33 \\ 1 & 0.33 & 0.67 & 0.5 & 0 \end{bmatrix}$$

During the process of resolving relation coefficient, suppose $\xi = 0.5$, then we can get relation coefficient matrix

$$r = \begin{bmatrix} 1 & 0.4286 & 0.6000 & 1 & 0.3333 \\ 0.4000 & 1 & 0.3333 & 0.5000 & 0.4286 \\ 0.6667 & 0.3333 & 1 & 0.3333 & 0.6000 \\ 0.3333 & 0.6000 & 0.4286 & 0.5000 & 1 \end{bmatrix}$$

Suppose the preference information $S_3 \succ S_1, S_2 \succ S_4$, using the above method we can construct the following multi-objective programming model

$$\min\{-\frac{(-0.3333w_1+0.0952w_2-0.4000w_3+0.6667w_4-0.2667w_5)^2}{(0.4444)^2}$$

Goal: $$-\frac{(0.0667w_1-0.4000w_2+0.0952w_3+0.5714w_5)^2}{(0.3265)^2},$$

$$0.9156w_1^2+0.9310w_2^2+0.9310w_3^2+0.9444w_4^2+0.9310w_5^2\}$$

Subject to:
$$-0.3333w_1+0.0952w_2+0.6667w_4-0.2667w_5>0;$$
$$0.0667w_1-0.4000w_2+0.0952w_3+0.5714w_5>0;$$
$$w_1+w_2+w_3+w_4+w_5=1;\quad w_1,w_2,w_3,w_4,w_5\geq 0$$

The methods for solving multi-objective are various, among which we adopt weighting method to solve it. Suppose the weights of the goal are α, β and $\alpha+\beta=1$. Using *MATLAB* to resolve the problem, we can get the result in Table 1.

Table 1 shows that no matter how to distribute weight to the two objectives, applying the solution of the programming to make decision, we can get the order

Table 1 Weight value of attribute and rank order of alternative in different parameter value

Parameter		Vector of attribute weight	Relation order
α	β		
1	0	(0.17 0.20 0.30 0.08 0.25)	$S_3 \succ S_4 \succ S_1 \succ S_2$
0.8	0.2	(0.22 0.22 0.33 0.10 0.13)	$S_3 \succ S_1 \succ S_4 \succ S_2$
0.6	0.4	(0.17 0.19 0.35 0.14 0.15)	$S_3 \succ S_1 \succ S_4 \succ S_2$
0.5	0.5	(0.22 0.22 0.30 0.10 0.16)	$S_3 \succ S_1 \succ S_4 \succ S_2$
0.3	0.7	(0.30 0.18 0.40 0..05 0.10)	$S_3 \succ S_1 \succ S_4 \succ S_2$
0.1	0.9	(0.33 0.21 0.35 0.04 0.07)	$S_3 \succ S_1 \succ S_4 \succ S_2$
0	1	(0.30 0.12 0.31 0.09 0.18)	$S_3 \succ S_1 \succ S_4 \succ S_2$

which can guarantee the preference information and the smallest sensitivity of the decision-making. It is the result that the decision-maker expects. This method has more practical significance for decision-maker making the reasonable and stable decision.

6 Conclusion

The chapter presents an optimization grey relation method, based on the minimum of attribute weight’s sensitivity. We demonstrate that sensitivity submits to the essential property of outer measure. According to the definition of sensitivity, characteristics of grey relation operator and reasonable objective weighting method, we construct a multi-objective quadratic programming model about weight and solve attribute weights using particle swarm algorithm. The optimal grey relation method obtained by attribute weights above, not only ensures decision makers' preference information, but also lowers the sensitivity of results of grey relation analysis, which has great and actual benefits for decision maker to make reasonable and stable decision. The approach avoids sensitivity and ensures the stability of decision-making on a certain extent. Of course, we only considered the sensitivity of grey relation analysis attribute weights. With regard to the sensitivity of attribute value, we need further study.

Acknowledgement. Thanks are due to the anonymous referees for many instructive suggestions, which have improved this chapter. This work was supported by National Natural Science Foundation of China (Grant No. 70971103) and Specialized Research Fund for the Doctoral Program of Higher Education (Grant No.200804970005)

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Research on Extended Cluster of Grey Incidences and Its Application*

Ke Zhang and Sifeng Liu

This chapter studies extended clusters of grey incidences for indexes in panel data. Firstly it discusses the expression of a panel data by matrix sequence, and describes its geometric characteristic though a cluster of curved surfaces. Thereafter, in a three dimensional space, the chapter analyzes the geometric similarity of indexes in panel data. According to the principle of grey incidence analysis, it proposes an absolute degree of grey incidences for matrixes, which maintains the consistent form with the classic one. Furthermore the formula of zeroing starting point operator and parameters are redefined. On this basis, the chapter constructs the extended incidence matrix of indexes and discusses the cluster analysis process of panel data. Finally, an instance is studied. The results prove the method is effective.

1 Introduction

The grey incidence analysis and clusters of grey incidences are not only the important components of the grey theory, but also the basis of modeling, forecasting and deciding in grey system (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). Because of less restriction of sample number and convenient computation, grey incidence analysis and clusters have been successfully applied to a great deal of domains, for example, economics, sociology, industry, agriculture, education and medicine (Chen and Zhou, 2008; Hu and Zhang, 2007; Ma and Hao, 2004). But current fruits of the grey incidence analysis, e.g., the degree of grey incidences (Deng, 1989), the absolute degree of grey incidences, the B-type incidences (Wang, 1987), C-type incidences (Wang and Zhao, 1999) and the T-type incidences (Tang, 1995), are only fit for the analysis of time series and cluster of cross section data. It is still a blank to study methods for incidences analysis and cluster among panel data.

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* The work is partially supported by National Natural Science Foundation of China though Grant NO. 70701017, 70473037, by the Research Fund for the Doctoral Program of National Ministry of Education though Grant NO. 200802870020. At the same time the authors would like to acknowledge the partial support of National Soft Science Research Program via Grant 2008GXS5D115, Also acknowledgements are given to Social Science Fund of National Education Ministry though Grant NO. 08JA630039.

Table I Three-Dimensional Table of a Panel Data

Time	1			…	N		
Sample	Index $X_1 \cdots X_L$			…	Index $X_1 \cdots X_L$		
1	$x_{11}(1)$	…	$x_{1L}(1)$	…	$x_{11}(N)$	…	$x_{1L}(N)$
…	$x_{i1}(1)$	…	$x_{iL}(1)$	…	$x_{i1}(N)$	…	$x_{iL}(N)$
M	$x_{M1}(1)$	…	$x_{ML}(1)$	…	$x_{M1}(N)$	…	$x_{ML}(N)$

At the same time, although there are a few clustering methods for panel data, these methods are almost based on the multivariate statistics which requires the large samples. For example, (Bonzo and Hermosilla, 2002) first introduces multivariate statistics into panel data analysis. He improves clustering algorithm in virtue of probability function, and applies clustering algorithm to panel data analysis. Zhu establishes the statistic for single index panel data, and constructs its similar criterion (Zhu and Chen, 2007). Zheng structures the similar criterion for muti-indexes panel data, through composing statistics. But when using statistic clustering method, there is the limitation for sample number. Moreover, the average value of variance and covariance in literature (Zhen, 2008) neglects the diversity of the data, and partially loses the data information.

Therefore, this chapter studies extended cluster of grey incidences for indexes in panel data, based on literature (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). First, we transform panel data into behavioral matrix sequence of indexes, and discuss the geometric expression of matrix sequence through a cluster of curved surfaces. According to the principle of grey incidence analysis, we propose a matrix absolute degree of grey incidences, which maintains the consistent form of the classic one, at the same time, its parameters and the formula of zeroing starting point operator are redefined. On this basis, we construct the extended incidence matrix of indexes and discuss the clustering analysis process of indexes in panel data. Finally, an instance is studied and the results prove the method is effective.

2 Geometric Expression of Panel Data

The form of panel data is more complex, including both cross section data and time series. Thereby, there are characteristics of both spatial dimension and time dimension in a panel data. In literature (Zhen, 2008; Cheng, 1988), three-dimensional table is employed to describe panel data. Assume the sample size is M, the number of a sample's indexes is L and the length of time is N. Then, $X_{ij}(t)$ expresses the value of the i th sample with the j th index at the t th time. A three-dimensional table of a panel can be turn into a series of two-dimensional tables which are illustrated in TABLE I.

Because it is inconvenient for three-dimensional table to express the geometric characteristic of the panel data, this chapter proposes a novel method to describe it. Assume a value $X_{ij}(t)$ in the panel data is a point in a three dimensional space, the coordinates of the point is the serial number of the samples and the time corresponding to the value $X_{ij}(t)$, then, the behavior data of an index is a matrix sized $M \times N$ and the panel data is a matrix sequence including L matrixes. Thus, we can use a surface to figure behavior matrix of an index, and use a cluster of surfaces to draw the panel data.

Definition 2.1. Assume there are L indexes, M samples and N moments of the time in panel data X, denoted

$$A_h = (a_{ij})_{M\times N} = \begin{bmatrix} a_{11} & \cdots & a_{1N} \\ \cdots & \cdots & \cdots \\ a_{M1} & \cdots & a_{MN} \end{bmatrix}$$

As the values of the h th index of M samples at N moments. Then A_h is called the behavior matrix of the h th index, and the panel data $X=\{A_1,\cdots,A_i,\cdots,A_L\}$ can be called the behavioral matrix sequence of the indexes.

Definition 2.2. Assume that

$$A_h = (a_{ij})_{M\times N} = \begin{bmatrix} a_{11} & \cdots & a_{1N} \\ \cdots & \cdots & \cdots \\ a_{M1} & \cdots & a_{MN} \end{bmatrix}$$

is behavioral matrix of an index. Then

$$Q = \{Ax + By + C \mid x \in [i, i+1], y \in [j, j+1], \\ i=1,2,\ldots M-1, j=1,2,\cdots N-1\}$$

is called the surface corresponding to the behavioral matrix A_h.

When $i + j \le x + y \le i + j + 1$,

$$A = a_{i+1,j} - a_{ij}, B = a_{i,j+1} - a_{ij}, C = a_{ij} - Ai - Bj$$

When $i + j + 1 < x + y \le i + j + 2$,

$$A = a_{i+1,j+1} - a_{i,j+1}, B = a_{i+1,j+1} - a_{i+1,j}, C = a_{i+1,j+1} - A(i+1) - B(j+1)$$

Definition 2.1 and 2.2 provide a method to describe the geometric characteristic of panel data. In behavioral matrix of an index, three neighbor elements constitute a spatial triangle. Therefore, an index is corresponding to an surface composed of triangles, and the whole panel data which can be transform into a sequence of behavioral matrixes is corresponding to a clusters of surfaces. For example, the surfaces corresponding to a panel data which include 2 indexes of 5 samples at 5 different times are illustrated in Figs.1.

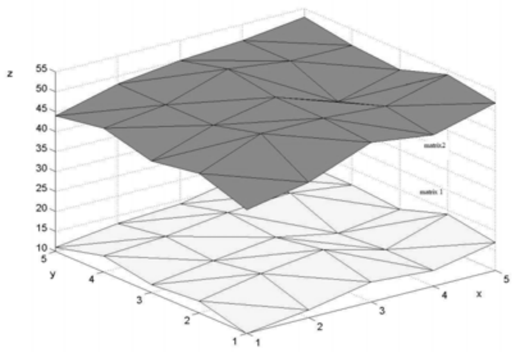

Fig. 1 Surfaces corresponding to panel data

3 Matrix Degree of Grey Incidences

With the help of definition 2.1 and 2.2, we will be able to study the relationship between indexes of a panel data in a three dimensional space. In this way, the degree of grey incidences between behavioral matrixes is defined by the distance function in the three dimensional space, in order to transform the analysis of similarity between two indexes matrixes into measure of approach between two surfaces. We will not always distinguish a behavioral matrix and its surface for convenience.

Definition 3.1. Assume that

$$A_h = (a_{ij})_{M\times N} = \begin{bmatrix} a_{11} & \cdots & a_{1N} \\ \cdots & \cdots & \cdots \\ a_{M1} & \cdots & a_{MN} \end{bmatrix}$$

is a behavioral matrix, and D is a matrix operator.

$$A_h D = (a_{ij}d)_{M\times N} = \begin{bmatrix} a_{11}d & \cdots & a_{1N}d \\ \cdots & \cdots & \cdots \\ a_{M1}d & \cdots & a_{MN}d \end{bmatrix} \tag{1}$$

Where $a_{ij}d = a_{ij} - a_{i1}$, $i = 1, 2, M; j = 1, 2, \cdots N$, then D is called a zeroing starting column operator with $A_h D$ as the image of zeroing starting column of A_h , denoted as

$$A_h^0 = A_h D = (a_{ij}^0)_{M\times N} .$$

For example, the images of zeroing starting column of the panel data in Figs.1 are illustrated in Figs.2.

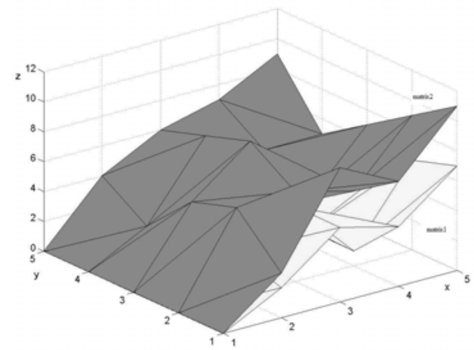

Fig. 2 Images of zeroing starting column

Proposition 3.1. Assume that

$$A_h = (a_{ij})_{M\times N} = \begin{bmatrix} a_{11} & \cdots & a_{1N} \\ \cdots & \cdots & \cdots \\ a_{M1} & \cdots & a_{MN} \end{bmatrix}$$

is a behavioral matrix, and that the surface of zeroing starting column of A_h is denoted as Q_h^0. Let

$$s = \int_1^M \int_1^N Q_h^0 dxdy$$

Then

1°when $\forall i \in [1, M], j \in [1, N]$, always $a_{i,j+1} \geq a_{i,j}$, then $s \geq 0$;

2°when $\forall i \in [1, M], j \in [1, N]$, always $a_{i,j+1} \leq a_{i,j}$, then $s \leq 0$;

3°else the sign of s is not fixed.

The proof of this proposition is based on the properties of double integral. Here all the details are omitted.

Proposition 3.2. Assume that the surfaces corresponding to images of zeroing starting column of two behavioral matrixes, $A_p = (a_{ij})_{M\times N}$, and $A_q = (b_{ij})_{M\times N}$ are Q_p^0, and Q_q^0, respectively. Let

$$s_p - s_q = \int_1^M \int_1^N (Q_p^0 - Q_q^0) dxdy$$

Then

1° if Q_p^0 is always above Q_q^0, then $s_p - s_q \geq 0$; and

2° if Q_p^0 is always underneath Q_q^0, then $s_p - s_q \leq 0$; and

3° if Q_p^0 and Q_q^0 alternate their positions, the sign of $s_p - s_q$ is not fixed;

The proof of this proposition is based on the properties of double integral. Here all the details are omitted.

Definition 3.2. Assume that two behavior matrixes $A_p = (a_{ij})_{M\times N}$ and $A_q = (b_{ij})_{M\times N}$ are the same type matrix, and s is defined as in Proposition 3.1. Then

$$\varepsilon_{pq} = \frac{1+|s_p|+|s_q|}{1+|s_p|+|s_q|+|s_p - s_q|} \tag{2}$$

is called matrix absolute degree of grey incidences of A_p and A_q, or matrix absolute degree of incidences for short.

The form of Eq. (2) is the same as that of absolute degree of grey incidences in literature (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), but the meanings of their parameters are different. In literature (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), $|s_i|$, $|s_j|$ and $|s_i - s_j|$ represent the area between zeroing zigzagged line and coordinate axis, or area between two zeroing zigzagged lines. In this chapter, $|s_p|$, $|s_q|$ and $|s_p - s_q|$ denote the volume among the zeroing surface and coordinate plane, or volume among two zeroing surfaces.

Matrix absolute degree of incidences apparently possesses the properties of normality, closeness and pair symmetry, but does not satisfy the wholeness property, because of the same form as the original one.

Theorem 3.1. Assume that $A_h = (a_{ij})_{M\times N}$ and $A_h^0 = A_h D = (a_{ij}^0)_{M\times N}$ is the zeroing image of A_h and s is defined as in Proposition 3.1. Then,

$$s = \int_1^M\int_1^N Q_h^0 dxdy = \sum_{i=1}^{M-1}\sum_{j=1}^{N-1}[\frac{1}{6}(a^0_{i,j} + a^0_{i+1,j+1}) + \frac{1}{3}(a^0_{i+1,j} + a^0_{i,j+1})] \tag{3}$$

Proof: Let

$$A_1 = a^0_{i+1,j} - a^0_{i,j}, B_1 = a^0_{i,j+1} - a^0_{i,j}; A_2 = a^0_{i+1,j+1} - a^0_{i,j+1}, B_2 = a^0_{i+1,j+1} - a^0_{i+1,j}$$

Where $i = 1,2\cdots m-1, j = 1,2\cdots, n\text{-}1$

$$s = \int_1^M\int_1^N Q_h^0 dxdy = \sum_{i=1}^{M-1}\sum_{j=1}^{N-1}\int_i^{i+1}\int_j^{j+1} Ax + By + Cdxdy =$$

$$\sum_{i=1}^{M-1}\sum_{j=1}^{N-1}[\int_i^{i+1}\int_j^{i+j+1-x} A_1x + B_1y - i\times A_1 - j\times B_1 + a^0_{i,j}dxdy$$

$$+\int_i^{i+1}\int_{i+j+1-x}^{j+1} A_2x + B_2y - (i+1)\times A_2 - (j+1)\times B_2 + a^0_{i+1,j+1}dxdy]$$

$$= \sum_{i=1}^{M-1}\sum_{j=1}^{N-1}[\frac{1}{6}A_1 + \frac{1}{6}B_1 + \frac{1}{2}a^0_{ij} - \frac{1}{6}A_2 - \frac{1}{6}B_2 + \frac{1}{2}a^0_{i+1,j+1}]$$

Substitute A_1, A_2, B_1, B_2, can obtain the conclusion.

Since theorem 3.1 presents the computational method of parameter in matrix degree of grey incidences, we can compute the degree of incidences conveniently using Eq. (2)-(3). E.g. the degree of grey incidences between two matrixes in Fig.1 is 0.83. It is easy to be seen from Fig.2 that the two surfaces corresponding to them are highly similar, so the computational result is consistent with qualitative judgment.

Theorem 3.2. Assume that $A_p = (a_{ij})_{M\times N}$, $A_q = (b_{ij})_{M\times N}$ are two behavioral matrixes, where $b_{ij} = a_{ij} + c$ and c is a constant then $\varepsilon_{pq} = 1$

Proof: Let $A_p^0 = A_p D = (a_{ij}^0)_{M\times N}$, $A_q^0 = A_q D = (b_{ij}^0)_{M\times N}$ is the zeroing image of A_p and A_q, s is defined as in Proposition 3.1. Then,

$$b_{ij}^0 = b_{ij} - b_{i1} = a_{ij} + c - a_{i1} - c = a_{ij} - a_{i1} = a_{ij}^0$$

According to theorem3.1:

$$s_p = s_q \text{ , } | s_p - s_q |= 0$$

So, $\varepsilon_{pq} = 1$.

According to Theorem3.2, we can conclude that the absolute degree of incidences between a behavioral matrix and its translation matrix is equal to 1 which is the maximum of the degree of incidences. In other words, the matrix absolute degree of incidences satisfies the parallel property of relational model. Therefore we can use it to analyze the geometric similarity of indexes in panel data.

4 Clusters of Grey Incidences for Panel Data

Definition 4.1. Assume that there exist M observational objects and that L characteristic data values for each objects have been collected for N times. We have the panel data like Eq. (4).

$$\begin{aligned} A_1 &= (a_{ij}^1)_{M\times N} \\ A_2 &= (a_{ij}^2)_{M\times N} \\ &\cdots\cdots \\ A_L &= (a_{ij}^L)_{M\times N} \end{aligned} \tag{4}$$

For all $i \le j, i, j = 1, 2, \ldots L$, we can calculate the matrix absolute degree ε_{ij} of incidences of A_i and A_j, and obtain the upper triangular matrix A^r

$$A^r = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} & \cdots & \varepsilon_{1L} \\ & \varepsilon_{22} & \cdots & \varepsilon_{2L} \\ & & \ddots & \vdots \\ & & & \varepsilon_{LL} \end{bmatrix} \tag{5}$$

where $\varepsilon_{ii} = 1; i = 1, 2 \cdots L$. A^r is call the extended incidence matrix of characteristic variables.

Take a fixed critical value $r \in [0,1]$ with the general requirement that $r > 0.5$. When $\varepsilon_{ij} > r, i \neq j$, the variables A_i and A_j are treated as those of the same indexes.

Defintion 4.2. The classification of characteristic variables under a fixed critical value r is called a cluster of r grey incidences.

The value of r can be chosen based on the practical needs. The closer to 1 the value of r is, the finer the classification is with fewer variables in each class. The smaller the value of r is, the coarser the classification is with relatively more variables in each class.

To sum up, we apply the degree of grey incidences and extended incidence matrix to clustering the indexes in panel data, including the following four steps.

Step 1: Tansform the panel data into the behavior matrixes sequence, according to the definition2.1.

Step 2: Comupte the images of zeroing starting column for every behavior matrix with the help of definition3.1.

Step 3: Calculate the degree of grey incidences between every two indexes in panel data, through definition3.2 and theorem3.1.

Step 4: Construct extended incidence matrix for all indexes, set critical value r, and obtain the classification of indexes.

5 Case Study

In order to establish evaluation model of urban people's live standard in Jiang Su province, we gain sixteen factors through consultation with experts. These factors are per capita average earning (X_1), price indices(X_2) annual disposable(X_3), per capita annual living expenditure(X_4), government expenditure by region (X_5), per capita health institutions(X_6), community service facilities (X_7), insured ratio (X_8), educational expenditure (X_9), gross regional product(X_{10}), per capita floor space (X_{11}), per capita greenbelt (X_{12}), employment rate (X_{13}), growth rate of population (X_{14}), per capita electricity consumption (X_{15}) and per capita transportation vehicle (X_{16}).

For selecting reasonable characteristic variables of the evaluation model, we need cluster these factors and choose representative indexes. Meanwhile for ensuring horizontal and longitudinal commensurability of the model, we use data of sixteen factors for Bei Jin, Shang Hai, Tian Jin, Jiang Su, Guang Dong, Si Chuan, He Nan and Ji Lin, during 2002 to 2006. The data source is China statistic yearbook. Here, the data are not listed, by the reason for its large magnitude. Because the data includes sixteen indexes of ten regions during five years, a clustering issue for panel data is formed. The existing grey cluster method can not deal with it. So, we realize the proposed method using matlab program.

First, compute the images of zeroing starting column for 16 behavior matrixes with the help of definition3.1. Then calculate the degree of grey incidences between every two indexes among 16 matrixes. Finally, we will obtain the incidences matrix for sixteen indexes which is listed in TABLE II.

Table II Extended Incidence Matrix of Indexes in Case Study

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
X_1	1	0.50	0.69	0.65	0.50	0.81	0.78	0.52	0.52	0.59	0.50	0.75	0.50	0.50	0.50	0.61
X_2	0.50	1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.56	0.50	0.68	0.64	0.51	0.50
X_3	0.69	0.50	1	0.88	0.50	0.81	0.84	0.54	0.51	0.74	0.50	0.60	0.50	0.50	0.50	0.78
X_4	0.65	0.50	0.88	1	0.50	0.73	0.76	0.56	0.51	0.82	0.50	0.57	0.50	0.50	0.50	0.88
X_5	0.50	0.50	0.50	0.50	1	0.50	0.50	0.50	0.56	0.50	0.50	0.50	0.50	0.50	0.50	0.50
X_6	0.81	0.50	0.81	0.73	0.50	1	0.95	0.53	0.51	0.65	0.50	0.65	0.50	0.50	0.50	0.68
X_7	0.78	0.50	0.84	0.76	0.50	0.95	1	0.53	0.51	0.66	0.50	0.64	0.50	0.50	0.50	0.69
X_8	0.52	0.50	0.54	0.56	0.50	0.53	0.53	1	0.50	0.59	0.51	0.51	0.50	0.50	0.54	0.58
X_9	0.52	0.50	0.51	0.51	0.56	0.51	0.51	0.50	1	0.50	0.50	0.53	0.50	0.50	0.50	0.50
X_{10}	0.59	0.50	0.74	0.82	0.50	0.65	0.66	0.59	0.50	1	0.50	0.55	0.50	0.50	0.51	0.93
X_{11}	0.50	0.56	0.50	0.50	0.50	0.50	0.50	0.51	0.50	0.50	1	0.50	0.68	0.73	0.57	0.50
X_{12}	0.75	0.50	0.60	0.57	0.50	0.65	0.64	0.51	0.53	0.55	0.50	1	0.50	0.50	0.50	0.56
X_{13}	0.50	0.68	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.68	0.50	1	0.90	0.53	0.50
X_{14}	0.50	0.64	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.73	0.50	0.90	1	0.50	0.50
X_{15}	0.50	0.51	0.50	0.50	0.50	0.50	0.50	0.54	0.50	0.51	0.57	0.50	0.53	0.50	1	0.51
X_{16}	0.61	0.50	0.78	0.88	0.50	0.68	0.69	0.58	0.50	0.93	0.50	0.56	0.50	0.50	0.51	1

Set the critical value r=0.8 , and classify the sixteen factors according to incidence matrix in TABLE II. The results are $\{X_1, X_3, X_4, X_6, X_7, X_{10}, X_{16}\}$, $\{X_{13}, X_{14}\}$, $\{X_2\}$, $\{X_5\}$, $\{X_8\}$, $\{X_9\}$, $\{X_{11}\}$, $\{X_{12}\}$, $\{X_{15}\}$.

The results show that urban people's income, expenditure, health care, transportation and community services in ten sample regions have been dynamic relationship with the GDP from 2002 to 2006; moreover, the developing trends of employment rate and population growth rate are very similar. Therefore, we can choose GDP (X_{10}) and employment rate (X_{13}) to represent the first and second classes for reducing variables. By virtue of panel data and extended grey cluster, the results can reflect the durative relationship between indexes at different time and space, and avoid clustering error caused by chance of data. So, the results possess the properties of space-time dynamics, high cohesion and low coupling.

6 Conclusion

It is the essence of grey clusters that determining the degree of incidences between objects according to their geometric similarity. Based on this chapter, we can draw conclusions as following.

The extended grey cluster method conforms to the essence of grey cluster analysis. It not only extends the scope of the grey clusters, but also enriches the clustering methods of panel data.

The extended grey clusters method is fit for the analysis of panel data, which overcome the shortcoming of classical methods; also it can describe the dynamic relationship between objects. The case study proves the new method possesses the properties of space-time dynamics, high cohesion and low coupling.

The method fully utilizes the information, and solves the problem of losing the data information in literature (Zhen, 2008). Because of convenient realization on computer, the method is very practical and has good applicable prospects in image process, automatic control, and other fields.

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Part III
Grey Cluster Evaluation Models

Study of an Improved Grey Integrated Clustering Method and Its Application

Fenyi Dong, Junjuan Liu, and Bin Liu

Literature on general grey clustering methods and their improved methods all give the clustering results based on the principle of the maximal element of a grey clustering coefficient vector. Such methods neglect the effect of other elements, except the maximal one of a grey clustering coefficient vector to the cluster result. Because the grey integrated clustering method comprehensively considers the effect of all elements of a grey clustering coefficient vector on the cluster result, it is an important development for grey clustering techniques. But the way that the value area of integrated clustering coefficients is divided into s equal intervals needs improving. This chapter puts forth an improved grey integrated clustering method, with which the value interval of a grey integrated clustering coefficient for a grey class was divided by k±0.5 as boundary points. It is proven that when the difference of clustering coefficients of ordinary grey clustering methods is more than 1-1/(s-1), there are the same clustering results for the improved grey integrated clustering and the ordinary grey clustering. At last, we illustrate the improved grey integrated clustering method with the evaluation of rural economic development in Henan Province.

1 Introduction

Grey system theory has obtained great development since its founding in 1982 (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). Grey clustering evaluation is a technique that was developed earliest and is widely used in grey system theory. It's also one of the grey techniques that is widely discussed. Commonly used grey clustering methods are the grey variable-weight clustering method, founded by Professor Deng (Deng, 1990); the grey fixed-weight clustering method, founded by Professor Liu (Liu, 1993); and the grey clustering based on the triangle whitenization function, founded by Professor Liu, Zhu (Liu et al., 1993). The process of grey clustering evaluation is given by the following definitions (Liu et al., 2004):

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Definition 1 (Liu et al., 2004)**.** Assume that there are *n* clustering objects, *m* clustering indexes, and *s* grey categories. x_{ij} are observations of clustering object *i(i=1,2, …,n)* about clustering index *j(j=1,2, …,n)* . $f_j^k(*)$ is the whitenization function of clustering index *j* about grey categroy *k.* η_j^k is the weight of clustering of index *j* about grey category *k,* which can be gotten from calculation or qualitative analysis. Getting the weight of the cluster through the critical value of the whitenization function belongs to the grey variable-weight clustering method. Getting the weight of clustering through qualitative analysis belongs to grey fixed-weight clustering. We call $\sigma_i^k = \sum_{j=1}^{m} f_j^k(x_{ij}) \cdot \eta_j^k$ the clustering coefficient of clustering object *i* belonging to grey category *k*.

Definition 2 (Liu et al., 2004)**.** Set $\max_{1 \le k \le s}\{\sigma_i^k\} = \sigma_i^{k^*}$. We set object *i* so that it belongs to grey cluster k^*.

Throughout the analysis process above, constructing grey whitenization weight functions and deciding the weight of every grey category are two key points. After the grey whitenization weight functions and the weights of clustering indexes are determined, we can get the clustering coefficients and the clustering result through the grey clustering evaluation software. We call the methods mentioned above ordinary grey clustering methods, which give the clustering results through a specific algorithm based on the maximization of the elements of the grey clustering coefficient vector.

The methods neglect the effect of other elements, except the maximal one of a grey clustering coefficient vector to the cluster result. For example, there is cluster object *i* with 4 grey categories. The coefficients vector of object *i* belonging to 4 categories is $\sigma_i = (\sigma_i^1, \sigma_i^2, \sigma_i^3, \sigma_i^4) = (0.355, 0, 0.2, 0.445)$. Keeping the fourth clustering coefficient 0.445 unchanged as the largest one, we can get six different sequences, three of which are: $(0, 0.2, 0.355, 0.445)$, $(0.355, 0.2, 0, 0.445)$, and $(0.2, 0.355, 0, 0.445)$

According to the results of ordinary grey clustering methods, *i* belongs to the fourth grey category. But the result of all four different clustering coefficients vectors of object *i* belonging to the fourth category is unbelievable intuitively. This leads to the third key point in grey clustering evaluation methods: the effect of the clustering coefficient vector on the cluster results and adjusting the clustering results.

2 Grey Integrated Clustering Method

The grey integrated clustering method was brought forward by (Dang et al., 2005) for dealing with the problem of no distinguishably different clustering coefficients.

Definition 3 (Dang et al., 2005). Set $\delta_i^k = \dfrac{\sigma_i^k}{\sum_{k=1}^{s}\sigma_i^k}$. We call δ_i^k the normalized clustering coefficient of clustering object *i* belonging to grey classification *k*; call $\delta_i = \left(\delta_i^1, \delta_i^2, \cdots, \delta_i^s\right)$, *(i=1,2,...,n)* the normalized clustering coefficient vector of object *i*.

Definition 4 (Dang et al., 2005). Assume there are *n* clustering objects and *m* grey categories. $\delta_i = \left(\delta_i^1, \delta_i^2, \cdots, \delta_i^s\right)$, *(i=1,2,...,n)* is the normalized clustering coefficient vector of object *i*. $\eta = (1,2,\cdots,s-1,s)^T$, and we call $\omega_i = \delta_i \cdot \eta = \sum_{k=1}^{s} k \cdot \delta_i^k$ the integrated clustering coefficient of object *i*. $\eta = (1,2,\cdots,s-1,s)^T$ is the weight vector of the integrated clustering coefficient.

They have proven that the value range of the integrated clustering coefficient of object *i* is $1 \le \omega_i \le s$ and divided the value range into *s* uncrossed ranges with the same length as $[1, 1+(s-1)/s]$, $[1+(s-1)/s, 1+2(s-1)/s]$, ..., $[s-(s-1)/s, s]$.

Definition 5 (Dang et al., 2005). When the integrated clustering coefficient of object *i* $\omega_i \in [1+(k-1)(s-1)/s, 1+k(s-1)/s]$, we say that object *i* belongs to *k* grey category.

Definition 6 (Dang et al., 2005). Assume the clustering coefficient vector is $\delta_i = \left(\delta_i^1, \delta_i^2, \cdots, \delta_i^s\right)$, *(i=1,2,...,n)*. We range the elements in clustering coefficient vector from largest to smallest, and the new sequence is $\delta_i^{(1)}, \delta_i^{(2)}, \cdots, \delta_i^{(s)}$, $\delta_i^{(1)} \ge \delta_i^{(2)} \ge \cdots \ge \delta_i^{(s)}$. Then the ordering clustering coefficient vector of object *i* is $\delta_i^{'} = (\delta_i^{(1)}, \delta_i^{(2)}, \cdots, \delta_i^{(s)})$.

Definition 7 (Dang et al., 2005). Assume the clustering coefficient vector is $\delta_i = \left(\delta_i^1, \delta_i^2, \cdots, \delta_i^s\right)$, and $\delta_i^{'} = (\delta_i^{(1)}, \delta_i^{(2)}, \cdots, \delta_i^{(s)})$ is its ordering clustering coefficient vector. If named $\theta_i = \delta_i^{(1)} - \delta_i^{(2)}$, we call θ_i the distinguished difference coefficient of object *i*. If $\theta_i = \delta_i^{(1)} - \delta_i^{(2)} \le 1 - \dfrac{2}{s}$, there is no distinguishable difference on clustering coefficient of *i*, otherwise there is a distinguished difference for the clustering coefficient of *i*.

They have also proved that if $\theta_i \geq 1 - \frac{2}{s}$, the grey integrated clustering method and ordinary grey clustering method have the same clustering results.

They determined the distinguished difference using the difference between the two largest elements in the coefficient vector, $\theta_i = \delta_i^{(1)} - \delta_i^{(2)}$. The grey integrated clustering method based on this can resolve grey clustering problems with no distinguished difference of clustering coefficients. Situations with no distinguished difference of clustering coefficients exist widely in ordinary clustering coefficient sequences. The grey integrated clustering method is a great advancement for the grey clustering analysis method, which has important theoretical and application value.

3 Improved Grey Integrated Clustering Method

Obviously, the value range of the integrated clustering coefficient of each object *i* is $1 \leq \omega_i \leq s$. But dividing the value range into s uncrossed ranges with the same length, each range having the same length as $(s-1)/s$ and defining the clustering object *i* as belonging to the grey category *i* if its integrated clustering coefficient $\omega_i \in [1+(k-1)(s-1)/s, 1+k(s-1)/s]$ is not so perfect and needing improvement.

For example, to normalize clustering coefficient vector $\delta_i = (\delta_i^1, \delta_i^2, \cdots, \delta_i^s) = (0, \cdots, 0, \delta_i^k, \delta_i^{k+1}, 0, \cdots, 0)$, $\delta_i^k + \delta_i^{k+1} = 1$. We can make a hypothesis that $\delta_i^k = 0.5 + \varepsilon$, $\delta_i^{k+1} = 0.5 - \varepsilon$. Then we can get $\delta_i = (0, \cdots, 0.5 + \varepsilon, 0.5 - \varepsilon, 0, \cdots, 0)$. The integrated clustering coefficient is $\omega_i = k(0.5+\varepsilon) + (k+1)(0.5-\varepsilon) = k + 0.5 - \varepsilon$. If $\varepsilon > 0$, object *i* belongs to grey category *k*, and $\omega_i < k + 0.5$. If $\varepsilon < 0$, object *i* belongs to grey category *k+1*, and $\omega_i > k + 0.5$. If $\varepsilon = 0$, $\omega_i = k + 0.5$, and object *i* is at the critical value between grey category *k* and *k+1*, the critical point of the grey integrated clustering coefficient belonging to grey categories *i* and *i+1* should be *k*+0.5, but not $1 + k(s-1)/s$. The analysis method selecting *k*+0.5 as a boundary point is more consistent with people's knowledge in practice.

Because of the information mentioned above, we divide the value range of grey clustering coefficient ω_i into s ranges as $[1.1.5]$, $[1.5, 2.5]$,..., $[k-0.5, k+0.5]$,..., $[s-0.5, s]$. Make orders: if $\omega_i \in [1, 1.5]$, we classify object *I* as the first grey category; if $\omega_i \in [k-0.5, k+0.5]$, $(k \neq 1, k \neq s)$, we classify object *i* as grey category *k*;

if $\omega_i \in [s-0.5, s]$, we classify object i as grey category s. We call this analysis method the improved grey integrated clustering method.

Theorem. To improve the grey integrated clustering method, if the distinguished difference of the clustering coefficient $\theta \geq 1-\frac{1}{s-1}$, there are the same results for ordinary grey clustering methods and the improved grey integrated clustering method.

Proof: Appendix.

The inverse proposition of this theorem is untenable. When we get the same clustering results from the general grey clustering method and the improved grey integrated clustering method, the condition that the prominent difference coefficient is bigger than $1-\frac{1}{s-1}$ was not necessarily met.

4 Instance Analysis

We evaluated the development level of the rural economy in eighteen cities of Henan province, based on data from the second national census of agriculture (2007) and the Statistical Yearbook of Henan (2007). Eight indexes classified into four types were adopted. They are (1) The proportion of the population not engaging in the primary industry among the working people in countryside; (2) Per capita output value of people engaging in primary industry; (3) Per capita net income of peasants; (4) Per capita expenditure of cost of living in the country; (5) Consumer durables ownership of every 100 families; (6) Proportion of villages having cultural and educational facilities; (7) Proportion of villages having medical facilities and medical staff; (8) Per capita saving.

We divide the development level of the rural economy in the eighteen cities of Henan province into four categories. They are the highly developed region, the medium developed region, the low developed region, and the least developed region. Then, we divide the difference between the maximal value and the minimal value of each index $\Delta_j = \max_i X_j^i - \min_i X_j^i$ into ten parts with the same length. We select

$$f_j^1[\min_i X_j^i + \frac{3}{5}\Delta_j, \min_i X_j^i + \frac{4}{5}\Delta_j), —, —];$$

$$f_j^2[\min_i X_j^i + \frac{2}{5}\Delta_j, \min_i X_j^i + \frac{1}{2}\Delta_j, —, \min_i X_j^i + \frac{4}{5}\Delta_j];$$

$$f_j^3[\min_i X_j^i + \frac{1}{5}\Delta_j, \min_i X_j^i + \frac{3}{10}\Delta_j, —, \min_i X_j^i + \frac{1}{2}\Delta_j];$$

$$f_j^4[—, —, \min_i X_j^i + \frac{1}{10}\Delta_j, \min_i X_j^i + \frac{3}{10}\Delta_j]$$

Table I Comparison of the Results of ordinary grey clustering and grey integrated clustering for the development level of the rural economy in Henan

Region	Ordinary grey clustering δ_i^k					Grey integrated clustering				
	1	2	3	4	Cluster result	ω_i	Clustering result	θ_i	Test of Distinguished	Consistency of results
Zhengzhou	0.860	0.075	0.0645	0	1	1.204	1	0.785	Distinguished	Yes
Kaifeng	0.355	0	0.201	0.444	4	2.735	3	0.090	Nondistinguished	No
Luoyang	0.143	0.432	0.324	0.101	2	2.384	2	0.108	Nondistinguished	Yes
Pingdingshan	0	0	0.480	0.520	4	3.520	4	0.040	Nondistinguished	Yes
Anyang	0.306	0.153	0.031	0.510	4	2.745	3	0.204	Nondistinguished	No
Hebi	0.227	0.431	0.268	0.074	2	2.189	2	0.163	Nondistinguished	Yes
Xinxiang	0.174	0.262	0.495	0.069	3	2.458	2	0.232	Nondistinguished	No
Jiaozuo	0.247	0.488	0.222	0.043	2	2.060	2	0.241	Nondistinguished	Yes
Puyang	0	0.035	0.247	0.718	4	3.683	4	0.471	Nondistinguished	Yes
Xuchang	0.019	0.613	0.312	0.056	2	2.406	2	0.300	Nondistinguished	Yes
Luohe	0	0.230	0.312	0.458	4	3.228	3	0.146	Nondistinguished	No
Sanmenxia	0.099	0.441	0.247	0.214	2	2.576	3	0.194	Nondistinguished	No
Nanyang	0.193	0.157	0.383	0.267	3	2.724	3	0.116	Nondistinguished	Yes
Shangqiu	0	0.049	0.047	0.904	4	3.855	4	0.855	Distinguished	Yes
Xinyang	0.3	0.1	0.1	0.5	4	2.800	3	0.200	Nondistinguished	No
Zhoukou	0	0.058	0.213	0.728	4	3.670	4	0.515	Distinguished	Yes
Zhumadian	0	0	0.335	0.665	4	3.665	4	0.330	Nondistinguished	Yes
Jiyuan	0.576	0.289	0.017	0.118	1	1.677	1	0.287	Nondistinguished	Yes

as whitenization weight functions of each index for the four categories. i denotes eighteen objects. Weights of the eight indexes are, respectively: 0.1, 0.1, 0.1, 0.15, 0.15, 0.1, 0.1, 0.2. We get the clustering coefficients and clustering results shown in Table 1.

Based on ordinary grey clustering, we make some adjustments. The four value ranges of integrated clustering coefficient ω_i are: [1.1, 7.5], [1.75, 2.5], [2.5 3.25], [3.25 4]. The condition for the distinguished difference of the normalized clustering coefficient is $\theta_i \geq 1-\frac{2}{s}$; that's to say $\theta_i \geq \frac{1}{3}$, which was shown in Table I.

From Table 1, we know that Kaifeng was classified as a low developed region from least developed region after grey synthetic clustering. This is in accordance with people's intuitive judgments of the clustering coefficient vector based on the general grey clustering method. In Table 1, only three objects have a prominent difference of the clustering coefficient, accounting for one-sixth of all objects. For the clustering coefficient, there are no prominent differences for the other fifteen objects. Among the fifteen objects, the clustering results of six objects changed, accounting for 40%. This shows the phenomenon that clustering results are different is universal if there is no prominent difference for the clustering coefficient. This fully explains the necessity of grey synthetic clustering based on the general grey clustering coefficient, when grey clustering analysis is adopted with more grey clusters.

We make some adjustments based on the improved grey integrated clustering method. The four value ranges of grey clusters of the improved grey integrated clustering coefficient are: [1, 1.5], [1.5, 2.5], [2.5 3.5], [3.5, 4]. The condition for the normalized clustering coefficient having a distinguished difference is $\theta_i \geq 1-\frac{1}{s-1}$; that's to say $\theta_i \geq \frac{2}{3}$. The results are shown in Table II.

Table II Comparison of the Results of ordinary grey clustering and improved grey integrated clustering for the development level of the rural economy in Henan

Region	Ordinary grey clustering δ_i^k					Improved grey integrated clustering				
	1	2	3	4	Clustering result	ω_i	Clustering result	θ_i	Test of distinguished	Consistency of results
Zhengzhou	0.860	0.075	0.0645	0	1	1.204	1	0.785	notable	consistent
Kaifeng	0.355	0	0.201	0.444	4	2.735	3	0.090	unobtrusive	not consistent
Luoyang	0.143	0.432	0.324	0.101	2	2.384	2	0.108	unobtrusive	consistent
Pingdingshan	0	0	0.480	0.520	4	3.520	4	0.040	unobtrusive	consistent
Anyang	0.306	0.153	0.031	0.510	4	2.745	3	0.204	unobtrusive	not consistent
Hebi	0.227	0.431	0.268	0.074	2	2.189	2	0.163	unobtrusive	consistent
Xinxiang	0.174	0.262	0.495	0.069	3	2.458	2	0.232	unobtrusive	not consistent
Jiaozuo	0.247	0.488	0.222	0.043	2	2.060	2	0.241	unobtrusive	consistent
Puyang	0	0.035	0.247	0.718	4	3.683	4	0.471	unobtrusive	consistent
Xuchang	0.019	0.613	0.312	0.056	2	2.406	2	0.300	unobtrusive	consistent
Luohe	0	0.230	0.312	0.458	4	3.228	3	0.146	unobtrusive	not consistent
Sanmenxia	0.099	0.441	0.247	0.214	2	2.576	3	0.194	unobtrusive	not consistent
Nanyang	0.193	0.157	0.383	0.267	3	2.724	3	0.116	unobtrusive	consistent
Shangqiu	0	0.049	0.047	0.904	4	3.855	4	0.855	notable	consistent
Xinyang	0.3	0.1	0.1	0.5	4	2.800	3	0.200	unobtrusive	not consistent
Zhoukou	0	0.058	0.213	0.728	4	3.670	4	0.515	unobtrusive	consistent
Zhumadian	0	0	0.335	0.665	4	3.665	4	0.330	unobtrusive	consistent
Jiyuan	0.576	0.289	0.017	0.118	1	1.677	2	0.287	unobtrusive	not consistent

From Table 2, we know Jiyuan was classified as a medium developed region from a highly developed region after the improved grey integrated clustering. At the same time, the distinguished difference for the clustering coefficient of Zhoukou become a non-distinguished difference.

5 Conclusion

The literature on ordinary grey clustering methods and their improved methods all give the clustering results based on the maximization of the elements of a grey clustering coefficient vector. Such methods neglect the effect of other elements, except the maximal one of a grey clustering coefficient vector on the cluster result. Because the grey integrated clustering method comprehensively considers the effect of all elements of a grey clustering coefficient vector on the clustering result, it is an important development for grey clustering techniques. This method has important theoretical and applicable value. For the problem of dividing value ranges of a grey integrated clustering coefficient belonging to a corresponding grey category, the value range of the integrated clustering coefficient $[1, s]$ was divided into s uncrossed ranges with same length $(s-1)/s$, and object i was classified as grey category k if $\omega_i \in [1+(k-1)(s-1)/s, 1+k(s-1)/s]$. This method is not perfect, because grey integrated clustering with $\delta_i = (0,\cdots,0,\delta_i^k,\delta_i^{k+1},0,\cdots,0)$ can't be resolved using this method. This method needs improving. The method put forth in this chapter divides grey integrated clustering coefficient by $k \pm 0.5$ as the critical point. The above problem can be resolved to some extent by this method. This chapter also proved that, when the distinguished difference of ordinary grey clustering coefficient $\theta \geq 1 - \dfrac{1}{s-1}$, the improved grey integrated clustering method and ordinary grey clustering methods have the same clustering results for a clustering object. At last, we look at a case analysis of the development level of the rural economy in Henan province in China. The improved grey integrated clustering method was feasible.

Appendix

Proof: There are three situations.

1) When δ_i^1 is the maximal one, object *i* belongs to the first grey category based on ordinary grey clustering methods. If we want get the same results for the improved grey integrated clustering method, $\omega_i \in [1, 1.5]$ must be satisfied. $\omega_i \geq 1$ is inevitable, so we can get the same results if only $\omega_i \leq 1.5$. Because $\omega_i = \sum_{k=1}^{s} k \cdot \delta_i^k$, ω_i will be maximal only when $\delta_i = (\delta_i^1, 0, \cdots, 0, \delta_i^s)$,

$\delta_i^1 - \delta_i^s$ has the minimal value here. Thus, $\begin{cases} \delta_i^1 - \delta_i^s \geq \theta_1 \\ \delta_i^1 + \delta_i^s = 1 \end{cases}$, from which we can get $\begin{cases} \delta_i^1 \geq (1+\theta_1)/2 \\ \delta_i^s = 1 - \delta_i^1 \end{cases}$.

So,

$$\omega_i = \delta_i^1 + s \cdot \delta_i^s = s - (s-1)\delta_i^1 \leq s - (s-1)\frac{1+\theta_1}{2}.$$

If $s-(s-1)\frac{1+\theta_1}{2} \leq 1.5$, we can get $\theta_1 \geq 1 - \frac{1}{s-1}$. The results show that object *i* belongs to the first category based on the ordinary grey clustering method, and in order to make the result of the improved grey integrated clustering method belong to the first category, the distinguished difference coefficient must satisfy the requirement as $\theta_1 \geq 1 - \frac{1}{s-1}$.

2) When δ_i^s is the maximal one, object *i* belongs to category *s* based on ordinary grey clustering methods. If we want to get the same results for the improved grey integrated clustering method, $\omega_i \in [s-0.5, s]$ must be satisfied. $\omega_i \leq s$ is inevitable, so we can get the same results if only $\omega_i \geq s - 0.5$. Because $\omega_i = \sum_{k=1}^{s} k \cdot \delta_i^k$, ω_i will be the minimal one only when $\delta_i = (\delta_i^1, 0, \cdots, 0, \delta_i^s)$ and $\delta_i^1 - \delta_i^s$ has the minimal value. Thus, $\begin{cases} \delta_i^s - \delta_i^1 \geq \theta_2 \\ \delta_i^1 + \delta_i^s = 1 \end{cases}$, from which we can get $\begin{cases} \delta_i^s \geq (1+\theta_2)/2 \\ \delta_i^1 = 1 - \delta_i^s \end{cases}$.

So

$$\omega_i = \delta_i^1 + s \cdot \delta_i^s = 1 + (s-1)\delta_i^s \geq 1 + (s-1)\frac{1+\theta_2}{2}.$$

If $1+(s-1)\frac{1+\theta_2}{2} \geq s - 0.5$, we can get $\theta_2 \geq 1 - \frac{1}{s-1}$. The results show that object *i* belongs to category s based on ordinary grey clustering methods, and in order to make the result of the improved grey integrated clustering method also belong to category s, the distinguished difference coefficient must satisfy the requirement as $\theta_2 \geq 1 - \frac{1}{s-1}$.

3) When δ_i^k $(k \neq 1, k \neq s)$ is the maximal one, object *i* belongs to category *k* based on the ordinary grey clustering method. If we want to get the same results for the improved grey integrated clustering method, $\omega_i \in [k-0.5, k+0.5]$ must be satisfied.

We first derive the prerequisite of the distinguished difference coefficient when $\omega_i \geq k-0.5$. Because $\omega_i = \sum_{k=1}^{s} k \cdot \delta_i^k$, ω_i will be minimal only when $\delta_i = (\delta_i^1, 0, \cdots, 0, \delta_i^k, 0, \cdots, 0)$, and $\delta_i^k - \delta_i^1$ has the minimal value. Thus, $\begin{cases} \delta_i^k - \delta_i^1 \geq \theta_3 \\ \delta_i^1 + \delta_i^k = 1 \end{cases}$, from which we can get $\begin{cases} \delta_i^k \geq (1+\theta_3)/2 \\ \delta_i^1 = 1 - \delta_i^k \end{cases}$.

So,

$$\omega_i = \delta_i^1 + k \cdot \delta_i^k = 1 + (k-1)\delta_i^k \geq 1 + (k-1)\frac{1+\theta_3}{2}.$$

If $1+(k-1)\frac{1+\theta_3}{2} \geq k-0.5$, we can get $\theta_3 \geq 1 - \frac{1}{k-1}$.

Second, we deduce the prerequisite of the distinguished difference coefficient when $\omega_i \leq k+0.5$. Only when $\delta_i = (0, \cdots, 0, \delta_i^k, 0, \cdots, 0, \delta_i^s)$ and $\delta_i^k - \delta_i^s$ has the minimal value, ω_i will have the maximal value. Thus, $\begin{cases} \delta_i^k - \delta_i^s \geq \theta_4 \\ \delta_i^k + \delta_i^s = 1 \end{cases}$, from which we can get $\begin{cases} \delta_i^k \geq (1+\theta_4)/2 \\ \delta_i^s = 1 - \delta_i^k \end{cases}$.

So,

$$\omega_i = k \cdot \delta_i^k + s \cdot \delta_i^s = s - (s-k)\delta_i^k$$
$$\leq s - (s-k)\frac{1+\theta_4}{2}.$$

If $s-(s-k)\frac{1+\theta_4}{2} \leq k+0.5$, we can get $\theta_4 \geq 1 - \frac{1}{s-k}$.

So, the distinguished difference coefficient θ that satisfied $k-0.5 \leq \omega_i \leq k+0.5$ must meet the conditions $\theta_3 \geq 1 - \frac{1}{k-1}$ and $\theta_4 \geq 1 - \frac{1}{s-k}$. Because $k < s$, $1 - \frac{1}{s-1} > 1 - \frac{1}{k-1}$. The condition that $\theta_3 \geq 1-\frac{1}{s-1}$ certainly satisfies the condition $\theta_3 \geq 1-\frac{1}{k-1}$. Because $s-1 > s-k$ from $k > 1$, $1-\frac{1}{s-1} > 1-\frac{1}{s-k}$. So, the condition $\theta_4 \geq 1-\frac{1}{s-1}$ must meet the condition $\theta_4 \geq 1-\frac{1}{s-k}$. That's to say, object *i* belongs to category *k* based on the ordinary grey clustering method. In order to make the results of the improved grey integrated clustering method belong to category *k*, the conditions $\theta_3 \geq 1-\frac{1}{k-1}$ and $\theta_4 \geq 1-\frac{1}{s-k}$ must be synchronously met. Obviously, $\theta \geq 1-\frac{1}{s-1}$ can synchronously satisfy $\theta_3 \geq 1-\frac{1}{k-1}$ and $\theta_4 \geq 1-\frac{1}{s-k}$.

Taking these three situations into account, we can conclude that the ordinary grey clustering method and the improved grey integrated clustering method will get the same clustering results when the distinguished difference coefficient $\theta \geq 1-\frac{1}{s-1}$.

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Study of the Influencing Factors of the Development of Chinese Medicine with Gray Clustering Analysis

Lizhong Duan, Ying Zhang, and Xingxing Fan

Due to the development of Chinese medicine, the grey clustering analytical method of influencing factors of the development of Chinese medicine was studied. The factors were put forth. The investigation results of the factors were simulated. The investigation results of the factor was quantified, analyzed, and ranked from strongest to weakest with the grey clustering analytical method. Some of the correlative departments in the government could be assisted with the research results.

1 The Problem with the Theory and Diagnosis and Treatment of Chinese Medicine Occurring

Whether Chinese medicine could exit or not is a problem of sensitivity nowadays. Management, hospitals, experts and the public are very interested in the subject. The problem is very important to everyone. Since Western scientific results (including Western medicine) came to China, people have argued four times whether or not to abolish Chinese medicine.

The first case was when "Chinese medicine was omitted by the education system" by the Beiyang government in the 20^{th} century. The second case "abolished Chinese medicine" in 1929. The third case was when it was thought that Chinese medicine was a superstition, forbidding Chinese medicine during the culture revolution. The last case was when Zhang Gong-yao (a professor in the technology and social development department in Zhongnan University) advocated that the commonalty underwrote on the web if they agreed to abolish Chinese medicine. It was said that there were a great number of people who underwrote on the web. The

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people agreed to abolish Chinese medicine. The contention is mainly about whether Chinese medicine is a science, whether it is a system of the relation between cause and effect, and whether it has a therapeutic effect (Bai et al., 2000; Wang, 1999).

Chinese medicine has experienced four challenges, and there will be more if Chinese medicine development lasts behind modernized science and technique development. Chinese medicine will be abolished if it does not go with modernized science and technique development.

Science is seen as the best value standard. If using this standard for comprehension and appraisal, Chinese medicine is not scientific and should therefore be abolished and reconstructed. Nowadays, life sciences develop very fast and the level that people know themselves has been raised quickly, but the development of Chinese medicine is very slow. Chinese medicine must combine with science if it wants to survive. The therapeutic effect of Chinese medicine could improve if taken with new science and techniques (Feng et al., 2003; Guo, 2006; Yan, 2006; Qin, 2007).

This paper will study the development of science and techniques and how the theory, diagnosis and treatment of Chinese medicine was influenced. The some influence factors of Chinese medicine development are put forth. The grey clustering analytical method will be used to analyze these factors. The research results can help the government make plans to improve the development of Chinese medicine.

2 Grey Clustering of the Influence Factors of the Theory, Diagnosis and Therapy of Chinese Medicine

2.1 Grey Clustering Analysis

Grey clustering analysis is a method that, based on the degree of association, decides with the relational modulus.

2.1.1 The Grey Incidence Model and Incidence Degree Compution

2.1.1.1 Dealt with the Datum to Initial Value

In the system, if the evaluated object is

$$\mathbf{S}_i = s_{ij} \ (i = 1,2,\cdots,m\,;\ j = 1,2,\cdots,n)\,,$$

the characteristic index sequence is $\mathbf{T}_i = t_{ij}$.

Based on the attributes of a given character index, the original data is non-dimensionalized and compress all analysis data within [0,1].

The index attribute that is smaller and better is

$$x_{ij} = \min t_{ij} / t_{ij} \tag{1}$$

The index attribute that is bigger and better is

$$x_{ij} = t_{ij} / \max t_{ij} \tag{2}$$

Analyze the practice question. List $\mathbf{T}_0$ is decided to be the greatest one in the same list t_{ij} in list $\mathbf{T}_j$, t_{i0} is in every line of list $\mathbf{T}_0$. Divide every number, which is in the same line of t_{ij} in list $\mathbf{T}_i$, so we can consult list $\mathbf{X}_0 = (x_{i0})$ and the comparative list $\mathbf{X}_i = (x_{ij}), (i = 1,2,\cdots,m\,;\ j = 1,2,\cdots,n)$.

2.1.1.2 Difference List and Least and Greatest Difference

If in k, $\mathbf{X}_0$ is $x_0(k)$; $\mathbf{X}_1$ is $x_i(k)$, and the result is

$$\Delta_i(k) = \left| x_0(k) - x_i(k) \right| \tag{3}$$

If a is the least difference and b is the greatest, the expression of a and b is

$$\min_i \ \min_k \Delta_i(k) = a$$

$$\max_i \ \max_k \Delta_i(k) = b$$

2.1.1.3 Relating Modulus and Relating Degree

$$\xi_i(k) = \frac{a + \delta b}{\Delta_i(k) + \delta b} \tag{4}$$

$\xi_i(k)$ is the relating modulus $\mathbf{X}_i$ to $\mathbf{X}_0$ at k and δ is the differentiate modulus. It is between 0 - 1, usually 0.5.

The average of the relation modulus is

$$r_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \tag{5}$$

r_i is the relating degree of $\mathbf{X}_i$ to $\mathbf{X}_0$ (Deng, 2002; 2005; Liu et al., 1991; Jin, 1993; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006).

2.1.2 The Computation of Clustering Analysis

If $\mathbf{S}$ is all the evaluated objects, the expression of $\mathbf{S}$ is $\mathbf{S} = S_i(i = 1,2,\cdots,m)$

For a certain element in $\mathbf{S}$, its comparative list is $\mathbf{X}_i = (x_{ij})$.

For the question, consult list $\mathbf{X}_0$ and then get the relating collection $\mathbf{R}$ from formula (4) and (5). The expression of $\mathbf{R}$ is $\mathbf{R} = (r_i)$; $(i = 1,2,\cdots,m)$

S_i is ordered by the magnitude of $\mathbf{R}$ in descent order.

ξ_{ij} of the relating modulus is from formula (4). The matrix $\boldsymbol{\xi} = (\xi_{ij})_{n\times m}$ is computed. If classes are defined by the values of n, then the d_{ij} distance was computed with border upon class. The expression of d_{ij} is

$$d_{ij} = \left[\sum(\xi_{ik} - \xi_{jk})^2\right]^{\frac{1}{2}} \tag{6}$$

Ordering $\mathbf{S}_i$ by descent, the d_{ij} distance of the border upon class was computed with formula (4) in the $\mathbf{S}_i$ list. Then, cluster the nearest ones as a kind from d_{ij}, find out the distance between the new kinds, and repeat until all classes combine as one kind (Deng, 2002; 2005; Liu et al., 1991; Jin, 1993; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006).

3 Establish the System of Factors Influencing the Development of the Theory, Diagnosis and Treatment of Chinese Medicine

The factors influencing the development of the theory, diagnosis, and treatment of Chinese medicine was classified into 28 kinds in 9 classes, with reference to datum and some experts. There are 5 kinds in the theory and study method of Chinese medicine, 5 kinds in the diagnosis and treatment of Chinese medicine, 2 kinds in the impact of west medicine, 4 kinds in the social impression, 2 kinds in the government, 2 kinds in the view from abroad, 4 kinds in the hospital of Chinese medicine, 2 kinds in the ideas and actions of doctors, and 2 kinds in the school of Chinese medicines. The results were listed in Tab.1.

We divided the factors that infect the development of the theory, diagnosis, and treatment of Chinese medicine into 5 grades, as the circs happened when large-scale investigative questionnaire. 5 is very strong, 4 is strong, 3 is normal, 2 is weak, and 1 is very weak.

Character parameters were investigated as a crowd, and we divided them into 8 kinds: male and female, town and country, sanitation operators and other workers, above junior college and below junior college. The results were listed in Tab.2.

The investigate results of the 8 kinds of people were simulated. The simulation results were computed with a computer.

Table 1 The factors influencing the development of the theory, diagnosis, and treatment of Chinese medicine

The 9 classes of factors	The 28 kinds of factors and name
the theory and study method of Chinese medicine	S_1 : logic of Chinese medicine
	S_2 : science of Chinese medicine
	S_3 : study method of Chinese medicine
	S_4 : professors of Chinese medicine
	S_5 : standardization of the language of Chinese medicine
the diagnosis and treat of Chinese medicine	S_6 : the path and method of the traditional Chinese drug
	S_7 : cure effective of Chinese medicine
	S_8 : enter the new technology
	S_9 : the tool for diagnosis and treatment of Chinese medicine
	S_{10} : the mode for diagnosis and treatment of Chinese medicine
the impact from west medicinal	S_{11} : the impact from west medicinal
	S_{12} : Chinese medicine and west medicinal combination
the social impressive	S_{13} : the trust from the country
	S_{14} : the change of the ill chart
	S_{15} : enter WTO
	S_{16} : the need from society
the government	S_{17} : mangers and organizers in sanitation department
	S_{18} : the law of the impact from west medicinal
the view from abroad	S_{19} : the view from abroad

Table 1 (*continued*)

	S_{20} : the overseas development of Chinese medicine
the hospital of Chinese medicine	S_{21} : the profit of the hospital of Chinese medicine
	S_{22} : the skill of the hospital of Chinese medicine
	S_{23} : the resource collocate of the hospital of Chinese medicine
	S_{24} : the intension build of Chinese medicine
the ideas and actions from the doctors	S_{25} : country doctors
	S_{26} : Chinese medicines
the school of Chinese medicines	S_{27} : education model of Chinese medicine
	S_{28} : the profit of the hospital of Chinese medicine

Table 2 The character parameter of the factors influencing the development of the theory, diagnosis, and treatment of Chinese medicine

character parameter	
t_1	male
t_2	female
t_3	Town denizen
t_4	Non town denizen
t_5	sanitation workers
t_6	Non sanitation workers
t_7	Above junior college
t_8	Bellow junior college

Table 3 The gray relating modulus and relating degree of the factors influencing the development of the theory, diagnosis, and treatment of Chinese medicine and sequencing (simulating the results)

	logic S_1	science S_2	study method S_3	professor S_4	standardization of the language S_5	the path and method of the traditional Chinese drug S_6	cure effective S_7	enter the new technology S_8	the tool for diagnosis and treatment S_9	the mode for diagnosis and treatment S_{10}	the impact from west medicinal S_{11}	Chinese medicine and west medicinal combination S_{12}	the trust from the country S_{13}	the change of the ill chart S_{14}
male $r_{i_1 j}$	0.446809	0.446809	0.446809	0.446809	0.446809	0.538462	0.677419	0.381818	0.446809	0.381818	0.333333	0.446809	0.333333	0.538462
according to $r_{i_1 j}$ array	3	4	3	4	4	1	1	2	2	6	6	4	5	3
female $r_{i_2 j}$	0.512195	0.512195	0.411765	0.512195	0.344262	0.411765	0.411765	0.677419	0.411765	0.677419	1.000000	0.512195	0.677419	1.000000
according to $r_{i_2 j}$ array	2	3	4	3	6	2	4	1	3	1	1	3	2	1
Town denizen $r_{i_3 j}$	0.512195	0.512195	0.677419	0.512195	0.512195	0.344262	0.677419	0.677419	0.411765	0.512195	0.344262	0.677419	1.000000	0.512195
according to $r_{i_3 j}$ array	2	3	1	3	3	4	1	1	3	3	5	1	1	4
Non town denizen $r_{i_4 j}$	0.381818	0.446809	0.446809	0.381818	0.538462	0.333333	0.381818	0.333333	0.333333	0.446809	0.677419	0.381818	0.677419	0.538462
according to $r_{i_4 j}$ array	4	4	3	5	2	5	5	4	4	4	2	5	2	3
sanitation workers $r_{i_5 j}$	0.446809	0.446809	0.446809	0.446809	0.381818	0.333333	0.381818	0.677419	0.677419	0.333333	0.677419	0.538462	0.381818	0.446809
according to $r_{i_5 j}$ array	3	4	3	4	5	5	5	1	1	7	2	2	4	5
Non sanitation workers $r_{i_6 j}$	0.344262	0.677419	0.677419	1.000000	0.677419	0.411765	0.512195	0.344262	0.677419	0.411765	0.677419	0.677419	1.000000	0.677419

Table 3 (*continued*)

according to $r_{i_6 j}$ array	5	1	1	1	1	2	3	3	1	5	2	1	1	2
Above junior college $r_{i_7 j}$	0.677419	0.538462	0.538462	0.538462	0.677419	0.381818	0.538462	0.333333	0.677419	0.538462	0.538462	0.333333	0.446809	0.446809
according to $r_{i_7 j}$ array	1	2	2	2	1	3	2	4	1	2	3	6	3	5
Bellow junior college $r_{i_8 j}$	0.381818	0.538462	0.538462	0.446809	0.538462	0.381818	0.677419	0.333333	0.677419	0.538462	0.446809	0.538462	0.381818	0.677419
according to $r_{i_8 j}$ array	4	2	2	4	2	3	1	4	1	2	4	2	4	2
the factors that influenced the development of Chinese medicine **R**	0.462916	0.514895	0.522994	0.535637	0.514606	0.392070	0.532289	0.469792	0.539169	0.480033	0.586890	0.513240	0.612327	0.604697
according to **R** array	24	13	12	8	15	28	9	21	6	19	3	16	1	2

Table 3 (Simulating the results)

	enter WTO S_{15}	the need from society S_{16}	mangers and organizers in sanitation department S_{17}	the law of the impact from west medicinal S_{18}	the view from abroad S_{19}	the overseas development S_{20}	the profit of the hospital S_{21}	the skill of the hospital S_{22}	the resource collocate of the hospital S_{23}	the intension build of the hospital S_{24}	country doctors S_{25}	Chinese medicines S_{26}	education model of Chinese medicine S_{27}	the viewpoint from the student S_{28}
male $r_{i_1 j}$	0.538462	0.446809	0.538462	0.446809	0.446809	0.381818	0.677419	0.446809	0.446809	0.446809	0.446809	0.381818	0.381818	0.446809
according to $r_{i_1 j}$ array	3	5	2	3	3	4	1	3	4	4	3	5	5	4
female $r_{i_2 j}$	0.344262	0.512195	0.512195	0.512195	0.677419	0.512195	0.344262	0.411765	0.677419	1.000000	0.411765	0.512195	0.411765	0.512195
according to $r_{i_2 j}$ array	6	4	3	2	1	2	6	4	2	1	4	3	4	3
Town denizen $r_{i_3 j}$	0.677419	1.000000	0.677419	0.411765	0.411765	1.000000	0.411765	0.411765	1.000000	0.411765	0.677419	0.512195	0.512195	1.000000
according to $r_{i_3 j}$ array	2	1	1	4	4	1	5	4	1	5	1	3	3	1
Non town denizen $r_{i_4 j}$	0.381818	0.446809	0.381818	0.333333	0.446809	0.446809	0.677419	0.381818	0.381818	0.538462	0.446809	0.381818	0.381818	0.446809
according to $r_{i_4 j}$ array	5	5	6	5	3	3	1	5	6	3	3	5	5	4
sanitation workers $r_{i_5 j}$	0.446809	0.538462	0.333333	0.538462	0.538462	0.446809	0.446809	0.538462	0.538462	0.446809	0.446809	0.538462	0.538462	0.333333
according to $r_{i_5 j}$ array	4	3	7	1	2	3	4	1	3	4	3	2	2	6
Non sanitation workers $r_{i_6 j}$	1.000000	0.677419	0.411765	0.512195	0.677419	0.512195	0.512195	0.512195	0.411765	0.411765	0.512195	0.677419	0.512195	0.411765
according to $r_{i_6 j}$ array	1	2	5	2	1	2	3	2	5	5	2	1	3	5

Table 3 (*continued*)

Above junior college $r_{i_7 j}$	0.381818	0.381818	0.446809	0.446809	0.538462	0.446809	0.538462	0.538462	0.381818	0.677419	0.381818	0.446809	0.677419	0.333333
according to $r_{i_7 j}$ array	5	6	4	3	2	3	2	1	6	2	5	4	1	6
Bellow junior college $r_{i_8 j}$	0.538462	0.538462	0.446809	0.446809	0.381818	0.446809	0.446809	0.381818	0.381818	0.538462	0.333333	0.381818	0.333333	0.538462
according to $r_{i_8 j}$ array	3	3	4	3	5	3	4	5	6	3	6	5	6	2
the factors that influenced the development of Chinese medicine **R**	0.538631	0.567747	0.468576	0.456047	0.514870	0.524180	0.506892	0.452887	0.527489	0.558936	0.457120	0.479067	0.468626	0.502838
according to **R** array	7	4	23	26	14	11	17	27	10	5	25	20	22	18

4 Analysis and Computation of the Relating Modulus, Degrees and Clustering

4.1 Compute the Relating Modulus and Relating Degree

The factors influencing the development of the theory, diagnosis, and treatment of Chinese medicine of the relating modulus were computed with formula (4). The relating degrees were computed with formula (5) by the relating modulus.

The relating modulus and relating degrees were arranged. The results were listed in Tab.3.

4.2 Cluster Analysis and Computation

Arranging S_j from 1 to 28 according to **R** in Tab.3, the big tree figure was constructed, as shown in Fig.1 (Deng, 2002; 2005; Liu et al., 1991; Jin, 1993;

S_{13} ←d=0.773990→ S_{14} ←d=0.452052→ S_{11} ←d=0.886708→ S_{16} ←d=0.871050→

S_{24} ←d=0.728808→ S_9 ←d=0.591447→ S_{15} ←d= 0.311188→ S_4 ←d=0.621229→

S_7 ←d=0.611844→ S_{23} ←d=0.250361→ S_{20} ←d= 0.403073→ S_3 ←d=0.193353→

S_2 ←d=0.265184→ S_{19} ←d=0.444819→ S_5 ←d=0.472197→ S_{12} ←d=0.570537→

S_{21} ←d=0.744329→ S_{28} ←d=0.558170→ S_{10} ←d=0.420845→ S_{22} ←d=0.449977→

S_8 ←d=0.515876→ S_{23} ←d=0.424434→ S_{17} ←d= 0.332472→ S_1 ←d=0.399426→

S_{25} ←d=0.345016→ S_{18} ←d=0.158307→ S_{22} ←d=0.303329→ S_6

Fig. 1 The Big Tree Figure

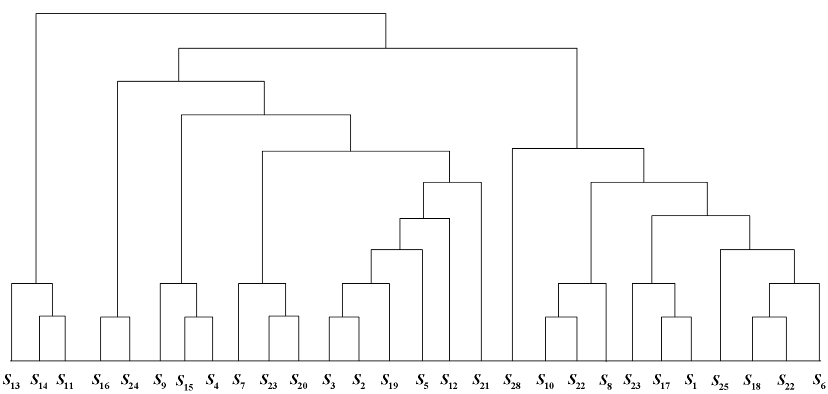

Fig. 2 The Grey Clustering Figure

Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). According to the border of S_j, d was computed with formula (4). The numerical values d were marked up figure 2 and clustered. So, the grey clustering figure was drawn (Deng, 2002; 2005; Liu et al., 1991; Jin, 1993; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), as shown in Fig.2.

Table 4 The results of clustering the factors influencing the development of the theory, diagnosis, and treatment of Chinese medicine and sequencing (simulating the results)

breed	Names
1	the trust from country S_{13}; change of the ill chart S_{14}; the impact from west medicinal S_{11}
2	the need from society S_{16}; the intension build of hospital S_{24};
3	the tools for diagnosis and treatment S_9; enter WTO S_{15}; professors of Chinese medicine S_4;
4	curing effective of Chinese medicine S_7; resource collocation of the hospital of Chinese medicine S_{23}; overseas development of Chinese medicine S_{20}; the view from abroad S_{19}
5	the study method of Chinese medicine S_3; the science of Chinese medicine S_2; standardization of the language of Chinese medicine S_5; east and west medicinal combination S_{12}; the profit of the hospital of Chinese medicine S_{21}
6	the profit of the hospital of Chinese medicine S_{28};
7	the mode for diagnosis and treatment of Chinese medicine S_{10}; the skill of the hospital of Chinese medicine S_{22}; entering new technology S_8; resource collocation of the hospital of Chinese medicine S_{23}; mangers and organizers in sanitation department S_{17}; the logic of Chinese medicine S_1; country doctors S_{25}; the law of the impact of west medicinal S_{18}; the skill of the hospital of Chinese medicine S_{22}; the path and methods of traditional Chinese drugs S_6

5 The Result of Grey Clustering Analysis

5.1 The Result of the Influencing Factors of Grey Clustering

Based on figure 2, the factors that influenced the development of Chinese medicine were distinguish. The factors had 7 breeds from strong to weak. The result was listed in Tab.4.

5.2 Analysis

According to the results, we divided the factors that influenced the development of Chinese medicine into 7 breeds from strong to weak. The first 3 breeds are the most important, the following 2 breeds are less important, and the last 2 breeds are the least important. This information can give the government some ideas when they make policies. For the first three kinds, the government should pay more attention to manpower, material resources and finances. According to the conclusion, some suggestions were brought forth to improve the development of Chinese medicine.

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Studies of Science and Technology Talent' Management of New Regional Industrial Development:* Research with Anhui Province as an Example

Benhai Guo, Zhigeng Fang, and Dejin Song

In the process of accelerating industrialization, different regions of China are giving great efforts to develop new industries in order to enhance the competitiveness of regional industries and overall economic strength; scientific and technological human resources are bound up with the development of emerging industries, and they are even at the core of the development of new industries. This chapter provides the case of Anhui Province, and it analyzes the province's present status and management problems of scientific and technical personnel in the development of new industries, and it also puts forth relevant countermeasures and suggestions.

1 Introduction

As a dynamic industrial concept, emerging industries represent the new requirements of the market to the whole output of the economic system and new direction of the conversion of industrial structure. The development of new industries relies on technological innovation to create an uncertain new market, building a new arena for industrial explorers who have numerous technique or capital. In the process of accelerating industrialization, different regions in China are accelerating the development of competitive manufacturing industry and focusing on developing advantageous high-tech industries that rely on its regional

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* The work presented in this chapter was subsidized by the National Soft Science Research Project (2008GXS5D115) and National Social Science Foundation Key Project (08AJY024).

advantages and comprehensive economic advantages, so that they can develop a number of new industries with characteristics, potential and marketability. Science and technology are primary production forces, and science and technology talent are at the core of the development of new industries. In the process of the development of new industries, the management of science and technology talent problems in different Chinese regions is a major issue worthy of study.

Li Fuzhu (Li and Ding, 2005; Liu and Li, 2005) and others thought that the management of science and technology talent should focus on the environment construction of science and technology talent, such as improving the remuneration of scientific and technological personnel, providing a good working system for scientific and technological personnel, establishing inter-district movement mechanisms of scientific and technological personnel and implementing different project mechanisms to tap the potential of scientific and technological talent. Literature (Yu, 2005) put forth the main managerial points of scientific and technological talent in the software industry. It thought software talent training mode innovation must be implemented, and reasonable and feasible talent strategy must be implemented on this basis in order to resolve the current crisis of scientific and technological talent in the software industry. Literature (Li and Xie, 2006) studied the supply and demand model of scarce talent in the emerging industry of China, and this model presented solutions for the emerging industry talent shortage. It thought that we must implement science and education strategies, change the mode of education and train more new talent. At the same time, enterprises also need to create a reasonable remuneration system to retain and motivate scientific and technological personnel. Literature (Fu, 2000) proposed a talent-strategy of high-tech industry development; the literature summarized the quality of talent in high-tech industries and their developing ways, and it put forth development and allocation strategies for high-tech industry personnel in cognizance of the present problems and situation of high-tech talent. Literature (Wang et al., 2008) studied the emerging industry of service outsourcing. It explored the market positioning the service outsourcing talent, and it summarized the corresponding government behavior, corporate behavior and social behavior.

In general, there are many deficiencies in the current studies of science and technology talent management of new regional industry development, especially since there is almost no related research of a specific area. As a central province, Anhui Province is in foreland areas that undertake the capital spillovers and industrial transfer of the developed coastal areas. To seize the new opportunity of industrial transfer, since “the tenth five-year”, Anhui Province set "speeding up the development, enriching people and strengthening the province" as their theme and also strategically adjusted their economic structure as the main line. It actively implemented the "leapfrog-development" strategy, "developing Wan by science and education" strategy and "industrial province" strategy, and it will vigorously develop new industries as an important strategic point. Studying science and technology talent management issues of new industrial development in Anhui Province not only has practical significance for the development of new industries in Anhui Province, but it also will have profound effects for the strategic adjustment of economic structure in Anhui. Moreover, it will have reference value for dealing with other science and technology personnel management issues of emerging industrial development in central and western provinces.

Based on the basic connotation of new industries, combined with the practicalness of Anhui Province, this chapter selected the following categories of new industries for a research sample:

(1) High-tech Industries: information-chemical manufacturing, pharmaceutical manufacturing, aviation and spacecraft manufacturing, electronics and communications equipment manufacturing, computer and office equipment manufacturing, medical equipment and instrumentation manufacturing, information transmission, computer services and software industry;
(2) Scientific Research and Comprehensive Technical Services: Research and experimental development, professional technical services, technology exchange and promotion services;
(3) Finance and Insurance Industry: banking, securities, insurance, other financial activities;
(4) Real Estate Industry: real estate development and management, property management, intermediary services of real estate, and other real estate activities;
(5) Culture, Sports and Entertainment: news publishing industry, radio television film and audiovisual industry, arts and culture industry, sports entertainment.

2 Analysis of the Fundamental Role of Scientific and Technological Talent in the Development of New Industry in Anhui Province

During 1998-2007 in Anhui Province, the annual average growth rate of the GDP was 11.5%, and that of emerging industries was 17.59%. The proportion of emerging industry adding value to the GDP was from 12.93% in 1998 to 19.25% in 2007. New industries provided 228 thousand employment opportunities in 1998, and the number was one million in 2007, which showed an annual average growth rate of 17.85%. (See Table 1).

After further study of the relationship between human input (the total number of technological people), financial inputs (expenditures of scientific and technological research and development) and the output of scientific and technological achievements (turnover of the technical market), and the emerging industrial added

Table 1 The development status of emerging industry for nearly 10 years in Anhui

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
The number of enterprises	21914	19891	20096	21949	21958	22818	23661	26008	25004	26527
Increased employed population (ten thousand persons)	22.8	25.6	30.58	31.61	32.9	51.84	70.79	76.24	92.51	100
The number of technological people (ten thousand persons)	7.05	6.85	8.33	8.95	8.82	8.60	8.45	8.95	9.57	11.22
Capital investment (one hundred million Yuan)	21.59	28.23	42.69	51.79	65.55	83.47	103.32	127.63	160.8	195.1
Output of scientific and technological achievements (one hundred million Yuan)	4.23	4.86	6.10	6.41	7.54	8.80	9.07	14.26	18.49	26.5
Added value of emerging industries (one hundred million Yuan)	328.85	351.87	380.02	417.08	464.91	549.68	646.73	876.93	1168.33	1413.88
The total GDP (one hundred million Yuan)	2542.96	2712.34	2902.09	3246.71	3519.72	3923.10	4759.30	5375.84	6141.9	7345.7
The proportion of emerging industrial added value in GDP (%)	12.93	12.97	13.09	12.85	13.21	14.01	13.59	16.31	19.02	19.25

Data Source: "Anhui Statistical Yearbook" (1999-2008); "Statistics Bulletin of the Economic and Social Development of Anhui Province " (2006, 2007).

value, the running results of SPSS software show that there is a high correlation between human input (the total number of technological people), financial inputs(expenditures of scientific and technological research and development) and the output of scientific and technological achievements (turnover of technical market), and the emerging industrial added value (see Table 2). This shows that scientific and technological progress and the input of technological talent are closely related, and region clustering of scientific and technological talent and the development of regional emerging industries are highly relevant. Scientific and technological personnel promote scientific and technological progress, thus they also promote the rapid development of emerging industries.

Table 2 Correlation analysis results of human input, capital input and output of scientific and technological achievements, and new industries added value

		human input	capital input	output of scientific and technological achievements	new industries added value
human input	Correlation	1.000	.878	.888	.855
	Significance(1-tailed)	.	.000	.000	.001
	df	0	8	8	8
capital input	Correlation	.878	1.000	.967	.983
	Significance (1-tailed)	.000	.	.000	.000
	df	8	0	8	8
output of scientific and technological achievements	Correlation	.888	.967	1.000	.990
	Significance (1-tailed)	.000	.000	.	.000
	df	8	8	0	8
new industries added value	Correlation	.855	.983	.990	1.000
	Significance (1-tailed)	.001	.000	.000	.
	df	8	8	8	0

3 Present Status Analysis of Anhui Science and Technology Talent and Forecast of the Demand of Emerging Industrial Development to Talent

3.1 Present Status Analysis of Science and Technology Talent

The total number of Anhui scientific and technological talent is relatively insufficient. At present, there are more than one million professional and technical personnel in Anhui Province, but among these, there are only 115,000 people engaged in scientific and technological activities, and only 30,000 people are R & D staff. In comparison to other central provinces, the amount of scientific and technological talent is relatively insufficient in Anhui Province. The total number of scientific and technological talent in Anhui Province ranks No. 5 among central regions (data of 2007), but the number of people who engage in scientific and technological activities and R & D activities in per ten thousand people is less than half of the national average, which ranks the bottom of the central region (see Table 3).

The distribution of scientific and technological talent is uneven. In Anhui, the regional distribution, industrial distribution, different ownership tissue distribution and different sectors distribution of scientific and technological personnel have shown a certain degree of imbalance.

The regional distribution of Anhui science and technology personnel has shown a trend of concentration in areas such as Hefei, Wuhu, Bengbu, Ma'anshan and Chuzhou, and the number of the S&T talent in the above-mentioned five cities

Table 3 Comparison of scientific and technological human resources in Central 6 provinces (data of the end of 2006)

Index	Anhui		Hubei	Hunan	He'nan	Shanxi	Jiangxi	Nation
	Year2006	Year2007						
The number of professional and technical personnel (ten thousand persons)	100.78	101.96	153.6	126.8	204.1	97.2	95.8	3256.8
The number of scientific and technological people (persons)	95,716	112,160	170,151	130,239	177,272	121,768	71，848	4,131,542
The number of scientists and engineers (persons)	62,658	74,149	122,241	87,989	108,592	71,254	44,199	2,797,839
The number of R&D people (persons /year)	28,826	33,380	62,100	39,752	59,692	38,767	25,797	1,502,472
The number of S&T people per ten thousand people (persons)	15	16	30	20	19	36	16	31
The number of R&D people per ten thousand people (persons /year)	5	5	11	6	6	11	6	11

accounted for 63.7% of the total number of the province. In the industry distribution, education concentrates the absolute majority of the professional and technical personnel, which accounts for 46.13%. It is followed by the health, social security and social welfare sector, which accounts for 13.31%. Then it is the manufacturing sector, accounting for 9.47%, while professional and technical personnel who engage in the emerging industries (the high-tech industry, information transmission, computer services and software industry, the financial industry, real estate, culture, sports and entertainment) account for 12%. From the sector distribution, the proportion of technological people in large and medium industrial enterprises accounted for more than half of that of the province. In 2007, there were 66.5 thousand scientific and technological workers in industrial enterprises, which accounted for 59.27% in the province. The number of scientific and technical workers in research institutions, universities and other executive branches were 4700, 29000 and 12000, accounting for 4.19%, 25.85% and 10.76%. The distribution of science and technology professionals in Anhui in different forms of ownership, enterprises and institutions is prominently uneven, and scientific and technological people are intensive in public economic units. In 2007, the proportion of scientific and technological talent in the state-owned economic units was 78.7%, so one would induce that scientific and technological talent in other non-state-owned economic units cannot be supplemented in a short time.

The remuneration of scientific and technical personnel is relatively low. The contribution that scientific and technical personnel in Anhui Province have made is out of proportion to their remuneration. In 2002, 88.2 thousand scientific and technical personnel made great contributions to the economic added value of 32.885 billion yuan in the emerging industry, while their labor cost only accounts for 2.7% in new value-added production and 0.36% in GDP. By 2007, the proportion of

Table 4 Comparison of the remuneration of people engaged in science and technology in Anhui from 2002 to 2007

The year	2002	2003	2004	2005	2006	2007
the number of people engaged in scientific and technological activities (ten thousand person)	8.82	8.60	8.45	8.94	9.57	11.22
the labor cost of scientific and technological personnel (billion yuan)	12.56	14.11	24.29	19.25	21.00	27.44
per capita (ten thousand person)	1.42	1.65	2.87	2.15	2.19	2.44
per capita labor cost accounts for technology capital investment (%)	2.17	1.95	2.78	1.68	1.36	1.25
the proportion in new value-added production (%)	2.7	2.56	3.75	2.58	1.80	1.94
the proportion in Anhui's GDP (%)	0.357	0.36	0.510	0.358	0.342	0.373

Source of information: Statistical Yearbook of Anhui Province 2003-2008.

scientific and technical personnel's labor cost in industrial added value not only has not increased but actually fell about 0.8 percentage points; in 2002-2007, the growth in per capita labor cost was limited, the per capita labor cost accounting for technology capital investment showing an overall downward trend. For 2002 to 2007, the average annual growth rate of scientific and technical personnel investment in Anhui Province was 24.38%, while the average annual growth rate of labor cost in scientific and technical personnel was 16.92%. The per capita average annual growth rate of labor cost was only 11.43%. The growth rate of scientific and technical personnel's remuneration not only can't catch up with the pace of industrial and economic development, but also the growth rate of invested funds in science and technology cannot either (as shown in table 4).

The loss of scientific and technological talent is serious. During the tenth five-year plan, the loss of scientific and technological talent in Anhui was also serious, having once experienced a negative growth. In 2001, the total number of science and technology personnel was 8.9 million people. However, this figure was only 84 thousand in 2004. In 2002-2004, the annual growth rates of scientific and technological personnel were as follows: -1.4%, -2.5%, -1.7%. Compared to 2001, the annual growth rate of 2004 is -5.5%. During 2001-2004, the number of scientists and engineers showed large fluctuations. It peaked at 58000 in 2002 and had a 4.8% rise over the previous year, but the number rapidly fell to 52000 in 2004, falling 9.9% when compared to 2002. The overall trend is still downhill, even though the situation has improved in 2005, but it has only returned to the level of 2001.

3.2 The Demand Forecast for Science and Technology Personnel due to the Development of New Industries in 2010-2015

As described above, the correlation coefficient between science and technology personnel input and the emerging industrial added value is 0.855, and they have a significant correlation. Based on data from 1998 to 2007 (Table 1), we estimate the emerging industrial added value in 2010-2015 in Anhui by trend extrapolation (calculated by using the average growth rate of 17.59% in the last decade), and then according to the extrapolated value, we make a regression forecast on the total demand for technology professionals in Anhui.

The results of the t-test showed that the intercept term (constant), namely, the parameter B0, is estimated at 0.011, less than the significant level of 0.05; the estimated value of scientific and technological personnel's parameter B1 is 260.833, and its corresponding probability is 0.002, less than the significant level of 0.05. Thus a regression equation can be drawn: Y = 260.833X-1603.938. The goodness of fit R2 and adjustment coefficient R2 is 0.731 and 0.697, respectively. The equation's goodness of fit is better. For the F test, the F value is 21.691, and its corresponding critical value is 0.002, less than the significant level of 0.05. There is a significant linear relationship between the two variables. Forecast results are as follows (Table 5):

Table 5 The demand forecasting results for IT personnel due to the development of emerging industry in Anhui from 2010 to 2015

	2010	2011	2012	2013	2014	2015
Emerging industrial added value Y (billion yuan)	2298.919	2703.299	3178.809	3737.962	4395.469	5168.633
The staff who engaged in scientific and technological activities X (ten thousand person)	14.96	15.51	18.34	20.48	23	25.97
Y=260.833X-1603.938						

The predicted results showed that if new industries in Anhui want to move forward and maintain an average annual growth rate of 17.59 percent in the next 6 years, then the total amount of staff engaged in scientific and technological activities in Anhui will have to maintain the average annual growth rate of 11.66 percent jus to keep up with the development. During the past ten years in Anhui Province, the average annual growth rate of scientific and technical personnel was only 5.3%. Thus, the development of emerging industry in Anhui is facing a considerable talent gap in the coming years.

4 The Main Problem Existing in Talent Management in the Development of Emerging Industry in Anhui

In recent years, Anhui has taken a series of measures in science and technology talent management. For example, they have focused on economic and industrial development needs and designed plans for scientific and technological human resources; promoted science and technology park building to drive talent concentration; carried out Yinzhi engineering and then have opened the green channel to attract high-level personnel; organized and implemented a new independent innovation system and its support system; strengthened the cultivation of innovative and entrepreneurial talent; promoted the dynamic integration of production and research; and boosted innovation and entrepreneurship. These initiatives have played a vital role in improving science and technology talent management and promoting the development of new industries in Anhui, but with the new situation of economic and social development, Anhui must vigorously develop new industries, promote industrial upgrading and enhance the quality of economic development and overall industrial competitiveness. Science and technology talent management faces more challenges and is easily affected by uncertainties, so it has reached the point where the problem of science and technology talent management must be solved.

4.1 The Level of Economic Development and Layer of Industrial Structure Are Low; Science and Technology Talent's Carrier Environment Needs to Be Improved

In horizontal comparison, the level of economic and industrial development in Anhui is low. During the tenth five-year plan, the per capita GDP in Anhui was 8597 yuan, which is lower than the national average of 5443 yuan, ranking the last among the six central provinces; the per capita revenue was 1012 yuan, equivalent to 41.7% of the country; the evolution of industrial structure, despite the acceleration of industry structure in the upgraded trend of recent years, hasn't gotten rid of rough agricultural and resource-based economic structure in general. The results of the economic census showed that during the tenth five-year plan, prime operating revenue of the traditional industrial sectors (coal, electricity, electronics, tobacco, transport equipment, construction materials, textile, food, beverage, petroleum, chemicals, ferrous metallurgy, non-ferrous metals and machinery, etc.) in Anhui took up nearly 90%, while the proportion of electronic and communications equipment and other high-tech industry was less than 2%, lower than the national average of 8.7 percent and much lower than developed provinces and cities, such as Shanghai, Jingsu, Guangdong. In addition, the non-public economic development lagged behind. During the tenth five-year plan, the number of non-public enterprises accounting for second and tertiary industries was 76.3%, under the nationwide average of 7 percentage points. Self-employed households were not only significantly lower than that of economically developed areas, such as Jiangsu, Zhejiang, Guangdong, but also less than central provinces, such as Hubei and Henan.

Anhui urgently needs to enhance its level of economic and industrial development and improve its scientific and technological talent growth environment to provide technology professionals with a good vehicle and reinforce the foundation to attract and retain technology professionals.

4.2 Industrial Development Planning Is Still Inadequate; Science and Technology Human Resources Plan Contains Flaws

First, the human resource plan did not receive adequate attention. The human resource plan is just regarded as "human security measures", and it shows that the work of scientific and technological talent in Anhui Province did not rise to the strategic level to some extent. Second, there is a lack of scientific and technological personnel structure planning. The human resource planning will be radiated by the flaw of the industrial development planning. To meet the development strategy in Anhui Province, the industrial development plan in Anhui during the eleventh five-year plan, characterized by a "focused" strategy, stood out the prominent national scientific and technological innovation-oriented pilot project in Hefei city, highlighting the high-tech industrial belt along the river and focusing on key park enterprises. The industry neglected the coordinated development of the regional economy, leading to concentrate the spatial distribution of all kinds of professional and technical personnel on Hefei, Wuhu and a few other urban areas. The problem of regional imbalances in the distribution is further exacerbated. In addition, the eleventh five-year industrial development plan ignored non-public economic development, and it is not conducive to guide the transfer of scientific and technological talent to the non-public economy.

4.3 The Science and Technology Capital Investment Was Insufficient; the Level of Technological Innovation and Entrepreneurial Talent Is Not High

Although Anhui Province has increased scientific and technological input annually since 2001, from the horizontal comparison, the financial investment of the Anhui provincial government is still very limited. Compared to other central provinces during the tenth five-year plan, the absolute number of government investment in science and technology in Anhui was only higher than that of Jiangxi, but the proportion of government investment in science and technology accounted for in fiscal expenditure was at the bottom of the six central provinces. To a large extent, the level of creative ability and scientific and technological achievements was limited by little scientific and technological input; input-output is relatively low. (Table 6)

International experience shows that the country or region where the proportion of R&D funding accounts for less than 1% of the GDP is basically at the level of technology introduction and application; the proportion of medium-developed countries or regions that had a strong technological introduction, digestion, and absorption capacity generally enjoys more than 1.5% of their GDP on R&D, while the proportion of more than 2% of their GDP’s is spent in developed countries or

Table 6 Comparison of science and technology input-output in Anhui form 2002 to 2007

	2002	2003	2004	2005	2006	2007
research funding expenditure (billion yuan)	65.55	83.47	103.32	127.63	160.8	209
R&D funding expenditure (billion yuan)	25.70	32.42	37.30	45.16	59.00	72.82
the proportion in R&D funding expenditure (%)	39.21	38.84	36.10	35.38	36.69	34.84
the proportion in Anhui's GDP (%)	0.73	0.83	0.78	0.84	0.96	0.99
technology market turnover (billion yuan)	7.54	8.8	9.07	14.26	18.5	26.5
the proportion in Anhui's GDP (%)	0.21	0.22	0.19	0.27	0.30	0.36
scientific and technological input-output ratio	8.7:1	9.5:1	11.4:1	8.9:1	8.7:1	7.9:1

Source of information: Statistical Yearbook of Anhui Province 2003-2008.

regions for them to maintain a strong ability to innovate. To judge, despite the fact that the proportion of current R & D funding in the GDP has increased each year, it is not reach 1%, so Anhui is still in the stage of technology introduction and application, and the capacity for independent innovation is not strong.

4.4 The Incentive Mechanism of IT Personnel Is Not Perfect; the Enthusiasm of Scientific and Technical Personnel Has Not Been Fully Mobilized

At present, the evaluation of scientific and technological personnel has not formed a scientific system in Anhui Province. Such as the evaluation of scientific and technological personnel engaged in basic research still using the SCI and other metric indicators, it is too inclined for quantitative evaluation, which contributes to the utility-based, skill-oriented and vulgarization of academic activities, so it is not conducive to inhibit impulsive academic and short-term behavior in scientific research. Another example is when evaluating the R&D personnel's real innovation and contribution, there are no clear indicators, instead of using the model to make assessment based on task forces. This model is extremely unfavorable for building collaborative relationships and studying the formation of the team. In addition, there is a phenomenon of serious administrative intervention in the evaluation process, where administrative staff play a leading role in personnel evaluation.

For science and technology personnel incentives, the reward coverage is narrow and the encouraging effect is limited. As a special fund for technology professionals established by Anhui, mainly targeting high-level talent and outstanding contributors, the recently established Youth Science and Technology Award only awarded 20 outstanding young scientists at the standard of 400 thousand per year. The high threshold of the reward has led to its narrow coverage, most ordinary scientific and technical personnel choosing the existing state due to the lack of proper incentives.

4.5 The Channel from Scientific and Technological Talent to Enterprises Is Not Clear Enough, and Enterprises Lack the High-Level Scientific and Technological Talent

The scientific and technological talent of Anhui Province is highly gathered in universities, research institutions and other non-corporate social organizations. The channel from scientific and technological talent into enterprises is not clear enough. Scientific and technological talent is the fundamental guarantee of enterprise independent innovation, and the shortage of them seriously hampered enterprise R&D. In developed countries that are enterprise innovation-oriented, the nationwide R&D talent is concentrated to enterprises; for example, the U.S. enterprises gathered 75.4% of the nationwide R&D talent, Japanese talent accounted for 64.80%, and British talent accounted for 68.5%. But in our country, a large part of scientific and technological talent is focused on scientific research institutes and universities. At universities, the scientific and technological personnel evaluation system is paper-oriented, government issues-oriented, incentives-oriented and so on. Considering the title evaluation, wages, and social security of university research institutes, the technological professionals cannot flow to enterprises according to market rules. The phenomenon is even more serious in Anhui Province, which is located in the Central Region.

At the same time, the training and motivation mechanism of business technological professionals is not sound. Enterprise technological brain drain is more serious. Many enterprises lack an effective mechanism for personnel selection, training and incentives. They do not to pursue performance maximization of talent use, instead one-sidedly pursuing cost minimization. Without a reasonable allocation mechanism and with short-term talent incentives and simplistic methods, the growth of enterprise technological innovation talent has been seriously affected, resulting in the loss of enterprise talent. Moreover, our country's attraction to high-level talent improved by a large margin due to a significant increase of science and technology investment in universities and research institutions. Some enterprises' leading talent have accepted the invitation of universities and research institutions, leaving enterprises for universities and research institutions. The talent flowed in reverse, from enterprises to universities and research institutions. The brain drain of enterprise and scientific and technological talent, especially that of key technological fields, has a greater negative impact on the safety of the enterprise research work

5 Countermeasures and Proposals

5.1 Plan the Industrial Layout Scientifically and Optimize the Distribution of Scientific and Technological Talent

On the basis of the industrial input-output influence coefficients and sensitivity coefficients, and taking full account of such factors as economic and energy consumption, Anhui Province should take ten more industries as leading sectors of industrial development in the future: communication equipment, computer and other electronic equipment manufacturing; transportation equipment manufacturing; the chemical industry; general and special equipment manufacturing; electrical machinery and equipment manufacturing; instrumentation and cultural office machinery manufacturing; modern food manufacturing and the tobacco processing industry; textile industry; metal smelting and calendering processing industry; and non-metallic mineral products industry. These sectors have good growth, enterprises in them have a certain maturity, and the products have a broader market space, which all have a great effect on the economics of Anhui. Not only should Anhui Province place the ten industries in important positions, but also it should allow them to become group advantages, that is, to future-mindedly cultivate leading industrial groups in order to play their leading role in the industrial structure system; to promote talent, technology and enterprise gathering; and to optimize the distribution structure of scientific and technological personnel, depending on the optimization of the industrial layout.

5.2 Improve the Combination Degree of Production, Education and Research, and Accelerate the Transformation of Technological Achievements

If we want to promote technological achievements and transform them into practical productive forces, we must combine production, education and research. First, we should give full play to the advantage of existing scientific and technological resources in Anhui Province (the university town, scientific island, and research units of Central Authorities in Anhui) and continue to organize "co-operations between province and schools", " co-building between province and colleges". Second, we should further run good high-tech industrial development zones and the University Science Park, make them truly become bases that nurture and develop high-tech industry. Third, we must make great efforts to develop intermediary service institutions of science and technology; foster a number of service agencies, such as productivity centers, property rights transactions institutions, achievements transformation centers, modern logistics institutions and so on; speed up the province and city (Hefei) to build innovative and pioneering service centers; and set up a co-operation platform among production, education and research.

5.3 Increase Scientific and Technological Investment and Improve the Level of Scientific and Technological Personnel Innovation and Intrapreneurship

First, we must increase financial and technological investment, timely establish special financial technology funds, and increase the growth range and speed of financial and technological investment in order to ensure the financial support of independent innovation capacity building. Second, we must establish a diversified and multi-level technological investment and financing mechanism to smooth investment and financing channels. We should actively explore the methods and measures of the combinations between finance and technology to enhance the leading function of financial investment, actively seeking credit funds to support the infrastructure and key industrial projects in line with macro-control needs. We should adjust investment and financing structure to encourage and support more qualified enterprises to find a way of listing and financing. We should promote the development and improvement of Anhui credit institutions to provide a government credit guarantee for scientific and technical personnel and projects. Third, we must set up a risk investment mechanism to create new input methods. The Anhui risk investment firm is still in its infancy with not much registered capital, so it’s very harsh in the choice of investment projects. Anhui Province should actively learn from advanced experience at home and abroad to try to establish and perfect the mechanism of risk investment and make innovations in investment approaches; to lead and support venture capital firms and financial institutions to increase investment in high-tech enterprises, especially in the medium and small high-tech enterprises; and to provide further financial assurance for strengthening technical innovation and industrialization of scientific and technological achievements.

5.4 Promote Institutional Innovation and Strengthen Incentives for Scientific and Technological Personnel

First of all, we must advance the reform of the personnel system and strive to form a kind of working mechanism with which scientific and technological personnel can move up or down, enter or exit, and be sorted based on their contributions. We should deal with the use of scientific and technological personnel, avoiding the phenomenon of high talent consumption. During the process of selecting and employing, we should adhere to confirming Heroes by their performance to avoid the "Gresham effect" (that is, the phenomenon of mediocrity push talent). Scientific and technical personnel should be given the full right to speak. Especially for vital decisions, we must allow them full play in their corresponding fields, as they are irreplaceable roles. Second, we must improve the evaluation system of scientific and technological personnel. We should build a scientific evaluation system of scientific and technical personnel, to distinguish the evaluation between basic research and applied research, and strive to form the institutional and standardized evaluation, to reduce the interference of human factors and administrative factors. Finally, we should strengthen the incentive system, to fully mobilize the enthusiasm, initiative and creativity of scientific and technological personnel. And then, we need to speed up distribution system reform and carry out revenue policies to stimulate scientific and technical personnel. We should strengthen the incentives for technological innovation and implement incentive methods according to scientific and technological innovation achievements to award the scientific and technical personnel who made outstanding contributions to enterprises. In addition, we can expand the coverage of incentives to inspire more potential scientific and technological personnel, to make innovation and entrepreneurship, and to create value for society.

5.5 Combine the Government with Corporations and Make a Difference among Management Issues of Scientific and Technological Talent at Different Levels

Government and enterprises should have complementary strengths in the management of scientific and technological talent in order to promote positive interactions between the development of the new industries and technological talent. The government should effectively change its personnel management functions and gradually turn to macro-management from micro-management. The government should significantly act on optimizing the external development environment of emerging industries and technological professionals, strengthening talent infrastructure construction. Moreover, the government must be more proactive in the process of promoting talent, technology and equipment and other manufacturing factors to flow to emerging industries. Enterprises should make great efforts to establish the management system according to the actual situation of enterprises, and they should establish the training mechanism aimed at scientific and technological talent of enterprises in order to train and bring up a large number of high-tech entrepreneurs and technical elites who are skilled; good at technology, business and management; and brave in innovation and fight. Enterprises must build their talent to attract more high-tech professionals and retain technological personnel, depending on its system, business, treatment, environment and culture. Lastly, enterprises should distribute their technological talent reasonably and establish a comprehensive assessment, the trinity system, of talent, based on post and performance.

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Empirical Research on the Selection of Regional Key Technology for International S&T Cooperation*

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The selection of key technology for international cooperation is a new field to be developed both domestically and abroad. Furthermore, there are few research documents on such basic research as how to systemically select high quality foreign technology and project sources based on analyzing the demand of local technology and the economy. In this paper, an urgent index and feasible index are proposed, in which the former is to evaluate the urgency of the technology demand for the local economy and the latter to measure the feasibility of obtaining key technology through international cooperation. By applying the Delphi method, the corresponding evaluation index system is set up based on which an integrated evaluation method of multiple objective fuzzy index is built. The proposed method is applied to the selection of key technology for international cooperation in Jiangsu province. The evaluation set is quantified to an extract urgent index and feasible index, followed by the incorporation of two indexes into an integrated one. Then the key technologies of international cooperation are ranked according to the integrated index. Finally, key technologies that are urgently needed and possibly gained by Jiangsu province through international technology cooperation are screened out.

1 Introduction

Affected by the rapidly developing S&T, increasingly international competition and production internationalization, international S&T cooperation is flourishing.

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* This work was supported by the Social Sciences Key Fund of China, Grant NO. 08AJY024, and by the Soft Science Key Fund of Jiangsu Province, Grant NO BR2008099.

International S&T cooperation is growing both in key and general technology. However, the cooperation of different kinds of technologies has different features. It is generally supported and unlimited for the international cooperation of general mature biotechnologies, patents, know-how's and general soft technologies. Exporting these technologies is beneficial to the exporters, including the country and the company. Developed countries encourage exporting these technologies because the many advantages: it can increase national employment and extend the technologies' lifecycle and accelerate the updating of technologies. For example, Japanese banks provide some preferential policies to encourage exporting, such as low-interest loans, export insurance and tax incentives. However, transferring key technologies is most limited. Because key technology is a strategic asset, it is controlled by many countries. To a different extent, US-led developed countries have made some policies on export control to limit key technology cooperation with China. These limited key technologies have a close relation with China's major S&T plan. Those limits impede China's technology introduction and affect the key technology cooperation scale and transfer direction. According to relative statistics, about 30% of technology export applications in the USA are objected every year. How to avoid these export limits and get more key technologies is the problem we must urgently solve. The selection of key technology for international cooperation is a new field to be developed both domestically and abroad. Furthermore, there are few research documents on such basic research as how to systemically select high quality foreign technology and project sources based on analyzing the demand of local technology and the economy. In this paper, a study on the selection of key technology for international cooperation is done based on analyzing the demand of local technology and the economy. Finally, key technologies that are urgently needed and possibly beneficial for Jiangsu province through international technology cooperation are screened out.

2 Urgent and Feasible Index System

Generally, a technology that plays a decisive role in achieving a strategic task or program objective, promotes the development of whole Industrial clusters and is practical or partly practical is called a key technology. To evaluate the urgency of the technology demand for the local economy and measure the feasibility of obtaining key technology through international cooperations, this paper proposes an urgent index and feasible index and builds two corresponding evaluation index systems.

The basic criteria for selecting local international key technology are as follows: it can promote economic development and new industry forming, it is beneficial for environment protection, it has an available foreign technology source, there are funding and policy guarantees, and it can be achieved in short time. According to these basic criteria, when defining the urgent index and feasible index, we must consider these factors: importance of pulling the market (technological bottlenecks, the formation of independent intellectual property rights, promoting the development of related industries), importance of pushing technology (technology

Table I Urgent Index System

criteria	index	weight	Estimated value
importance	belonging or not to an important technology area	0.15	A. yes D. no
	technology drop time (year)	0.1	A. more than 10 years B. 5-10 years C. 3-5 years D. less than 3 years
	technology bottlenecks' survival time	0.09	A. more than 10 years B. 5-10 years C. 3-5 years D. less than 3 years
	the ability to form independent intellectual property rights	0.14	A. form whole independent intellectual property rights B. form part of independent intellectual property rights C. can't form independent intellectual property rights
currency	the level of technology coverage	0.09	A. widely applicable B. industry general C. special
drive	the pull and push level about relevant areas	0.11	A. strongest B. strong C. general D. weak
practicality	transfer time	0.07	A. less than 1 year B. 1-3 years C. 4-5 years D. more than 5 years
	input/output ratio	0.13	A. highest B. higher C. general D. lower
sociality	environment protection	0.12	A. strongest B. strong C. general D. weak

covers a broad area, ability to promote the development of a variety of industries), technology sustentation (the company's internal and external conditions, transformation ability), practicality (commercialization time, economic efficiency), social factors (energy consumption, environment protection), technology availability (acquisition channels, technology sensitivity), and technology risk (cost, maturity).

The group invited 135 relevant experts from enterprises, research institutions and universities to do the Delphi inquiry. The second inquiry focused on the indicators, which have a big disagreement. Experts provided the weight anew and gave their reasons. Finally, the relative importance weights, index system and index weights were fixed. The relative importance weights between the urgent index and feasible index are 0.45:0.55. The urgent index system and weight are shown in Table I. The feasible index system and weight are shown in table II.

Table II Feasible index system

criteria	index	weight	Estimated value
foreign technology availability	degree belonging to sensitive technology	0.14	A. no sensitive B. sensitive C. more sensitive D. most sensitive
	number of acquisition channels	0.10	A. several B. sole C. none
	deadline of patent protection overseas	0.11	A. less than 3 years B. 3-5 years C. 5-10 years D. more than 10 years
ability of digestion and absorption	ability of digestion, absorption and innovation	0.18	A. strongest B. strong C. general D. weak
	personnel base	0.18	A. strongest B .strong C. general D. weak
technology risk	maturity level	0.17	A. mature B. general mature C. immature
	acquisition cost	0.12	A. lower B. low C. high D. higher

3 The Method of Key Technologic Selection for International Cooperation

A. Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation method evaluates things' belonging grade status from several factors with the principle of fuzzy relation synthesis.

Suppose there are two finite sets:

$$U = \{u_1, u_2, ..., u_n\}, V = \{v_1, v_2, ..., v_n\}$$

Here, U represents the index set, V represents the evaluation level set.

Let

$$A = \{a_1, a_2, ..., a_n\}, R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

Then the fuzzy transformation is

$$B = A \bullet R = (a_1, a_2, ..., a_n)\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

In the former formula, *A* is the fuzzy subset of *B*, *R* is the fuzzy relation matrix, and evaluation results *B* is the fuzzy subset of *V*.

If we regard *R* as a fuzzy translator, *A* as a fuzzy input and *B* as a fuzzy output, the fuzzy comprehensive evaluation is shown in figure 1.

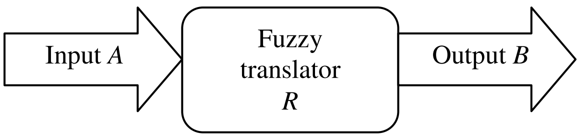

Fig. 1 Fuzzy comprehensive evaluation

Commonly used fuzzy operators are the following ones:

(1) $M(\wedge,\vee)$, that is, $b_j = \overset{m}{\underset{i=1}{\vee}}(a_i \wedge r_{ij})$, i=1,2,…,m;

(2) $M(\bullet,\vee)$, that is, $b_j = \overset{m}{\underset{i=1}{\vee}}(a_i r_{ij})$,i=1,2,…,m;

(3) $M(\wedge,\oplus)$, that is, $b_j = \min\{1, \overset{m}{\underset{i=1}{\vee}}(a_i r_{ij})\}$, i=1,2,…,m;

(4) $M(\bullet,\oplus)$, that is, $b_j = \min\{1, \sum_{i=1}^{m} a_i r_{ij})\}$, i=1,2,…,m;

When to choose a fuzzy operators depends on the actual issues.

B. Integrated Evaluation Method of Multiple Objective Fuzzy Indexes

The ideas of this method are as follows: according to the urgent and feasible index system and fuzzy relation synthesis principle, first evaluate the urgency and feasibility of international key technology with the urgent and feasible index. The next evaluation set is quantified to extract the urgent index and feasible index, followed by the incorporation of two indexes into an integrated one. Then the key technologies of international cooperations are ranked according to the integrated index.

Steps of the integrated evaluation of multiple objective fuzzy indexes are as follows:

(1) Define the index set *U*, $U = \{u_1, u_2, ..., u_n\}$;

(2) Define the evaluation level set $V = \{v_1, v_2, ..., v_m\}$.

For example, environment protection *V*= {strongest, stronger, strong, weak};

(3) Execute a single factor evaluation and build fuzzy relation matrix *R;*

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \qquad (0 \le r_{ij} \le 1)$$

Here, r_{ij} is a subordinate degree in the v_j evaluation given by the control index u_i in *U*.

(4) Fix the fuzzy weight subset $A = \{a_1, a_2, ..., a_n\}$, where a_i is the weight corresponding with factor u_i, and decide by their contribution to the evaluation results;

(5) Choose a fuzzy operator, synthesis *A* and *R,* that is,

$$B = A \bullet R = (a_1, a_2, ..., a_n) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

(6) Make fuzzy evaluation sets quantitative; calculate the urgent and feasible index of every technology program, followed by the incorporation of two indexes into an integrated one. Then, the key technologies of the international cooperations are ranked according to the integrated index.

4 An Example

This subject aims to choose some significant technologies that are the most urgent and can be introduced from abroad so that Jiangsu's S&T competitiveness can be enhanced. For a full grasp of the supply and demand of key technology for international S&T cooperations in Jiangsu and to choose some competitive key technologies, the subject group launched a province-wide collection work for technology projects of international cooperations. The targets are enterprises, research institutions and universities. These technology projects cover seven areas, including electronics, modern equipment manufacturing, new materials, bio-technology and medicine innovation, new energy and energy-saving environmental protection, and modern agriculture and social development. Finally, 371 technology projects were collected and 269 of them were chosen as candidate key

Table III The evaluation value set of the urgent index for the technology industrial PLC high-fequency data-cable

index	1	2	3	4	5
belonging or not to important technology areas	D	D	D	D	A
technology drop time (year)	C	C	C	D	D
technology bottlenecks' survival time	C	B	C	D	D
the ability to form independent intellectual property rights	C	B	B	B	B
the level of technology coverage	C	B	B	B	C
the pull and push level about relevant areas	C	C	B	C	C
transfer time	B	C	B	B	A
expected economic benefits	B	B	A	A	D
environment protection	A	D	C	C	C

Table IV The evaluation value set of the feasible index for the technology industrial PLC high-frequency data-cable

index	1	2	3	4	5
degree belonging to sensitive technology	A	B	B	A	A
number of acquisition channels	A	A	A	A	A
deadline of patent protection overseas	C	B	C	A	A
ability of digestion,absorption and innovation	C	B	B	A	C
personnel base	C	B	B	A	B
maturity level	B	B	A	A	A
acquisition cost	B	B	C	C	A

technologies. An expert investigation questionnaire was applied to the selection of key technologies for international cooperations. In every area, 5 experts were invited to evaluate the technology according to the index system the subject group builds.

Here, take the evaluation of a candidate key technology "industrial PLC high-frequency data cable" as an example, the process of selection of Jiangsu key technology for international S&T cooperation is shown as follows. According to the expert questionnaire, the evaluation value set that five experts gave were shown as table III and table IV.

A. Fuzzy Comprehensive Evaluation of Candidate Key Technology

Set the urgent index weight as A_J and the feasible index weight as A_K. Then, set the urgent index fuzzy relation matrix as R_J and the feasible index fuzzy relation matrix as R_K.

According to table1 and table 2, the urgent and feasible index weight is:

$$A_J = (0.15, 0.1, 0.09, 0.14, 0.09, 0.11, 0.07, 0.13, 0.12)$$

$$A_K = (0.14,0.10,0.11,0.18,0.18,0.17,0.12)$$

Then, the urgent and feasible index fuzzy relation matrixes of this technology are as follows:

$$R_J = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \\ r_{51} & r_{52} & r_{53} & r_{54} \\ r_{61} & r_{62} & r_{63} & r_{64} \\ r_{71} & r_{72} & r_{73} & r_{74} \\ r_{81} & r_{82} & r_{83} & r_{84} \\ r_{91} & r_{92} & r_{93} & r_{94} \end{bmatrix} = \begin{bmatrix} 0.2 & 0 & 0 & 0.8 \\ 0 & 0 & 0.6 & 0.4 \\ 0 & 0.2 & 0.4 & 0.4 \\ 0 & 0.8 & 0.2 & 0 \\ 0 & 0.6 & 0.4 & 0 \\ 0 & 0.2 & 0.8 & 0 \\ 0.2 & 0.6 & 0.2 & 0 \\ 0.4 & 0.4 & 0 & 0.2 \\ 0.2 & 0 & 0.6 & 0.2 \end{bmatrix}$$

$$R_K = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \\ r_{51} & r_{52} & r_{53} & r_{54} \\ r_{61} & r_{62} & r_{63} & r_{64} \\ r_{71} & r_{72} & r_{73} & r_{74} \end{bmatrix} = \begin{bmatrix} 0.6 & 0.4 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0.4 & 0.2 & 0.4 & 0 \\ 0.2 & 0.4 & 0.4 & 0 \\ 0.2 & 0.6 & 0.2 & 0 \\ 0.6 & 0.4 & 0 & 0 \\ 0.2 & 0.4 & 0.4 & 0 \end{bmatrix}$$

When sample is small, the fuzzy operator formula (4) can reflect the views of experts, avoiding the evaluation from becoming affected by extreme values. So formula (4) is selected as the fuzzy operator for fuzzy comprehensive evaluation.

With fuzzy operator b_j, the integrated value of the urgent and feasible index for "industrial PLC high-frequency data cable" was calculated.

$$B_J = A_J \circ R_J = (0.12, 0.30, 0.34, 0.25)$$

$$B_K = A_K \circ R_K = (0.43, 0.37, 0.2, 0)$$

B. Calculate the fuzzy integrated value and rank candidate key technologies

In this subject, the order of the index evaluation value of the urgent and feasible index is A>B>C>D.

Make the evaluation set quantitative and let evaluation set

$$V = (A, B, C, D) = (0.4, 0.3, 0.2, 0.1).$$

Then, the urgent index value (J_I) and feasible index value (K_I) are:

$$I_J = B_J \bullet V^T = (0.12, 0.3, 0.34, 0.25) \bullet (0.4, 0.3, 0.2, 0.1)^T = 23.1\%$$

$$I_K = B_K \bullet V^T = (0.43, 0.37, 0.2, 0) \bullet (0.4, 0.3, 0.2, 0.1)^T = 32.3\%$$

According to the relative weight of the urgent and feasible index

$$W = (w_J, w_k) = (0.45, 0.55),$$

The fuzzy integrated value is:

$Z_I = (I_J, I_K) \bullet (w_J, w_k)^T = (0.231, 0.323) \bullet (0.45, 0.55)^T = 28.2\%$ Similarly, the urgent and feasible index value and integrated value can be calculated.

Due to space limitations, this paper provides the results of 10 technologies, which were randomly selected in the electronic field, shown as table V.

Table V Evaluation examples of candidate key technology in the electronics field

number	technology	urgent index	feasible index	integrated value
1	5th-generation, thin-film crystal liquid crystal display panel technology management	26.4%	29.6%	28.2%
2	automotive pressure sensor, ASIC technology	27.5%	30.3%	29.1%
3	the current sensor technology of Nano-scale magnetic tunnel junction technology	44.3%	28.5%	35.6%
4	intelligent traffic monitoring technology based on wireless sensor networks	31.1%	30.2%	30.6%
5	urban Intelligent Transportation System-related technologies	28.2%	34.2%	31.5%
6	noise detection and filtering techniques in factories	35.0%	28.0%	31.2%
7	optical communication quartz and glass manufacturing technology components	25.8%	28.6%	27.4%
8	industrial PLC high-frequency data cable	23.1%	32.3%	28.2%
9	advanced polarizer technology	22.9%	28.2%	25.8%
10	high-speed optical digital signal processing system development technology	22.5%	24.7%	23.7%

According to table V, the key technologies of international cooperation are ranked according to the integrated index. Based on the ranked key technologies, the group fixed key technologies that need great support and general key technologies.

5 Conclusions

Selection of regional key technologies for international science and technology cooperations is a complex, uncertain decision making problem. It needs to analyze a variety of fuzzy information, so precise measurement and control is not suitable. However, human intuition is effective in processing this problem. Human intuition includes intuition based on people's thinking and realized subjective thought. Because the multi-objective comprehensive evaluation method can make full use of people's intuition and knowledge, it is a good method to solve uncertain decision problems with sick boundaries. In the paper, the urgent index and feasible index are proposed, in which the former is to evaluate the urgency of the technology demand for the local economy, and the latter to measure the feasibility of obtaining key technology through international cooperations. By applying the Delphi method, the corresponding evaluation index system is set up, based on which an integrated evaluation method of a multiple objective fuzzy index is built. The proposed method is applied to the selection of key technology for international cooperations in Jiangsu province. The evaluation set is quantified to extract the urgent index and feasible index, followed by the incorporation of two indexes into an integrated one. Then, the key technologies of international cooperations are ranked according to the integrated index. Finally, key technologies, which are urgently needed and possibly beneficial for Jiangsu province through international technology cooperation, are screened out.

The chosen key technologies were illustrated as realistic by the insiders. Meanwhile, the research results have been applied to guide the Jiangsu Province S&T Department to develop international cooperations. Also, it provided a reference for Jiangsu when carrying out international cooperations and developing a long-term strategy for international S&T cooperation.

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Dynamic Evaluation and Analysis of Regional Technological Innovation Capacity Based on a Gray Target*

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Regional technological innovation capacities of 31 regions in China from 2004 to 2007 are dynamicly evaluated and analyzed by using the gray target theory to find out their changes and development trends. The bull's eye degree was utilized to classify and sort the regional technological innovation capacity. Through the analysis of the contribution degree of the regional technological innovation capacity, the evaluation indicator identified the key influence factors and classified and sorted the evaluation indicator.

1 Introduction

Nowadays, the technological innovation capacity has become a decisive factor of the competitive capacity of a country or region. The enhancement independent innovation capacity and the construction innovation country are taken as an important strategy of the Eleventh Five-Year Plan of the People's Republic of China

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* This work was supported by the National Soft Science Foundation of China (No.2006GXQ3D108), the Research Fund for the Doctoral Program of Higher Education (No.20070386001), the Social Science Foundation of Fujian (No.2008C023 and No.2008A073), the Soft Science Foundation of Fujian (No.2009R0054), and the Science Foundation of Fuzhou University (No.2006-XY(S)-06).

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for National Economic and Social Development at the fifth Plenary Session of the Sixteenth Party Central Committee of the Communist Party of China. Objective and scientific evaluation and comparative research on the technological innovation capacity of various regions are helpful to identify their advantages and disadvantages. It is important to correctly select a regional technological innovation strategy and to lay down a scientific regional technological innovation policy.

At present, domestic and international scholars have carried out some research on regional technological innovation capacity (Riddel and Schwer, 2003; Chinese S&T Development Strategy Research Group, 2003; Shao et al., 2003; Shao and Tang, 2005; Zhu, 2004; Bi et al., 2005; He et al., 2006; Jian et al., 2006; Lu et al., 2008; Li 2009; Chen et al., 2009; Li et al., 2008; Li et al., 2009). For example, a Chinese science and technology (S&T) development strategy research group set up a regional technological innovation capacity evaluation indicator system and evaluated the regional technological innovation capacity of various provinces (Chinese S&T Development Strategy Research Group, 2003); Shao Yunfei, Tang Xiaowo and Chen Guang used an empirical cluster to analyze the capacity of the region technological innovation of China (Shao et al., 2003); subsequently, they used the principal component analysis study on the capacity of the regional technical innovation of China (Shao and Tang, 2005); Zhu Haijiu set up an evaluation indicator system of the regional technological innovation capacity (Zhu, 2004). Bi Kexin put forth a comprehensive evaluation method based on the fuzzy integral to measure and evaluate regional technological innovation in small and medium enterprises (Bi et al., 2005); He Yaqiong, Qing Pei and Sun Jun evaluated the growth efficiency of regional innovation capacity in thirty-one Chinese provinces (He et al., 2006); Jian Cheng Guan, Richard C.M. Yam, Chiu Kam Mok and Ning Ma (2006) set up a DEA model to study the relationship between the innovative capacity and competitiveness; Lu Shiyu and Zhao Shukuang (2008) used factor analysis to analyze and evaluate the situation of our regional technological innovation capacity; Li Xibao (2009) used the Stochastic frontier model to explain the difference of regional technological innovation capacity; Chen Yunwei (2009) evaluated the technological innovation capacity in eight economic regions in the PR China based on patents, and so on.

Most scholars used a single comprehensive evaluation method to statically evaluate the regional technological innovation capacity for an existing reference. Static evaluation pays more attention to the status quo of the regional technological innovation capacity, while the capacity of technological innovation is a dynamic development and continuous improvement process. Riddel and Schwer proposed that regional innovation capacity is a time variable, and any regional innovation capacity is not an easy thing. Some gaps generate, develop and expand in the dynamic changes; some gaps gradually shrink in the dynamic changes. Objective, fair and comprehensive analysis of dynamic changes and the evaluation of dynamic changes to grasp the change and trends of the various provinces' and cities' technological innovation capacity are very practical and can provide important feedback for upper policy-makers. Therefore, we use dynamic evaluation to reflect the development and change process of the regional technological innovation capacity and find its trend in order to get more scientific, meaningful evaluation results on the region technological innovation capacity.

Dynamic comprehensive evaluation is an important multi-attribute decision-making problem. This issue has attracted much attention but has been researched little. The main results of research are from Professor Guo Yajun. He put forth the timing perspective of the dynamic comprehensive evaluation methods as follows (Guo, 2008): the second-weighted method; the incentive (or punishment) characteristics of the dynamic comprehensive evaluation method; the longitudinal level of the analysis method; the longitudinal and transverse level of the evaluation method; based on dual incentives to control the line, the multi-stage information gathering methods; and an operator based on the timing of the dynamic comprehensive evaluation method. But these methods only get the comprehensive evaluation values and sorts and cannot classify results or identify the contribution of the evaluation indicator.

The gray target theory is used to evaluate the technological innovation capacity of 31 provinces and cities in China, covering a time period of 2004-2007, in order to grasp the dynamics of their development and changes. Using a bull's eye analysis to classify and sort the regional technological innovation capacity of 31 regions, we utilize a contributions degree analysis to classify and sort the evaluation indicators of the regional technological innovation to identify the key influencing factors.

2 Gray Target Theory

The gray target theory was put forth by Professor Deng Julong in recent years. It includes two parts: the bull's eye degree analysis and the contribution degree analysis. Its principle lies in satisfying the requirements of the information domain $\Phi(\theta)$, and in a set of model sequences, finding the target data that is closest to the sub-information domain $\Phi_i(\theta)$ to the structure standard mode. Then, the mode and standard mode aggregate together to constitute a gray target, and the standard model is a bull's eye. According to the meaning of sub-information domain $\Phi_i(\theta)$, the mode that is away from the bull's eye is regarded as the target side. The mode that is upper and away from the bull's eye is regarded as the upper target side, and the mode that is lower and away from the bull's eye is regarded as the lower target side. While the upper target side is large data, the lower target side is small data. The gray relation degree between each mode of information differences space and the bull's eye can be regarded as the degree of proximity to the bull's eye, namely, the bull's eye degree. Pattern recognition, classification and selection are based on the bull's eye degree. Based on the analysis of the contribution degree, it can analyze the impact of the indicator to bull's eye degree in order to find the key factor. It is very good at studying less data and uncertainty problems. It has been successful in many areas (Deng , 1993; 2000; Nie et al., 2005; Yang, et al., 2006).

A. Bull's Eye Degree Analysis (Deng , 1993; 2000; Nie et al., 2005; Yang, et al., 2006)

Let $Tw_0 = x_0$, w_0 be a standard pattern, x_0 be $x_0 = (x_0(1), x_0(2), ..., x_0(n)) = (1,1,...,1)$, and x_0 be called the standard bull's eye.

Suppose that $@_{GFR}$ is a gray relational factor set when $@_{GRF} = \{X_i | i \in I, x_i = Tw_i, w_i \in @_{INU}$, and T is the gray target transform}.

Suppose that Δ_{GR} stands for the $@_{GRF}$ of the different information spaces of the gray relation.

$$\Delta_{GR} = (\Delta, \xi, \Delta_{oi}(\max), \Delta_{oi}(\min)), \ \xi = 0.5$$

$$\Delta = \{\Delta_{oi}(k) | i \in I = \{1,2,...,m\}, k \in K = \{1,2,...,n\},$$

$$\Delta_{oi} = |x_0(k) - x_i(k)| = |1 - x_i(k)|, \ x_0(k) \in x_0 \Rightarrow x_0 = Tw_0\}$$

$$\Delta_{oi}(\max) = \max_i \max_k \Delta_{oi}(k) = \max_i \max_k |1 - x_i(k)|,$$

$$\Delta_{oi}(\min) = \min_i \min_k \Delta_{oi}(k) = \min_i \min_k |1 - x_i(k)|,$$

The gray incidence coefficient

$$\gamma(x_i(0), x_i(k)) = \frac{\min_i \min_k \Delta_i(0,k) + \xi \max_i \max_k \Delta_i(0,k)}{\Delta_i(0,k) + \xi \max_i \max_k \Delta_i(0,k)}$$

$\gamma(x_0, x_i)$ refers to x_i bull's eye degree:

$$\gamma(x_0, x_i) = \frac{1}{n} \sum_{k=1}^{n} \gamma(x_0(k), x_i(k))$$

B. Contribution Degree Theory (Deng , 1993; 2000; Nie et al., 2005; Yang, et al., 2006)

Suppose that $@_{GFR}$ is the gray relational factor set, and it can be described as follows:

$$@_{GRF} = \begin{cases} x(k) | k \in K \cup \{0\}, K = \{1,2,...,n\}, x(0) = (x_1(0), x_2(0), ..., x_m(0)), \\ \forall x_i(0) \in x(0) \Rightarrow x_i(0) = T_l w_i(0), x(k) = (x_1(k), x_2(k), ..., x_m(k)), \\ \forall x_i(k) \in x(k) \Rightarrow x_i(k) = T_v w_i(k), \\ T_v \in \{T_U, T_l, T_m\}, \\ T_v = T_u \ FOR \ POL w_i(k) \in POL(\max), \\ T_v = T_l \ FOR \ POL w_i(k) \in POL(\min), \\ T_v = T_m \ FOR \ POL w_i(k) \in POL(mem), \end{cases}$$

Then $@_{GRF}$ represents the contribution factor set, and $x(k)$ stands for the kth contribution factor; $\Delta_i(0,k)$ stands for the information difference between $x_i(0)$ and $x_i(k)$:

$\Delta_i(0,k) = \left|x_i(0) - x_i(k)\right|, i \in I, k \in K$;

$\Delta(0,k)$ stands for the information difference between $x(0)$ and $x(k)$:

$\Delta(0,k) = (\Delta_1(0,k)), \Delta_2(0,k), ..., \Delta_m(0,k))$;

Δ stands for the information difference set:

$\Delta = \{\Delta(0,k) \big| k \in K = \{1,2,...,n\}\}$;

$\Delta_{\max}(0,k)$ stands for the upper environment parameter in the contribution factor set:

$$\Delta_{\max}(0,k) = \max_i \max_k \Delta_i(0,k);$$

$\Delta_{\min}(0,k)$ stands for the lower environment parameter in the contribution factor set:

$$\Delta_{\min}(0,k) = \min_i \min_k \Delta_i(0,k);$$

Δ_{GR} stands for the GR information difference space of the contribution factor set:

$\Delta_{GR} = (\Delta, \xi, \Delta_{\max}(0,k), \Delta_{\min}(0,k))$,

$\xi = 0.5$

$\Delta = \{\Delta(0,k) \big| k \in K = \{1,2,...,n\}$,

$\Delta(0,k) = (\Delta_1(0,k), \Delta_2(0,k), ..., \Delta_m(0,k))$,

$\Delta_i(0,k) = \left|x_i(0) - x_i(k)\right|\}$;

And the gray relational coefficient is:

$$\gamma(x_i(0), x_i(k)) = \frac{\min_i \min_k (0,k) + \xi \max_i \max_k \Delta_i(0,k)}{\Delta_i(0,k) + \xi \max_i \max_k \Delta_i(0,k)}$$

which stands for the contribution coefficient of indicator *k* at pattern *i*. Gray incidence degree, and $\gamma(x_i(0), x_i(k)) = \frac{1}{m}\sum_{i=1}^{m} \gamma(x_i(0), x_i(k))$ stands for the contribution degree of indicator *k*.

3 Evaluation Indicator System for Regional Technological Innovation Capacity

In (Chen et al., 2008), based on the connotation and elements analysis of the regional technological innovation capacity and the existing research results, an initial comprehensive evaluation indicator system is formed; then, an evaluation indicator identification framework of the regional technological innovation capacity is established through expert appraisal, relative analysis, discrimination analysis and the effectiveness analysis of the indicator rules; meanwhile, a more comprehensive, reliable and effective evaluation indicator system is developed for the regional technological innovation capacity. Finally, the effectiveness of the indicator system is verified by using several comprehensive evaluation methods.

The per capita disposable income reflects the life quality of residents better than the total revenue, so "the net income of urban residents" indicator was changed to "the per capita disposable income of urban residents". The data of “the number of technology centers recognized by [the] nation” is from the website of thematic data of statistics that only provided those for 2004 and 2005. It is difficult to get data from other years, so in place of "the number of large and medium-sized industrial enterprises that included science and technological institutions". Finally, the regional technological innovation capacity evaluation indicator system is as follows (Li et al., 2009).

Regional technological innovation input capacity B1: R&D personnel D1; government appropriation D2; R&D expenditure D3; the number of large and medium-sized industrial enterprises, including science and technology institutions D4.

Regional technology transference and diffusion capacity B2: R&D funded by enterprises D5, transaction value in technology market D6, foreign technology introduction expenditure D7, domestic technology purchases expenditure D8, technology digestion absorption expenditure D9, foreign direct investment D10.

Regional technological innovation output capacity B3: domestic Chinese journal S&T papers D11, the number of S&T papers cited by overseas main search tool D12, patents granted D13, patent applications D14, the share of high-tech industry in the industrial enterprise added value above the designated size D15, the share of high-tech product exports in the total product exports D16, new product output value D17, GDP D18, value added of the industry D19, market volume of business D20.

Regional technological innovation support capacity B4: length of paved roads D21, business volume of post and telecommunication services D22, number of mobile telephone subscribers D23, number of internet users D24, the per capita disposable income of urban residents D25, risk capital amount D26.

The evaluation indicators coverage is broad, and intrinsically logical, and the quantity is moderate and feasible. So it is suitable to evaluate the region technological innovation capacity.

4 Empirical Research

C. Evaluation Objects

Thirty-one regions in China: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, Shanxi, Anhui, Jiangxi, He'nan, Hebei, Hunan, Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shanxi, Gansu, Qinghai, Ningxia, Xinjiang, Liaoning, Jilin, Heilongjiang.

D. Data Source

Data come from the Chinese statistics yearbook (2005—2008), the Chinese science and technology statistics yearbook (2005—2008), the website of the People's Republic of China Ministry of Science and Technology (http://www.most.gov.cn/kjtj/), which provides a major database of China's science and technology indicators. The database provides the main data of the indicators from 2004 to 2007, which include the major provincial and municipal science and technology indicators and the main socio-economic indicators in the major cities and provinces. The Chinese science and technology statistics yearbook (2008) provides the indicator value of the number of S&T papers cited by overseas; the main search tool is 2006, but we cannot get the data of 2007. They can be forecasted according to the growth trend. Data missing inevitably led to a number of indicators for evaluating the deviation from reality. But as a whole, the individual data missing does not affect the objectivity of evaluation (Chinese S&T Development Strategy Research Group, 2003). Because of the limits of length, the original indicator value data aren't listed here.

E. The Analysis of the Bull's Eye Degree of the Regional Technological Innovation Capacity

The bull's eye degree of 31 regions in China from 2004 to 2007 is shown in Table I.

According to the principle of minimum information, if $\gamma(x_0, x_i) \geq 0.3333$, we will divide the bull's eye degree into 7 levels: [0.9, 1], [0.8, 0.9], [0.7, 0.8], [0.7, 0.6], [0.5, 0.6], [0.4, 0.5], [0.3333, 0.4]. Therefore, Guangdong is the third level; Jiangsu is the fourth level; Beijing, Shanghai, Zhejiang and Shangdong are the fifth level; Tianjin and Liaoning are the sixth level; Sichun was the sixth level in 2005 and was the seventh level in 2004, 2007 and 2008; and the other 22 regions are the seventh level.

The sorting value of the bull's eye degree from 2004 to 2007 is shown in Table II.

There are 7 regions whose regional technological innovation capacity increased from 2004 to 2007: Zhejiang ranked sixth in 2004, fifth in 2005 and 2006, and

Table I The Bull's eye Degree of the Regional Technological Innovation of 31 Regions (2004 - 2007)

Region	2004	2005	2006	2007
Beijing	0.561438	0.559804	0.565517	0.557563
Tianjin	0.410059	0.436104	0.422114	0.414822
Hebei	0.39335	0.385886	0.387116	0.39266
Shanxi	0.362318	0.361764	0.363674	0.363687
Inner Mongolia	0.353174	0.352992	0.355039	0.355019
Liaoning	0.410011	0.401263	0.406945	0.409723
Jilin	0.362822	0.365477	0.365552	0.364843
Heilongjiang	0.377292	0.371813	0.369445	0.368501
Shanghai	0.543148	0.543087	0.589038	0.545196
Jiangsu	0.677439	0.654959	0.653415	0.69584
Zhejiang	0.516286	0.541973	0.547557	0.5491
Anhui	0.375554	0.376687	0.374995	0.377118
Fujian	0.396609	0.393233	0.397	0.394248
Jiangxi	0.362912	0.368676	0.364336	0.363959
Shandong	0.525933	0.523248	0.528688	0.530635
Henan	0.390357	0.388013	0.398586	0.397959
Hubei	0.399862	0.391905	0.38975	0.389761
Hunan	0.377833	0.375067	0.375798	0.376891
Guangdong	0.799561	0.79125	0.760015	0.778305
Guangxi	0.362138	0.365425	0.358488	0.358837
Hainan	0.346668	0.345669	0.345728	0.346929
Chongqing	0.384309	0.366204	0.366419	0.36658
Sichuan	0.398144	0.408203	0.391759	0.39748
Guizhou	0.351927	0.352395	0.351538	0.351723
Yunnan	0.35808	0.355468	0.357416	0.3561
Tibet	0.351851	0.346972	0.345533	0.348255
Shaanxi	0.381224	0.373369	0.375272	0.373914
Gansu	0.350876	0.351341	0.353252	0.352674
Qinghai	0.342011	0.34128	0.341715	0.341915
Ningxia	0.343154	0.342933	0.342936	0.343704
Xinjiang	0.349223	0.347892	0.348813	0.350325

fourth in 2007; Henan ranked thirteenth in 2004, twelfth in 2005, and ninth in 2006 and 2007; Gansu ranked 27th in 2004, 26th in 2005, and 25th in 2006 and 2007; Jilin ranked 20th in 2004 and 2005 and nineteenth in 2006 and 2007; Hunan ranked sixteenth in 2004, fifteenth in 2005 and 2007, and fourteenth in 2006; Xinjiang ranked 28th in 2004 and 27th from 2005 to 2007; Anhui ranked eighteenth in 2004, fourteenth in 2005, sixteenth in 2006, and fourteenth in 2007.

There are 5 regions whose regional technological innovation capacity decreased from 2004 to 2007: Hubei ranked ninth in 2004, eleventh in 2005, twelfth in 2006, and thirteenth in 2007; Chongqing ranked fourteenth in 2004, nineteenth in 2005, and eighteenth in 2006 and 2007; Tibet 26th in 2004, 28th in 2005 and 2007, and 29th in 2006; Shandong ranked fifth in 2004 and sixth from 2005 to 2007; Guizhou ranked 25th in 2004 and 2005 and 26th in 2006 and 2007.

There are 8 regions' rankings that remain unchanged from 2004 to 2007:Guangdong ranked first, Jiangsu ranked second, Tianjin ranked seventh, Heilongjiang ranked seventeenth, Yunnan ranked 23rdl; Inner Mongolia ranked 24th; Ningxia ranked 30th; and Qinghai ranked 31st. The regional technological capacity of the other 11 regions has little change.

Table II The Sorting of Bull's eye Degree (2004 - 2007)

Region	2004	2005	2006	2007
Guangdong	1	1	1	1
Jiangsu	2	2	2	2
Beijing	3	3	4	3
Shanghai	4	4	3	5
Shandong	5	6	6	6
Zhejiang	6	5	5	4
Tianjin	7	7	7	7
Liaoning	8	9	8	8
Hubei	9	11	12	13
Sichuan	10	8	11	10
Fujian	11	10	10	11
Hebei	12	13	13	12
Henan	13	12	9	9
Chongqing	14	19	18	18
Shaanxi	15	16	15	16
Hunan	16	15	14	15
Heilongjiang	17	17	17	17
Anhui	18	14	16	14
Jiangxi	19	18	20	20
Jilin	20	20	19	19
Shanxi	21	22	21	21
Guangxi	22	21	22	22
Yunnan	23	23	23	23
Inner Mongolia	24	24	24	24
Guizhou	25	25	26	26
Tibet	26	28	29	28
Gansu	27	26	25	25
Xinjiang	28	27	27	27
Hainan	29	29	28	29
Ningxia	30	30	30	30
Qinghai	31	31	31	31

F. Contribution Degree of Region Technological Innovation Capacity Evaluation Indicator

The contribution degrees of the region technological innovation capacity evaluation indicator are shown in Table III, and the sorting is shown in Table IV.

According to the principle of minimum information, if $\gamma(x(0), x(k)) \geq 0.3333$, we will divide the contribution degree into 7 levels: [0.9,1], [0.8,0.9], [0.7,0.8], [0.7,0.6], [0.5,0.6], [0.4,0.5], [0.3333,0.4].

There are 8 evaluation indicators in the second level: D3, D6, D10, D12, D13, D16, D20, and D26.They are key influence factors. There are 12 evaluation indicators in the third level: D1, D4, D5, D8, D11, D15, D17, D18, D19, D21, D23, and D24. There are 4 evaluation indicators contribution degrees declined from the second level to the third level: D2, D7, D14 and D22. D9 was the third level in 2004, second level in 2005, third level in 2006 and second level in 2007. D25 is the fifth level, and its contribution degree is small.

There are 10 evaluation indicators contributions that declined: D2, D7, D14, D22, D13, D3, D11, D23, D1, and D15. There are 7 evaluation indicators contributions that improved: D9, D20, D16, D26, D4,D8,D24.

Table III Contribution Degree of the Evaluation Indicator (2004 - 2007)

Indicator	2004	2005	2006	2007
D1	0.784481	0.784283	0.7668	0.765469
D2	0.800187	0.803092	0.80022	0.79372
D3	0.819356	0.818687	0.807754	0.80114
D4	0.768575	0.791636	0.796319	0.796054
D5	0.785091	0.785788	0.788638	0.792687
D6	0.873538	0.876929	0.880177	0.884422
D7	0.802292	0.785903	0.773905	0.796274
D8	0.743008	0.741258	0.779735	0.785764
D9	0.757199	0.819808	0.79602	0.803251
D10	0.816632	0.817082	0.814218	0.807833
D11	0.795888	0.789813	0.786209	0.778872
D12	0.858334	0.854331	0.842048	0.833569
D13	0.821829	0.826324	0.809697	0.806781
D14	0.812101	0.810906	0.80751	0.797106
D15	0.717852	0.719525	0.731285	0.73908
D16	0.809182	0.813197	0.811769	0.81199
D17	0.783063	0.787508	0.786503	0.774128
D18	0.704935	0.744338	0.74111	0.74138
D19	0.775343	0.782963	0.777009	0.773978
D20	0.817871	0.826713	0.819136	0.81777
D21	0.750631	0.760257	0.740468	0.75497
D22	0.811485	0.808998	0.801334	0.791855
D23	0.792984	0.79953	0.787511	0.776714
D24	0.754133	0.771145	0.767904	0.788506
D25	0.550842	0.560927	0.553043	0.547478
D26	0.800537	0.821077	0.802991	0.808766

Table IV The Sorting of the Contribution Degree (2004 - 2007)

Indicator	2004	2005	2006	2007
D6	1	1	1	1
D12	2	2	2	2
D13	3	4	6	7
D3	4	7	7	9
D20	5	3	3	3
D10	6	8	4	6
D14	7	10	8	10
D22	8	11	10	15
D16	9	9	5	4
D7	10	17	20	11
D26	11	5	9	5
D2	12	12	11	13
D11	13	15	17	18
D23	14	13	15	19
D5	15	18	14	14
D1	16	19	22	22
D17	17	16	16	20
D19	18	20	19	21
D4	19	14	12	12
D9	20	6	13	8
D24	21	21	21	16
D21	22	22	24	23
D8	23	24	18	17
D15	24	25	25	25
D18	25	23	23	24
D25	26	26	26	26

4 Conclusion

The gray target theory is used to dynamically evaluate and analyze the technological innovation capacity of 31 regions in China in this chapter. We also used the bull's eye degree to classify and sort the regional technological innovation capacity and used the contribution degree to find out the contribution degree of the regional technological innovation capacity evaluation indicator in order to find out their changes and development trends.

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Analysis of the Regional Characteristics of the Distribution of Scientific and Technological Talents in Jiangsu Province*

Sifeng Liu and Keqin Sheng

This chapter is an overall summary of the scientific and technological human resources of Jiangsu Province and builds an index system of the "regional characteristics of the distribution of scientific and technological talents" by selecting the four system cluster method to carry on the cluster analysis of distributions of scientific and technological talents in 13 municipalities of Jiangsu Province. On this basis, according to different types of areas, including scientific and technological talent-intensive areas, comparably intensive areas, the lacking scientific and technological talent areas and the areas having rare scientific and technological talents, this chapter makes an in-depth analysis of the typical features of the regional distribution of scientific and technological talents in Jiangsu Province.

1 Introduction

In general, scientific and technological talents refer to those with virtue and scientific and technological expertise, and they have mastered the knowledge or the technology of the production process. Nevertheless, it is a broad, abstract and dynamic concept that varies with the understandings of different people. Scientific and technological talents can be divided into three levels in accordance to the content and scope of scientific activities they have been engaged in: professional and technical personnel, scientific and technological activities and research and development personnel. In the context of a knowledge-based economy, science and technology personnel, as well as the development of science and technology decided by the scientific and technological talents, often play a dominant role in the economic development and technological innovation of a nation or region. So the study of the characteristics of the regional distribution of scientific and technological personnel and the analysis of the key issues of the development of

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* This work was subsidized by the National Soft Science Research Project (2008GXS5D115) and National Social Science Foundation Key Project (08AJY024).

scientific and technological personnel in different parts have a strong practical significance for decision-making departments to adopt targeted policies and measures for personnel, as well as a great and far-reaching importance for advancing regional economic development and improving the level of regional scientific and technological innovation.

Currently, the study of regional characteristics of the distribution of scientific and technological talents has just started. Existing literature have carried on beneficial discussions on the imbalance of the regional distribution of China's scientific and technological personnel, the structural characteristics of geographical distribution and the mobility of IT personnel, etc. Zhou Guirong, etc. (2005) has taken a systematic study of problems in the regional distribution of China's scientific and technological personnel and countermeasures. She thinks that the differences in the number of talents is widening between coastal and inland areas of China, and the proportion of regional scientific and technological talents to their geographic areas is losing its balance and that the uneven economic development in central and western regions of talent has fundamentally led to the uneven distribution. On this basis, she put forth the relevant countermeasures. Gui Zhaoming, etc. (2001) researched the spatial distribution and structural features of China's scientific and technological talents and analyzed the regional spatial characteristics of the distribution of scientific and technological talents. Wang Wei (2006) pointed out that the idleness and shortage of China's scientific and technological personnel co-exist, particularly in developed areas along the southeast coast, where there is serious talent idleness and waste, and analyzed this phenomenon with the use of the Gambling model. Zuo Hanbin (2004) made a detailed analysis of the distribution and structure of scientific and technological talents in Hubei Province and thought that the distribution of the province was a structural shortage of talent. LI Fuchu (2005) not only respectively calculated the deviation coefficient of each of the million scientific and technological talents between and within the different regions of central and western of China to analyze the differences to the degree, but also divided various cities into 5 types, and pointed out the typical types of provinces and cities according to the total science and technology human resources, the per capita indicators and the three departments that have the entropy value. Overall, research on the characteristics of the distribution of scientific and technological personnel has yet to be made further in-depth. Among the existing literatures, there are still few comprehensive studies in addition to studying only larger regions' characteristics of the geographic distribution of scientific and technological personnel. In view of this, it is particularly essential to conduct a detailed study on the regional characteristics of the distribution of scientific and technological personnel for typical provinces.

2 Overview of Science and Technology Human Resources in Jiangsu Province

In recent years, the number of scientific and technical personnel of Jiangsu Province has been expanding. The number of technological activities, scientists and

Table 1 The total scientific and technological personnel of Jiangsu Province compared to other coastal areas (2006). Unit: ten thousand persons.

Area	Technological activities personnel	Scientists and engineers	R & D personnel
Shandong	28.54	18.77	9.66
Jiangsu	38.11	23.9	13.89
Zhejiang	31.05	18.98	10.28
Fujian	10.11	6.48	4.02
Guangdong	36.88	25.93	14.72
Shanghai	20.07	15.04	8.02
National	413.15	279.78	150.25

Source: Ministry of Science and Technology of the People's Republic of China website.

engineers, and R & D personnel are ahead of the number of its neighboring provinces Shandong, Zhejiang, Fujian, and Shanghai, while the latter two are slightly lower than that in Guangdong Province (as shown in Table 1). Personnel of Jiangsu Province engaging in scientific and technological activities accounted for more of the total amount of technological activities in recent years, which results from the emphasis on innovation and the strengthening of the high-tech industrial development and science and technology talent of Jiangsu Province.

Since 2000, among the staff of scientific and technological activities of Jiangsu Province, personnel who have gotten high or intermediate professional titles or a university undergraduate degree or above have increased year by year, of which the average annual growth rate in the higher education institutions is 17.8%, and the growth rate even reaches 21.15 % in medium-sized enterprises, both of which far exceed the average annual growth rate of technological activities in Jiangsu Province.

In Jiangsu Province, the distribution of the scientific and technological talents industry is concentrated. For instance, R & D personnel are mainly in business and government R & D institutions and universities. For example, in 2005, Jiangsu Province had 128,028 full-time R & D personnel, a total of 12,326 of which were at government R & D institutions and accounted for 9.63%; R & D personnel in medium-sized enterprises were 72,388, accounting for 56.54%; and researchers of institutions of higher education are 16,535, accounting for 12.92%. The sum total of the three parts made up 79.09% of the province's R & D personnel. Other departments involved in D & R activities of the researchers accounted for only 20.91%.

In recent years, in Jiangsu Province, the research results obtained a rapid growth, and transaction contracts of the technological market were increased year by year. Among those from 2000 to 2007, the amount of received patent applications and invention patent applications granted increased, respectively, at a average rate of 38.62%, and 44.59%; the annual average growth rate of the two separately were 21.64%, and 27.61%. Thus, the vitality of innovation has been noticeably strengthened. The volume of full-year technology contracts in 2000 in Jiangsu Province reached 45 billion Yuan. In 2007, the province signed a total of 18,000

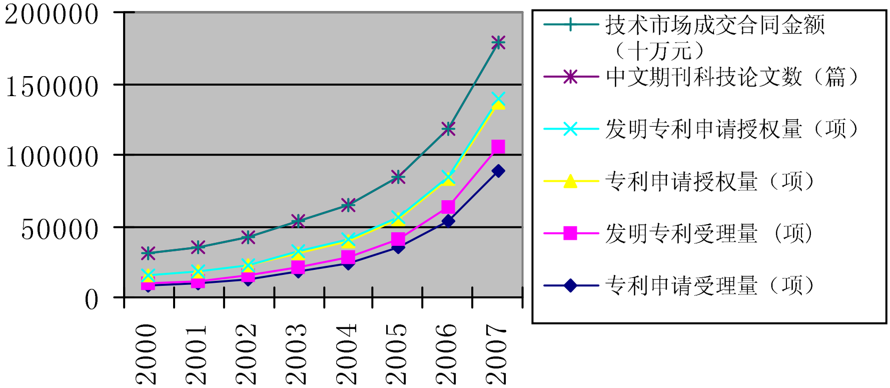

Fig. 1 In Jiangsu Province, the changes of research results in recent years, (2000 – 2007)

different types of technical contracts, among which the volume of the dealt contracts was up to 15.23 billion Yuan, an increase of 238.4%. This is shown in Figure 1.

3 The Cluster Analysis of the Regional Distribution of Scientific and Technological Personnel of Jiangsu Province

This chapter analyzes the 13 provincial cities in Jiangsu Province with four kinds of systematic clustering methods to build an indicator system of the "characteristics of the regional distribution of scientific and technological talents", such as what is shown in Table 2.

Table 2 Characteristics of the regional distribution of scientific and technological talents index system

Regional distribution of scientific and technological talents	Human resource base	X1, X2, X3
	The number of scientific and technological personnel	X4, X5, X6, X7, X8, X9, X10
	Scientific and technological activities	X12, X13, X14
	Hi-tech industry development	X15, X16, X17
	Labor productivity	X18
	Environmental governance	X19, X20
	Scientific and technological innovation	X21, X22
	Growth	X23, X24

In Table 2, X1 is numbers of students in secondary school and above for every ten thousand people in the population (persons / ten thousand people), X2 is professional and technical personnel numbers for every ten thousand people in the population (persons / ten thousand people), X3 is the graduation rate of junior high school (%), X4 stands for the technological activities staff (ten thousand), X5 represents D & R staff (ten thousand), X6 is the average rate of change in technological activities, X7 is all the kinds of professional and technical personnel (ten thousand people), X8 is the intermediate technical title and above (ten thousand people), X9 is scientific and technological activities accounting for the proportion of employees (%), X10 is R & D staff accounting for the proportion of technological activities (%), X11 is corporate R & D activities of staff accounting for the proportion of enterprise employees (%), X12 is the R & D expenditure of the whole society in proportion to the GDP (%), X13 is the government science and technology funding ratio of the total expenditure (%), X14 is the corporate R & D accounting for the proportion of sales revenue (%), X15 is the high-tech industry sales income (hundred million), X16 is the high-tech industry's contribution to the growth rate of industrial output (%), X17 is the high-tech industry exports accounting for the proportion of sales revenue (%), X18 is the labor productivity (Yuan / person), X19 is comprehensive management of the environmental quality index, X20 is the Resources Comprehensive Utilization Index, X21 is the number of patent applications for each of thousands of people, X22 is the number of patents per hundred thousand people, X23 is the per capita GDP, and X24 is the GDP growth rate (%).

Based on the cross-section data processed through SPSS software in 2007, using two methods of factor analysis and principal component analysis, these 24 indicators are represented by all four factors that are not relevant to each other, and the coverage of the amount of information reaches 88.928%. The score coefficient matrix of the new factors is shown in Table 3.

Table 3 Factor score coefficient matrix

Area	Y1	Y2	Y3	Y4	Area	Y1	Y2	Y3	Y4
Nanjing	3.07657	-0.73644	-0.10093	-0.26836	Huai'an	-0.80397	-0.57618	0.33622	-1.14577
Wuxi	0.48066	0.94835	1.02107	-0.56913	Yancheng	-0.31566	-0.36456	-1.32638	-0.65542
Xuzhou	-0.62266	-0.38378	1.11212	-1.39898	Yangzhou	-0.01173	-0.86548	1.11757	0.76094
Changzhou	0.25877	0.16871	0.05609	1.49837	Zhenjiang	-0.42147	0.27437	0.52194	0.92406
Suzhou	0.21134	2.81171	-0.66159	-0.5402	Taizhou	-0.45887	-0.33189	0.25264	1.13885
Nantong	-0.57803	0.39436	0.01452	1.19078	Suqian	-0.36375	-0.78192	-2.40985	0.15794
Lianyungang	-0.45119	-0.55726	0.0666	-1.09308					

Table 3 is the based data matrix of the systematic clustering study, with the four methods of the center of gravity: the deviation sum of squares method, group average chain method, and the shortest distance, which cluster the scientific and technological talents of Jiangsu Province. The running results of the SPSS software are shown in Table 4.

Table 4 Comparison of four different methods of clustering results

Center of gravity method	Deviation sum of squares method	Group average linkage method	The longest distance method
1: Nanjing 1	1: Nanjing 1	1: Nanjing 1	1: Nanjing 1
2: Wuxi 1	2: Wuxi 1	2: Wuxi 1	2: Wuxi 1
3: Xuzhou 2	3: Xuzhou 2	3: Xuzhou 2	3: Xuzhou 2
4: Changzhou 3	4: Changzhou 3	4: Changzhou 3	4: Changzhou 3
5: Suzhou 1	5: Suzhou 1	5: Suzhou 1	5: Suzhou 1
6: Nantong 3	6: Nantong 3	6: Nantong 3	6: Nantong 3
7: Lianyungang 2	7: Lianyungang 2	7: Lianyungang 2	7: Lianyungang 2
8: Huai'an 2	8: Huai'an 2	8: Huai'an 2	8: Huai'an 2
9: Yancheng 4	9: Yancheng 4	9: Yancheng 4	9: Yancheng 4
10: Yangzhou 3	10: Yangzhou 3	10: Yangzhou 3	10: Yangzhou 3
11: Zhenjiang 3	11: Zhenjiang 3	11: Zhenjiang 3	11: Zhenjiang 3
12: Taizhou 3	12: Taizhou 3	12: Taizhou 3	12: Taizhou 3
13: Suqian 4	13: Suqian 4	13: Suqian 4	13: Suqian 4

It can be found that despite the different clustering methods used, the results of the clustering are the same. According to Table 10, these cities of different levels in Jiangsu Province jurisdiction can be divided into four categories, according to the characteristics of the distribution of scientific and technological personnel: in the first category are Nanjing, Wuxi, and Suzhou, which are located in the most developed areas in southern Jiangsu; in the second category are Xuzhou, Lianyungang, and Huai'an, in more developed regions of northern Jiangsu; in the third category are Changzhou, Nantong, Yangzhou, Zhenjiang, and Taizhou, which borders of southern Jiangsu and central Jingsu; in the fourth category are Yancheng and Suqian, belonging to backward regions in northern Jiangsu. This chapter furthers the regional definition according to the characteristics of the distribution of scientific and technological talents. The scientific and technological personnel-intensive areas are Nanjing, Wuxi, and Suzhou; comparably intensive areas are Changzhou, Nantong, Yangzhou, Zhenjiang, and Taizhou; the lack of scientific and technological talents district is of Xuzhou, Lianyungang, Huaian; and scientific and technological talent-poor areas are Yancheng and Suqi.

4 The Typical Characteristics of the Regional Distribution of Scientific and Technological Personnel of Jiangsu Province

4.1 The Regional Distribution of Scientific and Technological Talents Has Apparently Become Non-equilibrium

View the results of the clustering, the uneven distribution of scientific and technological personnel in each city of Jiangsu Province and the regional economics mainly is the same as the development imbalances that are inseparable between geographical location, economic environment, and historical development in Jiangsu Province. The distribution of scientific and technological personnel in different kinds of regions has distinct characteristics.

Nanjing, Wuxi and Suzhou all belong to the southern Jiangsu area and are also the main gathering places of high-tech industry development, so it is nature for high-tech talent to gather there. Nanjing is a city; Jiangsu is the most concentrated with politics, economy, culture, science and technology, education, transportation, international markets, information and other resources, and it has the largest the number of research institutions and universities in the province, so its status and location advantages of are not accessible for other cities. Suzhou is located south of the fertile Yangtze River Delta. It is in this city that the new technology industry rapidly develops with an increased scale and speed, thus enhancing the whole economy of Suzhou at a constant rapid growth and drawing global attention to the emerging technological cities. Wuxi is located in Taihu Lake and is an important industrial and tourist city, having long been "little Shanghai". It is now renowned for its textile, microelectronics, machinery and industry. Taking new roads to industrialization with science and technology as support, southern Jiangsu forms electronic information, biological medicine, new materials and a number of high-tech industries, and the petrochemical industry, metallurgy, machinery and other traditional industries; it glows with a new vitality after a high-tech transformation.

From a geographical point of view, scientific and technological personnel-intensive areas are mainly located in the southern and central parts of Jiangsu and in the transition location. The cities in these areas emphasize the development of high-tech industries, and a crowd of more types of scientific and technological talents is also gathered here. To speed up the transformation of scientific and technological achievements of overseas students, Jiangsu Province has established a "talent zone" and vigorously given priority to the returned overseas Chinese talent. Along the Yangtze River in eight cities, Jiangsu establishes an employment zone in eight cities, except Nanjing, Wuxi, and Suzhou. "Talent special economic zones" strengthen science and technology entrepreneurship parks, high-tech incubator base construction, innovation and entrepreneurial excellence, and the students can build a "special platform," to attract more high-tech talent to join. At present, internationally renowned enterprises have stationed in the Changzhou High-tech Zone, so the high-tech region continues to absorb international advanced technology, and the high-tech economy continues to increase. Zhenjiang is the ship industry, and the development of the domestic part of the ship is on behalf of the shipbuilding technology level of our country's marine technology research and development. Jiangsu Science and Technology University has the mechanical strength of a domestic first-class engineering group and is located in Zhenjiang, as well as Jiangsu University. Zhenjiang has a more competitive edge over other cities in the shipping industry, scientific research, design and professional skills. Taizhou City has a state-level Torch Plan Project. Jiangyan is a car key components industry base and medicine and industrial base. There is a Russian cooperation along the Yangtze River in Taixing, Jiangsu, within the inside of the new material industrial park and the National "863" plan Chunlan Group industrial base. These are seven state-level, high-tech characteristic industry bases. Yangzhou, with its unique ecological, historical and cultural advantages, has a formation of cultural industries, and its eco-industry complements the modern economy; motor vehicles and parts, metal sheet processing and equipment manufacturing and semiconductor lighting are classified as state-level industrial bases. CAS application technology, R & D and industry Jan-based centers and similar institutions settle down here, so it will form high-tech enterprises in Yangzhou with a certain amount of momentum and will form a strong combined effect of scientific and technological talents. Nantong continuously increases the introduction of high-level personnel training efforts and organizes experts and academic leaders at all levels for selection and training. High-level professionals continue to increase.

Xuzhou, Lianyungang, and Huai'an, which are in the lack of scientific and technological talents district, are located in the northern Jiangsu area. They are also relatively well developed in the northern Jiangsu area. The Northern Jiangsu area, with an excellent natural environment and land, fresh water, non-metallic minerals and more abundant marine resources, has strong education and well-grounded, deep cultural heritage, abundant labor resources, and strong power in mining, machinery, marine, agriculture and other fields of scientific research. The construction of the Longhai industrial belt cities of Xuzhou and Lianyungang has brought new opportunities for development, and high-tech talent aggregation is higher. Huai'an city is located in the hinterland of the northern plains, and the main concentration of high-tech talent is in the Huai'an economic development zone.

Yancheng is located in the hinterland of the North Jiangsu Plain with an unbalanced development of the three industries in the region. Although the secondary industry takes a dominant position, the proportion of primary industry is still quite large; the third industries are not being developed. An irrational industrial structure causes sluggish growth in the electronics, machinery, medical and other high-tech industries, as well as poor high-tech talent. Suqian city has certain economic advantages because it has the coastal Longhai economic zones along the Yangtze River economic belt cross-radiation zone; but because of the region's weak economic foundation, long-term economic development lags behind, and the Suqian high-tech industry has not yet developed.

4.2 The Human Resource Base in Various Regions Is Quite Different

The development of higher education and the distribution of professional and technical personnel are the base of science and technology talent development.

As of the end of 2007, Jiangsu Province has a total of 121 colleges and universities, of which there were 44 undergraduate colleges and 77 higher vocational schools; in 2007, Jiangsu Province had a regular higher education enrollment of 454.7 thousand people, of which 1.5688 million students were undergraduates and 333.6 thousand people had graduated. Enrollment for post-graduates was 33,600 people, with 96,500 in-school graduates and 24,000 graduates. The higher education gross enrollment rate is 37%. The province's secondary vocational education students reached 1.5253 million. Although Jiangsu's higher education in the overall development trend is good, a big gap between the developments of the provincial municipality still exists. Nanjing, Wuxi, and Suzhou City, with a total of 71 colleges and universities, account for 58.6% of the total number of the province's colleges and universities, and the colleges and universities gathered for the regional scientific and technological talents to provide a strong support; meanwhile, Suqian and Yancheng have only six colleges and universities, and the scientific and technological personnel training foundation is weak.

Professional and technical personnel in modern industrial society are the backbone of the middle-class group. They are both advanced productive forces and representatives of a culture, as well as innovators and communicators of the dominant value system and ideology of society. They are to maintain social stability, stimulate social progress and provide an important force for the main echelon of scientific and technological talent. In 2007, Jiangsu’s science and technology talent-intensive areas and the more intensive areas of professional and technical officers accounted for 75.21% of the province's professional and technical staff, which is three times the sum of the other two regions. Obviously, such a distribution is not conducive to professional and technical personnel in Jiangsu Province for balanced development between the different regions at the same time. This situation is also largely restricted to the development of high-tech industries in backward areas and the northern Jiangsu area’s economy as a whole.

4.3 The Regional Science and Technology Investment Significantly Are Different in Jiangsu Province

Scientific and technological input provides the necessary conditions for scientific and technological progress and innovation and would enhance scientific and technological ability to continuously innovate. In recent years in Jiangsu Province, both human input and financial resources in science and technology inputs are presented to increase with a year-by-year trend, but there is also a significant gap around the city. In 2007, the results of the scientific and technological progress and technology statistics bulletin shows that the scientific and technological personnel in the poor Suqian Yancheng district, whether it is R & D staff accounting for the proportion of technological activities or corporate R & D activities of staff accounting for the proportion of all enterprise employees, are in the province's final 2, while in the scientific and technological personnel-intensive areas of Nanjing, Wuxi and Suzhou, science and technology activities accounting for the proportion of employees were 2.26%, 1.57% and 1.65%, at the forefront of Jiangsu Province.

Table 5 In 2007 in Jiangsu Province, the input of manpower and financial resources

Area	Scientific and technological activities accounting for the proportion of employees (%)		R & D activities in technological activities accounting for the proportion (%)		Corporate R&D activities, the proportion of staff accounting for enterprise workers (%)		Whole society's R & D expenditure to GDP ratio (%)	
	Statistics	Sort	Statistics	Sort	Statistics	Sort	Statistics	Sort
Nanjing	2.26	1	46.55	1	4.04	1	2.65	1
Suzhou	1.65	2	41.51	11	1.1	11	1.72	4
Changzhou	1.62	3	40.26	2	2.34	2	1.78	3
Wuxi	1.57	4	48.74	5	1.82	5	2.00	2
Zhenjiang	1.29	5	43.43	4	1.87	4	1.50	5
Yangzhou	0.8	6	52.36	6	1.73	6	1.43	6
Nantong	0.62	7	41.02	7	1.67	7	1.22	8
Taizhou	0.61	8	43.05	3	1.88	3	1.37	7
Yancheng	0.39	9	32.06	12	0.87	12	0.16	13
Xuzhou	0.38	10	51.55	8	1.61	8	1.09	9
Lianyungang	0.27	11	36.07	9	1.34	9	0.93	10
Huaian	0.21	12	44.28	10	1.19	10	0.68	11
Suqian	0.08	13	24.4	13	0.36	13	0.41	12

Source: the results of scientific and technological progress and technology statistics bulletin of Jiangsu Province in 2008.

During the "Tenth Five-Year" period, the overall financial technology industry spent 11.057 billion Yuan, which is more than the "ninth five-year," increasing 6.483 billion Yuan, with an increase of 141.7 percent and an average annual increase of 22.2%. In 2007 in Jiangsu Province, the whole R & D expenditure to GDP accounts for 16.94%, of which the science and technology talent-intensive area's three municipalities (Nanjing, Wuxi, Suzhou) combined for a proportion of 6.37%. It is nearly twice as much of that of northern Jiangsu area, namely, the lack of scientific and technological personnel district (Xuzhou, Lianyungang, Huai'an), and the technology professionals-poor areas' (Yancheng and Suqian) total (3.27%), while the scientific and technological talents in the more developed areas' (Changzhou, Nantong, Yangzhou, Zhenjiang, Taizhou) whole R & D spending accounts for a proportion of the GDP, totaling 7.3% with a rapid development momentum. The specific circumstances are in table 5.

4.4 The Effect of Reverse Brain Drain in Less Developed Areas in Jiangsu Is Even More Critical for Scientific and Technological Talents

G. Myradal (1957) put forth economy effects of two opposing effects the economically developed areas put on the less developed regions: First, the back effect, which is the performance of each factor of production from underdeveloped regions to developed regions, inevitably producing differences in the expansion of regional economic development. Secondly, the diffusion effect, which is the performance of each factor of production from the developed regions to developed regions so that the regional development differences are narrowing. Prior to reaching a critical point in the market mechanism, the return flow is much larger than the spillover effect, leading to more developed regions and less-developed regions. Looking at different regions of Jiangsu Province and their scientific and technological personnel changes, the return flow is typically much larger than the diffusion effect.

During the "Tenth Five-Year" period in Jiangsu Province, with a total of 13 municipal areas for technology professionals, major changes in the distribution pattern did not occur; at the first stage of the "Eleventh Five-Year", this trend had not been fundamentally reversed and even possibility of further exacerbated. Table 6 is for Jiangsu Province science and technology activities and R & D activities for the geographical distribution of staff. The table data shows that over 50% of workers' science and technology activities are in Jiangsu Province, and R & D activities are concentrated in Nanjing, Wuxi, and Suzhou. There is an inadequate proportion for Suqian of 1%; Xuzhou, Huaian, Lianyungang, Yancheng and Suqian, are basically the first and second industry, and the high-tech industrial development is slow, so the economic development gap is further widened. The flow of scientific and technological personnel performance represents the grounds for the main flow in northern Jiangsu and the southern flow of small cities to major cities, namely, from the area lacking scientific and technological personnel and poor area-intensive areas to the talent-intensive scientific and technological areas. At present in Jiangsu Province, the imbalanced distribution of technological innovation for all kinds of talent are mostly concentrated in Nanjing, Suzhou, Wuxi and other cities in southern Jiangsu, especially in universities, research institutes, large enterprises and foreign-funded enterprises. However, in the northern small and medium cities, especially those in areas below the county-level, scientific and technological personnel are in shortage. For pay and benefits, social environment, living environment, personal career development and meeting the spiritual needs, such areas cannot compete with the large and medium cities in southern Jiangsu. On one hand, trained students and graduate students who are sent out are unwilling to return to work; on the other hand, most of the middle-aged experts with high-level technical positions are of the serious-tech brain drain. The reverse brain drain effect could lead to areas lacking scientific and technological personnel and poor areas of scientific and technological talent cities. The science and technology talent gap is serious, and the situation is more severe; particularly those small and medium-sized companies, which are rich in potential for development but face a severe manpower shortage.

Table 6 The geographical distribution of technological activities of Jiangsu Province (Unit: million persons)

Area	Technological activities				R & D personnel			
	2007		2005		2007		2005	
	Total	Proportional	Total	Total	Total	Proportional	Total	Proportional
Nanjing	7.3995	20.40%	5.6054	6.2467	3.4445	21.54%	2.3229	23.20%
Wuxi	4.8340	13.32%	3.9042	3.7630	2.3561	14.73%	1.5414	15.40%
Xuzhou	1.7828	4.91%	1.4470	1.4634	0.9190	5.75%	0.6179	6.17%
Changzhou	4.1535	11.45%	3.2114	2.8482	1.6722	10.46%	0.9782	9.77%
Suzhou	7.1148	19.61%	5.0569	4.3520	2.9534	18.47%	1.8776	18.76%
Nantong	2.7866	7.68%	1.8665	1.8606	1.1431	7.15%	0.6381	6.37%
Lianyungang	0.6527	1.80%	0.6145	0.5364	0.2354	1.47%	0.1941	1.94%
Huaian	0.5915	1.63%	0.4106	0.4853	0.2619	1.64%	0.1142	1.14%
Yancheng	1.2439	3.43%	0.9551	0.8912	0.3988	2.49%	0.2500	2.50%
Yangzhou	1.9511	5.38%	1.7734	1.8951	1.0216	6.39%	0.6343	6.34%
Zhenjiang	1.9760	5.45%	1.1135	1.2764	0.8582	5.37%	0.3697	3.69%
Taizhou	1.5609	4.30%	1.2220	1.1454	0.6720	4.20%	0.4703	4.70%
Suqian	0.2309	0.64%	0.1338	0.1608	0.0563	0.35%	0.0016	0.02%

Source: The results of a 2008 scientific and technological progress and technology statistics bulletin in Jiangsu Province.

5 Conclusion

The distribution of scientific and technological personnel in Jiangsu Province closely relates to different regional characteristics of the region's economic development, social development, and regional factors, such as the environment. There are also objective reasons and work-related issues; the current regional distribution of the formation of scientific and technological personnel gap will have a far-reaching impact on the economic and social development in Jiangsu Province, especially for North Jiangsu and other economically underdeveloped areas. To reverse the current negative situation of the distribution of scientific and technological personnel and to relieve the pressure of demanding talents in echnology professional-poor areas (Yancheng and Suqian) and the manpower shortage areas (Xuzhou, Lianyungang, Huai'an), there is a need to work together in Jiangsu from top to bottom. In particular, mobilizing these two types of enthusiasm in the region, changing the idea of human resources work, and increasing personnel policy innovations are needed. On the other hand, there is a need for IT personnel in Jiangsu Province to further study the status of the regional distribution of deep-seated problems so that they can reveal the development of the internal mechanism and evolution in order to provide theoretical support for solving the problem of the development of more science and technology professionals in Jiangsu Province. A follow-up study associated with this chapter will focus on these areas.

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The Novel Energy Policy Evaluation Method and Its Application in Oil and Gas Fields in China

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With industrialization and urbanization constantly speeding up in China, the energy consumption grows rapidly. As the energy consumption rapidly increases, the energy production has been unable to meet the requirements of the energy consumption growth. Energy saving is mainly focused on energy-saving technologies and the choice of energy-saving measures, but the research of appraisal on energy conservation policies are few. Based on the property of the energy policy evaluation, the evaluation method of the three-point interval number comparison matrix is put forth to solve the problem of preference information that is often lost by modeling complex group decision-making processes. The proposed method's consistency, weight estimation approach and group decision-making aggregation approach are studied. Based on the complete consistency definition of the three-point interval number matrix, a definition of the possible value error is introduced. Lastly, several energy policies on oil and gas fields in China are evaluated via the suggested approach, and it illustrates the steps and its validity.

1 Introduction

With industrialization and urbanization constantly speeding up in China, the energy consumption grows rapidly. The growth rate of the GDP in 2003 and 2004 was 9.5%, while the growth rate of energy consumption reached 15.33% and 15.24%, respectively, greatly exceeding the GDP growth rate. As energy consumption increases rapidly, energy production has been unable to meet the requirements of energy consumption growth since 1992. The energy gaps increased sharply from

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1998 to 2000, and it achieved a historical peak in 2000. The unit GDP energy consumption in 2002, 2003 and 2004 is 1.30, 1.36 and 1.43 tons of standard coal per thousand. Although the unit GDP energy consumption dropped in 2006, the energy use situation was still stern. High energy consumption often brings high pollution. In recent years, dust and smoke emissions in China haven't been significantly reduced. The emissions of SO_2 have increased gradually. The air pollution is serious, and the environmental situation is bad. The Chinese government is firmly determined in regards to energy consumption, and energy-saving policies appeared one by one. "The saving energy law of the People's Republic of China" brought China energy conservation work to the legal system track. The "11th Five-Year Plan" identified that the unit of the GDP will reduce 20 percent in 2010 compared to 2005. It was the first time energy conservation was established in the form of legal documents that must be completed. Although the government has the ambition to conserve energy, the energy conservation work encountered many obstacles. Energy-saving work faces tremendous pressure and challenges in the first year of the "11th Five-Year Plan". The effectiveness of the government's energy conservation policy is actually the appraisal of the government energy conservation policies. In regards to fundamental energy conservation research, Klein (2004) discussed the DSS department, which the energy conservation project developed to support local authorities in implementing the energy conservation projects. Nandwani (2006) discussed Costa Rica's existing resource condition and its electricity generation, and the frugal energy condition that uses solar energy. At present, papers on energy saving mainly focus on their own research on energy-saving technologies and the choice of energy-saving measures, but the research on the appraisal of energy conservation policies are few.

Because of differences in knowledge structure, judgment level and individual preference, decision-makers express their judgment preferences via different structured decision-making processes (see Chiclana et al., 1998). Owing to the complexity and uncertainty of decision-making problems and the fuzziness of human thought, it is unrealistic to depict complex problems in the certain preference style. When investigating uncertain decision-making scenarios, some scholars focus on uncertain mathematical methods, such as interval numbers (see Zhu et al., 2004; Mikhailov, 2004; Bryson et al., 2000; Wang et al., 2005), fuzzy numbers (see Buckley et al., 2001; Zhu et al., 1999), the random theory (see Basak, 1998; Haines, 1998) and unascertained numbers (see Zhu et al., 2005; Liu et al., 1999; Wan et al., 2004). These are all widely used in the decision-making field. Based on existing studies (see Bu et al., 2001; Wang et al., 1996), the three-point interval number comparison matrix is suggested here as an alternative method of expressing the decision-maker's uncertain preferences. For decision-making preference structures, group decision-making aggregation approaches include aggregation of the same kind of preference structure and the different kinds of preference structures. The study on the aggregation of the same kind of preference structure has received a deal of attention (see Beynon et al., 2000; Ray et al., 1998), but the study of the aggregation of the different kinds of preference structures is still a new field (see Delgado et al., 1998; Xiao et al., 2001). In groups, individual decision-makers provide different preference structures, due to differences in their knowledge structure, judgment level, and individual preferences. The development of intelligent decision-making support systems, integrated by communication and computer technologies, should improve the practicality and feasibility of group decision-making. A new way to express decision-makers' preferences via a three-point interval number comparison matrix is put forth. Because of the complexity of the energy policy evaluation and because many people are involved in the evaluation process, how to express the preference and aggregate many decision-makers preferences in an open decision-making case needs to be studied. The key problems are as followers: (1) A unified and comprehensive multi-scale evaluation criterion is lacking. The measure of a policy implementation effect is involved in policy-making, implementation and performance, etc. It isn't sufficient to indicate the effect and potency of the policy solely from some aspects. (2) The evaluation system combining prior evaluations, matter in the evaluations and ex-post evaluations is lacking. Prior evaluation is a basis for policy development work, but it doesn't receive the attention it deserves. Because of the separation of evaluation execution and the unimpeded information feedback channel, the matter in the evaluation system hasn't been formed effectively. (3) The evaluation methods and system research of information asymmetry and incomplete information policy are lacking. Because of the diversity of policy resources, the existence of policy overlap and the universality of policy influence, it's difficult to collect policy information, so the evaluation process involves a lot of uncertainty.

2 The Three-Point Interval Number Reciprocal Comparison Matrix

2.1 Induction of the Three-Point Interval Number

When working on uncertain decision-making problems, scholars have expanded the AHP (Analytical Hierarchy Process) in various ways, including the development of the interval AHP, the fuzzy AHP, and the random AHP. These approaches broaden the AHP's scope of application. However, they struggle when the comparison elements do not form a continuous distribution, as estimated by the weight vector. The continuous distribution assumption may not reflect the decision-makers' preferences in any given case. A three-point interval number is, therefore, suggested to express the decision-makers' uncertain preferences and the new interval number style $\overline{a_{12}} = [1, 3, 5]$ is adopted. In the example, the value "3" is the most possible judgment and the judgment possibility is 80%.

Definition 1. The interval number $[c_{ij}{}^{L}, c_{ij}{}^{M}, c_{ij}{}^{U}]$ is called a 'three-point interval number' if the relationship $c_{ij}{}^{L} \le c_{ij}{}^{M} \le c_{ij}{}^{U}$ is satisfied. The value $c_{ij}{}^{L}$ is the lower possible value of the judgment, the value c_{ij}^{U} is the upper possible value, and c_{ij}^{M} is the most possible judgment value.

When applying the three-point interval number in the decision-making process, a single decision-maker can adopt the two-point interval number to estimate the upper and lower value $[c_{ij}^{L}, c_{ij}^{U}]$. Meanwhile, he should provide the most possible judgment value c_{ij}^{M} according to his estimation. For group decision-making, a statistical approach can be used to fit decision-makers' preferences, and a three-point interval number judgment can be obtained. The distribution probability of the most possible value $P(c_{ij}) \geq \delta, \delta$ is constant, and its value is decided by the decision-makers' experience. Only when δ reaches a certain degree, can it be called the most possible value. In group decision-making, if $\delta < 60\%$, it indicates that the preference is too diverse.

2.2 *Consistency and Weight Estimation of Three-Point Interval Number Comparison Matrices*

Definition 2. The comparison matrix $\overline{C} = (c_{ij}^{L}, c_{ij}^{M}, c_{ij}^{U})_{n\times n}$ is called a 'three-point interval number reciprocal comparison matrix' where: $c_{ij}^{L} \leq c_{ij}^{M} \leq c_{ij}^{U}$, $\overline{c_{ji}} = [1/c_{ij}^{U}, 1/c_{ij}^{M}, 1/c_{ij}^{L}]$ and $\overline{c_{ii}} = [1,1,1]$.

This is a new way of expressing uncertain preferences using a three-point interval number composed of upper, lower and most possible values. The decision-makers' real preference is amongst the upper, lower and most possible values, but it is difficult to ascertain. One cannot simply split the three-point interval number comparison matrix into a matrix composed of the lower judgment value, most possible value, and upper one. In addition, the matrix composed of upper and lower judgments may be non-consistent (see Zhu et al., 2004).

Definition 3. The set $w_i, i = 1, \cdots, n$ is said to be the "weight" of a three-point interval number reciprocal comparison matrix. If formula (1) is satisfied, the three-point interval number reciprocal comparison matrix is completely consistent. If the $w_i, i = 1, \cdots, n$ does not satisfy formula (1), the three-point interval number reciprocal comparison matrix is not completely consistent.

$$c_{ij}^{L} \leq c_{ij}^{M} = \frac{w_i}{w_j} \leq c_{ij}^{U}, i, j = 1, \cdots, n, i \neq j \tag{1}$$

If a matrix $\overline{C}$ is completely consistent, formula $c_{ij}{}^{M} = \frac{w_i}{w_j}$ is satisfied, which means the decision-makers' judgment corresponds to the most possible value. If $\overline{C}$ is not completely consistent, $c_{ij}{}^{M} \neq \frac{w_i}{w_j}$, or $c_{ij}{}^{L} \geq \frac{w_i}{w_j}$, or $c_{ij}{}^{U} \leq \frac{w_i}{w_j}$. Error variables cpo_{ij}, cdo_{ij} are introduced to the relationship of $c_{ij}{}^{M} \neq \frac{w_i}{w_j}$, such that it satisfies $cpo_{ij} \geq 0, cdo_{ij} \geq 0, cpo_{ij} \times cdo_{ij} = 0$. This satisfies formula (2):

$$c_{ij}{}^{M} w_j - w_i + cpo_{ij} - cdo_{ij} = 0, i, j = 1, \cdots, n, i \neq j \tag{2}$$

If formula (2) does not satisfy $c_{ij}{}^{L} \leq \frac{w_i}{w_j} \leq c_{ij}{}^{U}$, the error variables cp_{ij}, cd_{ij} are introduced, with $cp_{ij} \geq 0, cd_{ij} \geq 0$. This satisfies formula (3):

$$\begin{cases} c_{ij}{}^{L} w_j \leq w_i + cp_{ij}, i, j = 1, \cdots, n, i \neq j \\ w_i \leq c_{ij}{}^{U} w_j + cd_{ij}, i, j = 1, \cdots, n, i \neq j \end{cases} \tag{3}$$

The lower the value of $\sum_{i,j} cpo_{ij} + cdo_{ij}$, the shorter the deviation distance from the most possible value $c_{ij}{}^{M}$. In addition, the lower the value of $\sum_{i,j} cp_{ij} + cd_{ij}$, the shorter the deviation distance from the upper and lower values. The better the consistency of the three-point interval number comparison matrix, the lower the values of $\sum_{i,j} cpo_{ij} + cdo_{ij}$ and $\sum_{i,j} cp_{ij} + cd_{ij}$. One can record the error as $\sum_{i,j} s(cpo_{ij} + cdo_{ij}) + t(cp_{ij} + cd_{ij})$, where s, t are constants that denote the priority of these two errors. If $\sum_{i,j} s(cpo_{ij} + cdo_{ij}) + t(cp_{ij} + cd_{ij}) \rightarrow \min$, the consistency of the three-point interval number comparison matrix is improved. Based on these ideas, P_1 is suggested to estimate the weight of the three-point interval number comparison matrix:

$$\min c = \sum_{i,j} s(cpo_{ij} + cdo_{ij}) + t(cp_{ij} + cd_{ij}) \quad (4)$$

$$\text{s.t.}\begin{cases} c_{ij}^{M} w_j - w_i + cpo_{ij} - cdo_{ij} = 0, i, j = 1,\cdots,n, i \neq j & (5) \\ c_{ij}^{L} w_j \leq w_i + cp_{ij}, i, j = 1,\cdots,n, i \neq j & (6) \\ w_i \leq c_{ij}^{U} w_j + cd_{ij}, i, j = 1,\cdots,n, i \neq j & (7) \\ \sum_{i=1}^{n} w_i = 1 & (8) \\ w_i \geq 0, cpo_{ij} cdo_{ij} = 0, cp_{ij}, cd_{ij}, cpo_{ij}, cdo_{ij} \geq 0, i, j = 1,\cdots,n & (9) \end{cases} \quad (P_1)$$

In P_1, formula (4) is used to set up the weight such that the error sum deviates minimally from the upper, lower and possible values. Formula (5) indicates the deviation relation between the weight and possible value. Formula (6-7) indicates the deviation relation between the weight and upper-lower value. Formula (8) indicates that the weight satisfies the normalization condition. Formula (9) states that the weight and error variables are not negative.

The optimal value of P_1 can be recorded as c^*. After estimating P_1, one can obtain the optimal value for c^* and a set of weights w_i. Then, rank w_i to obtain the ultimate order of the alternatives. In fact, when the value of c^* is 0, the comparison matrix is completely consistent. But how does one measure the value to indicate whether the comparison matrix's consistency is accepted? It's obvious that the most possible value is very important for consistency in a three-point interval number comparison matrix, so the consistency of the most possible value comparison matrix is used to determine the consistency of three-point interval number comparison matrix in this chapter. It means that when the consistency of the most possible value comparison matrix $CR \leq 0.1$ (see Saaty, 2003), the policy-makers' logical uniformity is good. Otherwise, the policy-makers' logical uniformity is bad. It needs to let the policy-makers judge again until there is an acceptable consistency of the three-point interval number comparison matrix.

3 Consistence and Weight Estimation of Three-Point Interval Number Complementary Comparison Matrices

Definition 4. The matrix $\overline{B} = (\overline{b_{ij}})_{n\times n}$ is called as an interval number complementary comparison matrix, where: $\overline{b_{ij}} = [b_{ij}^{L}, b_{ij}^{U}]$, $b_{ij}^{L} \leq b_{ij}^{U}$, $\overline{b_{ji}} = [1-b_{ij}^{U}, 1-b_{ij}^{L}]$ and $\overline{b_{ii}} = [0.5, 0.5]$.

Definition 5. The matrix $\overline{D}=(\overline{d_{ij}})_{n\times n}$ is called a three-point interval number complementary comparison matrix, where: $\overline{d_{ij}}=[d_{ij}{}^{L},d_{ij}{}^{M},d_{ij}{}^{U}]$, $d_{ij}{}^{L}\le d_{ij}{}^{M}\le d_{ij}{}^{U}$, $\overline{d_{ji}}=[1-d_{ij}{}^{U},1-d_{ij}{}^{M},1-d_{ij}{}^{L}]$ and $\overline{d_{ii}}=[0.5,0.5,0.5]$.

If the decision-maker's preferences form the three-point interval number complementary comparison matrix $\overline{D}=[d_{ij}{}^{L},d_{ij}{}^{M},d_{ij}{}^{U}]_{n\times n}$, the error values $dp_{ij},dd_{ij}dpo_{ij},ddo_{ij}$ can be introduced, and wd_i can be recorded as the weight. If it is completely consistent (see xu, 2004), formula (10) is satisfied.

$$d_{ij}{}^{L}\le d_{ij}{}^{M}=\frac{wd_i}{wd_i+wd_j}\le d_{ij}{}^{U} \tag{10}$$

If $\overline{D}$ is completely consistent, one can introduce the error variables dpo_{ij},ddo_{ij}. The error $d_{ij}{}^{M}=\dfrac{wd_i}{wd_i+wd_j}$ can be obtained, and the relationships $dpo_{ij}\ge 0,ddo_{ij}\ge 0$,and $dpo_{ij}\times ddo_{ij}=0$. Formula (11) is then satisfied:

$$d_{ij}{}^{M}(wd_i+wd_j)-wd_i+dpo_{ij}-ddo_{ij}=0 \tag{11}$$

If formula (10) does not satisfy $d_{ij}{}^{L}\le\dfrac{wd_i}{wd_i+wd_j}\le d_{ij}{}^{U}$, one can introduce the error variable dp_{ij},dd_{ij}, and formula (12) is satisfied:

$$\begin{cases} d_{ij}{}^{L}(wd_i+wd_j)\le wd_i+dp_{ij} \\ wd_i\le d_{ij}{}^{U}(wd_i+wd_j)+dd_{ij} \end{cases} \tag{12}$$

The lower the value of $\sum_{i,j} dpo_{ij}+ddo_{ij}$, the shorter the distance of deviation from the possible value $d_{ij}{}^{M}$. The lower the value of $\sum_{i,j} dp_{ij}+dd_{ij}$, the shorter the distance of deviation from the upper-lower value. One can record the deviation distance value as $\sum_{i,j} dpo_{ij}+ddo_{ij}+dp_{ij}+dd_{ij}$. If $\sum_{i,j} dpo_{ij}+ddo_{ij}+dp_{ij}+dd_{ij}\to\min$, the consistency of the three-point interval number complementary comparison matrix is improved. P_2 is suggested to estimate is weight:

$$\min d = \sum_{i,j} dp_{ij} + dd_{ij} + dpo_{ij} + ddo_{ij} \tag{P$_2$}$$
$$\text{s.t.}\begin{cases} d_{ij}^{M}(wd_i + wd_j) - wd_i + dpo_{ij} - ddo_{ij} = 0 \\ d_{ij}^{L}(wd_i + wd_j) \le wd_i + dp_{ij}, i, j = 1, \cdots, n, i \ne j \\ wd_i \le d_{ij}^{U}(wd_i + wd_j) + dd_{ij}, i, j = 1, \cdots, n, i \ne j \\ \sum_{i=1}^{n} wd_i = 1 \\ wd_i \ge 0, dpo_{ij} ddo_{ij} = 0, dp_{ij}, dd_{ij}, dpo_{ij}, ddo_{ij} \ge 0, i, j = 1, \cdots, n \end{cases}$$

Then the most possible value comparison matrix of the three-point interval number comparison matrix is changed to the reciprocal judgment matrix (see Xu, 2004). When the proportion of $CR \le 0.1$, the policy-makers' logical uniformity is good. Otherwise, the policy-makers' logical uniformity is bad. It needs to let the policy-makers judge again until there is an acceptable consistency of the most possible value comparison matrix.

4 Oil and Gas Energy Policy Evaluation in China via the Suggested Approach

4.1 Evaluate Policy and Background Analysis

The characters of the Chinese oil industry management system can be depicted as follows: firstly, the energy board is set up to manage Chinese energy affairs while the natural gas industry management function is still scattered in a number of comprehensive economic management and law enforcement departments. Secondly, the oil industry is the state's important energy sector. The majority of producers have almost set up a special body to manage the affairs. However, oil companies in China have been restructured. To strengthen management functions, energy policy, oil strategy and market regulators are put forth by the government. In fact, it is weakened, not uniform and unclear. The government is both the policy-making department and supervision department. It is lacking an effective supervision mechanism. The main policy of the oil and gas industry in China can be described as follows:

(1) The reform of the original. The notice of refined oil circulation system can be obtained. (State of the [1994] No. 21, April 5, 1994, China). The notification requires the government to do a good job comprehensively balancing demand and supply. The price of crude oil will be implemented by the government, and the circulation chain is reduced.
(2) The reform of crude oil price. The goals and principles of crude oil and the finished oil price formation mechanism are reformed. The price of the domestic will be set by consultation between the two sale sides. The price of gasoline and diesel oil will be instructed by the government.

(3) The principle of the price of refined oil. "On the principle of refined oil price notice" requires the price of liquefied petroleum gas, kerosene lamps, chemical light oil, and heavy oil to be set by the companies of oil and petrochemical. Moreover, the price of the four oils must maintain a reasonable price. The ability of consumers' purchasing abilities should be considered to adjust the price of civilian gas prices.
(4) The reform of oil price. Adjust the price of domestic oil products further and improve the oil price formation mechanism to achieve the international market price. The state council decided to further speed up the step of the oil price formation mechanism to achieve the international market price. The state development planning commission formulated the benchmark price in accordance to international market prices of crude oil and refined oil. Adjust once a month. It is to implement the state council's decision and is also an important indication of the formation mechanism.
(5) Chinese oil laws and regulations. Firstly, ownership of oil resources: the ownership of oil resources belongs to the countries. It will not change because of their attachment to land ownership and different uses. Secondly, oil mining rights: oil mining rights is an important part of property rights for the country's mineral resources. It is not only a result of a national ownership and executive power, but also a possibility of the pursuit of self-interest. They can be denoted as Chinese oil and gas fields' typical major policies before 2000.

There are four policies, referred to as Policy P1, Policy P2, Policy P3, and Policy P4. Policy1, the oil and gas exploration and mining registered Interim Measures; Policy2, the State Council passed the State Development Planning Commission, State Economic and Trade Commission for the reform of crude oil, also finishing the oil circulation system views notice; Policy3, crude oil finished oil price reform program; Policy4, foreign cooperative exploitation of land mines to use oil resources to pay for temporary regulations.

4.2 Policy Appraisal Index System

Suppose m decision-makers are invited to make decisions (m≥2) on the goodness or badness of the oil and gas policy of Chinese situations. The three-point number reciprocal comparison matrix and three-point number complementary comparison matrix are adopted separately to express their preference. Example data are just for the suggested approach application steps.

During the process of policy-making (A), which includes: The need for policy-making (A1): It's serious for policy-making and urgent for the implementation of policy-making objectively. The rationality of policy objectives (A2): It must be targeted, specific, non-ambiguous, clear expression. It also has to be cleared whether it can be implemented with politics, the economy, culture, technology and individuals. Science of policy options (A3): It must be cleared that the policy options are set up at a reliable basis and have been full proofed. Is it flexible? Is it consistent with other policies in the internal and external fields? What are the benefits of policy implementation for the target groups, economy and society? What are the gains and losses for individuals, groups and society, materialistically and spiritually? Legitimacy of policy-making (A4): Inspect the entire policy-making. Make sure it has the scientific integrity of the policy-making process.

(2) During the Policy implementation (B), which includes: Policy acceptance (B1): Is the function of policy consistent with the functions of government behavior, company behavior and market behavior? Does the public, especially the objects of the policy, accept the policy? Main policy implementation (B2): There are specialized agencies, personnel and systems to ensure policy implementation. The policy staff must be a rational division of labor and have right to clear. They must communicate and coordinate effectively. The implementation staff must be professional, responsible and organized. Objects of policy (B3): The policy objects must have good acceptance, the ability and degree of policy implementation. Implementation supervision mechanisms (B4): There are specialized agencies to investigate the behavior of violating policies and revise them.

(3) Policy performance (C), which includes: The effect of policy implementation (C1): The realized degree of the policy predetermined target and the display degree of the policy must be controlled. The efficiency of policy implementation (C2): the gains and losses of input and output of the policies must be considered. The satisfaction of policy implementation (C3): the current and long-term, regional and overall influence of policies must be considered.

4.3 The Appraisal Process and Result Analysis

(1) Comparison matrix based on the target level

According to the method of the three-point interval number comparison matrix in this chapter, the policy-maker carries the judgment based on the appraisal target. Then the three-point interval number comparison matrix can be set up. Considering the differences of policy-makers' preferences, the reciprocal comparison matrix and supplementary comparison matrix of three-point interval number comparison matrix can be obtained. The processes of comparison matrixes are abbreviated.

(3) Result analysis

According to the model proposed in this chapter, the weights of comparison matrixes can be obtained. It is shown in Table1.

Table 1 Results of weights

Index name	Index weight	Index name	Consistency (CR)	P1	P2	P3	P4
A CR=0.004	0.444	A1	0.008	0.375	0.375	0.125	0.125
	0.222	A2	0.008	0.300	0.100	0.300	0.300
	0.222	A3	0.004	0.500	0.125	0.125	0.250
	0.111	A4	0.025	0.350	0.350	0.150	0.150
B CR=0.073	0.200	B1	0.069	0.168	0.648	0.007	0.112
	0.200	B2	0.018	0.536	0.107	0.179	0.178
	0.467	B3	0.007	0.200	0.200	0.133	0.467
	0.133	B4	0.055	0.333	0.222	0.222	0.222
C CR=0.001	0.250	C1	0.017	0.364	0.364	0.182	0.009
	0.50	C2	0.017	0.353	0.118	0.176	0.353
	0.250	C3	0.023	0.300	0.300	0.200	0.200
O CR=0.001	0.250	A	/	0.383	0.256	0.167	0.194
	0.375	B	/	0.279	0.274	0.142	0.306
	0.375	C	/	0.343	0.225	0.184	0.249

From the results, policy P1 and P2 are good at formulating the necessity, because policy P1 pays more attention to formulation necessity, but policy P2 is insufficient in goal rationality. Compared with the other two policies, policy P3 and P4 are insufficient in the legitimacy of procedure. Policy P2 gets the highest score in acceptance, and policy P1 gets the highest score in main implementation, but policy P2 is insufficient in this aspect. Policy P4 pays more attention to the objects, but policy P3 is insufficient in this aspect. These four policies are similar in execution supervision. Policies P1 and P2 get higher scores than policies P3 and P4 for the implementation effect. Policy P2 is insufficient for implementation efficiency. Policy P1 and P2 are good at implementation satisfaction. Based on the process of the policy formulation, for policy P1, the weight of A3 is biggest and the weight of A2 is smallest. For policy P2, the weight of A1 is biggest and the weight of A2 is smallest. For policy P3, the weight of A2 is biggest and the weight of A1 and A4 are smallest. For policy P4, the weight of A2 is biggest and the weight of A1 is smallest. Based on the process of policy implementation, for policy P1, the weight of B2 is biggest and the weight of B1 is smallest. For policy P2, the weight of B1 is biggest and the weight of B2 is smallest. For policy P3, the weight of B4 is biggest and the weight of B1 is smallest. For policy P4, the weight of B3 is biggest and the weight of B1 is smallest. Based on the effect of policy implementation, for policy P1, the weight of C1 is biggest and the weight of C3 is smallest. For policy P2, the weight of C1 is biggest and the weight of C2 is smallest. For policy P3, the weight of C3 is biggest and the weight of C2 is smallest. For policy P4, the weight of C2 is biggest and the weight of C1 is smallest. Overall, the order of these four policies is $P_1 > P_4 > P_2 > P_3$.

5 Conclusion

In this chapter, a new energy policy evaluation method is suggested, which is based on the new uncertainty preference expression. As decision-making problems increase in complexity, more and more people join the decision-making process; group decision-making is now widely used. Decision-makers adopt wide varieties of preferences and preference structures, and it is often unrealistic to depict complex problems using definite preference techniques. To address this issue, a three-point interval number comparison matrix is suggested. This chapter discusses the consistency and weight estimation and proposes three-point interval number comparison matrices. This chapter presents a new uncertain mathematical method that solves the problem of preference information lost by many existing systems used to model complex group decision-making processes. Some theoretical questions should be studied in further work, specifically the availability of other effective approaches for weight estimation. For the research of the energy problem, the energy policy suggestions should also be considered.

Acknowledgements. This work is supported by the National Natural Science Foundation of China (70701017), the Education Department Human and Social Science Project of China (07JC630064), and the China Postgraduate Science Research Fund Project (2005038575).

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Part IV
Grey Forecast Model

The Comparison of Transfer Model and Metabolism GM(1,1) Model in Fuzhou Port's Throughput Prediction*

Kejia Chen, Jiaying Chen, and Qishan Zhang

Both transfer model and metabolism GM (1, 1) model are usually used to establish dynamic prediction model. This chapter applies these two models to Fuzhou port's throughput prediction and compares the results. The results show that both models can obtain satisfying predicted values. Furthermore, metabolism GM (1, 1) needs fewer data and performs better in terms of prediction accuracy.

1 Introduction

Ports are key infrastructures and play great roles in the economy progress. The development of a port can be reflected by its throughput. The port's throughput prediction is an important part in the port development strategy study. The correct throughput prediction is of significance to the reasonable port layout and transportation planning (Fung, 2002; Lam et al., 2004; Chen and Zhao, 2006).

Different prediction models have different modeling methodologies and are adopted in various situations. The preferred models are the ones that need few data, have simple procedure, and perform well in most conditions. Both transfer model and metabolism GM (1, 1) model are usually used to establish dynamic prediction model. This chapter applies these two models to Fuzhou port's throughput prediction and compares the results. The results show that both models can obtain satisfying predicted values. Furthermore, metabolism GM (1, 1) needs fewer data and

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* This work is financially supported by National Natural Science Foundation of China under the project of 70871024, Fujian Natural Science Foundation of China under the project of 2009J05159, Fujian Social Science Foundation of China under the project of 2008A020, Social Scientific Research Fund of Fujian Provincial Education Department of China under the project of JA07017S, and Talent Foundation of Fuzhou University under the project of XRC-0635.

performs better in terms of prediction accuracy. For recent works on the GM(1,1) model, please consult with (Lin et al., 2002; Sydow, Lin, et al., 2001; Lin and Liu, 2000).

2 Transfer Model Prediction

A. Transfer Model

In real economic systems, the influence of one economic variable on another one often appears some periods later, not immediately. In order to better describe this dynamic process, we introduce transfer model.

Transfer model, which is also called ARIMAX model, is a multivariate time series model and is the combination of time series analysis and regression analysis.

The procedure of building a transfer model includes three steps: model identification, parameter estimation and diagnostic testing. Before building a model, we often require that the behavioral sequence is stable. However, in practice, this requirement often can not be satisfied. Thus, we usually use difference operation to make it stable. For one input variable, denote *X* as the input variable and *Y* as the response variable.

$$\nabla^d Y_t = u + \sum_i \frac{\omega_i(L)}{\phi_i(L)} X_{i,t-k} + \frac{\theta(L)}{\phi(L)} \varepsilon_i \tag{1}$$

where ∇: difference operator, *d*: difference order, *u*: mean, *L*: lag operator, *k*: k-th lag, ε_t: error term, satisfying $E(\varepsilon_t)=0$, $Var(\varepsilon_t)=\sigma^2$, $Cov(\varepsilon_i,\varepsilon_j)\neq 0$ $(i\neq j)$.

For $\omega_i(L)$, $\phi_i(L)$, $\theta(L)$ and $\phi(L)$, we have

$$\begin{aligned}
\omega_i(L) &= 1-\omega_{i,1}L-\omega_{i,2}L^2-L-\omega_{i,h}L^h \\
\phi_i(L) &= 1-\phi_{i,1}L-\phi_{i,2}L^2-L-\phi_{in}L^n \\
\theta(L) &= 1-\theta_1 L-L+\theta_q L^q \\
\phi(L) &= 1-\phi_1 L-L+\phi_s L^s
\end{aligned} \tag{2}$$

The difference between transfer model and ARMA model is that transfer model should whiten the input variable before computing the cross correlation coefficient between the response variable and the input variable. In other words, we can employ Box-Jaenkins to establish ARMA model for the input variable sequence and make it whitened (Elliott et al., 2006; Box et al., 2008).

B. Prediction Results

Generally, the port's throughput in one area depends on the economic development level in that area. Therefore, we select Fuzhou's gross domestic product (GDP) as the input variable and Fuzhou port's throughput (Y) as the response variable (TABLE I).

First, we use the data in 1980-2004 as the sample and predict the values in 2005-2006.

Table I Fuzhou's gross domestic product (GDP) and Fuzhou port's throughput (Y) in 1980-2006

Year	Y(10^6 t)	GDP(10^9 RMB)	Year	Y(10^6 t)	GDP(10^9 RMB)
1980	2.09	1.82	1994	9.14	34.91
1981	2.18	2.05	1995	10.99	46.41
1982	2.60	2.36	1996	12.48	57.56
1983	3.11	2.67	1997	13.71	68.73
1984	3.47	3.25	1998	12.88	77.67
1985	3.57	3.98	1999	14.81	82.74
1986	4.42	4.48	2000	24.25	87.64
1987	4.40	5.37	2001	29.61	94.32
1988	4.45	7.59	2002	39.07	101.17
1989	5.98	9.53	2003	47.53	116.21
1990	5.61	10.24	2004	59.39	133.52
1991	7.25	11.88	2005	74.43	147.63
1992	7.21	15.00	2006	88.48	166.41
1993	9.40	24.57			

Data source: http://www.stats-fj.gov.cn/

The trends of Fuzhou's gross domestic product (GDP) and Fuzhou port's throughput (Y) are illustrated in Fig. 1. According to ADF testing, both sequences are not stable and are second order integrated time series. We can use second order difference transformation to make them stable.

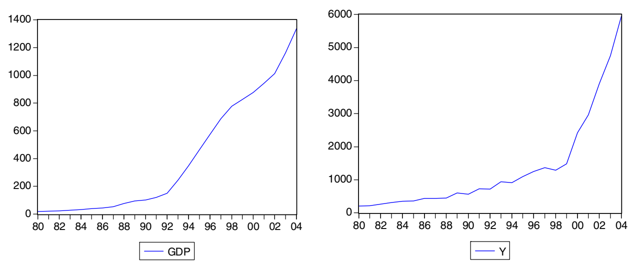

Fig. 1 Trends of Fuzhou's gross domestic product (GDP) and Fuzhou port's throughput (Y)

Using EVIEWS, we can build the following ARMA models for Fuzhou's gross domestic product (GDP) and Fuzhou port's throughput (Y).

$$d(gdp, 2)=7.013+[ma(3)=-0.825] \tag{3}$$

$$d(y, 2)=47.123+[ar(1)=-0.536] \tag{4}$$

On the basis of residual tests (Fig. 2), we find that the residual is a white noise sequence when lagging one period.

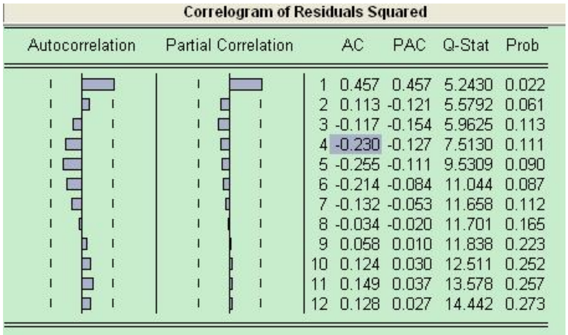

Fig. 2 Autocorrelation and partial correlation between filtered input variable and output variable

Then, we have the following transfer model:

$$d(gdp, 2)=7.013+[ma(3)=-0.825, backcast=1982] \quad (5)$$

$$d(y, 2)=0.075*d(gdp, 2)+[ar(1)=-0.596] \quad (6)$$

The actual values, the fitted values and the residual of Fuzhou port's throughput in 1980-2004 are shown in Fig. 3.

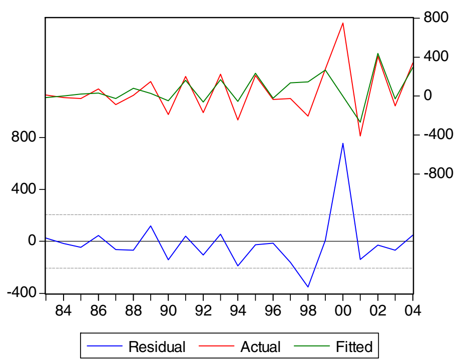

Fig. 3 Transfer model simulation results

Now, we can utilize the transfer model to forecast Fuzhou port's throughput in 2005-2006 as demonstrated in TABLE II.

Table II Transfer model prediction results

Year	Actual values(10^6 t)	Predicted values(10^6 t)
2005	74.43	72.07
2006	88.48	87.46

3 Metabolism GM (1, 1) Model Prediction

C. Metabolism GM (1, 1) Model

Assume that $X^{(0)} = (x^{(0)}(1), x^{(0)}(2),..., x^{(0)}(n))$ is a non-negative sequence, where $x^{(0)}(k) \geq 0$, k = 1, 2… n.

And $X^{(1)}$ is the 1-AGO sequence of $X^{(0)}$:

$$X^{(1)} = (x^{(1)}(1), x^{(1)}(2),..., x^{(1)}(n)),$$

where $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i)$, k = 1, 2…n.

And $Z^{(1)}$ is the generated mean sequence of consecutive neighbors of $X^{(1)}$ given as $X^{(1)} = (x^{(1)}(1), x^{(1)}(2),..., x^{(1)}(n))$, where $z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1)$, k = 2, 3…n.

The equation $x^{(0)}(k) + az^{(1)}(k) = b$ is called the model GM (1, 1).

If $\hat{a} = [a, b]^T$ is a sequence of parameters, and

$$Y=\begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ ... \\ x^{(0)}(n) \end{bmatrix}, B=\begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ ... & ... \\ -z^{(1)}(n) & 1 \end{bmatrix},$$

then the least square estimate sequence of the grey differential equation $x^{(0)}(k) + az^{(1)}(k) = b$ satisfies $\hat{a} = [B^T B]^{-1} B^T Y$.

The solution (or called a time response function) of the whitenization function $\frac{dx^{(1)}}{dt} + ax^{(1)} = b$ is given by $x^{(1)}(t) = [x^{(1)}(0) - \frac{b}{a}]e^{-at} + \frac{b}{a}$.

The time response sequence of the GM (1, 1) grey differential equation $x^{(0)}(k) + az^{(1)}(k) = b$ is given by

$$\hat{x}^{(1)}(k+1) = [x^{(1)}(0) - \frac{b}{a}]e^{-ak} + \frac{b}{a}, \quad k = 1,2,3,…,n.$$

Let $x^{(1)}(0) = x^{(0)}(1)$, then $\hat{x}^{(1)}(k+1) = [x^{(0)}(1) - \frac{b}{a}]e^{-ak} + \frac{b}{a}$, k = 1, 2, 3… n. The restored values can be given by

$$\hat{x}^{(0)}(k+1) = \alpha^{(1)}\hat{x}^{(1)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k), \; k = 1, 2, 3… n.$$

Let $x^{(0)}$(n+1) be a newest piece of information. Inserting $x^{(0)}$(n+1) into the sequence $X^{(0)} = (x^{(0)}(1), x^{(0)}(2),..., x^{(0)}(n))$. Then the GM (1,1) model, built on

$$X^{(0)} = (x^{(0)}(1), x^{(0)}(2),..., x^{(0)}(n), x^{(0)}(n+1)),$$

is called a new information GM (1,1).

The GM (1, 1) model, built on the following new sequence obtained by inserting $x^{(0)}$(n+1) and deleting $x^{(0)}$(1),

$$X^{(0)} = (x^{(0)}(2),..., x^{(0)}(n), x^{(0)}(n+1)),$$

is called a metabolic GM (1,1) (Deng, 1982; Liu, 2004; Wen, 2004; Zhang and Chen, 2004).

D. Prediction Results

Let us use Fuzhou port's throughput in 2000-2004 to build a GM (1, 1) model. Now, we have $X^{(0)}$=(24.25, 29.61, 39.07, 47.53, 59.39), whose 1-AGO sequence is $X^{(1)}$=(24.25, 53.86, 92.93, 140.46, 199.85), and the sequence of the mean generation of consecutive neighbors of $X^{(1)}$ is given by $Z^{(1)}$=(39.06, 73.40, 116.70, 170.16). Thus,

$$\hat{a} = [B^T B]^{-1} B^T Y = \begin{bmatrix} -0.2231 \\ 21.631 \end{bmatrix}.$$

The GM (1,1) time response sequence of $X^{(1)}$ is

$$\hat{x}^{(1)}(k+1) = [x^{(0)}(1) - \frac{b}{a}]e^{-ak} + \frac{b}{a} = 121.21e^{0.2231k} - 96.96.$$

Then, we can obtain the predicted sequence of $X^{(0)}$ as follows:

$$\hat{X}^{(0)} = (\hat{x}(2005)) = (73.94).$$

Inserting a piece of new information (the predicted data in 2005) and deleting an old piece information (the data in 2000) give us the modeling sequence $X^{(0)}$=(29.61, 39.07, 47.53, 59.39, 73.94).

Now, $\hat{a} = [B^T B]^{-1} B^T Y = \begin{bmatrix} -0.2146 \\ 28.1522 \end{bmatrix}$. So, the GM (1,1) time response sequence is

$$\hat{x}^{(1)}(k+1) = [x^{(0)}(1) - \frac{b}{a}]e^{-ak} + \frac{b}{a} = 160.7856e^{0.2146k} - 131.1756.$$

Then, the predicted sequence can be obtained:

$$\hat{X}^{(0)} = (\hat{x}(2006)) = (90.82).$$

TABLE III indicates the metabolism GM (1, 1) model prediction results.

Table III Metabolism GM (1, 1) Model prediction results

Year	Actual values(10^6 t)	Predicted values(10^6 t)
2005	74.43	73.94
2006	88.48	90.82

4 Comparison

The comparison between transfer model and metabolism GM (1, 1) model is given in TABLE IV, which includes predicted values, errors, and relative errors.

We collect the data of Fuzhou's gross domestic product and Fuzhou port's throughput in 1980-2004 and establish transfer model. The predicted values of Fuzhou port's throughput in 2005-2006 are 72.07 and 87.46 (10^6 t), respectively. The average relative error is 2.16%. On the other hand, based on metabolism GM (1, 1) model, we use the data of Fuzhou port's throughput in 2000-2004 and predict the values in 2005-2006. The average relative error is 1.65%. The results show that both models can obtain satisfying predicted values. Furthermore, metabolism GM (1, 1) needs fewer data and performs better in terms of prediction accuracy.

Table IV Comparison between transfer model and metabolism GM(1,1) Model

		Predicted Values (10^6 t)		Errors (10^6 t)		Relative Errors	
Model Type	Model Data	$\hat{x}(2005)$	$\hat{x}(2006)$	$\varepsilon(2005)$	$\varepsilon(2006)$	$\Delta(2005)$	$\Delta(2006)$
Transfer model	1980-2004	72.07	87.46	2.36	1.01	3.17	1.15
Metabolism GM(1,1) model	2000-2004	73.94	90.82	0.49	-2.34	0.66	2.64

5 Conclusion

In this study, we discuss transfer model as well as metabolism GM (1, 1) model and apply them to Fuzhou port's throughput prediction. The comparison results show that both models are useful in throughput prediction. Moreover, better prediction results can be obtained from metabolism GM (1, 1) model, even if fewer data are needed. Therefore, in practical applications, if the data available are not sufficient, metabolism GM (1, 1) model can greatly improve the prediction accuracy.

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Research on MGM $(1,N|\tau,r)$ Model and Application

Huan Guo, Xinping Xiao, and Xiuqin Feng

In accordance with the characteristics of complex system, its multivariable, nonlinear and delayed, based on MGM $(1, N)$. This chapter proposes a new multivariable grey model (MGM $(1,N|\tau,r)$) which is established by introducing delayed factor τ and nonlinear factor r. The main work of this chapter is to research modeling process, parameter estimation, precision inspection, forecasting and so on. During modeling, the particle swarm optimization (PSO) algorithem is used to solve the parameters τ, r. Finally, MGM $(1,N|\tau,r)$ is applied for forecasting input and output of Wuhan new hi-tech industry. By comparing the forecast results of MGM $(1,N|\tau,r)$ and MGM $(1, N)$, we can obtain that the new model possesses have much higher precision and grey correlation degree. MGM $(1,N|\tau,r)$ is a reasonable and effective method to resolve the delayed and nonlinear system.

1 Introduction

Grey system universally existes in the field of nature, human society.etc., and forecast modeling is the key problem during the research of grey system. GM (1, 1) is the most popular grey dynamic predictive model in the grey theory (Deng, 2000), which is made up of an approximate first order differential equation about one variable, can reveal the inherent development rules for a single time series. However, the actual system often involves a few parameters which are interdependence, mutual influence and development together. That is, the progress of a variable is not isolation, on the contray, is related to all the others. J. Zai,Y.J. Feng, and J.M. Sheng proposed MGM $(1, N)$, which is an extension of the GM (1, 1) for n variables, aiming at solving the above problem (Zhai et al., 1997). MGM $(1, N)$ offer a new approach and consolidate the base for grey forecast technology. Thereafter, the

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model has been extensively used in city programming, society economic forecasting, mode controlling, and has got good results in application, as in (Chen and Zhang, 2005; Xiao et al., 2008; Xu et al., 2006; Wang et al., 2006).

MGM(1, N) is approximate first order differential equations, which reflects that the change of a variable in t lies on the value of others in t. Whereas practical system has delayed effect universally, that is to say, the input in t impacts not only the output and change at t but also the output and change after t. Comprehensively considering the nonlinear and delayed of system, Professor J.L. Deng structured GM (1, 1|τ, r) based on GM (1, 1) (Deng, 2001a). He also presented matrix form of the model and the parameter range (Deng, 2001b; 2001c). The model was widely applied in port resource distribution, economic policy modulate and so on, and has obtained the very good effect (Huang and Kuo, 2004; Zhang and Zou, 2002). Nevertheless, the study about the delayed and nonlinear of a complex system is few till now. As in the input and output system of new hi-tech industry, the factors which influence the total output value are not independent but correlated with the input and return of each other, and it is not a simple linear correlation. Furthermore, the effect of the input in t, which is not one-off, will influence return not only in t but also after t. Generally speaking, delayed effects is more significant. As we all know, the present grey model are seldom considering the delayed and nonlinear. Therefore, Based on MGM(1, N), we propose a new model MGM$(1, N|\tau, r)$ by introducing delay factor and nonlinear factor, then apply the model to analyze and forecast the input and output of wuhan new hi-tech industry simultaneously. Finally, the simulation and forecast results are given to show the reasonable and effective of the proposed model.

2 Modeling

Let $x_i^{(0)} = \left(x_i^{(0)}(1),\ x_i^{(0)}(2), \cdots,\ x_i^{(0)}(m)\right)$ be a time series, and $x_i^{(1)} = \left(x_i^{(1)}(1),\ x_i^{(1)}(2), \cdots,\ x_i^{(1)}(m)\right)$ denote the sequence obtained through accumulating generation; that is

$$x_i^{(1)}(k) = \sum_{j=1}^{k} x_i^{(0)}(j) \tag{1}$$

where $i = 1, 2, \cdots, N$ and N is the number of time-series; $k = 1, 2, \cdots, m$ and k denotes the time. Considering the relationship and influence of one another of n time-series, Reference (Zhai et al., 1997) extended the differential equation of GM(1, N) as follows:

$$\frac{dx_1^{(1)}(t)}{dt} = a_{11}x_1^{(1)}(t) + a_{12}x_2^{(1)}(t) + \cdots + a_{1n}x_n^{(1)}(t) + u_1$$

$$\frac{dx_2^{(1)}(t)}{dt} = a_{21}x_1^{(1)}(t) + a_{22}x_2^{(1)}(t) + \cdots + a_{2n}x_n^{(1)}(t) + u_2 \tag{2}$$

$$\vdots$$

$$\frac{dx_n^{(1)}(t)}{dt} = a_{n1}x_1^{(1)}(t) + a_{n2}x_2^{(1)}(t) + \cdots + a_{nn}x_n^{(1)}(t) + u_n$$

Noting $X^{(0)}(k) = \left(x_1^{(0)}(k), x_2^{(0)}(k), \ldots, x_n^{(0)}(k)\right)^T$, $X^{(1)}(k) = \left(x_1^{(1)}(k), x_2^{(1)}(k), \ldots, x_n^{(1)}(k)\right)^T$,

$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ & \vdots & & \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$, $U = \left(u_1, u_2, \ldots, u_n\right)^T$, the matrix representation of (2) is as follows:

$$\frac{dX^{(1)}(t)}{dt} = AX^{(1)}(t) + U \tag{3}$$

Based on the above model, introducing delay factor τ and nonlinear factor r, the differential equation of MGM (1, N) is changed as following:

$$\frac{dX^{(1)}(t)}{dt} = AX^{(1)}(t) + B_1X^{(1)}(t-1) + B_2X^{(1)}(t-2) + \cdots + B_\tau X^{(1)}(t-\tau) + Ut^r \tag{4}$$

where $t \geq \tau$, $l = 1, 2, \ldots, \tau$, and

$$B_l = \begin{bmatrix} b_{11}^l & b_{12}^l & \cdots & b_{1n}^l \\ b_{21}^l & b_{22}^l & \cdots & b_{2n}^l \\ & \vdots & & \\ b_{n1}^l & b_{n2}^l & \cdots & b_{nn}^l \end{bmatrix}$$

Therefore

$$\frac{dX^{(1)}(t)}{dt} = AX^{(1)}(t) + \sum_{l=1}^{\tau} B_l X^{(1)}(t-l) + Ut^r \tag{5}$$

Supposing $x_1^{(0)}(t), x_2^{(0)}(t), \ldots, x_n^{(0)}(t)$ are equidistant discrete time-series, the grey differential equation of (5) is following:

$$X^{(0)}(k+1) = AX^{(1)}(k) + \sum_{l=1}^{\tau} B_l X^{(1)}(k-l) + Uk^r \tag{6}$$
$$(k = \tau+1, \tau+2, ..., m-1)$$

where $\sum_{l=1}^{\tau} B_l X^{(1)}(k-l)$ displays delayed effect; Uk^r shows the nonlinear states in a system; Coefficient matrix B_l reflects the degree of output influence which was attributed to input during delay time; $l = 1, 2, ..., \tau$ and τ is the delay time in a system. Equation (6) is the MGM $(1, N|\tau, r)$ considering delayed factor and nonlinear factor. If there is no delayed or nonlinear phenomenon in a system, that is to say, $\tau = 0$ and $r = 0$, then MGM $(1, N|\tau, r)$ degenerates into MGM (1, N). Therefore, MGM $(1, N|\tau, r)$ is the extension of MGM (1, N), which will enlarge application range of the grey model.

3 Correlation Problems of the Model

A. Model Parameter Identification

Let $B = \begin{bmatrix} A & B_1 & B_2 & \cdots & B_\tau \end{bmatrix}$, $M_k = \begin{bmatrix} X^{(1)}(k)^T & X^{(1)}(k-1)^T & \cdots & X^{(1)}(k-\tau)^T \end{bmatrix}^T$, where B is a $n \times n(\tau+1)$ matrix, M_k is a $n(\tau+1)$ vector, then (6) is changed as follows:

$$X^{(0)}(k+1) = BM_k + Uk^r \tag{7}$$

Via coordinating (7), we can obtain

$$X^{(0)}(k+1) = \begin{bmatrix} M_K^T & k^r E \end{bmatrix} \begin{bmatrix} B & U \end{bmatrix}^T$$

when $k = \tau+1, \tau+2, ..., m-1$, the corresponding error equation is as follows:

$$V = M\hat{D} - Q \tag{8}$$

where

$$M = \begin{bmatrix} M_{\tau+1}^T & (\tau+1)^r \\ M_{\tau+2}^T & (\tau+2)^r \\ \vdots & \\ M_{m-1}^T & (m-1)^r \end{bmatrix} = \begin{bmatrix} X^{(1)}(\tau+1)^T & X^{(1)}(\tau)^T & \cdots & X^{(1)}(1)^T & (\tau+1)^r \\ X^{(1)}(\tau+2)^T & X^{(1)}(\tau+1)^T & \cdots & X^{(1)}(2)^T & (\tau+2)^r \\ & \vdots & & & \\ X^{(1)}(m-1)^T & X^{(1)}(m-2)^T & \cdots & X^{(1)}(m-\tau-1)^T & (m-1)^r \end{bmatrix}$$

$$Q=\begin{bmatrix} X^{(0)}(\tau+2)^T \\ X^{(0)}(\tau+3)^T \\ \vdots \\ X^{(0)}(m)^T \end{bmatrix}, \text{ and } \hat{D}=\begin{bmatrix}\hat{B} & \hat{U}\end{bmatrix}^T$$

By the least-square method, we have:

$$\hat{D}=\left(M^T M\right)^{-1} M^T Q$$

$$\begin{bmatrix}\hat{B} & \hat{U}\end{bmatrix}=\hat{D}^T=Q^T M\left(M^T M\right)^{-1}$$

Based on the above analysis, the time response formula of MGM $(1,N|\tau,r)$ is as follows:

$$\hat{X}^{(0)}(k+1)=AX^{(1)}(k)+\sum_{l=1}^{\tau}B_l X^{(1)}(k-l)+Uk^r$$

B. Determine Delayed Factor and Nonlinear Factor

For identifying delayed factor τ and nonlinear factor r of MGM $(1,N|\tau,r)$, we define average fitting relative error as follows:

$$\varepsilon_{\tau,r}=\frac{1}{(m-\tau-1)n}\sum_{i=1}^{n}\sum_{j=\tau+2}^{m}\frac{\left|\hat{x}_i^{(0)}(j)-x_i^{(0)}(j)\right|}{\left|x_i^{(0)}(j)\right|} \tag{9}$$

where n and m are known, τ and r are unknown. Obviously, the average fitting relative error varies with τ and r. For better forecasting and reflecting the relation of the n variables by using MGM $(1,N|\tau,r)$, we should choose proper τ and r by which $\varepsilon_{\tau,r}$ is as small as possible, then use particle swarm optimization (PSO) to resolve the problem.

C. Partical Swarm Optimization

PSO, inspired by the social behavior of animals, is initiallized with a population of random solution of the fitness function (Kennedy and Eberhart, 1995). The individuals in the population, called particles, “fly” through the search space. The trajectory is dynamiclly altered according to the corresponding particle’s experience and its companions’ experience. The position vector and the velocity vector of the i th particle can be represented as $X_i=(x_{i1},x_{i2},\cdots,x_{im})$ and

$V_i = (v_{i1}, v_{i2}, \cdots, v_{im})$. In generation $k+1$, the velocities and the positions are updated as follows:

$$v_{ij}^{k+1} = wv_{ij}^{k} + c_1 r(\, pbest_{ij}^{k} - x_{ij}^{k}\,) + c_2 R(\, gbest_{j}^{k} - x_{ij}^{k}\,) \tag{10}$$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1} \tag{11}$$

where $i = 1, 2, \cdots, N$ and N is the population size; $j = 1, 2, \cdots, m$ and m is the dimension of the search space; w is the inertia weight; c_1 and c_2 are two positive constants and called acceleration factors generally; r and R are random values uniformly distributed in the range [0, 1]; $pbest_{ij}^{k}$ and $gbest_{j}^{k}$ are the personal best and the global best of the population respectively. The inertia weight w is employed to control the impact of the previous velocities on the current one; hence it influences the trade-off between the global and the local exploration abilities of the particles (Shi and Eberhart, 1998). In this study, the inertia weight w is suggested as 0.4 (Coello et al., 2004).The performance of each particle is measured by a predefined fitness function which relate to the problem concerned. In this chapter, the average fitting relative error function $\varepsilon(\tau, r)$ is the fitness function and the solution (τ, r) is the particle.

Based on the above discussions, the pseudo code of PSO is described in Table1.

Table 1 The Peeudo Code of PSO

```
Algorithm: PSO

{v_ij, x_ij, k, N, pbest_ij, gbest_j}_{i=1,j=1}^{N,m} = initialize ()
fitness function ()
for  k = 1: k_max
    verify the algorithm termination conditions
    for  i = 1: N
        for  j = 1: m
            v_ij^{k+1} = w v_ij^k + c_1 r(pbest_ij^k - x_ij^k) + c_2 R(gbest_j^k - x_ij^k)
            x_ij^{k+1} = x_ij^k + v_ij^{k+1}
        end
    end
    update personal best ()
    update globe best ()
end
```

4 Science and Technology Found Analysis of Wuhan New Hi-Tech Industry

D. Index extraction by relation analysis and growth rate

The new hi-tech industry is the core of the construction of innovative country, Whenas there are some problems need to pay attention to, such as the input and output of science technology action in the industry. It is a complex system which is determined by multiple factors, and the factors are interacting and nonlinear. However, the process of input and output has delayed effect. That is to say, when we invest capital in a project, the profit will not come back instantly and completely. The capital is distributed to different aspects, such as purchasing equipment, research and development (R&D), production cost and so on. As we all known, R&D which is a difficult and significant work always need a period, then we will not gain profit until the investment in this aspect is actually transformed into the product. Therefore, delayed effect virtually existed in the system.

On the process of implementing sci-tech stratagem, Wuhan new hi-tech industry has developed significantly, and the effect is remarkable. Nevertheless, delayed effect actually existed in the development. According to Wuhan statistical yearbook on science and technology (Wuhan Sci-tech Action, 2007), the most economic indexes of Wuhan new hi-tech industry is displaying in Table 2.

From Table 2, it is easy to say that economic indexes' interaction determine the development of new hi-tech industry. For finding out more potencial information, we compute the development speed and growth rate of economic indexes according to the statistic yearbook. Moreover, some key indexes would directly affect the project investing purpose, which were proposed to be treated as VIP in the industry. Then we emphatically analyze the development of the key indexes for effective decision. Therefore, in order to extracting key indexes, we do relation analysis between all economic indexes and the whole output value, the detail is display in Table 3.

Frome Table 3, the development of Wuhan new hi-tech industry is in good condition on the whole. According to relation analysis, we know there are some key

Table 2 Economic indexes of Wuhan new Hi-tech industry from 2001 to 2006 (Units : Hundred Million Yuan)

	Total Output Value	Value Added	Sales Income	Total Tax of Interest	Value-added Tax Due	Local Financial Allocation of Sci-tech	Total Fund Expenditure of Sci-tech	R&D Fund Expenditure	Total Fund Collection of Sci-tech Action
2001	428.61	158.44	384.82	74.06	22.67	2.07	38.09	3.60	42.60
2002	497.35	178.42	457.18	71.21	25.93	2.16	41.55	6.38	48.09
2003	572.23	200.68	536.08	73.56	24.22	3.37	51.95	11.53	50.33
2004	641.02	226.17	604.05	74.15	24.21	3.59	62.04	10.62	63.30
2005	837.02	292.00	795.30	94.60	34.01	3.72	77.02	20.25	71.31
2006	1110.69	384.54	1025.72	120.44	40.85	5.24	73.47	18.76	82.63

Table 3 Analyze the Economic indexes of Wuhan new Hi-tech industry from 2001 to 2006

	Total Output Value	Value Added	Sales Income	Total Tax of Interest	Value-added Tax Due	Local Financial Allocation of Sci-tech	Total Fund Expenditure of Sci-tech	R&D Fund Expenditure	Total Fund Collection of Sci-tech Action
Average Development Speed	1.2098	1.1940	1.2166	1.1022	1.1250	1.2227	1.2794	1.3911	1.2547
Average Growth Rate	0.2098	0.1940	0.2166	0.1022	0.1250	0.2227	0.2794	0.3911	0.2547
Relation Analysis	1.0000	0.9440	0.9563	0.6615	0.7595	0.9670	0.9738	0.6333	0.8894

Table 4 Wuhan Sci-tech Economic indexes from 2001 to 2006 (Units : Hundred Million Yuan)

	2001	2002	2003	2004	2005	2006
X1	42.60	48.09	50.33	63.30	71.31	82.63
X2	38.09	41.55	51.95	62.04	77.02	73.47
X3	2.07	2.16	3.37	3.57	3.72	5.24
X4	428.61	497.35	572.23	641.00	837.02	1110.69

indexes affecting the total output of wuhan new hi-tech industry, such as total fund expenditure of sci-tech, local financial allocation of sci-tech and so on. However, the average growth rate of total sci-tech fund expenditure is obviously faster than the average growth rate of total output value, value added, sales income and total tax of interest. It indicates that Wuhan spent more on the most important index of sci-tech actions. Simultaneously, the growths of input and output are not synchronized. That is to say, there exists delayed effect in the system, the fund invested in input is affecting on the output, but will not gain profit instantly. For effectively project planning, we should consider the delayed effect and the relation among indexes. Therefore, we apply MGM $(1,N|\tau,r)$ to analyze and forecast the system which has the following characteristics: poor information, multi-index, nonlinear and delayed. Then we extract the key indexes: total fund collection of sci-tech action (X1), total fund expenditure of sci-tech (X2), local financial allocation of sci-tech (X3), total output value (X4), and construct MGM $(1,N|\tau,r)$ model which was solved by PSO. For conveniently comparing, we display the index values in Table 4.

E. Build forecasting model of Wuhan's sic-tech input and output

Based on Table 4, we establish MGM $(1,N|\tau,r)$ using the data from 2001 to 2005 where $N = 4$. That is, we can obtain MGM $(1,4|\tau,r)$. According to (7)-(9), τ, r are searched using MATLAB programmings on the basis of PSO.

Table 5 The fitted outcome of MGM $(1,4|\tau,r)$ model

	Fitted Value								Relative Error (%)				Relation
	X1	X2	X3	X4	Y1	Y2	Y3	Y4	Y1	Y2	Y3	Y4	Analysis
2001	42.60	38.09	2.07	428.61	42.60	38.09	2.07	428.61	0	0	0	0	1.0000
2002	48.09	41.55	2.16	2.16	48.09	41.55	2.16	497.35	0	0	0	0	1.0000
2003	51.07	52.97	3.31	575.32	50.33	51.95	3.37	572.23	1.47	1.96	1.78	0.54	0.9949
2004	62.81	63.12	3.64	645.12	63.30	62.04	3.57	641.00	0.79	1.74	1.96	0.64	0.9882
2005	72.38	77.68	3.79	849.26	71.31	77.02	3.72	837.02	1.50	0.86	1.88	1.46	0.9991

Table 6 Forecast Results

	MGM(1,4 | τ,r) Forecast Results				MGM(1,4) Forecast Results			
	X1	X2	X3	X4	X1	X2	X3	X4
2006	80.9419	75.3600	5.3021	1121.720	79.62	80.28	6.53	1275.35
Relative Error (%)	2.04	2.57	1.19	0.99	3.64	9.27	24.62	14.83
Average Relative Error (%)	1.70				13.09			
Relation Analysis	0.9787				0.8996			

On the process of searching, the one-dimension array (τ, r) is the particle to be resolved. For widely pursued and saving time in calculation, we assume the population of particle is 20, iteration times are 50, and inertia weight w is 0.4. Through searching, we find $\tau = 2$ and $r = 3.5$. According to MGM $(1,4|\tau,r)$, the fitted values are obtained in Table 5.

From Table 5, comparing fitted value with statistic value, the biggest relative error is 0.0196, the relation analysis are all bigger than 0.98 and the above analysis demonstrates that the effect of MGM $(1,4|\tau,r)$ is satisfactory.

F. Forecasting Wuhan sic-tech input and output

The forecast results of MGM $(1,4|\tau,r)$ are listed in Table 6. From it, the biggest forecast relative error by MGM $(1,4|\tau,r)$ is 0.0257, the average relative error is 0.0170 and the relation analysis between the forecast and real value is 0.9787. The results demonstrate that MGM $(1,4|\tau,r)$ is obviously better than MGM (1, 4), and it has higher forecast precision. MGM (1, 4) does not consider the correlation among indexes and delayed effect of the system. However, in Wuhan sci-tech industry the factors are interacting and nonlinear, and delayed effect virtually exists in the system. Therefore, MGM $(1,N|\tau,r)$ has obvious advantage and is more suitable to cope with the nonlinear and delayed system.

5 Conclusion

Grey modeling and forecasting are important issues in grey system theory. Researching on grey modeling, which is nonlinear and delayed, we are expected to make the grey system theory itself to be more and more close to the essence of practical problems. By comprehensive consideration of nonlinear and delay, this chapter proposed MGM $(1, N|\tau, r)$ and made detailed elaboration on the process of modeling, parameter estimation and model testing. What's more, combining with statistical data of Wuhan science and technology, based on PSO, we have programmed the grey model on MATLAB, simulated and forecasted the input and output of Wuhan new hi-tech industry using this model simultaneously. By comparing simulation and forecasting result with MGM $(1, N)$, we can see that this model is effective to resolve the delay and nonlinear states of systems. As the practical system is nonlinear, there are interrelated constraints and interactions between variables, and the delay phenomenon is increasingly outstanding, referring to the above questions in practical system, how to make decisions is difficult for obtaining optimal input and output. The MGM $(1, N|\tau, r)$ can commendably resolve the difficult problem. Therefore, MGM $(1, N|\tau, r)$ has broad application prospects in the complex system, but the more abstract theory of the model need further study.

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A Modified GM(1,1) Model and Its Application

Peirong Ji, Hongbo Zou, and Xinyu Hu

A modified GM (1, 1) model is constructed by producing new data sequence with the method of transforming every datum of raw data sequence into its n-th root. It is demonstrated that the property of the modified GM (1, 1) model is superior to GM (1, 1) model by numerical experiment. Moreover the modified model is applied in the prediction of fruit price index in China. The actual results also show that the modified model is more accurate.

1 Introduction

Grey forecasting model (GM (1, 1) model) (Deng, 2002; Tsai and Yang, 2003; Lin et al., 2002; Sydow et al., 2001; Lin and Liu, 2000) presented by Professor Deng Julong, has been successfully used in many fields. The model is fit for non-negative raw data, which accords with or basically accords with exponential form and doesn't have quick growth rate (Wang and He, 1990; Xiong and Chen, 1992 ; Ji et al., 1997). The literature (Ji et al., 2007) interprets that GM (1, 1) model is useful when the change of the raw data sequence is slower; otherwise GM (1, 1) model is useless. In this chapter, the authors put forward a modified GM (1, 1) model. The results of statistical experiment show that the accuracy of the modified GM (1, 1) model is better than that of GM (1, 1) model. And the modified GM (1, 1) model is used to model the fruit price index in China from 2001 to 2006. The results show the accuracy of the model is very high and the prediction of fruit price index in China from year 2007 to 2014 is also given in the chapter.

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2 GM (1,1) Model

Let $x^{(0)}(1), x^{(0)}(2), x^{(0)}(3)..., x^{(0)}(N)$ be a raw sequence, and $x^{(0)}(k) \geq 0, k = 1, 2, ..., N$ .Using these data to build GM (1, 1) model, the steps are as follows:

(1) Give $x^{(1)}$ by applying first-order accumulating generation operator (1-AGO) on $x^{(0)}$

$$x^{(1)}(k) = \sum_{m=1}^{k} x^{(0)}(m), k = 1, 2, ..., n \tag{1}$$

(2) Ascertain data matrixes B , Y_N

$$B = \begin{pmatrix} -\frac{1}{2}\left[x^{(1)}(1) + x^{(1)}(2)\right] & 1 \\ -\frac{1}{2}\left[x^{(1)}(2) + x^{(1)}(3)\right] & 1 \\ \vdots & \vdots \\ \frac{1}{2}\left[x^{(1)}(N-1) + x^{(1)}(N)\right] & 1 \end{pmatrix}, \quad Y_N = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(N) \end{bmatrix}$$

(3) Solve the parameter column

$$\begin{bmatrix} \hat{a} & \hat{u} \end{bmatrix}^T = \left(B^T B\right)^{-1} B^T Y_N \tag{2}$$

(4) Establish the model of new data sequence

$$\frac{dx^{(1)}}{dt} + \hat{a} x^{(1)} = \hat{u} \quad \hat{x}^{(1)}(k+1) = (x^{(0)}(1) - \frac{\hat{u}}{\hat{a}})e^{-\hat{a}k} + \frac{\hat{u}}{\hat{a}}, k = 1, 2, ... \tag{3}$$

(5) Establish the model of raw data sequence

$$\hat{x}^{(0)}(1) = x^{(0)}(1) \tag{4}$$

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1)$$

$$= (1 - e^{-\hat{a}})(x^{(0)}(1) - \frac{\hat{u}}{\hat{a}})e^{-\hat{a}(k-1)}, k = 2, 3... \tag{5}$$

where $\hat{x}^{(0)}(k), k = 1, 2, ..., N$ are called fitting values of the raw data sequence $x^{(0)}\left(k\right), k = 1, 2, ..., N$, while $\hat{x}^{(0)}(k), k > N$ are called prediction values of the raw data sequence

3 Characteristics of GM(1,1) Model

We have given a detail analysis on the characteristics of GM (1, 1) model in (Ji et al., 2007). Some key contents of the analysis are repeated here for convenience of the readers of the chapter.

A. Formula Development

Assume a system $x(t) = Ae^{at}$ is written in a discrete form:

$$x^{(0)}(k) = Ae^{a(k-1)}, k = 1, 2, ..., N, ... \tag{6}$$

Take the first N items as the raw data sequence, the first-order accumulating generation sequence is:

$$x^{(1)}(k) = A\frac{1-e^{ak}}{1-e^{a}}, k = 1, 2, ..., N \tag{7}$$

Construct a GM(1,1) model, then

$$B = \begin{bmatrix} -\frac{1}{2}A\frac{2-e^{a}-e^{2a}}{1-e^{a}} & 1 \\ -\frac{1}{2}A\frac{2-e^{2a}-e^{3a}}{1-e^{a}} & 1 \\ ... & ... \\ -\frac{1}{2}A\frac{2-e^{(N-1)a}-e^{Na}}{1-e^{a}} & 1 \end{bmatrix}, Y_N = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ ... \\ x^{(0)}(N) \end{bmatrix}$$

Then

$$B^T B = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \tag{8}$$

In formula,

$$a_{11} = \frac{1}{4}A^2 \frac{4(N-1)(1-e^{a}) + (1+e^{a})(e^{a}-e^{Na})(e^{a}+e^{Na}-4)}{(1-e^{a})^3}$$

$$a_{12} = a_{21} = -\frac{1}{2}A\frac{2(N-1)(1-e^{a}) - (1+e^{a})(e^{a}-e^{Na})}{(1-e^{a})^2}$$

$$a_{22} = N-1$$

Then

$$(B^T B)^{-1} = \frac{1}{\left\| B^T B \right\|} \begin{bmatrix} a_{22} & -a_{21} \\ -a_{12} & a_{11} \end{bmatrix} \tag{9}$$

In formula

$$\left\| B^T B \right\| = \frac{1}{4} A^2 \frac{(1+e^a)(e^a - e^{Na})\left[\left(N-2\right) e^a - Ne^{2a} + Ne^{Na} - \left(N-2\right) e^{(N+1)a} \right]}{\left(1-e^a\right)^4}$$

Then

$$\left(B^T B\right)^{-1} B^T = \frac{1}{\left\| B^T B \right\|} \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1(N-1)} \\ b_{21} & b_{22} & \dots & b_{2(N-1)} \end{bmatrix} \tag{10}$$

In formula

$$b_{1k} = \frac{1}{2} A \frac{(1+e^a)[e^{Na} - e^a + (N-1)e^{ka}(1-e^a)}{(1-e^a)^2}, k = 1, 2, \dots, N-1$$

$$\frac{(1+e^a)\left\{ 2\left(ee^{Na} - e^a\right) + 2\left(N-1\right) e^{ka}(1-e^a) + \left(e^a - e^{Na}\right)\left[e^a + e^{Na} - e^{ka}(1+e^a) \right] \right\}}{(1-e^a)^3},$$

$k = 1, 2, \dots, N-1$

Therefore

$$\begin{bmatrix} \hat{a} \\ \hat{u} \end{bmatrix} = \left(B^T B\right)^{-1} B^T Y_N = \begin{bmatrix} \dfrac{2\left(1-e^a\right)}{1+e^a} \\ \dfrac{2A}{1+e^a} \end{bmatrix} \tag{11}$$

Form those results, we can get

$$\hat{x}^{(1)}(k+1) = \frac{-Ae^a}{1-e^a} e^{-\hat{a}k} + \frac{A}{1-e^a}, k = 1, 2, \dots, N-1 \tag{12}$$

Finally, the fitting results are

$$\hat{x}^{(0)}(1) = A \tag{13}$$

$$\hat{x}^{(0)}(k) = \frac{-Ae^a\left(1-e^{\hat{a}}\right)}{1-e^a} e^{-\hat{a}(k-1)}, k = 2, 3, \dots, N \tag{14}$$

Assume $a' = -\hat{a}, K = \dfrac{-e^{a}\left(1-e^{a}\right)}{1-e^{a}}$, then the formula (14) can be written as

$$\hat{x}^{(0)}(k) = KAe^{a'(k-1)}, k = 2,3,...,N \tag{15}$$

B. Theoretical Analysis

1) Comparing formula (15) with formula (6), we know that, if the GM(1,1) model is unbiased, the following two conditions must be satisfied.

$$a' = a \tag{16}$$

$$K = 1 \tag{17}$$

Only when $a = 0$, these two conditions can simultaneously be satisfied, the raw sequence is constant sequence in this situation.

2) When $|a|$ is very small, $\lim\limits_{|a|\to 0} e^{a} = 1 + a$, then

$$\lim_{|a|\to 0} a' = \lim_{|a|\to 0} \frac{-2(1-e^{a})}{1+e^{a}} = \lim_{|a|\to 0} \frac{2a}{2+a} = a$$

$$\lim_{|a|\to 0} K = \lim_{|a|\to 0} \frac{-e^{a}\left(1-e^{-a'}\right)}{1-e^{a}} = \lim_{|a|\to 0} \frac{-e^{a}\left(1-e^{-a}\right)}{1-e^{a}} = 1$$

The formula (16) and the formula (17) can be satisfied approximately.

3) When $|a|$ is very large, the following two kinds of limiting cases can be discussed.

When $a \to +\infty$,

$$\lim_{a\to\infty} a' = \lim_{a\to\infty} \frac{-2\left(1-e^{a}\right)}{1+e^{a}} = 2$$

$$\lim_{a\to\infty} K = \lim_{|a|\to\infty} \frac{-e^{a}\left(1-e^{-a'}\right)}{1-e^{a}} = 1 - e^{-2}$$

When $a \to -\infty$,

$$\lim_{a\to-\infty} a' = \lim_{a\to-\infty} \frac{-2\left(1-e^{a}\right)}{1+e^{a}} = -2$$

$$\lim_{a\to-\infty} K = \lim_{a\to-\infty} \frac{-e^{a}\left(1-e^{-a'}\right)}{1-e^{a}} = 0$$

Therefore, when $a \to +\infty$, the fitting curve which is confirmed by the GM(1, 1) model is near to the curve $\left(1-e^{-2}\right)Ae^{2t}$; when $a \to -\infty$,then is near to 0.

Above analysis theoretically explain the reason why GM (1, 1) model can be used when the variation of raw data sequence is slow, and GM (1, 1) model is useless when the variation of raw data sequence is fast.

4 The Modified GM (1, 1) Model

This chapter puts forward a modified GM (1, 1) model based on the results in (Ji et al., 2007). The first step of the model is to gain the n-th root of raw data sequence, in this way the growth rate of the raw data sequence can be reduced. The second step is to use GM (1, 1) model to model the extracted data sequence. The final step is to compute n-th power of the data produced in the second step.

Let $x^{(0)}(1), x^{(0)}(2), x^{(0)}(3)..., x^{(0)}(N)$ be a raw sequence, and $x^{(0)}(k) \geq 0, k=1,2,...,N$ .Using these data to build the modified GM (1, 1) model, the steps are as follows:

(1)Get the n-th root of raw data sequence:

$$x'^{(0)}(k)=\sqrt[q]{x^{(0)}(k)}, k=1,2,...,n, q=2,3,... \tag{18}$$

(2)Bring data by applying first-order accumulating generation operator (1-AGO)

$$x^{(1)}(k)=\sum_{m=1}^{k} x'^{(0)}(m), k=1,2,...,n \tag{19}$$

(3)-(4) are the same with (2) - (3) of GM(1,1) model.

(5) Establish the model of the new data sequence

$$\hat{x}^{(1)}(k+1)=(x'^{(0)}(1)-\frac{\hat{u}}{\hat{a}})e^{-\hat{a}k}+\frac{\hat{u}}{\hat{a}}, k=1,2,... \tag{20}$$

(6) Establish the model of n-th root of raw data sequence

$$\hat{x}'^{(0)}(1)=x'^{(0)}(1) \tag{21}$$

$$\hat{x}'^{(0)}(k+1)=(e^{-\hat{a}}-1)(x'^{(0)}(1)-\frac{\hat{u}}{\hat{a}})e^{-\hat{a}k},\ k=1,2... \tag{22}$$

(7) Restore the model of raw data sequence

$$\hat{x}^{(0)}(1)=(x'^{(0)}(1))^{q} \tag{23}$$

$$\hat{x}^{(0)}(k)=(\hat{x}'^{(0)}(k))_{q}, k=2,3..., q=2,3... \tag{24}$$

5 Comparison between the Two Models

In practical forecasting, the sequences to be forecasted are not a strict exponential sequence. Many sequences can be considered to be made up of strict exponential sequence and certain disturbance. Here, we do research by using the statistical experiment method. Let the raw data $x^{(0)}(k) \geq 0, k = 1,2,...,N$ be an exponential sequence with certain deviation (disturbance), R denote the deviation, which changes between 1% with10%.That is,

$x^{(0)}(k) = Ae^{(k-1)a}(1 + R * unifrnd(-1,1)), (k = 1,2,...,n)$ Where $unifrnd(-1,1)$ is a function of Matlab language, the role of which is to generate the symmetrical random numbers within (-1, 1).

For each R , 2500 random samples are taken. GM (1, 1) model and the modified GM (1, 1) model are used to model 2500 samples respectively. When q is 2,3,4,5,… respectively, the modified GM (1, 1) model can be correspondingly named as 2-th root GM (1, 1) model, 3-th root GM (1, 1) model, 4-th root GM (1, 1) model, 5-th root GM (1, 1) model et al. In the experiment, use *MAPLE* to measure the accuracy of models, and let

$$MAPE = \frac{1}{2500} \sum_{i=1}^{2500} MAPE_i$$

where

$$MAPE_i = \frac{1}{n} \sum_{i=2}^{n} \left| \frac{x_i - \hat{x}_i}{x_i} \right| \times 100\%$$

Let $A = 10, a = 0.03, N = 10$, the experimental results are shown in Table I. Let $A = 10, a = 0.3, N = 10$, the experimental results are shown in table II.

Table I Experiment results of mape ($a = 0.03$)

R	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
GM(1,1) model	0.38603%	0.77159%	1.15759%	1.54507%	1.92002%	2.30919%	2.70760%	3.07235%	3.48530%	3.86839%
2-th root GM(1,1)	0.38580%	0.77101%	1.15669%	1.54418%	1.91847%	2.30732%	2.70517%	3.06880%	3.48219%	3.86345%
3-th root GM(1,1)	0.38575%	0.77089%	1.15652%	1.54405%	1.91816%	2.30696%	2.70464%	3.06796%	3.48157%	3.86228%
4-th root GM(1,1)	0.38575%	0.77085%	1.15645%	1.54401%	1.91805%	2.30682%	2.70444%	3.06762%	3.48132%	3.86179%
5-th root GM(1,1)	0.385746%	0.77083%	1.15642%	1.54399%	1.91799%	2.30675%	2.70433%	3.06743%	3.48121%	3.86151%

From Table I and Table II we can learn that the mean absolute percentage error $MAPE$ of GM (1, 1) model and four modified GM (1, 1) models increase with the growth of R . When the development coefficient a is small, the accuracy of GM (1, 1) model is satisfactory, the accuracy of four modified GM (1, 1) models are slightly better than that of GM (1, 1) model, where the accuracy of 5-th root modified GM (1, 1) model is best(Table1). When the development coefficient a is large, with the growth of R , the $MAPE$ of GM (1, 1) model is obviously different from the $MAPE$ of modified models, the accuracy of four modified GM (1, 1) models are much better than that of GM (1, 1) model, but the difference among four modified models are not very large , where the accuracy of 5-th root GM (1, 1) model is best (Table II). The reason can be considered as that the growth rate of n-th root of raw data is less than that of the raw data, so the development coefficient reduces. The result is completely consistent to the theory shown in (Ji et al., 2007).

Table II Experiment results of mape ($a = 0.3$)

R	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
GM(1,1) model	1.63459%	1.89050%	2.26235%	2.70231%	3.21073%	3.64996%	4.24505%	4.78976%	5.28557%	5.92719%
2-th root GM(1,1)	0.62968%	0.91931%	1.27571%	1.64110%	2.02849%	2.42124%	2.79467%	3.20402%	3.59948%	3.98996%
3-th root GM(1,1)	0.46747%	0.81964%	1.19559%	1.56762%	1.95564%	2.34924%	2.71676%	3.12363%	3.51228%	3.89070%
4-th root GM(1,1)	0.42308%	0.79405%	1.17513%	1.54980%	1.93748%	2.33155%	2.69824%	3.10527%	3.49149%	3.86686%
5-th root GM(1,1)	0.40588%	0.78416%	1.16732%	1.54296%	1.93051%	2.32479%	6 91140%	3.09863%	3.48332%	3.85729%

6 Application of the Modified GM(1,1) Model

The fruit price index (100 is a standard) in China from year 2001 to 2006 (Zhu, 2007) is shown in table III. Using GM (1, 1) model and the modified GM (1, 1) model to build models separately, the fitting results shown in table IV can be obtained.

Here, using MAPE (mean absolute percentage error) to measure the precision of the models, we can gain the comparison results of accuracy between GM (1, 1) model and the modified GM (1, 1) models, which is shown in table V. From the results in table V, we can see that the precision of 5-th root GM (1, 1) model is superior to other GM (1, 1) models.

Table III The fruit price index (100 is a standard) in china from year 2001 to 2006

year	2001	2002	2003	2004	2005	2006
fruit price index	99.9	103.1	103.0	104.0	102.2	123.6

Table IV The fitting result of GM(1,1) and modified GM(1,1) models to the fruit price index in china

year	2001	2002	2003	2004	2005	2006
GM(1,1)	99.9	98.97	102.90	106.99	111.24	115.66
2-th root GM(1,1)	99.9	99.28	103.04	106.95	111.00	115.20
3-th root GM(1,1)	99.9	99.38	103.09	106.93	110.91	115.05
4-th root GM(1,1)	99.9	99.43	103.10	106.92	110.87	114.97
5-th root GM(1,1)	99.9	99.45	103.12	106.91	110.85	114.93

Table V The comparison of accuracy between GM(1,1) and modified GM(1,1) models

model	GM(1,1)	2-th root GM(1,1)	3-th root GM(1,1)	4-th root GM(1,1)	5-th root GM(1,1)
MAPE	3.7071%	3.6635%	3.6585%	3.6559%	3.6543%

Table VI The prediction results of the fruit price index in china from year 2007 to 20014

year	2007	2008	2009	2010	2011	2012	2013	2014
fruit price index	119.16	123.55	128.09	132.81	153.47	159.12	164.98	171.05

Using 5-th root GM (1, 1) model to forecast the fruit price index in China from year 2007 to 2014, the results are shown in the table VI.

7 Conclusions

In this chapter, the authors put forward the modified GM (1, 1) models. When the development coefficient a is small, the accuracy of the modified GM (1, 1) models is slightly better than that of GM (1, 1) model. When the development coefficient a is large, the accuracy of the modified GM (1, 1) models is much better than that of GM (1, 1) model. So the modified GM (1, 1) models are superior to GM (1, 1) model.

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The Interval Forecasting Method Based on Non-Equidistant GM(1,1) with Application to Regional Grain Production*

Bingjun Li and Chunhua He

Based on a raw sequence with some aberrant data, it is difficult for any prediction technique to give out an accurate point forecasting value. However, an interval forecasting value obtained by one or more different techniques should be reasonable and acceptable. In this chapter, a data sequence having a linear tendency with upper/positive and lower/negative aberrances is analyzed. Upon the linear regression analysis, the data sequence is classified into three parts: upper/positive aberrant data, lower/negative aberrant data and normal data. Then introducing the non-equidistant GM (1, 1), we establish three models: a non-equidistant GM (1, 1) based on upper aberrant data, a non-equidistant GM (1, 1) based on lower aberrant data and a linear regression model based on the remaining normal data. Using the established models, we can obtain three prediction intervals. Applying it to the prediction of regional grain production, we demonstrate the good performance and effectiveness of the proposed prediction method.

1 Introduction

Prediction is an estimation of unknown situation based on the investigation on all available knowledge and information including past and present data. In principle, it is based on the discovery of the law of the system and a model identification using

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* The work was supported in part by the Science-tech Innovative talents plan project of Henan Province (No.551(2008)); the Soft-science Foundation of Henan Province (No.072400420650); Innovation Scientists and Technicians Troop Construction Projects of Henan Province (094100510013).

given data so that numerical estimation about the future is possible. It is difficult in many situations to get an accurate point forecasting value by one, even more methods. However, an interval forecasting value obtained by one or more different techniques should be rather easy, reasonable and acceptable. For some of very interesting discussions on prediction in general, please refer to (Lin and OuYang, 2010; OuYang and Lin, 2002; Lin, 2001). In this chapter, a data sequence having a linear tendency with upper/positive and lower/negative aberrances, which widely appears in the real world, is analyzed by non-equidistant GM (1, 1) from the grey systems theory and the conventional linear regression model.

Grey systems theory (Liu et al., 2004; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), proposed by Professor Deng Ju-long in 1982, is a new method to study uncertain problems with a few data and poor information. It works on uncertain systems with partially known and partially unknown information. The grey system theory enables us to describe correctly or emulate effectively systems behavior by drawing out valuable information through the generalization and development of the given partial information. GM (1, 1) is one of the most important forecasting models (Lin et al., 2002; Sydow et al., 2001; Lin and Liu, 2000) in the grey systems theory. Since it was presented in 1982, the model has been widely applied to economy, management, agriculture, industry, education, ecological environment and engineering technology. Until now, many scholars have improved the conventional GM (1, 1) model. For example, Tan Guan-jun (Tan, 2000), Luo Dang et al. (2003) and Song Zhongmin et al. (2001) improved GM modeling precision by ameliorating the different context values. Mu Yong (2003) and Wang Yinao et al. (2001) improved GM modeling precision by optimizing the grey differential whitenization value. Liu Sifeng and Deng Julong (2000), Zheng Zhaoning et al. (2001) studied the applications of GM (1, 1) model in various aspects. Such studies advance the GM (1, 1) model and expand the area of applications greatly.

Linear regression analysis is a way, according to the system's evolution continuity, correlation between the system's causes and affects as well as the system's evolution law that can regard the future state of the system as the current's continuation under a relatively stable condition. Linear regression can give out a better result in a short-term forecast than in a long-term forecast.

For a raw sequence with some upper/positive aberrant data and lower/negative aberrant data, which appears widely in the world especially in grain production data under policy influences, flood disasters and so on, linear regression can model well the linear growth tendency, while GM(1,1) model can model well the exponential growth tendency without requiring many data (Wang et al., 2001; Liu and Deng, 2000). In fact, the sequences composed of some upper/positive aberrant data and lower/negative aberrant data are often non-equidistant, so it is necessary to establish non-equidistant GM (1, 1), but not conventional GM (1, 1). This chapter attempts to get interval forecasting values based a raw sequence with some aberrant data by non-equidistant GM (1, 1) and linear regression model. Firstly, to make the linear regression model of the raw data, and get all simulated values of the raw data by the model. Secondly, to calculate the sequence of errors between the raw data and the corresponding simulated data, the raw data can be regarded as a so-called aberrant point or abnormal point if the error of a raw data is bigger than a given critical value. At this time, the raw data sequence with some abnormal data is classified into three parts: upper/positive aberrant data, lower/negative aberrant data and normal data. Thirdly, we establish three models: a non-equidistant GM (1, 1) model based on upper aberrant data, a non-equidistant GM (1, 1) model based on lower aberrant data and a linear regression model based on the remaining normal data. Finally, we can use the three established models to obtain three prediction intervals. A positive study shows that this forecasting method can effectively get some better forecasting results.

2 Classification of Raw Data

A. The rough procedure of classifying raw data

Analyzing raw data reasonably is an important task of modeling. In a raw data sequence, what kinds of values are abnormal? In general, people often use their experience and subjective criteria to determine what values are normal and what are not. But it is hard to get ideal results in many situations due to the limitations of people's experience and choice of subjective criteria. Where, we propose a new approach to classify raw data. The rough procedure of the proposed approach is given as follows: First, applying the linear regression model obtained by the least square method for a data sequence having a linear tendency, we calculate estimated values and the signed residual errors at all data points. Then, the raw data can be classified into so-called aberrant data points (upper/positive and lower/negative) and normal data points depending on the residual errors. If the residual error is positive and larger than a predetermined threshold, the data is regarded as an upper/positive aberrant data. If the residual error is negative and its absolute value is larger than the threshold, the data is regarded as a lower/negative aberrant data. Otherwise, the data is regarded as normal.

B. The concrete steps of classifying raw data

The concrete steps of classifying raw data are followed:

Step 1: Assume that $X^{(0)}$ and $Q^{(0)}$ are raw data sequence and time sequence respectively:

$$X^{(0)} = (X^{(0)}q(1)), X^{(0)}(q(2)), \cdots, X^{(0)}(q(m)) \quad (1)$$
$$Q^{(0)} = (q(1), q(2), \cdots, q(m)) \cdot$$

Step 2: Based on $X^{(0)}$ and $Q^{(0)}$, we get the linear regression function

$$X^{(0)} = a_0 + b_0 Q^{(0)} . \quad (2)$$

Then, we can get a residual error sequence ε^0 between $X^{(0)}$ and the simulated $\hat{X}^{(0)}$ through the function (2).

$$\begin{aligned}\varepsilon^0 &= (\varepsilon(1), \varepsilon(2), \ldots, \varepsilon(m)) \\ &= (X^0 q(1) - \hat{X}^0 q(1), X^0 q(2) - \hat{X}^0 q(2), \ldots, \\ &\quad X^0 q(k) - \hat{X}^0 q(k), \ldots, X^0 q(m) - \hat{X}^0 q(m)\end{aligned} \tag{3}$$

Step 3: If the absolute value of $\varepsilon(k)$ is bigger than the given abnormal critical value ξ (according to the required linear regression precision, we may give the value. It is acceptable to set an upper critical value and a lower critical value if necessary), we can deem the corresponding data as the aberrant data points, if not then the normal data point. Therefore according to positive or negative residual error, we can classify the aberrant data points into two parts: upper/positive aberrant data, lower/negative aberrant data.

Let $P^{(0)}$ and $X_A^{(0)}$ denote the upper/positive aberrant time sequence and data sequence, respectively. Then we have

$$P^{(0)} = (p(1), p(2), \cdots, p(s)), \tag{4}$$

$$X_A^{(0)} = (X^{(0)} p(1)), X^{(0)}(p(2)), \cdots, X^{(0)}(p(s)) \tag{5}$$

Let $R^{(0)}$ and $X_B^{(0)}$ denote the lower/negative aberrant time sequence and data sequence, respectively. Then we have

$$R^{(0)} = (r(1), r(2), \cdots, r(t)), \tag{6}$$

$$X_B^{(0)} = (X^{(0)} r(1)), X^{(0)}(r(2)), \cdots, X^{(0)}(r(t)) \tag{7}$$

Step 4: Assume that $L^{(0)}$ and $X_C^{(0)}$ are other normal data time sequence and data sequence respectively. Then we have

$$L^{(0)} = (l(1), l(2), \cdots, l(m))(m = n - s - t), \tag{8}$$

$$X_C^{(0)} = (X^{(0)} l(1)), X^{(0)}(l(2)), \cdots, X^{(0)}(l(m)). \tag{9}$$

3 The Establishment of Forecasting Models

The conventional GM (1, 1) modeling is based on the equidistant data sequence. In fact, the raw data sequence we often get is incomplete or lack of some data so that it is hard to establish appropriate GM (1, 1) based on non-equidistant data sequence by the principle of the conventional GM (1, 1) modeling. So we have to study the principle of non-equidistant GM(1,1).

C. The Principle of Non-equidistant GM (1, 1)

For $X^0 = \{x^0(T_1), x^0(T_2), \ldots, x^0(T_n),\}$, if the distance ΔT_i is equal to $T_i - T_{i-1}$, and not equal to one constant value. We call sequence X^0 non-equidistant one (Si et al., 2006).

Assume that one non-equidistant sequence is

$$X^0 = \{x^0(T_1), x^0(T_2), \cdots, x^0(T_n),\}$$

Its modeling process is as follows (Huang and Li, 2004):

1) Calculate the distance and spacing between every observation point and the first one:

$$t_i = T_i - T_1 (i = 1, 2, \ldots, n) \tag{10}$$

$$\Delta t_i = t_i - t_{i-1} \tag{11}$$

2) Compute the mean spacing:

$$\Delta t_0 = \frac{1}{n-1} \sum_{i=1}^{n-1} \Delta t_i = \frac{1}{n-1}(t_n - t_1) \tag{12}$$

3) Compute the mean time coefficient of spacing t_i and the mean spacing Δt_0 on every period:

$$\mu(t_i) = \frac{t_i - (i-1)}{\Delta t_0} \tag{13}$$

4) Compute the summed difference value of every period:

$$\Delta x^0(t_i) = \mu(t_i)[x^0(t_i) - x^0(t_{i-1})] \tag{14}$$

Where, $x^0(t_i)$ is the original observational value at time t_i.

1) Compute grey number $z^0(t_i)$ of equal interval, and get equal series Z^0:

$$z^0(t_i) = x^0(t_i) - \Delta x^0(t_i) \tag{15}$$

$$Z^0 = \{z^0(t_1), z^0(t_2), \ldots, z^0(t_n)\} \tag{16}$$

2) Make $GM(1,1)$ model according to equal series Z^0:

First step: make one accumulated generating operation $(1-AGO)$ to Z^0, and we can get

$$Z^1 = \{z^{(1)}(1), z^{(1)}(2), \ldots, z^{(1)}(n)\}$$

Second step: Fit the first order linear differential equation based on $Z^{(1)}$, that is

$$\frac{dZ^{(1)}}{dt} + aZ^{(1)} = u$$

Last step: Calculate the undetermined parameters a, u, and the time response sequence is defined as:

$$\hat{z}^{(1)}(k+1) = [z^0(1) - \frac{u}{a}]e^{-ak} + \frac{u}{a} \tag{17}$$

Where

$$\hat{a} = (a,u)^T = (B^T B)^{-1} B^T Y$$

$$B = \begin{bmatrix} -\frac{1}{2}[z^{(1)}(1) + z^{(1)}(2)] & 1 \\ -\frac{1}{2}[z^{(1)}(2) + z^{(1)}(3)] & 1 \\ \vdots & \vdots \\ -\frac{1}{2}[z^{(1)}(n-1) + z^{(1)}(n)] & 1 \end{bmatrix}, \; Y = \begin{bmatrix} z^{(0)}(2) \\ z^{(0)}(3) \\ \vdots \\ z^{(0)}(n) \end{bmatrix}$$

3) Transform (17) into the function of t about the original non-equidistant series. Where t is the time spacing from the first observation time.

$$\hat{x}^{(1)}(t) = [x^0(1) - \frac{u}{a}]e^{-at/\Delta t_0} + \frac{u}{a} \tag{18}$$

$$\hat{x}^{(0)}(t) = \hat{x}^{(1)}(t) - \hat{x}^{(1)}(t - \Delta t_0) \tag{19}$$

D. The Test Method of Non-equidistant GM (1, 1)

Let the error of model

$$\varepsilon(T_i) = x^{(0)}(T_i) - \hat{x}^{(0)}(T_i), i = 1,2,\cdots,n \tag{20}$$

Assume that $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x^{(0)}(T_i)$ and $S_1{}^2 = \frac{1}{n}(x^{(0)}(T_i) - \hat{x}^{(0)}(T_i))^2$ are the mean and variance of $x^{(0)}(T_i)$ respectively. And $\bar{\varepsilon} = \frac{1}{n}\sum_{i=1}^{n} \varepsilon(T_i)$ *and* $S_2{}^2 = \frac{1}{n}\sum_{i=1}^{n}(\varepsilon(T_i) - \bar{\varepsilon})^2$ are the mean and variance of $\varepsilon(T_i)$ respectively. If we define the ratio of mean square deviation C as $\frac{S_2}{S_1}$, for given C_0, when $C < C_0$, we call this model the suitable model of mean square deviation.

Let $P = P(|\varepsilon(T_i) - \overline{\varepsilon}| < 0.6745 S_1)$ be small error probability, for given P_0, when $P < P_0$, we call this model the suitable model of small error probability. The accuracy grade table of grey forecasting model is as follows:

Table 1 Accuracy Grade

ACCURACY GRADE	INDEX CRITICAL VALUE		
	RELAT IVE ERROR	RATIO OF MEAN SQUARE DEVIATION	SMALL ERROR PROBABILITY
FIRST GRADE	0.01	0.35	0.95
SECOND GRADE	0.05	0.50	0.80
THIRD GRADE	0.10	0.65	0.70
FORTH GRADE	0.20	0.80	0.60

E. The Establishment of Forecasting Models

For upper/positive aberrant data and lower/negative aberrant data sequence $X_A{}^{(0)}$ and $X_B{}^{(0)}$, we can get the prediction models $\hat{X}_A^{(0)}$ and $\hat{X}_B^{(0)}$ according to the principle of non-equidistant GM (1, 1).

$$\hat{X}_A^{(1)}(t) = [X^{(0)} p(1) - \frac{u}{a}]e^{-at/\Delta t_0} + \frac{u}{a} \tag{21}$$

$$\hat{X}_A^{(0)}(t) = \hat{X}_A^{(1)}(t) - \hat{X}_A^{(1)}(t - \Delta t_0) \tag{22}$$

$$\hat{X}_B^{(1)}(t) = [X^{(0)} r(1) - \frac{u}{a}]e^{-at/\Delta t_0} + \frac{u}{a} \tag{23}$$

$$\hat{X}_B^{(0)}(t) = \hat{X}_B^{(1)}(t) - \hat{X}_B^{(1)}(t - \Delta t_0) \tag{24}$$

For other normal data $L^{(0)}$ and their corresponding values $X_C{}^{(0)}$, we can establish a new linear regression function of $L^{(0)}$ and $X_C{}^{(0)}$

$$\hat{X}_C = a + bL \tag{25}$$

When making prediction on the date $q(k)$, we could get three predicted values:

(1) If using the upper aberrant non-equidistant forecasting function, we will get the estimated value $\hat{X}_A^{(0)}(q(k)-p(1))$ by (22).

(2) If using the lower aberrant non-equidistant forecasting function, we will get the estimated value $\hat{X}_B^{(0)}(q(k)-r(1))$ by (24).

(3) If using the new linear regression forecasting function, we can get the value $\hat{X}_C^{(0)}(q(k))$ by (25).

Where, $\hat{X}_C^{(0)}(q(k))$ is regarded as the conservative predictive value, $\hat{X}_A^{(0)}(q(k)-p(1))$ as the optimistic predictive value and $\hat{X}_B^{(0)}(q(k)-r(1))$ as the pessimistic result on the date of $q(k)$. Based on $\hat{X}_A^{(0)}(q(k)-p(1))$, $\hat{X}_B^{(0)}(q(k)-r(1))$ and $\hat{X}_C^{(0)}(q(k))$, we can get three prediction intervals. The bigger interval is $\left[\hat{X}_B^{(0)}(q(k)-r(1)), \hat{X}_A^{(0)}(q(k)-p(1))\right]$ which will be our choice if we know less about the development tendency of the forecasted object; the two smaller intervals are respectively $[\hat{X}_B^{(0)}(q(k)-r(1)), \hat{X}_C^{(0)}(q(k))]$ and $[\hat{X}_C^{(0)}(q(k), \hat{X}_A^{(0)}(q(k)-p(1))]$ when we face to conservative or optimistic tendency.

4 Case Study: Prediction of Regional Grain Production

Regional grain production is a very complex biological and ecological process. The advancement of science and technology, agricultural policies, natural factors and so on can greatly influence on it (Hu and Wu, 2006; Fan, 2006; Fan, 2007). So, regional grain production can be regarded as an uncertain problem with partially known and partially unknown information.

On the base of Grain Production of Henan Province from 1980 to 2006 (See Table 2), viewing 1980 year as a base point 1. Meanwhile, we have the date sequence from 1980 to 2006 year, denoted as $Q^{(0)}$:

$$Q^{(0)}=(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,2021,$$
$$22,23,24,25,26,27)$$

Data sequence is denoted as $X^{(0)}$:

$$X^{(0)} = (2148.68,2314.5,2217.1,2904,2893.5,2710.53,\\ 2545.67,2948.41,2663,3149.44,3303.66,3010.3,3109.6,\\ 3639.21,3253.8,3466.5,3839.9,3894.66,4009.61,\\ 4253.25,4101.5,4119.88,4209.98,3569.5,4260,4582,5115.3$$

According to the concrete steps of classifying raw data, we can do:

Step One: Based $X^{(0)}$ and $Q^{(0)}$, we can make a scatter figure of the raw data, and further find that the general tendency of these raw data is linear.

Step Two: From $X^{(0)}$ and $Q^{(0)}$, get the regression function:

$$\hat{y}_1 = 2141.483 + 91.04082x$$
$$(R^2 = 0.887666, F = 197.5513)$$

and its residual error sequence ε^0:

ε^0 = (-83.8434,-9.06418,-197.505,398.354,296.813,22.8025,-233.098,78.6009,-297.85,97.5492,160.728,-223.672,-215.403,223.156,-253.295,-131.636,150.723,114.443,138.352,290.951,48.1602,-24.5007,-25.4415,-756.992,-157.503,73.456,515.715).

Table 2 Grain Yield of Henan Province from 1980 to 2006

YEAR	NO.	GRAIN YIELD	YEAR	NO.	GRAIN YIELD
1980	1	2148.68	1994	15	3253.8
1981	2	2314.5	1995	16	3466.5
1982	3	2217.1	1996	17	3839.9
1983	4	2904	1997	18	3894.7
1984	5	2893.5	1998	19	4009.6
1985	6	2710.53	1999	20	4253.3
1986	7	2545.7	2000	21	4101.5
1987	8	2948.4	2001	22	4119.88
1988	9	2663	2002	23	4209.98
1989	10	3149.4	2003	24	3569.47
1990	11	3303.7	2004	25	4260
1991	12	3010.3	2005	26	4582
1992	13	3109.6	2006	27	5115.3
1993	14	3639.21			

Note: Data from “Henan Statistic Yearbook” (Henan statistic department, 2007).

Step Three: For one given critical abnormal value $\xi = 220$, we can find out what are the aberrant time points and what are their corresponding grain yield values.

If the residual error is more than 220, we think the corresponding data is upper/positive aberrant point. According to the fact, we can get upper/positive aberrant time sequence $P^{(0)}$ and data sequence $X_A^{(0)}$

$$P^{(0)} = (4,5,14,20,27) \tag{26}$$

$$X_A^{(0)} = (2904,2893.5,3639.21,4253.25,5115.3) \tag{27}$$

If the residual error is less than -220, we think the corresponding data is lower/negative aberrant point. According to the fact, we can get lower/negative aberrant time sequence $R^{(0)}$ and data sequence $X_B{}^{(0)}$

$$R^{(0)} = (7,9,12,15,24) \tag{28}$$

$$X_B^{(0)} = (2545.67,2663,3010.3,3253.8,3569.47) \tag{29}$$

Step Four: For $P^{(0)}$, $X_A^{(0)}$ and $R^{(0)}$, $X_B{}^{(0)}$, we can have

$$\begin{aligned}\hat{X}_A^{(1)}(k+1) &= 15875.675933\mathrm{e}^{0.175697k}\text{-}12971.675933\\ \hat{X}_B^{(1)}(k+1) &= 34027.27485\mathrm{e}^{0.081491\mathrm{k}}\text{-}31481.60485\end{aligned} \tag{30}$$

Because the two development coefficient respectively is 0.175697 and 0.081491, the simulation precision of GM (1, 1) model is quite reliable; Give the upper measured model as:

$$\begin{aligned}\hat{X}_A^{(1)}(t) &= 15875.675933\mathrm{e}^{0.175697t/5.75}\text{-}12971.675933\\ \hat{X}_A^{(0)}(t) &= \hat{X}_A^{(1)}(t) - \hat{X}_A^{(1)}(t-5.75)\end{aligned} \tag{31}$$

Give the lower measured model as:

$$\begin{aligned}\hat{X}_B^{(1)}(t) &= 34027.27485\mathrm{e}^{0.081491\mathrm{t}}\text{-}31481.60485\\ \hat{X}_B^{(0)}(t) &= \hat{X}_B^{(1)}(t) - \hat{X}_B^{(1)}(t-4.25)\end{aligned} \tag{32}$$

The ratio of mean square deviation C of upper non-equidistant GM (1, 1) is 0.1622, $p = 1$; and the ratio of mean square deviation C of lower non-equidistant GM (1, 1) is 0.3029, $p = 0.99$, so their accuracy grades all are the first grade .

Step Five: Comparing the two calculated errors between by non-equidistant GM (1, 1) and by linear regression model regarding upper/positive aberrant data points, as shown in Table 3:

Table 3 Comparison of two calculated errors

ABERRANT SEQUENCE	ERROR OF LINEAR REGRESSION	ERROR OF GM(1,1)
4	385.680	345.986
5	375.491	256.116
14	223.788	167.004
20	299.952	82.369
27	473.828	-50.289

From Table 3, we can see that fitting degree of non-equidistant GM (1, 1) model is better than that of linear regression model for these upper/positive aberrant data points.

Comparing the two calculated errors between by non-equidistant GM (1, 1) and by linear regression model regarding lower/negative aberrant data points, as shown in Table 4. Where, we can see that it is obvious that fitting degree of GM (1, 1) model is better than that of linear regression model for lower/negative aberrant data points.

Table 4 Comparison of the two calculated errors

ABERRANT SEQUENCE	ERROR OF LINEAR REGRESSION	ERROR OF GM(1,1)
7	-241.688	-117.27
9	-303.766	-104.044
12	-225.534	79.42
15	-251.101	149.38
24	-742.635	-119.676

Step Six: Establishing new linear regression model. After eliminating upper/positive aberrant time point $P^{(0)}$, lower/negative aberrant point $R^{(0)}$ and their corresponding data, we can get $L^{(0)}$ and $X_C^{(0)}$.

For $L^{(0)}$ and $X_C^{(0)}$, we can have

$$\hat{X}_C^{(0)} = 2111409 + 93.33L^{(0} \tag{33}$$
$$R^2 = 0.9755, F = 596.46$$

Step Seven: Make prediction of the grain production of Henan Province in 2007 and 2008 year, and comparison with the actual production.

Let t be $28-4, 29-4$ respectively in model (31), and then let t be $28-7, 29-7$ in model (32) and $L^{(0)}$ be 28, 29 respectively in model (33).

The forecasting grain production of Henan Province in 2007 and 2008 year respectively is 5325.865, 3983.227, 4724.588 and 5491.114, 4060.34, 4817.916. While the real grain production of Henan Province in 2007 and 2008 year are 5245.22 and 5370.The values are shown in Table 5:

From the Table 5, the actual grain production in 2007 year is 5245.22 which is in the interval [4724.588, 5325.865], and the production in 2008 is 5365.48 in [4817.916, 5491.114]. The real grain production of Henan Province in 2007 and 2008 year is located in the interval between the new linear fitted value and the upper fitted value. It indicates that the development tendency of the grain production of Henan Province in 2007 and 2008 year is increasing.

Table 5 Comparison of Fitted Values with Actual Values in 2007 and 2008 Year

YEAR	REAL VALUE	UPPER PREDICTED VALUE	LINEAR PREDICTED VALUE	LOWER PREDICTED VALUE
2007	5245.22	5325.865	4724.588	3983.227
2008	5365.48	5491.114	4817.916	4060.34

Step Eight: Give the forecasting result of 2009 year.

From the end of 2008 to the beginning of 2009, one serious drought swept across the whole Henan Province. Although the drought situation was relieved partially at end of February, the loss of grain production is unable to be compensated in some areas, which will inevitable influence the yield-increasing effect of summer crops in 2009. Based on the above-mention reasons, the high, middle, and lower predicted grain production of Henan Province in 2009 are 5661.49, 4911.244 and 4138.945 respectively. So various elements and real situation should be considered, we choose the interval [4911.24, 5661.49] as our prediction interval. The result is acceptable. They can reflect the basic law of Grain Production of Henan Province.

5 Conclusions

The non-equidistant GM (1, 1) has more advantages in some situations than the conventional GM (1, 1). For a data sequence having a linear tendency with upper/positive and lower/negative aberrances, it is more reasonable that the raw data sequence is classified by means of data own characters, and that non-equidistant GM (1, 1) and linear regression models are set up based on different class data for various predictions. The process can reduce the forecasting error from abnormal data to some extent.

The grain production of one area has connection with many aspects of the national economy, and at the same time, as time goes by, many unknown factors in the future will be involved in and have influence on our estimated results. So very accurate simulated value is too hard to achieve, the reason is that the system of grain is easily affected by policies of sino-foreign, economic environment, cultivated land area decrease, fine varieties extension, grain price and production cost and so on. Therefore, when we make a forecast, it is reasonable and acceptable to predict an interval value.

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An Optimization Method of Estimating Parameters in GM(1,1) Model

Xuemei Li, Yaoguo Dang, and Jiejue Zhao

According to Principle of New Information Priority in grey theory, giving the new information larger weight in modeling can improve the effectiveness of gray model. For the *GM*(1,1) model has very small samples, and the high overall simulation accuracy does not necessarily guarantee high prediction accuracy, we put forward weighted least square method to estimate parameters in *GM*(1,1) model. Focusing on improving the simulation accuracy of new information, focusing on grasping the latest development' law of things, and aiming at improving the prediction accuracy by giving residual sum of squares of new information larger weight. Finally, we use an example to verify the practicality and reliability of the model.

1 Introduction

GM(1,1) model is one of the core content of gray prediction models, which has been widely used in industry, agriculture, social, economic and other fields because it requires very small samples with simple calculation. It is especially on the case of small samples and poor information uncertain systems that it was successfully applied. Many scholars have done a lot of research in order to improve the prediction accuracy. These studies mainly concentrated in the following respects: 1. Do pre-processing on the original sequence using sequence operator, buffer operator and date transformation in order to make them suitable to *GM*(1,1) model (Dang et al., 2006; Dai and Li, 2004; Li and Dai, 005; Cui and Dang, 2009; Lin et al., 2002; Sydow et al., 2001; Lin and Liu, 2000); 2. Optimize the background date (Tan, 2000; Luo et al., 2003; Wang et al., 2007); 3. Optimize method of estimating

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parameters in *GM*(1,1) model (Deng, 2002a; Liu, 2004; He et al., 2004; He et al., 2005; Ji et al., 2000). For that we often use the average relative error to test the model accuracy, He Wen-zhang puts forward linear programming method to estimate parameters in *GM*(1,1) model by minimizing the average relative error or maximum relative error. He gets a family of algorithms of estimating parameters. Pei Ji-rong proves that the traditional gray model is deviation and makes an unbiased gray prediction model, which has a great expansion of the scope of application to eliminate the inherent bias. The new estimation (Ji et al., 2000) is $\hat{a}' = \ln \frac{2-\hat{a}}{2+\hat{a}}$; 4. Explore the determination of boundary condition of *GM*(1,1) method (Zhang and Hu, 2001; Dang, et al., 2005); 5. Optimize the time response function (Zhang et al., 2002; Liu et al., 2003). In addition, Song Zhong-min divides data sequence into two appropriate groups of data sequence, and makes two sets of models, then use translational operator to obtain prediction values.

Optimizing parameters in the past focus on improving the simulation accuracy. In fact the main purpose of simulation is used to predict the small average relative error and the residual sum of squares that cannot ensure high prediction accuracy. According to Principle of New Information Priority (The principle that the new information on the role of cognitive information is better than the old) in grey theory, giving the new information larger weight in modeling process can improve the effectiveness of gray model. The system we studied is changing, although the research on historical information has a certain extent, the closer information is more valuable to the study of the characteristics of the system (Song and Zhang, 2002; Deng, 2002b; Fu, 1992). We make improvement on the original model based on Principle of New Information Priority, and use weighted least square method to estimate parameters in *GM*(1,1) model. The parameters focus on improving the simulation accuracy of new information and on grasping the latest development law of things which aim at improving the prediction accuracy by giving residual sum of squares of new information larger weight.

2 Optimization Method of Estimating Parameters in *GM*(1,1) Model

2.1 Estimating Parameters in GM(1,1) Model Based on Least Square Method

Theorem 1. Assume that $X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$ is a non-negative sequence $X^{(1)} = (x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n))$ is the sequence of 1-AGO generated from $X^{(0)}$, and $Z^{(1)}$ is the sequence of mean generated with consecutive neighbors of $X^{(1)}$. $\widehat{a} = (a,b)^T$ is the parameter, and

$$Y=\begin{pmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{pmatrix}, \quad B=\begin{pmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{pmatrix},$$

then the parameter in $x^{(0)}(k)+az^{(1)}(k)=b$ of GM(1,1) model based on least square method is $\hat{a}=(a,b)^T=\left(B^TB\right)^{-1}B^TY$ and

$$\begin{cases} a=\dfrac{\dfrac{1}{n-1}\sum\limits_{k=2}^{n}x^{(0)}(k)\sum\limits_{k=2}^{n}z^{(1)}(k)-\sum\limits_{k=2}^{n}x^{(0)}(k)z^{(1)}(k)}{\sum\limits_{k=2}^{n}\left(z^{(1)}(k)\right)^2-\dfrac{1}{n-1}\left(\sum\limits_{k=2}^{n}z^{(1)}(k)\right)^2} \\ b=\dfrac{1}{n-1}\left[\sum\limits_{k=2}^{n}x^{(0)}(k)+a\sum\limits_{k=2}^{n}z^{(1)}(k)\right] \end{cases} \tag{1.1}$$

2.2 Estimating Parameters in GM(1,1) Model Based on Weighted Least Square Method

Theorem 2. Assume that B, Y, a are the same as in Theorem1, and the weight of residual sum of squares of date which is No. k is ω_k, $\left(\omega_i \geq \omega_j, i \geq j\right)$, then the parameter in $x^{(0)}(k)+az^{(1)}(k)=b$ of GM(1,1) model based on weighted least square method is

$$\begin{cases} \tilde{a}=\dfrac{\dfrac{1}{\sum\limits_{k=2}^{n}\omega_k}\sum\limits_{k=2}^{n}\omega_k x^{(0)}(k)\sum\limits_{k=2}^{n}\omega_k z^{(1)}(k)-\sum\limits_{k=2}^{n}\omega_k x^{(0)}(k)z^{(1)}(k)}{\sum\limits_{k=2}^{n}\omega_k\left(z^{(1)}(k)\right)^2-\dfrac{1}{\sum\limits_{k=2}^{n}\omega_k}\left(\sum\limits_{k=2}^{n}\omega_k z^{(1)}(k)\right)^2} \\ \tilde{b}=\dfrac{1}{\sum\limits_{k=2}^{n}\omega_k}\left[\sum\limits_{k=2}^{n}\omega_k x^{(0)}(k)+a\sum\limits_{k=2}^{n}\omega_k z^{(1)}(k)\right] \end{cases} \tag{1.2}$$

Proof. For a pair of evaluated values of $\tilde{a},\tilde{b}$, using $-\tilde{a}z^{(1)}(k)+\tilde{b}$ to substitute $x^{(0)}(k), k=2,3,\cdots n,$ gives the error sequence $\varepsilon = Y - B\tilde{a}$. Let $s=\sum_{k=2}^{n}\omega_k\left(x^{(0)}(k)+\tilde{a}z^{(1)}(k)-\tilde{b}\right)^2$. The $\tilde{a},\tilde{b}$ values making s the minimum should satisfy

$$\begin{cases}\dfrac{\partial s}{\partial \tilde{a}}=2\sum_{k=2}^{n}\omega_k z^{(1)}(k)\left(x^{(0)}(k)+az^{(1)}(k)-\tilde{b}\right)=0\\ \dfrac{\partial s}{\partial \tilde{b}}=-\sum_{k=2}^{n}\omega_k\left(x^{(0)}(k)+az^{(1)}(k)-\tilde{b}\right)=0\end{cases}$$

That is,

$$\begin{cases}\sum_{k=2}^{n}\omega_k z^{(1)}(k)\left(x^{(0)}(k)+az^{(1)}(k)-\tilde{b}\right)=0 & (1.3)\\ \sum_{k=2}^{n}\omega_k\left(x^{(0)}(k)+az^{(1)}(k)-\tilde{b}\right)=0 & (1.4)\end{cases}$$

So, solving this system gives that

$$\tilde{b}=\frac{1}{\sum_{k=2}^{n}\omega_k}\left[\sum_{k=2}^{n}\omega_k x^{(0)}(k)+\tilde{a}\sum_{k=2}^{n}\omega_k z^{(1)}(k)\right] \tag{1.5}$$

by (1.4).

$$\tilde{a}=\frac{\frac{1}{\sum_{k=2}^{n}\omega_k}\sum_{k=2}^{n}\omega_k x^{(0)}(k)\sum_{k=2}^{n}\omega_k z^{(1)}(k)-\sum_{k=2}^{n}\omega_k x^{(0)}(k)z^{(1)}(k)}{\sum_{k=2}^{n}\omega_k\left(z^{(1)}(k)\right)^2-\frac{1}{\sum_{k=2}^{n}\omega_k}\left(\sum_{k=2}^{n}\omega_k z^{(1)}(k)\right)^2} \tag{1.6}$$

is gotten by take (1.5) into (1.3). End.

Proposition 1. Model becomes meaningless, when

$$\sum_{k=2}^{n}\omega_k\left(z^{(1)}(k)\right)^2\to\frac{1}{\sum_{k=2}^{n}\omega_k}\left(\sum_{k=2}^{n}\omega_k z^{(1)}(k)\right)^2.$$

Proof. Because

$$\tilde{a}=\frac{\frac{1}{\sum_{k=2}^{n}\omega_k}\sum_{k=2}^{n}\omega_k x^{(0)}(k)\sum_{k=2}^{n}\omega_k z^{(1)}(k)-\sum_{k=2}^{n}\omega_k x^{(0)}(k)z^{(1)}(k)}{\sum_{k=2}^{n}\omega_k\left(z^{(1)}(k)\right)^2-\frac{1}{\sum_{k=2}^{n}\omega_k}\left(\sum_{k=2}^{n}\omega_k z^{(1)}(k)\right)^2}$$

When

$$\sum_{k=2}^{n}\omega_k\left(z^{(1)}(k)\right)^2\to\frac{1}{\sum_{k=2}^{n}\omega_k}\left(\sum_{k=2}^{n}\omega_k z^{(1)}(k)\right)^2$$

$\tilde{a}\to\infty,\tilde{b}\to\infty$, we are unable to determine the parameters of the model, so *GM*(1,1) model is meaningless.

Theorem 3. After obtaining $\tilde{a},\tilde{b}$ by using the weighted least square method, the following hold true:

(1) The time response sequence of the GM (1, 1) grey differential equation

$$x^{(0)}(k)+az^{(1)}(k)=b$$

is given by

$$\hat{x}^{(1)}(k+1)=\left(x^{(0)}(1)-\frac{b}{a}\right)e^{-\tilde{a}k}+\frac{\tilde{b}}{\tilde{a}};k=1,2\cdots,n$$

(2) The restored values of $\hat{x}^{(0)}(k)$ can be given by

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k)=\left(1-e^{\tilde{a}}\right)\left(x^{(0)}(1)-\frac{\tilde{b}}{\tilde{a}}\right)e^{-\tilde{a}k};k=1,2\cdots,$$

$\hat{x}^{(0)}(k)$ is the simulation value when $k\le n$, $\hat{x}^{(0)}(k)$ is the prediction value when $k>n$.

Nature1 The $\tilde{a},\tilde{b}$ based on weighted least square method are the same as *a, b* based on least square method.

Proof. (1.1) can be gotten by letting $\omega_k=1,k=2,3,\cdots n$ in (1.2).

Table I The Error comparison of old model and new model

	Initial data $x^{(0)}(k)$	Simulationed value $\hat{x}^{(0)}(k)$		Residual $\varepsilon(k)=x^{(0)}(k)-\hat{x}^{(0)}(k)$		Relative error $e_k=\frac{\lvert\varepsilon(k)\rvert}{x^{(0)}(k)}$	
		Old model	New model	Old model	New model	Old model	New model
1	80052	80052	80052	0	0	0	0
2	98786	99652.17	97860.4	-866.1741	-925.6248	0.877%	0.937%
3	131243	130491.9	131295.1	751.0855	-52.1376	0.572%	0.040%
4	175503	170875.7	171488.7	4627.2525	4014.333	2.637%	2.287%
5	224715	223757.3	223986.7	957.6798	728.3117	0.426%	0.324%
6	297902	293004.4	294640.3	4897.6441	3262.027	1.644%	1.095%

3 Case Study

We use the number of national human resources in higher education in 2001-2006 as an example to analyze. $X^{(0)}$ = (80052, 98786, 131243, 175503, 224715, 297902) • Top5 dates are used to model, the last data for prediction test. The time response sequence of traditional *GM*(1,1) is

$$x^{(1)}(k+1)=322005.169e^{0.2696k}\text{-}241953.169,$$

let $\omega_k = k$, the new one is $x^{(1)}(k+1)=328363.1057e^{0.26707k}\text{-}248311.1057$. The restored values are

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k).$$

Although the first relative error is larger, that is the oldest information. The average relative error and minimum relative error are both smaller, and the most important is one step prediction error is improved compare to the traditional *GM*(1,1) model. In addition, the new model will be better if combined with other optimization methods such as time-response function and the optimization of the background value.

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Research on Grey Wave Forecasting Model*

Qin Wan, Yong Wei, and Xiongqiong Yang

This chapter is according to the basic process and principle of grey wave forecasting. It presents concrete method and steps of how to choose effective contour lines. Then the author have made improvement on the forecasting formula of grey wave forecasting model, so that the forecasting formula would be closer to original intention of the grey wave forecasting theory founder. In the end it can enhance the validity and the accuracy of grey wave forecasting model.

1 Introduction

The grey system forecasting is to find development rule of system through the primary data processing and the grey model establishing, then makes scientific and quantitative forecasting of system's future. When data in the primitive sequence is fluctuating and its swing range is greater, it's difficult to find a suitable model for the primitive sequence. Then we can consider forecasting the wave of behavioral data development in the future based on the wave of original data, and this kind of forecasting is called wave forecasting [1]. Wave forecasting is one of the grey forecasting system's important content with a modeling process that is clear and simple, so wave forecasting obtains high application value in many domains. Wave forecasting model divides six steps approximately, and the author emphasizes on

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* This work was supported in part by Research fund of Si chuan Education Department (2006A007) and basic application research fund of Sichuan (2008JY0112).

the step of obtaining contour lines with the step of generating the forecasting formula of grey wave forecasting model. Then the author presents concrete method with steps on how to choose effective contour line, and makes improvement on the forecasting formula of grey wave forecasting model.

2 Summary of the Grey Wave Forecasting Model's Basic Concept and Method

Definition 1. (Liu et al., 2007) Let original sequence be $X = (x(1), x(2), x(3), \ldots x(n))$, then $x_k = x(k) + (t-k)[x(k+1) - x(k)]$ is called the k-th section broken line of sequence X, and $\{x_k = x(k) + (t-k)[x(k+1) - x(k)] \| k = 1,2,\ldots,n-1\}$ is called the broken line of sequence X and is still denoted as X, namely $X = \{x_k = x(k) + (t-k)[x(k+1) - x(k)] \| k = 1,2,\ldots,n-1\}$

Concerning the expression of the k-th section broken line of sequence X, the author considers that we can obtain the expression by this way: Based on the known coordinates of two points $(k+1, x(k+1))$ and $(k, x(k))$, and we can get the linear equation, in which k and $k+1$ are equal interval and adjacent time points. The independent and dependent variable of the equation is respectively $x_k(t)$ and t ($k < t < k+1$). Obviously, the linear equation is the expression of the k-th section broken line of sequence X, so

$$x_k(t) = x(k) + (t-k)\frac{x(k+1) - x(k)}{(k+1) - k}$$
$$= x(k) + (t-k)[x(k+1) - x(k)]$$

The following is the basic process of grey wave forecasting model:

Step1. Obtaining point set of the k-th section broken line L_k = $\{x_k(t) \mid k < t < k+1\}$ based on original sequence, while the broken line of the original sequence is $X = \bigcup_{k=1}^{n} L_k$.

Step2. Obtaining contour line:

Let $\sigma_{\max} = \max_{1\le k\le n}\{x(k)\}$, $\sigma_{\min} = \min_{1\le k\le n}\{x(k)\}$, for $\forall \xi \in [\sigma_{\min}, \sigma_{\max}]$, the line $X = \xi$ is called ξ-contour line.

Step3. Calculating contour point:

The solution of the equations

$$\begin{cases} X = \{x_k = x(k) + (t-k)[x(k+1) - x(k)] \| k = 1,2,...,n-1\} \\ X = \xi \end{cases}$$

is called ξ-contour point. Namely, ξ-contour point is the intersection which is generated by contour line $X = \xi$ and the broken line of original sequence X .

Step4. Obtaining contour time sequence:

Let $X_\xi = (P_1, P_2, ...P_m)$ be ξ-contour time sequence, in which P_i is located in the k_i-th section broken line and its coordinate is $(k_i + \frac{\xi - x(k_i)}{x(k_i+1) - x(k_i)}, \xi)$.

Let be $q(i) = k_i + \frac{\xi - x(k_i)}{x(k_i+1) - x(k_i)} (i = 1,2,...m)$, and then $Q^{(0)} = (q(1), q(2),..., q(m))$ is called ξ-contour time sequence.

Step5. Establishing GM (1, 1) model group, then forecast each contour time sequence:

For $\forall \xi \in [\sigma_{\min}, \sigma_{\max}]$, we can establish GM(1,1) model (Lin et al., 2002; Sydow et al., 2001; Lin and Liu, 2000) based on the ξ-contour time sequence, thus make simulation and prediction with the contour time sequence, and then obtain forecasting value with it.

Definition 2. (Liu et al., 2007) let $X = \xi_i (i = 1,2,..,s)$ be s different contour lines, $Q_i^{(0)} = (q_i(1), q_i(2),..., q_i(m_i))$ $i = 1,2,...,s$ be the $\xi_i -$ contour time sequence, $\hat{q}_i(m_i+1), \hat{q}_i(m_i+2),..., \hat{q}_i(m_i+k_i), i = 1,2,...,s$ be the forecasting value of the $\xi_i -$ contour time sequence form the GM (1, 1) model. If there exists $i \neq j$, makes $\hat{q}_i(m_i + l_i) = \hat{q}_j(m_j + l_j)$, then $\hat{q}_i(m_i + l_i)$ and $\hat{q}_j(m_j + l_j)$ is called a pair of ineffective forecasting time.

Step6. Generating forecasting wave:

Let $\hat{q}_i(m_i+1), \hat{q}_i(m_i+2),..., \hat{q}_i(m_i+k_i)$ be forecasting value of the $\xi_i -$ contour time sequence from the GM (1, 1) model. Ranking all of the rest forecasting value trend to be larger after rejecting the ineffective forecasting time among them, when $X = \xi_{\hat{q}(k)}$ is the contour line corresponding to $\hat{q}(k)$, then the forecasting broken line of sequence X is $\hat{X} = \{\xi_{\hat{q}(k)} + (t - \hat{q}(k))(\xi_{\hat{q}(k+1)} - \xi_{\hat{q}(k)}) \mid k = 1,2,..., n_s\}$

3 How to Choose Effective Contour Lines

In above 6 steps of grey wave forecasting model, the purpose of the step of obtaining contour line and the step of calculating point is to obtain contour time sequence of each contour line, and collecting data for establishing GM (1, 1) model. The author considers that there are two problems needed attention: 1) we can take any value from $[\sigma_{\min}, \sigma_{\max}]$ as ξ, and let the line $X = \xi$ be contour line. But we always expect that the contour line $X = \xi$ and the broken line of original sequence X will generate four or more intersections. Because we can just establish GM (1, 1) model on four or more data, therefore we call the contour line which can generate four or more contour points as an effective contour line. However, not any contour line $X = \xi$ is an effective contour line, so we often waste much time and energy on verification whether the number of intersections which is generated by the contour line and the broken line of original sequence meets the requirement of establishing GM(1,1) model or not. 2) The waveform graph that we have forecasted consists of several broken lines, and the amount of broken lines has great relationship with the amount of contour lines. It can be considered that if obtain more contour lines, then the forecasting waveform graph would be closer to the actual situation. That is to say, choosing contour lines is a crucial link in the preparatory work of grey wave forecasting. The author presents a method of choosing effective contour lines. On the premise that obtaining enough contour lines, we can insure that every contour line which be chosen would generate four or more contour points by this method. It greatly reduces the working load of choosing effective contour lines.

A. The related definition and theorem

Definition 3. We call the contour line which can generate four or more contour points as an effective contour line.

Definition 4. Drawing the waveform graph of original sequence X in a coordinate planes which is composed by the lateral axis t and the longitudinal axis x .1) If for $t = t_i$, it exits a neighborhood $\delta(t_i)$ of t_i , which makes $\forall t \in \delta(t_i)$, $x(t_i) > x(t)$, then $x(t_i)$ is called a wave crest of X ; 2) If for $t = t_j$, it exits a neighborhood $\delta(t_j)$ of t_j , which makes $\delta(t_j)$, $x(t_j) < x(t)$, then $x(t_j)$ is called a wave trough of X ;(There may be two wave troughs adjacent to a wave crest, we can differentiate them with left-adjacent wave trough and right-adjacent wave trough; also there may be two wave crests adjacent to a wave trough, we can differentiate them with left-adjacent wave crest and right-adjacent wave crest).

Theorem 1. Among any three wave crests $f(1), f(2), f(3)$ and their right-adjacent wave troughs $g(1), g(2), g(3)$, let $f = \min\{f(1), f(2), f(3)\}$, $g = \max\{g(1), g(2), g(3)\}$. If $f > g$, namely the minimum wave crest is bigger than the maximum wave trough, we can obtain any $\xi \in (g, f)$, and then the contour line $x = \xi$ and the original sequence X will generate at Least five contour points.

Proof: As we known $f = \min\{f(1), f(2), f(3)\}$ $g = \max\{g(1), g(2), g(3)\}$ and $f > g$, so we can get $(g, f) \subseteq (g(i), f(j))$, $i, j \in \{1,2,3\}$. Because there are at least five broken lines between the wave crests $f(1), f(2), f(3)$ and the right-adjacent wave troughs $g(1), g(2), g(3)$, then the contour line $x = \xi$ would intersect with above five broken lines respectively, so we can obtain five contour points from the contour line $x = \xi$. End.

B. The concrete method and steps of how to choose effective contour lines

Draw the waveform graph of original sequence X, and find out all wave crests and wave troughs. Then rank all wave crests trended to be larger as $f(k_1) < f(k_2) < ...... < f(k_n)$, rank all wave troughs trended to be smaller as $g(s_1) > g(s_2) > ...... > g(s_m)$.

Step1: Find out the maximum wave trough $g(s_{i1})$ which is smaller than the wave crest $f(k_1)$, and find out the wave trough $g(s_{j1})$ which is the right-adjacent wave crest of $f(k_1)$. Obviously, $g(s_{i1}) \geq g(s_{j1})$. Let $A = \{g(s_1), g(s_2), ..., g(s_{m-2})\}$ (still trended to be smaller), namely A is a set which consists of all wave troughs except the last two; Let $B = \{g(s_{i1}), g(s_{i1}+1), g(s_{i1}+2)......, g(s_{j1})\}$ (still trended to be smaller), namely B is consisted by the wave troughs which is between $g(s_i)$ and $g(s_j)$; Let $G = A \cap B$, for $\forall g(s_t) \in G$, we can take any $\xi \in (g(s_t), f(k_1))$ and form the contour line $x = \xi$. Then the contour line $x = \xi$ and the original sequence X will generate at least five contour points.

Proof: Observing the arrangements of all wave crests and all wave troughs:

$$\begin{cases} f(k_1) < f(k_2) < ...... < f(k_{n-2}) < f(k_{n-1}) < f(k_n) \\ g(s_1) > g(s_2) > ...... > g(s_{m-2}) > g(s_{m-1}) > g(s_m) \end{cases} \quad (1)$$

It is easy to see that wave crest $f(k_1)$ is the minimum among all wave crests. $\forall g(s_t) \in G$, we can always find out two wave troughs are both smaller than it. (Because the smaller two wave troughs are both beyond the set G).

1) When the wave trough $g(s_t)$ which we have chosen is the right-adjacent wave crest of $f(k_1)$, let the wave trough $g(s_{t1})$ and $g(s_{t2})$ both smaller than $g(s_t)$. Let the left-adjacent wave crests $f(s_{t1})$ and $f(s_{t2})$ which are corresponding to $g(s_{t1})$ and $g(s_{t2})$ respectively. And $f(k_1)$ is the minimum among all wave crests, so $f(s_{t1})$ and $f(s_{t2})$ are both bigger than $f(k_1)$. That is to say, $g(s_t)$ is the biggest one in three wave trough and $f(k_1)$ is the smallest one in three wave crests. Namely the conditions in theorem 1 have been satisfied, we can obtain the contour line $x = \xi$ in which $\xi \in (g(s_t), f(k_1))$, and it would generate at least five contour points according to theorem 1.

2) When the wave trough $g(s_t)$ which we have chosen isn't the right-adjacent wave crest of $f(k_1)$, let be the wave trough $g(s_{t1})$ is smaller than $g(s_t)$. Then among the wave trough $g(s_t)$ and its left-adjacent wave, the wave trough $g(s_{t1})$ and its left-adjacent wave, the wave crest $f(k_1)$ and its right-adjacent wave trough, we can find that $g(s_t)$ is the biggest one in three wave troughs and $f(k_1)$ is the smallest one in three wave crests. Namely the conditions in theorem 1 have been satisfied, we can obtain the contour line $x = \xi$ in which $\xi \in (g(s_t), f(k_1))$, and it would generate at least five contour points according to theorem 1.

So we can get several effective contour lines with the minimum wave crest $f(k_1)$ by step1.

Step2: Removing the minimum wave crest $f(k_1)$ and its right-adjacent wave trough $g(s_{j1})$ in the formula (1). Carry step1 on the existing minimum wave crest $f(k_2)$ again, then we can get several effective contour lines with the wave crest $f(k_2)$. Namely find out the maximum wave trough $g(s_{i2})$ which is smaller than the wave crest $f(k_2)$, and find out the wave trough $g(s_{j2})$ which is right-adjacent to $f(k_2)$. Obviously, $g(s_{i2}) \geq g(s_{j2})$. Let $A = \{g(s_1), g(s_2), ..., g(s_{m-2})\}$ (still trended to be smaller), namely A is a set which consists of all the rest wave troughs except the last two; Let $B = \{g(s_{i2}), g(s_{i2}+1), g(s_{i2}+2)......, g(s_{j2})\}$ (still trended to be smaller), namely

B is consisted by the wave troughs which is between $g(s_{i2})$ and $g(s_{j2})$; Let $G = A \cap B$, for $\forall g(s_t) \in G$, we can take any $\xi \in (g(s_t), f(k_2))$ and form the contour line $x = \xi$. Then the contour line $x = \xi$ and the original sequence X will generate at least five contour points.

Step3: Removing the minimum wave crest $f(k_2)$ and its right-adjacent wave trough $g(s_{j2})$ in the formula (1) again. Carry step1 on the existing minimum wave crest $f(k_3)$ again, then we can get several effective contour lines with the wave crest $f(k_3)$.

Until get several effective contour lines with the wave crest $f(k_{n-2})$.

In a word, expect the biggest two wave crests; we can obtain several effective contour lines with every rest wave crest accurately by the new method.

4 The Improvement on Forecasting Formula of the Grey Wave Forecasting Model

In the sixth step of grey wave forecasting model, after ranking the forecasting value of the contour time sequence trend to be larger, the broken line between $\hat{q}(k), \hat{q}(k+1)$ is the k-th section forecasting broken line of original sequence X. Then its expression should be the linear equation which is generated by the coordinates of two points $(\hat{q}(k), \xi_{\hat{q}(k)})$ and $(\hat{q}(k+1), \xi_{\hat{q}(k+1)})$, and the independent with dependent variables of the equation is respectively $\hat{x}_k$ and t ($\hat{q}(k) < t < \hat{q}(k+1)$). Namely the k-th section forecasting broken line is $\hat{x}_k = \xi_{\hat{q}(k)} + (t - \hat{q}(k)) \dfrac{(\xi_{\hat{q}(k+1)} - \xi_{\hat{q}(k)})}{\hat{q}(k+1) - \hat{q}(k)}$, and the forecasting broken line of sequence X is $\hat{X} = \left\{ \xi_{\hat{q}(k)} + (t - \hat{q}(k)) \dfrac{(\xi_{\hat{q}(k+1)} - \xi_{\hat{q}(k)})}{\hat{q}(k+1) - \hat{q}(k)} \middle| k = 1,2,\ldots,n \right\}$

The footnote of the forecasting value $\hat{q}(k), \hat{q}(k+1)$ is k and $k+1$ respectively, and the footnote of them is adjacent. But when we find out the value of $\hat{q}(k), \hat{q}(k+1)$ on the lateral axis t, the spacing in the value of

$\hat{q}(k), \hat{q}(k+1)$ may not just be a unit, may be $\hat{q}(k+1) - \hat{q}(k) \neq 1$. However, the traditional method of obtaining forecasting formula considered that $\hat{q}(k+1) - \hat{q}(k) = 1$, so the forecasting broken line of sequence X is $\hat{X} = \{\xi_{\hat{q}(k)} + (t - \hat{q}(k))(\xi_{\hat{q}(k+1)} - \xi_{\hat{q}(k)}) | k = 1,2,..., n_s\}$ in (Liu et al., 2007; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006).

The author holds that the k-th section forecasting broken line of original sequence X is $\hat{x}_k = \xi_{\hat{q}(k)} + (t - \hat{q}(k))\frac{(\xi_{\hat{q}(k+1)} - \xi_{\hat{q}(k)})}{\hat{q}(k+1) - \hat{q}(k)}$, this expression is more reasonable than the k-th section forecasting broken line of original sequence X in reference (Liu et al., 2007).

What is worth stating is that the forecasting formula in reference (Chen et al., 2006) $\hat{x}_k = \xi_{\hat{q}(k)} + (t - \hat{q}(k))(\xi_{\hat{q}(k+1)} - \xi_{\hat{q}(k)})$ is not reasonable, but its forecasting waveform graph may be drawn by the Matlab software which can draw waveform graph through linking the broken lines between the point ranges $(x_i, y_i), i = 1,..., k$. The essence of the calculation formula in the software is same with that in this chapter rather than that in reference (Chen et al., 2006). So the forecasting waveform graph in reference (Chen et al., 2006) and the forecasting waveform graph from the calculation formula in this chapter have no difference.

5 Example Analysis

Take the wave forecasting of the comprehensive index in Shanghai Stock Exchange [1] for example. Based on the week close index of Shanghai Stock Exchange, we can get the week close index diagram from 1997-2-21 to 1998-10-31 as shown in Fig 1.

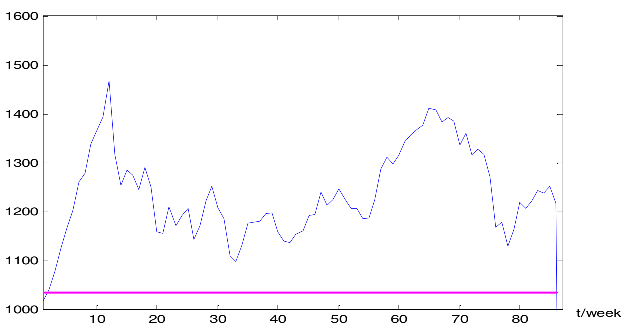

Fig. 1 The week close index diagram of Shanghai Stock Exchange 1997.2.21.—1998.10.31

The following is making grey wave forecasting based on above data, making simulation and prediction for the week close index of Shanghai Stock Exchange from November 1998 to the end of 1999.

Though observing Fig 1, we can discover that the contour line $x = 1050$ would not generate four or more contour points, and then we consider this contour line is ineffective.

At first, choosing effective contour lines by the method presented in this chapter. We take the mean of the minimum wave crest and the maximum wave among any three wave crests and their right-adjacent wave troughs as ξ. Then obtain the contour lines and its corresponding contour point sequence as follows:

For $\xi_1 = 1157.06$: $Q_1^{(0)} = \{q_1(k)\}_1^9$ = {20.5000, 21.0412, 25.7777, 26.4866, 31.3667, 34.5748, 40.0792, 43.4654, 78.8086};

For $\xi_2 = 1174.23$: $Q_2^{(0)} = \{q_2(k)\}_2^{15}$ = {5.1989, 19.8362, 21.3531, 22.9133, 23.1538, 25.5052, 27.0488, 31.1374, 34.9505, 39.6010, 44.4321, 75.9398, 76.6472, 77.0706, 79.1964};

For $\xi_3 = 1191.39$: $Q_3^{(0)} = \{q_3(k)\}_3^{15}$ = {5.6823, 19.6475, 21.6647, 22.4733, 23.9345, 25.2327, 27.3973, 30.7159, 37.7458, 39.1640, 44.9830, 53.7005, 55.1078, 75.7733, 79.5114};

For $\xi_4 = 1217.67$: $Q_4^{(0)} = \{q_4(k)\}_4^{14}$ = {6.2573, 19.3585, 27.9311, 29.7907, 46.5147, 47.8570, 48.4145, 51.4284, 55.8364, 75.5182, 79.9938, 80.0309, 81.7318, 85.9930};

For $\xi_5 = 1238.42$: $Q_5^{(0)} = \{q_5(k)\}_5^{13}$ = {6.6133, 19.1303, 28.5694, 29.3064, 46.9677, 47.0571, 50.3766, 56.2376, 75.3169, 82.7899, 83.7504, 84.1021, 85.3845 };

For $\xi_6 = 1247.76$: $Q_6^{(0)} = \{q_6(k)\}_6^{10}$ = {6.7735, 16.8793, 17.0801, 19.0276, 28.8757, 29.0884, 56.3870, 75.2262, 84.7418, 85.1106 };

For $\xi_7 = 1269.73$: $Q_7^{(0)} = \{q_7(k)\}_7^{8}$ = {7.4991, 13.7492, 14.5002, 16.1778, 17.5453, 18.5246, 56.7384, 75.0130};

For $\xi_8 = 1304.81$: $Q_8^{(0)} = \{q_8(k)\}_8^{6}$ = {8.4417, 13.1802, 57.7365, 58.4996, 59.3931, 74.2641};

For $\xi_9 = 1320.77$: $Q_9^{(0)} = \{q_9(k)\}_9^{6}$ = {8.7099, 12.9679, 60.1980, 71.8680, 72.5004, 73.6111};

For $\xi_{10} = 1347.88$: $Q_{10}^{(0)} = \{q_{10}(k)\}_{10}^{6}$ = {9.3656, 12.7888, 61.3130, 69.7474, 70.5002, 71.2775};

For $\xi_{11} = 1388.14$: $Q_{11}^{(0)} = \{q_{11}(k)\}_{11}^{6}$ = {10.8051, 12.5227, 64.3481, 66.8117, 67.5005, 68.6529}.

Though generating the sequence $Q_1^{(1)}$ based on $Q_1^{(0)}$ 1-AGO, then we can obtain the response of its GM (1, 1) model $\hat{q}_1^{(1)}(k+1) = 77.3301e^{0.1938} - 56.8301$.

Simultaneously, we can obtain the response of GM(1,1) model with $Q_i^{(0)} (i = 2,3,...,11)$ (omission).

Let $\hat{q}_i(k+1) = \hat{q}_i^{(1)}(k+1) - \hat{q}_i^{(1)}(k)$, we can obtain ξ_i- contour time forecasting sequence（ $i = 1,2,...,11$ ）:

$\hat{Q}_1^{(0)} = \{\hat{q}_1(10), \hat{q}_1(11), \hat{q}_1(12)\} = \{94.5464, 114.7597, 139.2946\}$

$\hat{Q}_2^{(0)} = \{\hat{q}_2(16), \hat{q}_2(17), \hat{q}_2(18)\} = \{111.7, 127.3, 145.1\}$

$\hat{Q}_3^{(0)} = \{\hat{q}_3(16), \hat{q}_3(17), \hat{q}_3(18), \hat{q}_3(19)\} = \{96.8373, 109.4591, 123.7260, 139.8525\}$

$\hat{Q}_4^{(0)} = \{\hat{q}_4(15), \hat{q}_4(16), \hat{q}_4(17), \hat{q}_4(18), \hat{q}_4(19)\} = \{95.5754, 105.2375, 115.8764, 127.5908, 140.4895\}$

$\hat{Q}_5^{(0)} = \{\hat{q}_5(14), \hat{q}_5(15), \hat{q}_5(16), \hat{q}_5(17), \hat{q}_5(18)\} = \{89.0488, 99.1198, 110.3297, 122.8075, 136.6964\}$

$\hat{Q}_6^{(0)} = \{\hat{q}_6(11), \hat{q}_6(12)\} = \{100.5, 126.0\}$

$\hat{Q}_7^{(0)} = \{\hat{q}_7(9), \hat{q}_7(10)\} = \{93.8, 140.7\}$

$\hat{Q}_8^{(0)} = \{\hat{q}_8(7), \hat{q}_8(8), \hat{q}_8(9)\} = \{95.8, 118.0, 145.4\}$

$\hat{Q}_9^{(0)} = \{\hat{q}_9(7), \hat{q}_9(8)\} = \{101.7, 123.2\}$

$\hat{Q}_{10}^{(0)} = \{\hat{q}_{10}(7), \hat{q}_{10}(8), \hat{q}_{10}(9), \hat{q}_{10}(10)\} = \{81.3, 97.7, 117.4, 141\}$

$\hat{Q}_{11}^{(0)} = \{\hat{q}_{11}(7), \hat{q}_{11}(8), \hat{q}_{11}(9)\} = \{92.4, 109.6, 130.1\}$

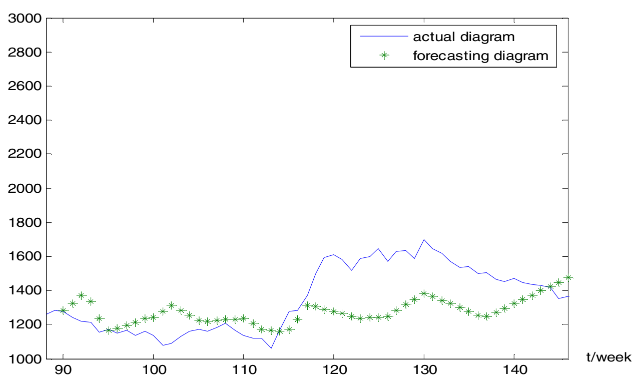

Fig. 2 The week close index forecasting diagram of Shanghai Stock Exchange (1998.11.6. - 1999.12.30)

After rejecting the ineffective forecasting time, we can draw the week close index forecasting diagram of Shanghai Stock Exchange from November 1998 to the end of 1999 based on the forecasting formula presented in this chapter. Then compare the forecasting diagram with actual situation as shown in Fig 2.

From Figure 2, we can find that the agreement between forecasting wave and the actual wave is good. The similarity degree between the short or middle-term forecasting wave and the actual wave is higher. It confirms the grey wave forecasting has certain validity and the usability.

6 Conclusions

This article according to the basic process and principle of grey wave forecasting presents concrete method and steps on how to choose effective contour lines. It also gives a strict proof that the counter lines which is chosen by the method in this chapter will generate at least five contour points, thus we can establish GM (1, 1) model to forecast the development of behavioral data wave in the future. Secondly, the author have made improvement on the forecasting formula of grey wave forecasting model, so that the forecasting formula would be much closer to original intention of the grey wave forecasting theory founder. Then it can enhance the validity and the accuracy of grey wave forecasting model.

Acknowledgment. Research fund of Si chuan Education Department (2006A007) And basic application research fund of Sichuan (2008JY0112).

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A Method of Modeling Logistics

Yinao Wang, Lifeng Wu, and Fengjing Cai

Based on the grey system direct modeling method, we put forward a method of modeling Logistic under the criterion on minimized the sum of the squares of the modified relative error (SSMRE). Then applied it in the U.S.A population forecasting, with results showing that this method can remarkably reduce mean absolute percentage error (MAPE) and the built model can preferably represent the whole historical population law. The process of modeling shows that this method is more convenient than the traditional modeling method.

1 Introduction

Grey system theory has already been widely used in many fields since 1982 (Deng, 1982; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), and grey modeling method is an important component of the grey system theory. As one of the grey modeling methods, direct modeling method has been presented (Wang, 1988) and the characteristics of the direct modeling method are studied (Wang et al., 2000; Wang, 2003; Mu, 2003; Shui and Qin, 1998).

In this chapter we consider the fitting problem for Logistic model (Jukic and Scitovski, 2003)

$$\frac{dx/dt}{x} = r - sx, \quad r, s > 0, \tag{1}$$

Parameter $r > 0$ can be interpreted as the maximum possible rate of population growth, while parameter $\frac{1}{s}$ is the upper limit of population growth and it is called

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carrying capacity, therefore the solution of the verhulst's model is the so-called logistic function (Jukic and Scitovski, 2003). To date Logistic model had been widely adopted, such as various technological changes (Carrillo and Gonzalez, 2002), estimating household electricity consumption (Fuks and Salazar, 2008), agriculture (Nguyen, 2008), and growth of single-species populations (Sakanoue, 2007), etc.

There are many scholars proposed new method to improve the fitting precision of the Logistic model. For example, necessary and sufficient conditions which guarantee the existence of optimal parameters of Logistic model are given (Jukic and Scitovski, 2003). Grey verhulst modeling is introduced (Liu and Lin, 2006). Locally D-optimal designs for logistic models with three and four parameters are investigated (Li and Majumdar, 2008). A technique which constructs an approximation to the solution of a logistic model with slowly varying coefficients is demonstrated (Grozdanovski et al., in press). In all the cases above, estimation of the model parameters often used ordinary least squares method under the criterion of minimized the sum of squared error (SSE). Because this model is nonlinear, and ordinary least squares method requires an initial approximation which is as good as possible, if we chose the initial approximation which is not good, then MAPE will be big after the iterations (Jukic and Scitovski, 2003). In this chapter, we put forward a method of modeling Logistic which does not require an initial approximation. First, we obtain the maximum possible rate of population growth by means of grey system direct modeling method. Then estimate another two parameters under the criterion of minimized the SSMRE.

2 The Criteria of Evaluation Logistical Model

Generally, assume that $X = \{x(t_k) \mid x(t_k) \in R, t_k \in R\}, k \in \{1,2,\cdots,n\}$ be an actual sequence, the method of modeling Logistic is as follows (Jian et al., 2003): assume the relative growth rate of $x(t_k)$ is linear function concerning t_k, by using the method of separation of variables we can obtain that:

$$x(t_k) = \frac{x_m}{1 + (\frac{x_m}{x_{t_1}} - 1)e^{-rt_k}} \tag{2}$$

r and x_m are parameters (to be estimated), determined x_m by $s = \frac{r}{x_m}$, or wrote as

$$x(t_k) = \frac{1}{be^{-rt_k} + c}, \tag{3}$$

where $b = \frac{1}{x_{t_k}} - x_m$, $c = \frac{1}{x_m}$.

The steps of estimating the parameters r, s are as follows:

1) Use Gauss method of numerical differentiation, we obtain the approximate value of dx / dt .
2) Then obtain the approximate value of $\frac{dx / dt}{x}$.
3) Obtain the estimated value of the parameters r , s by using least squares method.

However this method of modeling Logistic is excessive dependent on the x_{t_1} . When x_{t_1} obviously deviate from the whole historical law, the built model will deviate from the whole historical law. Obviously, choosing good initial conditions of model (1) can optimize the model (2). In order to optimize the model (2), we first discuss the criterion of evaluating the model.

Commonly, given a collection of data which obey Logistic law, its later stage value is more than 10 times or dozens of times as big as the earlier stage value, thus under the criterion of minimized the SSE, the problem is to determine the parameters of $x(t_k)$ to minimize

$$\sum_{k=1}^{n}\left(x(t_k) - \hat{x}(t_k) \right)^2$$

where $\hat{x}(t_k)$ is simulated value, the smaller SSE means the better model, but in most cases our obtained model is better fit for the later stage value, and the relative error of the earlier stage simulated value is very big. A better model not only represents the law of the later stage value, but also must represent the whole historical law of the collection of data.

In order to make the earlier stage value and the later stage value take approximately same effect in the process of parameters estimation, we must use the criterion of minimized the MAPE, and the problem is to determine the parameters of $x(t_k)$ to minimize

$$\text{MAPE}(\%) = \frac{1}{n}\sum_{k=1}^{n}\frac{|x(t_k) - \hat{x}(t_k)|}{|x(t_k)|} \tag{4}$$

But we need to differentiate the sum (4) with respect to the parameters of $x(t_k)$ to find the critical points. However, the various derivatives of the sum fail to be continuous because of the presence of the absolute values, so we will not pursue this criterion. Instead, for the convenience of application, we could use the criterion of minimized the sum of squared relative error

$$\sum_{k=1}^{n}\left(\frac{x(t_k) - \hat{x}(t_k)}{x(t_k)} \right)^2 \tag{5}$$

Especially for the logistic model (3), we consider the criterion of minimized the SSMRE, that is, determine the parameters of $x(t_k)$ to minimize

$$\text{SSMRE} = \sum_{k=1}^{n}\left(\frac{x(t_k) - \hat{x}(t_k)}{\hat{x}(t_k)}\right)^2 \tag{6}$$

The smaller SSMRE means the better model, thus estimation of the parameters of $x(t_k)$ can be solved easily.

An optimum modeling method of logistic

The steps of modeling Logistic by using grey direct modeling method are as follows (Wang, 1988):

1) by differential equation model (1)

$$\frac{dx/dt}{x} = r - sx$$

$$\frac{dx}{dt} = rx - sx^2$$

We use grey direct modeling method to obtain

$$\frac{x(t_k) - x(t_{k-1})}{t_k - t_{k-1}} \approx rz(t_k^{'}) - sz(t_k^{'})^2,$$

where

$$z(t_k^{'}) = \frac{x(t_k) + x(t_{k-1})}{2} \qquad k = 2, \cdots n.$$

Then the least squares estimate of the parameter sequence $\hat{a} = [r\ s]^T$ of the model (1) is given by (Wang, 1988)

$$\hat{a} = [B^T B]^{-1} B^T Y$$

$$B = \begin{bmatrix} \frac{x(t_1)+x(t_2)}{2} & -\left(\frac{x(t_1)+x(t_2)}{2}\right)^2 \\ \frac{x(t_2)+x(t_3)}{2} & -\left(\frac{x(t_2)+x(t_3)}{2}\right)^2 \\ \cdots & \cdots \\ \frac{x(t_{n-1})+x(t_n)}{2} & -\left(\frac{x(t_{n-1})+x(t_n)}{2}\right)^2 \end{bmatrix}, \quad Y = \begin{bmatrix} \frac{x(t_2)-x(t_1)}{t_2-t_1} \\ \frac{x(t_3)-x(t_2)}{t_3-t_2} \\ \cdots \\ \frac{x(t_n)-x(t_{n-1})}{t_n-t_{n-1}} \end{bmatrix}$$

Then obtain estimated value $\hat{r}, \hat{s}$ of the parameters r, s of model (1), by $s = \frac{r}{x_m}$, $\hat{b} = \frac{1}{x_0} - \hat{x}_m$, $\hat{c} = \frac{1}{\hat{x}_m}$, we obtain estimated value $\hat{r}, \hat{x}_m$ of the parameters r, x_m of model (2), substitute $\hat{r}, \hat{x}_m$ into model (2), we obtain

$$\hat{x}(k) = \frac{1}{\hat{b}e^{-\hat{r}t_k} + \hat{c}}, \text{ where } \hat{b} = \frac{1}{x_{t_1}} - \hat{x}_m , \hat{c} = \frac{1}{\hat{x}_m} \tag{7}$$

Thus

$$\text{SSMRE} = \sum_{k=1}^{n} \left(\frac{x(t_k) - \hat{x}(t_k)}{\hat{x}(t_k)} \right)^2$$
$$= \sum_{k=1}^{n} \left[x(t_k)(\hat{b}e^{-\hat{r}t_k} + \hat{c}) - 1 \right]^2$$

in order to make the SSMRE smaller, $\hat{b}$ and $\hat{c}$ can be regards as the unknown parameters, $\hat{r}$ is known parameter, thus object function the SSMRE is linear concerning $\hat{b}$ and $\hat{c}$, by means of the ordinary least squares method, the, $\hat{b}$ and $\hat{c}$ making the SSMRE minimum should satisfy

$$\begin{cases} \frac{\partial S}{\partial \hat{b}} = \hat{b}\sum_{k=1}^{n} \left[x(t_k)e^{-rt_k} \right]^2 + \hat{c}\sum_{k=1}^{n} [x(t_k)]^2 e^{-rt_k} \\ \qquad - \sum_{k=1}^{n} x(t_k)e^{-rt_k} = 0 \\ \frac{\partial S}{\partial \hat{c}} = \hat{b}\sum_{k=1}^{n} [x(t_k)]^2 e^{-rk} + \hat{c}\sum_{k=1}^{n} [x(k)]^2 - \sum_{k=1}^{n} x(t_k) = 0 \end{cases}$$

That is

$$\begin{cases} \hat{b}\sum_{k=1}^{n} \left[x(t_k)e^{-rt_k} \right]^2 + \hat{c}\sum_{k=1}^{n} [x(t_k)]^2 e^{-rt_k} - \sum_{k=1}^{n} x(t_k)e^{-rt_k} = 0 \\ \hat{b}\sum_{k=1}^{n} [x(t_k)]^2 e^{-rt_k} + \hat{c}\sum_{k=1}^{n} [x(t_k)]^2 - \sum_{k=1}^{n} x(t_k) = 0 \end{cases}$$

So, solving this system gives that

$$\hat{b} = \frac{D_1}{D} \ , \ \hat{c} = \frac{D_2}{D} \ , \tag{8}$$

where

$$D = \begin{vmatrix} \sum_{k=1}^{n}\left[x(t_k)e^{-rt_k}\right]^2 & \sum_{k=1}^{n}\left[x(k)\right]^2 e^{-rt_k} \\ \sum_{k=1}^{n}\left[x(t_k)\right]^2 e^{-rt_k} & \sum_{k=1}^{n}\left[x(t_k)\right]^2 \end{vmatrix},$$

$$D_1 = \begin{vmatrix} \sum_{k=1}^{n} x(t_k)e^{-rt_k} & \sum_{k=1}^{n}\left[x(t_k)\right]^2 e^{-rt_k} \\ \sum_{k=1}^{n} x(t_k) & \sum_{k=1}^{n}\left[x(t_k)\right]^2 \end{vmatrix}, \text{ and}$$

$$D_2 = \begin{vmatrix} \sum_{k=1}^{n}\left[x(t_k)e^{-rt_k}\right]^2 & \sum_{k=1}^{n} x(t_k)e^{-rt_k} \\ \sum_{k=1}^{n}\left[x(t_k)\right]^2 e^{-rt_k} & \sum_{k=1}^{n} x(t_k) \end{vmatrix}$$

2) then we obtain the estimated value $\hat{b}$ and $\hat{c}$ of parameters b and c, by substituting $\hat{c}$, $\hat{b}$ and $\hat{r}$ into (3), we obtain that

$$\hat{x}(t_k) = \frac{1}{\hat{b}e^{\hat{r}t_k} + \hat{c}} \quad t_k \in R, k \in \{1,2,\cdots,n\}$$

3 Examples

We use two examples to explain the validity of this kind of modeling method; the first example is American population data from the first census in 1790 to 2000. The U. S. A. takes a census for every 10 years, so the value of 2000 is more than 72 times as big as the value of 1790. We simulate the data of Census from 1790 to 2000 using the method we proposed, then we have

$$x(t_k) = \frac{301.5620}{1 + 4.5839 \times 10^{23} \times e^{-0.0281 * t_k}} \tag{9}$$

Where $t_k = 1790 + 10 * (k-1), k \in \{1, 2, \cdots 22\}$, then we regard the parameters value of the above model as the initial approximation value, set object function as the following

$$\text{Minimize: } \sum_{k=1}^{n}\left(x(t_k) - \frac{1}{be^{-rt_k} + c}\right)^2$$

where $x(t_k)$ is the actual value, use the fminunc function in mathematical software Matlab environment to obtain the estimated value $\hat{r}$, $\hat{c}$ and $\hat{b}$ of parameters r, c and b, then we have

Table I Simulation value and error

Year	$\hat{A}_{t_k}$	$\hat{p}_{t_k}$ model (9)	RE model (9)	$\hat{p}_{t_k}$ model (10)	RE model (10)
1790	3.9	4.3519	-11.59	3.7578	3.65
1800	5.3	5.7358	-8.22	4.9535	6.54
1810	7.2	7.5485	-4.84	6.5222	9.41
1820	9.6	9.9149	-3.28	8.5744	10.68
1830	12.9	12.9904	-0.70	11.2500	12.79
1840	17.1	16.9643	0.79	14.7223	13.9
1850	23.2	22.0611	4.91	19.2019	17.23
1860	31.4	28.5355	9.12	24.9368	20.58
1870	38.6	36.6609	5.02	32.2072	16.56
1880	50.2	46.7041	6.96	41.3107	17.71
1890	62.9	58.8870	6.38	52.5340	16.48
1900	76.0	73.3335	3.51	66.1092	13.01
1910	92.0	90.0095	2.16	82.1553	10.7
1920	106.5	108.6719	-2.04	100.6134	5.53
1930	123.2	128.8472	-4.58	121.1941	1.63
1940	131.7	149.8580	-13.79	143.3583	-8.85
1950	150.7	170.9048	-13.41	166.3530	-10.39
1960	179.3	191.1823	-6.63	189.3033	-5.58
1970	204.0	209.9989	-2.94	211.3411	-3.6
1980	226.5	226.8611	-0.16	231.7312	-2.31
1990	251.4	241.5060	3.94	249.9589	0.57
2000	281.4	253.8833	9.78	265.7590	5.56
MAPE			5.67		9.69

$$x(t_k)=\frac{330.4117}{1+5.0224\mathrm{e}\times10^{23}\times e^{-0.0280*t_k}} \tag{10}$$

where $t_k = 1790 + 10*(k-1),\ k \in \{1, 2, \cdots 22\}$,

Refer to table I (actual value, simulation value and error), compare each result. From the table I, we can see that the error between the actual value and the simulation value from 1790 to 1930 is positive according to the mode (10), so model (10) does not represent the whole historical law of the data. On the contrary, according to the mode (9), the error between the actual value and the simulation value from 1790 to 1830 is negative, from 1840 to 1910 is positive, and from 1920 to 1980 is negative, so the model (9) can preferably represent the whole historical law of the data. From the mode (9), we can see the error approximately obey sine rule, we can combine the model (9) with sine model, the fitting accuracy and forecasting accuracy will be better. From the table I, we can see that obtained model (9) and (10) are not better fit for the later stage value, and that's because a great number of foreigners immigrated to America with the development of globalization since 1950.

The second example from (Zhu, 2002), refer to table II (actual value, simulation value and error), compare each result with (Zhu, 2002), we can see that this method has remarkably reduced the MAPE.

Table II Simulation value and error

Order	$\hat{p}_{t_k}$ this chapter	RE this chapter	$\hat{p}_{t_k}$ (Zhu, 2002)	RE (Zhu, 2002)
1	0.3439	-114.9	2.833	-1670
2	1.2483	16.78	4.584	-205.6
3	4.2480	-17.67	7.348	-103.55
4	11.9699	-15.94	11.612	18.46
5	23.3781	-3.49	17.955	20.52
6	31.4163	-18.69	26.904	-1.64
7	34.6110	6.46	38.624	-4.39
MAPE		27.71		289.25

$\hat{A}_{t_k}$ is the actual value at time t_k, $\hat{p}_{t_k}$ is the simulation value at time t_k,

RE=$\dfrac{\hat{A}_{t_k}-\hat{p}_{t_k}}{\hat{A}_{t_k}}\times 100\%$.

4 Conclusion and Analysis

It is difficult to estimate the parameters of the Logistic model. To solve this problem, we give a method for estimating its parameters based on grey direct modeling under the criterion of minimized the SSMRE. This method is very easy to implement in mathematical software Matlab environment, thus comparisons of the obtained results with the results of existing approach demonstrate that this method can reduce the MAPE of Logistic model and estimation of the parameters of Logistic model must be under the criterion of minimized the SSMRE.

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An Application of $\mathrm{GM}(0, N)$ on Analyzing the First Van Hiele Geometrical Thinking Level*

Der-Bang Wu, Hsiu-Lan Ma, Guey-Shya Chen, and Hei-Tsz Chang

This study is going to use Grey System Theory on analyzing the different types of the first van Hiele's geometric thinking level. There are five levels of the van Hiele's geometric thought: "visual", "descriptive", "theoretical", "formal logic", and "the nature of logical laws" as well as nine types in the first level. The results of this study is not only identify the easiest and the most difficult concepts for students, but also displays that the Grey Model can really found out the fact, therefore the analysis of Grey Model is better than that of tradition method.

1 Introduction

Geometry is one of the most important topics in mathematics (MET, 1993; 2000; 2003; NCTM, 1989; 1991; 1995; 2000). Geometry curriculum is developed and designed according to the van Hiele model of geometric thought (MET, 1993; 2000; 2003).

In 1957, the van Hiele model was developed by two Dutch mathematics educators, P. M. van Hiele, and his wife (Van Hiele, 1986). Several studies have

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* This work was supported in part by the National Science Council of Taiwan under Grant NSC92-2521 -S-142-004.

been conducted to discover the implications of the theory for current K 12 geometry curricula, and to validate aspects of the van Hiele model (Burger and Shaughnessy, 1986; Clements and Battista, 1992; Eberle, 1989; Fuys et al., 1988; Ma and Wu, 2000; Mayberry, 1983; Molina, 1990; Senk, 1983; Usiskin, 1982; Wu, 1995; Wu and Ma, 2005a; 2005b; 2006). Most of researchers focus on the geometry curricula of secondary school. To discover the implications of the van Hiele theory for elementary school students, however, it is also very important. The focus of this study is at the elementary level.

The main objective of this study was as follows:

The grey model GM(0,*N*) is used to analyze the first van Hiele level.

2 The Van Hiele Geometric Thinking

There are five levels of the van Hiele's geometric thought: "visual", "descriptive", "theoretical", "formal logic", and "the nature of logical laws" (Van Hiele, 1986). These five levels have two different labels: Level 1 through Level 5 or Level 0 through Level 4. Researchers have not yet come to a conclusion of which one to use. In this study, these five levels were called Level 1 through Level 5, and the focus of this study was on Level 1, visual.

At the first level, students learned the geometry through visualization. "Figures are judged by their appearance. A child recognizes a rectangle by its form and a rectangle seems different to him than a square (Van Hiele, 1986)." At this first level students identify and operate on shapes (e.g., squares, triangles, etc.) and other geometric parts (e.g., lines, angles, grids, etc.) according to their appearance (Wu and Ma, 2005a; 2005b; 2006).

At the second level, figures are bearers of their properties. That a figure is a rectangle means that it has four right angles, diagonals are equal, and opposite sides are equal. Figures are recognized by their properties. If one tells us that the figure drawn on a blackboard has four right angles, it is a rectangle even if the figure is drawn badly. But at this level properties are not yet ordered, so that a square is not necessarily identified as being a rectangle (Van Hiele, 1986).

At the third level, Properties are ordered. They are deduced one from another: one property precedes or follows another property. At this level the intrinsic meaning of deduction is not understood by the students. The square is recognized as being a rectangle because at this level definitions of figure come into play (Van Hiele, 1986).

Wu and Ma catalog nine types based on its geometric attributions in van Hiele level one (Wu and Ma, 2005a; 2005b; 2006). They are Type 1: Identification of open and closed figures, Type 2: Identification of convex and concave figures, Type 3: Identification of straight line and curve line, Type 4: Identification of rotate figure, Type 5: Identification of figures of different sizes, Type 6: Identification of extremely obtuse figures, Type 7: Identification of wide and narrow figures, Type 8: Identification on the width of contour line, Type 9: Identification on filled and hollow figures (Wu and Ma, 2005a; 2005; 2006).

Some types are not taught in the elementary school. In order to understand the important rank of types $\mathbf{GM}(0,N)$ is used to analyze factors affecting in this study. In addition, the data was processed and analyzed by the software "gn01.p", designed by Nagai, *et. al.* and Wen, *et. al.* (Nagai et al., 2005b; Wen et al., 2007) using the package Matlab. The results of this study would offer the directions for teaching geometry in the elementary school.

3 Methods and Procedures

A. Participants

The participants were 2,848 elementary school students who were randomly selected from 23 elementary schools in 23 counties/cities in Taiwan. There were 1,409 girls and 1,439 boys. The numbers of participants, from 1^{st} to 6^{th} grades, were 428, 471, 472, 478, 477, 522 students, respectively.

B. Instrument

The instrument used in this study, Wu's Geometry Test (WGT), was specifically designed for this project due to there were no suitable Chinese instruments available (Wu and Ma, 2005a; 2005b; 2006). This instrument was designed base on van Hiele level descriptors and sample responses identified by Fuys, Geddes, and Tischler (Fuys et al., 1988). There are 25 multiple-choose questions of the first van Hiele level (Part 1); 20 multiple-choose questions of the second van Hiele level in the second (Part 2); and 25 multiple-choose questions of the third van Hiele level (Part 3). The test is focus on three basic geometric concepts: triangle, quadrilateral and circle. The result of the first part of WGT was used in this research report.

Twenty-five questions at level one were characterized into nine types based on its geometric attributions. The questions 1, 2, and 3 are included in Type 1. The questions 4, 5, and 6 are included in Type 2 as well as questions 7, 8, and 9 are included in Type 3. The questions 10, 11, and 12 are included in Type 4 as well as questions 13, 14, and 15 are included in Type 5. Type 6 is included in questions 16 and 17 as well as Type 7 include questions 18 and 19. The questions 20, 11, and 22 are included in Type 8 as well as questions 23, 24, and 25 are included in Type 9.

The scoring criteria were based on the van Hiele Geometry Test (VHG), developed by Usiskin, in the project "van Hiele Levels and Achievement in Secondary School Geometry" (CDASSG Project) (Usiskin, 1982). In the VHG test, each level has five questions. If the student answers four or five the first level questions correctly, he/she has reached the first level. If the students (a) answered 4 questions or more correctly from the second level; (b) reached the criteria of the first level; and (c) did not correctly answer 4 or more questions, from level 3, level 4, and level 5, they were classified as in second level. Therefore, using the same criteria set by Usiskin (1982), the passing rate of this study was set at 60%.

C. Validity and Reliability of the Instrument

The attempt to validate the instrument (WGT) involved the critiques of a validating team. The members of this team included elementary school teachers, graduate students majored in mathematics education, and professors from Mathematics Education Departments at several pre-service teacher preparation institutes. The team members were given this instrument, and provide feedback regarding whether each test item was suitable or not. They also gave suggestions about how to make this test better.

In order to measure the reliability of the WGT, 289 elementary school students (Grades 1-6) were selected to take the WGT. These students were not participants in this study. The alpha reliability coefficient of the first part of WGT was .6754 ($p < .001$) using SPSS for Windows (Wu and Ma, 2005a; 2005b; 2006).

D. Procedure

The one-time WGT was given during April 2006. The class teachers of the participants administered the test in one mathematics class. The tests were graded by the project directors.

4 Mathematics Model of the Grey Model

The standard formula of GM(0,*N*) is as following (Nagai et al., 2005b; Wen et al., 2007; Akabane et al., 2007; Warfield, 1973; Li et al., 2005; Deng, 2004; Nagai et al., 2005a; Yamaguchi et al., 2007).

$$\begin{aligned} & az_1^{(1)}(k) \\ &= \sum_{j=2}^{N} b_j x_j^{(1)}(k) \\ &= b_2 x_2^{(1)}(k) + b_3 x_3^{(1)}(k) + \ldots + b_N x_N^{(1)}(k) \end{aligned} \tag{1}$$

where

$$z_1^{(1)}(k) = 0.5x_1^{(1)}(k-1) + 0.5x_1^{(1)}(k), \quad k = 2,3,\cdots,n$$

E. Substituting the value of AGO, then we have:

$$\begin{aligned} a_1 z_1^{(1)}(2) &= b_2 x_2^{(1)}(2) + \cdots + b_N x_N^{(1)}(2) \\ a_1 z_1^{(1)}(3) &= b_2 x_2^{(1)}(3) + \cdots + b_N x_N^{(1)}(3) \\ a_1 z_1^{(1)}(4) &= b_2 x_2^{(1)}(4) + \cdots + b_N x_N^{(1)}(4) \\ &\cdots\cdots \\ a_1 z_1^{(1)}(n) &= b_2 x_2^{(1)}(n) + \cdots + b_N x_N^{(1)}(n) \end{aligned} \tag{2}$$

F. Dividing 1 a in both sides, then transfer into matrix form:

$$\begin{bmatrix} 0.5x_1^{(1)}(1)+0.5x_1^{(1)}(2) \\ 0.5x_1^{(1)}(2)+0.5x_1^{(1)}(3) \\ \vdots \\ 0.5x_1^{(1)}(n-1)+0.5x_1^{(1)}(n) \end{bmatrix} = \begin{bmatrix} x_2^{(1)}(2),\cdots,x_N^{(1)}(2) \\ x_2^{(1)}(3),\cdots,x_N^{(1)}(3) \\ \vdots \\ x_2^{(1)}(n),\cdots,x_N^{(1)}(n) \end{bmatrix} \begin{bmatrix} \frac{b_2}{a_1} \\ \frac{b_3}{a_1} \\ \vdots \\ \frac{b_N}{a_1} \end{bmatrix} \tag{3}$$

Assume $\frac{b_j}{a_1} = \hat{b}_m$, where $j = 1,2,3,\cdots,m$ then Equation (3) can be rearranged into

$$\begin{bmatrix} 0.5x_1^{(1)}(1)+0.5x_1^{(1)}(2) \\ 0.5x_1^{(1)}(2)+0.5x_1^{(1)}(3) \\ \vdots \\ 0.5x_1^{(1)}(n-1)+0.5x_1^{(1)}(n) \end{bmatrix} = \begin{bmatrix} x_2^{(1)}(2),\cdots,x_N^{(1)}(2) \\ x_2^{(1)}(3),\cdots,x_N^{(1)}(3) \\ \vdots \\ x_2^{(1)}(n),\cdots,x_N^{(1)}(n) \end{bmatrix} \begin{bmatrix} \hat{b}_2 \\ \hat{b}_3 \\ \vdots \\ \hat{b}_N \end{bmatrix} \tag{4}$$

3. In the same way, using the matrix solving equation $\hat{B} = \left(Y^T Y\right)^{-1} Y^T X$ to find the values of $\hat{b}_m$, where

$$X = \begin{bmatrix} 0.5x_1^{(1)}(1)+0.5x_1^{(1)}(2) \\ 0.5x_1^{(1)}(2)+0.5x_1^{(1)}(3) \\ \vdots \\ 0.5x_1^{(1)}(n-1)+0.5x_1^{(1)}(n) \end{bmatrix} \tag{5}$$

$$Y = \begin{bmatrix} x_2^{(1)}(2),\cdots,x_N^{(1)}(2) \\ x_2^{(1)}(3),\cdots,x_N^{(1)}(3) \\ \vdots \\ x_2^{(1)}(n),\cdots,x_N^{(1)}(n) \end{bmatrix} \tag{6}$$

$$\hat{B} = \begin{bmatrix} \hat{b}_2 \\ \hat{b}_3 \\ \vdots \\ \hat{b}_N \end{bmatrix} \tag{7}$$

The numerical range of $\hat{b}_m$ represents the weighting range between the comparative sequence and standard sequence.

5 Results

The passing numbers and passing rate for each type and each geometric shape at level 1 were reported in Table I.

Table I The numbers passed and passing rate of each type and shape

	Triangle N=2848	Quadrilateral N=2848	Circle N=2848	Total
Type 1	71.21%	70.19%	75.81%	72.40%
Type 2	84.06%	7.44%	95.44%	62.31%
Type 3	94.14%	87.64%	95.79%	92.52%
Type 4	79.56%	65.91%	89.01%	78.16%
Type 5	58.60%	67.59%	78.62%	68.27%
Type 6	65.10%	43.75%		54.42%
Type 7	57.06%	59.52%		58.29%
Type 8	87.99%	83.46%	79.74%	83.73%
Type 9	80.86%	86.76%	74.23%	80.62%
Total	75.40%	63.58%	84.09%	72.30%

G. Overall performance on basic figures

From the data of Table I, the total passing rate was 72.30%. The overall passing rates of the triangle concept were 75.40%, 63.58% for quadrilateral, and 84.09% for circle. It seemed that the circle concept is the easiest one for students, followed by triangle concept, and quadrilateral concept. The passing rates of each shape are shown in Fig. 1.

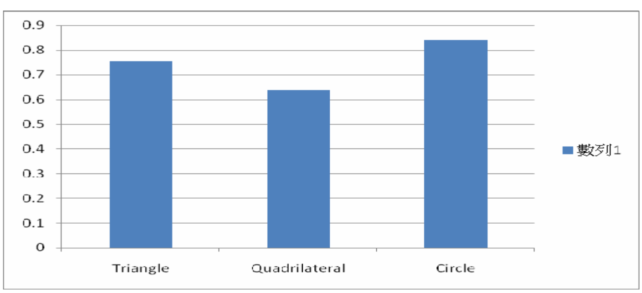

Fig. 1 The passing rate of each shape.

H. Overall performance on each type

The passing rates of each shape are shown in Fig. 2.

The overall passing rates, from Type 1 to Type 9, were 72.40%, 62.31%, 92.52%, 78.16%, 68.27%, 54.42%, 58.29%, 83.73%, and 80.62% respectively.

It seemed that Type 3 is the easiest one for students, followed by Type 8, and Type 9. Type 6 was the most difficult one, followed by Type 7, and Type 2.

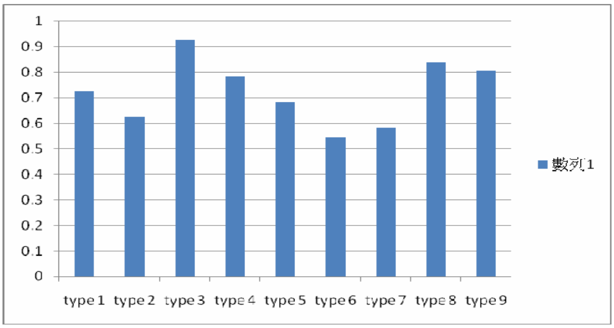

Fig. 2 The passing rate of each shape.

Type 1) Identification of Open and Closed Figure : The example of Type 1 questions is shown in Fig. 3. The passing rates of the triangle concept were 71.21%, 70.19% for quadrilateral, and 75.81% for circle. It showed that students could easily identify the open and closed figures in circular concept and have difficulties on quadrilateral.

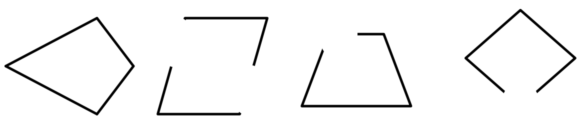

Fig. 3 The identification of open and closed figure

Type 2) Identification of Convex and Concave Figures: The example of Type 2 questions is shown in Fig. 2. The passing rates of the triangle concept were 84.06%, 7.44% for quadrilateral, and 95.44% for circle. It showed that students could easily identify the convex and concave figures in circular concept and have difficulties on quadrilateral.

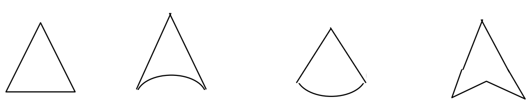

Fig. 4 The identification of convex and concave figure.

Type 3) Identification of Straight Line and Curve Line: The example of Type 3 questions is shown in Fig. 3. The passing rates of the triangle concept were 94.14%, 87.64% for quadrilateral, and 95.79% for circle. It showed that students could easily identify the straight line and curve lines in circular concept and have difficulties on quadrilateral.

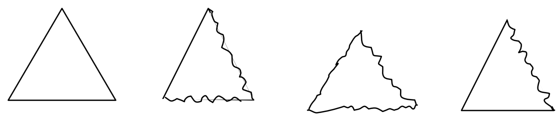

Fig. 5 The identification of straight line and curve line.

Type 4) Identification of Rotate Figure: The example of Type 4 questions is shown in Fig. 4. The passing rates of the triangle concept were 79.56%, 65.91% for quadrilateral, and 89.01% for circle. It showed that students could easily identify the rotate figures in circular concept and have difficulties on quadrilateral.

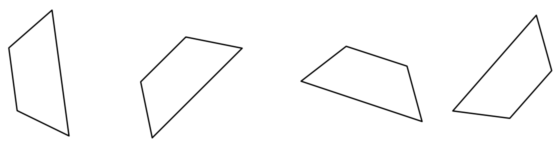

Fig. 6 The identification of rotate figures.

Type 5) Identification of Figures of Different Sizes: The example of Type 5 questions is shown in Fig. 5. The passing rates of the triangle concept were 58.60%, 67.59% for quadrilateral, and 78.62% for circle. It showed that students could easily identify the figures of different sizes in circular concept and have difficulties on quadrilateral.

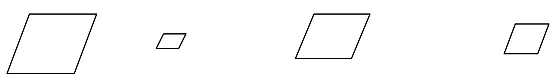

Fig. 7 The identification of figures of different sizes.

Type 6) Identification of Extremely Obtuse Figures: The example of Type 6 questions is shown in Fig. 6. The passing rates of the triangle concept were 65.10%, and 43.75% for quadrilateral. It showed that students could easily identify the figures of extremely obtuse figures in triangular concept and have difficulties on quadrilateral.

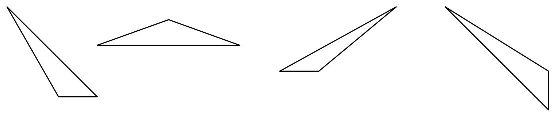

Fig. 8 The identification of extremely obtuse figures.

Type 7) Identification of Wide and Narrow Figures: The example of Type 7 questions is shown in Fig. 7. The passing rates of the triangle concept were 57.06% and 59.52% for quadrilateral. It showed that students could easily identify the figures of wide and narrow figures in quadrilateral concept and have difficulties on triangular.

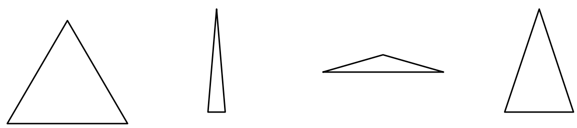

Fig. 9 The identification of wide and narrow figures.

Type 8) Identification on Width of the Contour Line: The example of Type 8 questions is shown in Fig. 8. The passing rates of the triangle concept were 87.99%, 83.46% for quadrilateral, and 79.74% for circle. It showed that students could easily identify the width of the contour line in triangular concept and have difficulties on circle.

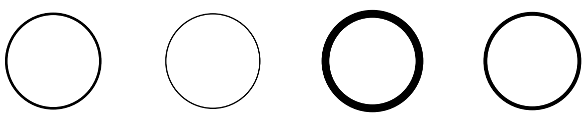

Fig. 10 The identification of width of the contour line.

Type 9) Identification on Filled and Hollow Figures: The example of Type 9 questions is shown in Fig. 9. The passing rates of the triangle concept were 80.86%, 86.76% for quadrilateral, and 74.23% for circle. It showed that students could easily identify the filled and hollow figures in triangular concept and have difficulties on circle.

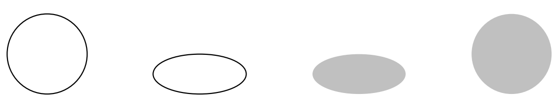

Fig. 11 The identification of filled and hollow figures.

6 Analysis with Grey Model

The raw scores of each type of students are shown in Table II.

GM$(0, N)$ is chosen as our approach. The analysis steps are shown as follows.

1) Building the original sequences:

$$\begin{aligned} x_1^{(0)} &= (3,3,3,3,3,\cdots,3) \\ x_2^{(0)} &= (3,3,3,0,3,\cdots,2) \\ x_3^{(0)} &= (3,3,3,3,3,\cdots,2) \\ &\ldots \\ x_9^{(0)} &= (3,1,3,3,3,\cdots,2) \end{aligned} \tag{8}$$

2) Building the AGO sequences:

$$\begin{aligned} x_1^{(1)} &= (3,6,9,12,15,\cdots,8544) \\ x_2^{(1)} &= (3,6,9,\cdots,6186) \\ &\cdots\cdots\cdots \\ x_9^{(1)} &= (3,4,10,\cdots,6888) \\ z_1^{(1)} &= (\text{——},4.5,7.5,10.5,\cdots,8542.5) \end{aligned} \tag{9}$$

3) Substituting Eq. with the values from Table II, where the output is full point and the result of Table III is obtained.

4) Because of the amount of data are enormous, therefore, the computer toolbox is also used to analyze and verify.

Table II The raw scores of each type of students

	1	2	3	4	5	…	2848
Type 1	3	3	3	0	3	…	2
Type 2	2	2	2	2	2	…	1
Type 3	3	3	3	3	3	…	2
Type 4	1	2	3	2	3	…	1
Type 5	1	0	1	1	3	…	0
Type 6	1	0	0	0	2	…	1
Type 7	0	0	1	0	2	…	0
Type 8	3	0	3	3	3	…	0
Type 9	3	1	3	3	3	…	2
Full Point	3	3	3	3	3	…	3

The first three ranks of Types are Type 2, Type 3, and Type 8 and the last three ranks of Types are Type 9, Type 4, and Type 6. The graph of the weightings is shown in Fig. 12.

Table III The analyzed weighting of Grey model

Geometrical Types	Weighting	Rank
Type 1: open and closed figure	**0.2430**	**4**
Type 2: convex and concave figures	**1.5076**	**1**
Type 3: straight line and curve line	**0.6277**	**2**
Type 4: rotate figure	**0.1027**	**8**
Type 5: figures of different sizes	**0.1210**	**7**
Type 6: extremely obtuse figures	**0.1351**	**6**
Type 7: wide and narrow figures	**0.1710**	**5**
Type 8: identification on width of the contour line	**0.2750**	**3**
Type 9: identification on filled and hollow figures	**0.0023**	**9**

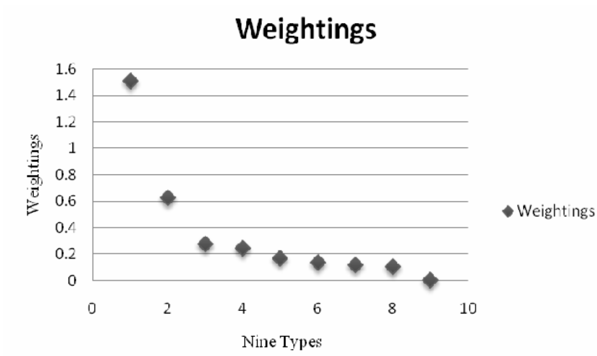

Fig. 12 The graph of the weightings.

7 Conclusions

At the first van Hiele level (visual), students judged the figures by their appearance. The circular concept is the easiest for students; on the other hand, the concept of quadrilateral is the most difficult to students. Based on the analysis of the Grey Model, Type 9 (identification on filled and hollow) is the easiest for students and Type 2 (convex and concave figures) is the most difficult one among these nine different types of figures in this study. Because the concave figures are not taught in the elementary school, only 7.44% students make the correct answer. This finding displays that the Grey Model can really found out the fact, therefore the analysis of Grey Model is better than that of tradition method.

The results of this study identified the easiest and the most difficult concepts for students, it is important to investigate the reason behind this result. The authors of this study are interested to investigate why elementary students have difficulties in identifying extremely obtuse figures. One reason might be that extremely obtuse figures are rarely shown in the textbook, and in their daily lives. Researchers might consider this as their research interests and use the Interpretive Structure Modeling of Grey System to analyze the geometrical structure.

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The Discrete Grey Prediction Model Based on Optimized Initial Value*

Tianxiang Yao, Zaiwu Gong, Naiming Xie, and Hong Gao

When GM (1, 1) model is applied to simulate a pure exponential sequence, the errors usually occur. There are many limitations to the development coefficient and the primary sequence. The characteristics of the discrete GM (1, 1) model are analogous to the GM (1, 1) model. It can be regarded as the precise form of the formal model. The chapter studied the growth rate of the simulation values under different initial values of discrete GM (1, 1) model. Appling optimization technique to solve the initial value, it proved that the modified discrete GM (1, 1) model can perfectly simulate the exponential sequence.

1 Introduction

GM(1,1) model is widely used (Liu and Lin, 1998; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006; Lin et al., 2002; Sydow et al., 2001; Lin and Liu, 2000) as

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* This work was supported in part by the National Natural Science Foundation of China under Grants 70901041 and 70901043, Humanities and Social Sciences Foundation of Ministry of Education of China, Doctoral Fund of Ministry of Education of China under Grants 20093218120032 and 200802870020, and Philosophical and Social Science Foundation of Higher Education of Jiangsu Province of China under Grants 09SJD630059 and 09SJB630043.

some scholars studied the suitable range and simulation accuracy of GM(1,1) model (Liu and Deng, 1999). The improvement methods mainly include discrete GM (1, 1) model (Xie and Liu, 2005; Yao, et al., 2009; Yao and Liu, 2007), constructing background value (Tan, 2005), error correction (Liu and Lin, 2006; Deng, 2002), optimizing grey differential derivative method (Wang et al., 2001), and central approach method (Song et al., 2001). Because GM(1,1) model has error when is applied to simulate geometric sequence, it is necessary to improve GM (1, 1) model (Ji et al., 2001). The basic form of GM (1, 1) model is discrete function, but the whitenization form is continuous form. The jump from discrete function to continuous form leads to the errors and instabilities of simulation values (Xie and Liu, 2005). The research of reference (Xie and Liu, 2005) indicates discrete GM (1, 1) model is the accurate form of traditional GM (1, 1) model. This chapter applied the parameters solution formula and incursion formula put forward by the reference (Xie and Liu, 2005) to study the characteristic of growth rate of different initial values. It applied optimization theory to solve the initial values and studied exponential curve fitting by the improved discrete GM (1, 1) model.

2 The Optimization Solution of Initial Value of Discrete GM(1,1) Model

Definition 2.1. (Xie and Liu, 2005) $x^{(1)}(k+1)=\beta_1 x^{(1)}(k)+\beta_2$ is called discrete GM (1, 1) model (DGM), where β_1 is development coefficient.

The time response sequence of DGM is (Xie and Liu, 2005)

$$\hat{x}^{(1)}(k+1)=\beta_1^k x^{(1)}(1)+\frac{1-\beta_1^k}{1-\beta_1}\beta_2, k=1,2,...,n-1 \tag{1}$$

The parameters solution formula is

$$\beta_1=\frac{\sum_{k=1}^{n-1}x^{(1)}(k+1)x^{(1)}(k)-\frac{1}{n-1}\sum_{k=1}^{n-1}x^{(1)}(k+1)\sum_{k=1}^{n-1}x^{(1)}(k)}{\sum_{k=1}^{n-1}(x^{(1)}(k))^2-\frac{1}{n-1}(\sum_{k=1}^{n-1}x^{(1)}(k))^2} \tag{2}$$

$$\beta_2=\frac{1}{n-1}(\sum_{k=1}^{n-1}x^{(1)}(k+1)-\beta_1\sum_{k=1}^{n-1}x^{(1)}(k)) \tag{3}$$

Theorem 2.1. Let the simulation sequence of DGM be $\hat{X}^{(0)}=\left\{\hat{x}^{(0)}(2),\hat{x}^{(0)}(3),...,\hat{x}^{(0)}(n)\right\}$. $\hat{u}(k)$ is the growth rate of simulation sequence. Let $\hat{u}(k)=\frac{\hat{x}^{(0)}(k+1)-\hat{x}^{(0)}(k)}{\hat{x}^{(0)}(k)}$, where $k=2,3,...,n$, so $\hat{u}(k)=\beta_1-1$.

Proof. From Definition 2.1 and (1),

$$
\begin{aligned}
& x^{(0)}(k+1) \\
&= \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \\
&= \beta_1^k \hat{x}^{(1)}(1) + \frac{1-\beta_1^k}{1-\beta_1}\beta_2 - (\beta_1^{k-1}\hat{x}^{(1)}(1) + \frac{1-\beta_1^{k-1}}{1-\beta_1}\beta_2) \\
&= \beta_1^{k-1}(\hat{x}^{(1)}(1)(\beta_1 - 1) + \beta_2) \qquad (4)
\end{aligned}
$$

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) = \beta_1^{k-2}(\hat{x}^{(1)}(1)(\beta_1 - 1) + \beta_2), \quad \hat{u}(k) = \frac{\hat{x}^{(0)}(k+1) - \hat{x}^{(0)}(k)}{\hat{x}^{(0)}(k)} = \beta_1 - 1 \qquad (5)$$

It is similar to GM(1,1) model that the growth rate of simulation value is a constant and the simulation sequence is a geometric sequence. Assume $\hat{x}^{(1)}(1) = x^{(0)}(1)$ and the reference (Xie and Liu, 2005) obtains the initial value.

If letting $\hat{x}^{(1)}(n) = x^{(1)}(n)$, then we can obtain the recurrence formula in which the new value is the initial value. If letting $\hat{x}^{(1)}(1) = \xi$, then by solving the optimization problems $\min_{\xi}\sum_{k=2}^{n}[\hat{x}^{(0)}(k) - x^{(0)}(k)]^2$ or $\min_{\xi}\sum_{k=1}^{n}[\hat{x}^{(1)}(k) - x^{(1)}(k)]^2$, we can obtain other two recurrence formula. From theorem, to any initial value, the growth rate of simulation values is a constant and the simulation sequence is a geometric sequence. Now find the initial value by optimization method.

If the initial value is obtained by optimization method, we call it optimized discrete GM (1, 1) model (ODGM).

Let $\hat{x}^{(1)}(1) = \xi$, so

$$\hat{x}^{(1)}(k) = \beta_1^{k-1}\xi + \frac{1-\beta_1^{k-1}}{1-\beta_1}\beta_2 \qquad (6)$$

So

$$
\begin{aligned}
\hat{x}^{(0)}(k) &= \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) \\
&= (\beta_1^{k-1} - \beta_1^{k-2})\xi + \frac{\beta_1^{k-2} - \beta_1^{k-1}}{1-\beta_1}\beta_2 \\
&= \beta_1^{k-2}((\beta_1 - 1)\xi + \beta_2), k = 2, 3, \ldots \qquad (7)
\end{aligned}
$$

Let

$$Q = \sum_{k=2}^{n}[\hat{x}^{(0)}(k) - x^{(0)}(k)]^2 .$$

Solve the optimization problem

$$\min_{\xi}\sum_{k=2}^{n}[\hat{x}^{(0)}(k) - x^{(0)}(k)]^2,$$

$$Q = \sum_{k=2}^{n}[\hat{x}^{(0)}(k) - x^{(0)}(k)]^2 = \sum_{k=2}^{n}[(\beta_1^{k-1} - \beta_1^{k-2})\xi + \beta_1^{k-1}\beta_2 - x^{(0)}(k)]^2$$

$$
\begin{aligned}
&= \sum_{k=2}^{n} (\beta_1^{k-1} - \beta_1^{k-2})^2 \xi^2 \\
&\quad + 2\sum_{k=1}^{n} (\beta_1^{k-1} - \beta_1^{k-2})(\beta_1^{k-1}\beta_2 - x^{(0)}(k))\xi \\
&\quad + (\beta_1^{k-1}\beta_2 - x^{(0)}(k))^2
\end{aligned} \tag{8}
$$

$$
\begin{aligned}
\frac{dQ}{d\xi} &= 2\sum_{k=2}^{n} (\beta_1^{k-1} - \beta_1^{k-2})^2 \xi \\
&\quad + 2\sum_{k=2}^{n} (\beta_1^{k-1} - \beta_1^{k-2})(\beta_1^{k-1}\beta_2 - x^{(0)}(k))
\end{aligned} \tag{9}
$$

Let $\frac{dQ}{d\xi} = 0$, namely

$$
\sum_{k=2}^{n} (\beta_1^{k-1} - \beta_1^{k-2})^2 \xi = \sum_{k=2}^{n} (\beta_1^{k-1} - \beta_1^{k-2})(x^{(0)}(k) - \beta_1^{k-1}\beta_2) \tag{10}
$$

$$
\xi = \frac{\sum_{k=2}^{n} (\beta_1^{k-1} - \beta_1^{k-2})(x^{(0)}(k) - \beta_1^{k-1}\beta_2)}{\sum_{k=2}^{n} (\beta_1^{k-1} - \beta_1^{k-2})^2} \tag{11}
$$

Here $Q = \sum_{k=2}^{n} [\hat{x}^{(0)}(k) - x^{(0)}(k)]^2$ is a minimum.

3 The Properties of ODGM

Theorem 3.1. Let $X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)\}$. Establish ODGM model and obtain the simulation sequence $\hat{X}^{(0)} = X^{(0)}$. Let $Y^{(0)} = \lambda X^{(0)}$, so the simulation value of $Y^{(0)}$ is $\hat{Y}^{(0)} = Y^{(0)}$.

Proof. Let

$$
X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)\}, Y^{(0)} = \{y^{(0)}(1), y^{(0)}(2), \ldots, y^{(0)}(n)\},
$$

The parameters of $X^{(0)}$ and $Y^{(0)}$ are $[\beta_1, \beta_2]$, $[\gamma_1, \gamma_2]$, respectively. Let

$$
M_1 = \sum_{k=1}^{n-1} x^{(1)}(k+1)x^{(1)}(k), \quad M_2 = \sum_{k=1}^{n-1} x^{(1)}(k+1)\sum_{k=1}^{n-1} x^{(1)}(k),
$$

$$
M_3 = \sum_{k=1}^{n-1} (x^{(1)}(k))^2, \quad M_4 = (\sum_{k=1}^{n-1} x^{(1)}(k))^2.
$$

From the formula in the reference (Xie and Liu, 2005)

$$
\beta_1 = \frac{(n-1)M_1 - M_2}{(n-1)M_3 - M_4}. \tag{12}
$$

Similarly, let

$$N_1=\sum_{k=1}^{n-1}y^{(1)}(k+1)y^{(1)}(k),\ N_2=\sum_{k=1}^{n-1}y^{(1)}(k+1)\sum_{k=1}^{n-1}y^{(1)}(k),$$

$$N_3=\sum_{k=1}^{n-1}(y^{(1)}(k))^2,\ N_4=(\sum_{k=1}^{n-1}y^{(1)}(k))^2,$$

So

$$\gamma_1=\frac{(n-1)N_1-N_2}{(n-1)N_3-N_4}.$$

From $x^{(1)}(k)=\sum_{i=1}^{k}x^{(0)}(i)$, $Y^{(0)}=\lambda X^{(0)}$, We can obtain

$$y^{(1)}(k)=\sum_{i=1}^{k}y^{(0)}(i)=\sum_{i=1}^{k}\lambda x^{(0)}(i)=\lambda x^{(1)}(k) \tag{13}$$

$$N_1=\sum_{k=1}^{n}y^{(1)}(k+1)y^{(1)}(k)\ =\sum_{k=1}^{n}\lambda^2x^{(1)}(k+1)x^{(1)}(k)=\lambda^2M_1 \tag{14}$$

Similarly we can obtain

$$N_2=\lambda^2M_2\,,N_3=\lambda^2M_3\,,N_4=\lambda^2M_4\cdot\ \gamma_1=\frac{(n-1)N_1-N_2}{(n-1)N_3-N_4}=\frac{(n-1)\lambda^2M_1-\lambda^2M_2}{(n-1)\lambda^2M_3-\lambda^2M_4}=\beta_1 \tag{15}$$

From $\beta_2=\frac{1}{n-1}(\sum_{k=1}^{n-1}x^{(1)}(k+1)-\beta_1\sum_{k=1}^{n-1}x^{(1)}(k))$ we can obtain (Xie and Liu, 2005)

$$\begin{aligned}\gamma_2&=\frac{1}{n-1}(\sum_{k=1}^{n-1}y^{(1)}(k+1)-\gamma_1\sum_{k=1}^{n-1}y^{(1)}(k))\\&=\frac{1}{n-1}(\sum_{k=1}^{n-1}\lambda x^{(1)}(k+1)-\gamma_1\sum_{k=1}^{n-1}\lambda x^{(1)}(k))\\&=\frac{\lambda}{n-1}(\sum_{k=1}^{n-1}x^{(1)}(k+1)-\beta_1\sum_{k=1}^{n-1}x^{(1)}(k))=\lambda\beta_2\end{aligned} \tag{16}$$

From the recurrence formula and $\gamma_1=\beta_1$, $\gamma_2=\lambda\beta_2$. So

$$\begin{aligned}\hat{y}^{(1)}(k+1)&=y^{(0)}(1)\cdot\gamma_1^k+\frac{1-\gamma_1^k}{1-\gamma_1}\gamma_2\\&=\lambda x^{(0)}(1)\cdot\beta_1^k+\frac{1-\beta_1^k}{1-\beta_1}\times\lambda\beta_2\\&=\lambda\hat{x}^{(1)}(k+1)\end{aligned} \tag{17}$$

So

$$\hat{y}^{(0)}(k)=\hat{y}^{(1)}(k)-\hat{y}^{(1)}(k-1)=\lambda\hat{x}^{(1)}(k)-\lambda\hat{x}^{(1)}(k-1)=\lambda\hat{x}^{(0)}(k) \tag{18}$$

From $\hat{x}^{(0)}(k)=x^{(0)}(k)$, we have $\hat{y}^{(0)}(k)=\lambda x^{(0)}(k)=y^{(0)}(k)$, namely, $\hat{Y}^{(0)}=Y^{(0)}$.

Theorem 3.2. Let $X^{(0)}=\left\{x^{(0)}(1),x^{(0)}(2),...,x^{(0)}(n)\right\}$, $x^{(0)}(k)=a^k$, $a\neq 1$, $x^{(1)}(k)=\sum_{i=1}^{k}x^{(0)}(i)$, if $\hat{x}^{(0)}(k)$ is the restored values by establish ODGM model. The initial value is obtained by solve the optimization problem $\min_{\xi}\sum_{k=2}^{n}[\hat{x}^{(0)}(k)-x^{(0)}(k)]^2$, so $\hat{x}^{(0)}(k)=a^k$, where $k=1,2,...,n$.

Proof. From the parameters formula (2) and (3), let

$$M_1=\sum_{k=1}^{n-1}x^{(1)}(k+1)x^{(1)}(k),\ M_2=\sum_{k=1}^{n-1}x^{(1)}(k+1)\sum_{k=1}^{n-1}x^{(1)}(k),$$

$$N_1=\sum_{k=1}^{n-1}(x^{(1)}(k))^2,\ N_2=(\sum_{k=1}^{n-1}x^{(1)}(k))^2$$

$$\begin{aligned}M_1&=\sum_{k=1}^{n-1}\frac{a(1-a^{k+1})}{1-a}\times\frac{a(1-a^{k+1})}{1-a}\\&=\frac{a^2}{(1-a)^2}\sum_{k=1}^{n-1}(1-a^k-a^{k+1}+a^{2k+1})\\&=\frac{a^2}{(1-a)^2}((n-1)-\frac{a(1-a^{n-1})}{1-a}\\&\quad-\frac{a^2(1-a^{n-1})}{1-a}+\frac{a^3(1-a^{2n-2})}{1-a^2})\end{aligned}\tag{19}$$

$$\begin{aligned}M_2&=(\sum_{k=1}^{n-1}\frac{a(1-a^{k+1})}{1-a})(\sum_{k=1}^{n-1}\frac{a(1-a^{k})}{1-a})\\&=\frac{a^2}{(1-a)^2}((n-1)^2-\frac{a(1-a^{n-1})}{1-a}(n-1)\\&\quad-\frac{a^2(1-a^{n-1})}{1-a}(n-1)+\frac{a^3(1-a^{n-1})^2}{(1-a)^2})\end{aligned}\tag{20}$$

$$\begin{aligned}&(n-1)M_1-M_2\\&=\frac{a^5(1-a^{n-1})}{(1-a)^3}(\frac{1+a^{n-1}}{1+a}(n-1)-\frac{1-a^{n-1}}{1-a})\end{aligned}$$

$$\begin{aligned}N_1&=\frac{a^2}{(1-a)^2}(n-1-2\sum_{k=1}^{n-1}a^k+\sum_{k=1}^{n-1}a^{2k})\\&=\frac{a^2}{(1-a)^2}(n-1-\frac{2a(1-a^{n-1})}{1-a}\\&\quad+\frac{a^2(1-a^{2n-2})}{1-a^2})\end{aligned}\tag{21}$$

$$N_2 = \left(\frac{a}{1-a}\left(n-1-\sum_{k=1}^{n-1} a^k\right)\right)^2 = \frac{a^2}{(1-a)^2}\left((n-1)^2 - \frac{2a(1-a^{n-1})}{1-a}(n-1) + \frac{a^2}{(1-a)^2}(1-a^{n-1})^2\right) \tag{22}$$

$$(n-1)N_1 - N_2 = \frac{a^4(1-a^{n-1})}{(1-a)^3}\left(\frac{1+a^{n-1}}{1+a}(n-1) - \frac{1-a^{n-1}}{1-a}\right) \tag{23}$$

$$\beta_1 = \frac{(n-1)M_1 - M_2}{(n-1)N_1 - N_2} = a \tag{24}$$

$$\beta_2 = \frac{1}{n-1}\left(\sum_{k=1}^{n-1}\frac{a(1-a^{k+1})}{1-a} - a\sum_{k=1}^{n-1}\frac{a(1-a^k)}{1-a}\right) = a \tag{25}$$

Let $Q = \sum_{k=1}^{n}[\hat{x}^{(0)}(k) - x^{(0)}(k)]^2$. Solve the optimization $\min_{\xi}\sum_{k=2}^{n}[\hat{x}^{(0)}(k) - x^{(0)}(k)]^2$.

Let $\hat{x}^{(1)}(1) = \xi$. So

$$\hat{x}^{(1)}(k+1) = \hat{x}^{(1)}(1)\cdot\beta_1^k + \frac{\beta_2}{1-\beta_1}\cdot(1-\beta_1^k) = a^k\xi + \frac{a}{1-a}\cdot(1-a^k) = a^k\xi + \frac{a-a^{k+1}}{1-a} \tag{26}$$

The restored values

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) = (a^{k-1} - a^{k-2})\xi + \frac{a^{k-1} - a^k}{1-a} \tag{27}$$

$$Q = \sum_{k=2}^{n}[\hat{x}^{(0)}(k) - x^{(0)}(k)]^2 = \sum_{k=2}^{n}[\hat{x}^{(0)}(k) - a^k]^2$$
$$= \sum_{k=2}^{n}\left[(a^{k-1} - a^{k-2})\xi + \frac{a^{k-1} - a^k}{1-a} - a^k\right]^2 = \sum_{k=2}^{n}\left[(a^{k-1} - a^{k-2})\xi + \frac{a^{k-1} - 2a^k + a^{k+1}}{1-a}\right]^2 \tag{28}$$

$$Q = \sum_{k=2}^{n}(a^{k-1} - a^{k-2})^2\xi^2 + \sum_{k=1}^{n}\frac{(a^{k-1} - 2a^k + a^{k+1})^2}{(1-a)^2} + 2\sum_{k=2}^{n}\frac{(a^{k-1} - a^{k-2})(a^{k-1} - 2a^k + a^{k+1})}{1-a}\xi \tag{29}$$

Let

$$\frac{dQ}{d\xi} = 2\sum_{k=1}^{n}(a^{k-1} - a^{k-2})^2\xi + 2\sum_{k=2}^{n}\frac{(a^{k-1} - a^{k-2})(a^{k-1} - 2a^k + a^{k+1})}{1-a} = 0,$$

so we have

$$\sum_{k=2}^{n}(a^{k-1}-a^{k-2})^2\xi-\sum_{k=1}^{n}(a^{k-2})^2(a-2a^2+a^3)=0 \tag{30}$$

$$\sum_{k=2}^{n}(a^{k-1}-a^{k-2})^2\xi-a\sum_{k=2}^{n}(a^{k-1}-a^{k-2})^2=0 \tag{31}$$

Namely, when $\xi=a$, $\frac{dQ}{d\xi}=0$. Substitute $\xi=a$ into $Q=\sum_{k=2}^{n}[\hat{x}^{(0)}(k)-x^{(0)}(k)]^2$, we obtain $Q=0$. Because $Q\geq 0$, when $\xi=a$, the average relative error of the simulation values is a minimum, namely $\hat{x}^{(0)}(k)=\hat{x}^{(1)}(k)-\hat{x}^{(1)}(k-1)$ $=(a^k+\frac{a-a^k}{1-a})-(a^{k-1}+\frac{a-a^{k-1}}{1-a})$ $=(a^k-a^{k-1})+\frac{a^{k-1}(1-a)}{1-a}=a^k$. Namely, $\hat{x}^{(0)}(k)=x^{(0)}(k)$, $k=1,2,...,n$.

Similarly we can prove that when the initial value is $x^{(1)}(1)=x^{(0)}(1)$ or $x^{(1)}(1)=x^{(0)}(n)$, DGM model can completely fit the geometric sequence.

Theorem 3.3. (Yao and Liu, 2007) Let $X^{(0)}=\left\{x^{(0)}(1),x^{(0)}(2),...,x^{(0)}(n)\right\}$, where

$$x^{(0)}(k)=a^k,\ x^{(1)}(k)=\sum_{i=1}^{k}x^{(0)}(i),\ \hat{x}^{(1)}(1)=x^{(0)}(1)\ (\text{or}\ \hat{x}^{(1)}(1)=x^{(0)}(n)\ ).$$

Assume $\hat{x}^{(0)}(k)$ is the restored values of DGM model, then $\hat{x}^{(0)}(k)=a^k$, where $k=1,2,...,n$.

Proof. Omitted.

Corollary 3.1. For the sequence $X^{(0)}$ we have $x^{(0)}(k)=\lambda a^k$, $k=1,2,...,n$, $a\neq 1$. Assume $\hat{x}^{(0)}(k)$ is restored value by establishing ODGM model. The initial value is obtained by solving the optimization problem $\min_{\xi}\sum_{k=2}^{n}[\hat{x}^{(0)}(k)-x^{(0)}(k)]^2$, so $\hat{x}^{(0)}(k)=\lambda a^k$, where $k=1,2,...,n$.

Proof. Let $Z^{(0)}=\left\{z^{(0)}(1),z^{(0)}(2),...,z^{(0)}(n)\right\}$, $Z^{(0)}$ is a geometric sequence, namely, $z^{(0)}(k)=a^k$, from Theorem 3.3, we obtain $\hat{Z}^{(0)}=Z^{(0)}$. From $X^{(0)}=\lambda Z^{(0)}$ and Theorem 3.1 we can obtain $\hat{X}^{(0)}=X^{(0)}$, namely, $\hat{x}^{(0)}(k)=\lambda a^k$, $k=1,2,...,n$ ....

4 Conclusion

Different initial values can obtain different recurrence formula. This chapter studied several kinds of DGM model. The growth rate of simulation data is a constant for these models. Utilize optimization method to obtain the initial value and the simulation accuracy can be improved. The research results indicate ODGM model can obviously improve the simulation accuracy.

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The Excel Test Modeling via Four Data in Evaluation of Education Information

Chi Tang and Boming Yin

In this chapter, we are using 4 data of the proficiency degree of adopting the IT (Information Technology) by all the teachers in Chinese, Mathematics and English groups in 20 schools of Pudong New Area. We are using test-method modeling Verhulst Model in Excel, and making three categories on the 20 schools. At the same time, first derivation to the model in the education study, this gets the speed of adoption the IT for a school at different stages.

1 Introduction

Author statistics, that assessment in the field of primary and secondary education the use of qualitative reasoning and analytical study account for 92.6%, the use of forms and percentage etc. general Quantitative methods account for 6.3%, and the application of analysis of variance, hypothesis testing, regression analysis only account for 1.1% (Yin, 2001).

To this end, author has been trying to introduce assessment into the field of primary and secondary schools for the thinking and method of the gray system.

The proficiency degree of adoption the IT is an important component in the information level of personal attainment of the contemporary teachers, and is an important component of information level for a school.

In May 2006, Pudong New Area carried out the evaluation to the 20 experimental schools of information level. At each school, the expert group based on systems theory put through a questionnaire to obtain data in a table format using the method of modeling via four Data (Deng, 2005). Test method modeling a Verhulst Math-model for proficiency degree of adoption the six IT (Word, Excel,

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PowerPoint, Flash, FrontPage, Geometer's Sketchpad) for the teachers in Chinese, Mathematics and English group in every school (Yin, 2009).

Professor Deng Julong has discussed the power GM in Classic Gray system monograph (Deng, 2005). Professor Liu Sifeng also has discussed the power GM (Liu, 2004; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). To this end, the methods of gray system preparation used to study. In the same time, they pointed out the power GM is based on the GM(1,1) (Lin et al., 2002; Sydow et al., 2001; Lin and Liu, 2000), and the power GM turns into a grey Verhulst model when the index α equals to two (Liu, 2004).

For application of Grey Verhulst model, Wang Haoping published "Application of Grey Verhulst model to close Planting of the Blacknerrylily" (Wang, 1991). Fang Ying published "The mathematical model of incidence curve for malaria and its gray range forecast" (Deng, 1990). Ni Yan issued a "population growth projections" (Deng, 1990). Yin Boming has published papers about Verhulst Model for Beijing SARS (Yin, 2003a; 2003b).

Since 2001, in order to permeate the grey system theory and methods to Primary and secondary school teachers, Yin Boming took up with the test method modeling in Excel (Yin, 2001; Yin, 2000; Yin, 2005).

2 The Modeling via Four Data Sets in Process of the Evaluation for Information Level

A. Collection the Data for adopting the IT

At each school, We collected the data for adopt the Word, Excel, PowerPoint, Flash, FrontPage, Geometer's Sketchpad etc. six IT tools software by all the teachers in Chinese, Mathematics, and English group. According to commonly status of proficiency degree, at the different situations such as the understanding, use of start, use several times, skilled use etc., collection and aggregation the data, are shown in table I. Due to space limitations, Only one example of a school PN, which out of the aggregate data for 56 teachers×6 six IT tools = 336 person-time, so that 15/336 = 4.46%, and similar to the rest, in the table I.

Table I Collection Person-time of Adoption Six IT for Proficiency Degree

UNDER-STANDING	USE OF START	USE OF SEVERAL TIMES	SKILLED USE
15	31	92	110
4.46%	9.22%	27.38%	32.74%

B. One method of math-modeling (least squares)

When the collection of data in distribution is S-shaped curve, we may be math-modeling by both of the original sequence and IAGO (Inverse Accumulated Generating Operation) sequence (Liu, 2004; Deng, 1986; 1993). From table I, we gain the original sequence, IAGO (Inverse Accumulated Generating Operration) sequence, and data array for adopting the IT:

x 0 (n) = (15, 31, 92, 110),
x -1 (n) = (0, 16, 61, 18), yn = (16, 61, 18)T

$$B=\begin{bmatrix}-0.5(15+31) & 31^2\\ -0.5(31+92) & 92^2\\ -0.5(92+100) & 110^2\end{bmatrix}=\begin{bmatrix}-23 & 961\\ -61.5 & 8465\\ -101 & 12100\end{bmatrix}$$

$$(B^{\mathrm{T}}B)^{-1}B^{\mathrm{T}}y_n=\begin{bmatrix}14512.25 & 1764739\\ 1764739 & 218972617\end{bmatrix}^{-1}\begin{bmatrix}-39701\\ 749480\end{bmatrix}=\begin{bmatrix}-1.62\\ -0.03695\end{bmatrix}$$

Therefore, b = 0.03695,

K = – 1.62/ –0.03695 = 43.84
C = K / x0(0) –1 = 43.84/4.46 – 1 = 8.83

There is the Verhulst Model of adoption the IT of PN School in recent years:

$$v(n)=\frac{K}{1+C\mathrm{e}^{-bKn}}=\frac{43.84}{1+8.83\mathrm{e}^{-1.62n}} \tag{1}$$

Where, v is the degree of adoption (the percentage of the person-time number), e = 2.718 is the end of the natural logarithm, n = 0, 1, 2, 3 for the degree of proficiency (the same below).

Because classical least squares method attending to the starting point for time-oriented data x0(0), therefore the overall accuracy of the model might not be very high. In some cases, to give up a little accuracy of the starting point, and give attention to some of the overall data, the model can improve the accuracy of it.

C. Second way to build math-models (test method modeling via four data with the Excel)

In order to reduce the threshold of the difficulty in math-modeling, we will improve the overall accuracy of the model. In recent years, we have proposed a simple “Verhulst modeling via four Data by Excel testing” (see Fig. 1, Fig. 2).

To obtain the corresponding Verhulst Math-mode of PN School:

$$v(n)=\frac{K}{1+C\mathrm{e}^{-bKn}}=\frac{38}{1+12.39\mathrm{e}^{-1.6184n}} \tag{2}$$

Order derivative to equation (2), may be:

$$\frac{dv}{dn}=\frac{38\times12.39\times1.6184\times\mathrm{e}^{-1.6184n}}{(1+12.39\mathrm{e}^{-1.6184n})^2} \tag{3}$$

According to equation (3), we could obtain the speed of adoption the IT for PN School at different stages (order derivative, shown in Fig.1 at the end of column):

The speed of “the use several times” stage for 13.54%; the speed of “skilled use” phase for 4.94%, there has been saturation phenomenon.

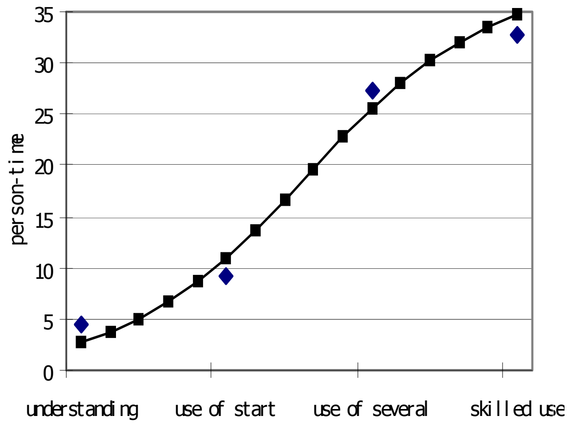

Fig. 1 The S-shaped curve have been closed to 4 original points of person-time for adopting six IT

H20 = =SUM(H9:H19)/3

	A	B	C	D	E	F	G	H	I	J
2	*n*	proficiency	person-	%	saturation	*exp(- bKn)*	index	index	percent	order
3		degree	time		*K*		*(-bKn)*	*(bK)*	of model	derivati
4	0	understanding	15	4.464	33	1.0003	0.0003		2.84	4.25
5	0.2								3.81	5.55
6	0.4								5.08	7.12
7	0.6								6.68	8.91
8	0.8								8.65	10.81
9	1	use of start	31	9.226	33	0.4033	-0.9082	0.908	11.00	12.65
10	1.2								13.68	14.17
11	1.4								16.63	15.13
12	1.6								19.69	15.35
13	1.8								22.72	14.79
14	2	use of	92	27.381	33	0.0321	-3.4384	1.719	25.56	13.54
15	2.2	several time							28.10	11.85
16	2.4								30.28	9.95
17	2.6								32.09	8.08
18	2.8								33.53	6.39
19	3	skilled use	110	32.738	33	0.0013	-6.6830	2.228	34.66	4.94
20	56(person)×6(software)=336			73.810	coefficient *C*		6.39	1.618		

Fig. 2 Verhulst modeling via four data by Excel testing For the speed of adoping the IT

D. The mathmatical basis of the test method modeling via Four data with the Excel

1) Geometric basis: On a plane, two points can decide a straight line y = ax + b. Three points (x1, y1) , ... , (x3, y3) can decide a conic curve, such as y = ax2 + bx + c.

2) Algebra basis: General, the algebraic expression of conic curve, there are three parameters, such as a, b, c. Another example, the complexity of the Verhulst Model, there are three parameters K, C, bK. All three parameters of math-models have required three connection equations to solve, and once it is clear that the three parameters, such as Verhulst etc. all the models of three parameters will be set up the finish.

3) Modeling by 4 data: The ranging of model is (-∞, +∞), If there is initial position, it is necessary to have the fourth set of data (x4, y4), that is the initial location data; the ranging of modeling by 4 data is (x4, + ∞).

3 There Are 15 Schools in the Development Period of Growth to Adopt IT

Follow the PN School modeling the speed of adoption IT, and to set up the speed of the math-models for the other 19 schools teachers to adoption IT.

E. As an example

In JC high School, average is the rate of 17% growth in the development to adopt IT, see the Fig.3. The model of skill degree of adoption IT for JC high school is that

$$v_{JC} = \frac{100}{1+60.2\mathrm{e}^{-1.2501n}}$$

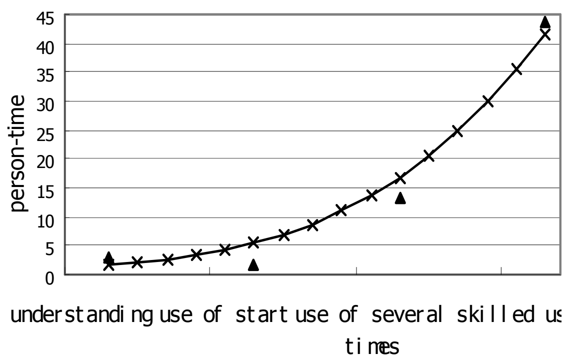

Fig. 3 JC High School to adopt IT, is the average rate of 17% growth in the development

F. There are 8 schools, which's the scatter points of "use of start", that is located far from the top of curve

When possible, the schools adopt measures include encourage, or give incentives to teachers, but also may have been combined a new school or to enter more new teachers. These schools have a considerable number of teachers in IT use at of start.

And shown in the math-model and shown on its counterparts curve: "use of start" scatter points, that are relatively located at far end from the top of curve, see the Fig.4. For example, the degree model of adoption IT for SL High School:

$$v_{SN} = \frac{100}{1+46.2\mathrm{e}^{-1.40801n}}$$

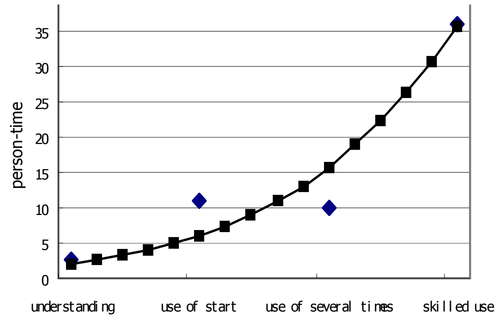

Fig. 4 In SL High School, the scatter points of "use of start" is located is far from the top of curve

G. Although there is a school in the development of growth phase, but increased less space at this stage

Know from the model, the JX Primary School K = 32:

$$v_{JX} = \frac{32}{1 + 35.73e^{-1.5n}}$$

The school is trying to increase open space, see the Fig.5.

Proposals: there are 15 schools, which adoption IT in the development period in order to maintain a good momentum of development, and in which individual schools have increased the space to try to open.

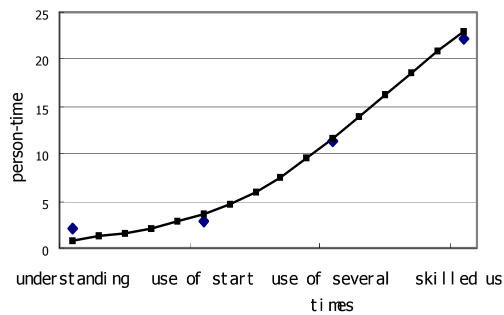

Fig. 5 The JX Primary School in the development of growth phase, but increased less space at this stage

4 There Are 4 Schools, which Development Speed in Adopting IT Appears with a Saturation Tendency

H. There are 2 Schools that have some slight tendency to saturation

There is probably not enough training, or time is limited for teachers, or school incentive is not enough. But there is a small number of schools, such as PN Primary

Schools, the degree of adoption IT have emerged with some slight tendency of saturation, see the fig.2. For these schools, the model of skill degree in adoption IT is shown in the equation (2).

I. There are 2 Schools have a more obvious tendency in saturation

There are 2 schools where their number of teachers to "use of several times" are slightly more than the quantity of "skilled use" stages, see the Fig.6. For example, the model of proficiency degree for LQ primary schools of adopting IT:

$$v_{LQ} = \frac{23}{1 + 2.833\mathrm{e}^{-1.6034n}}$$

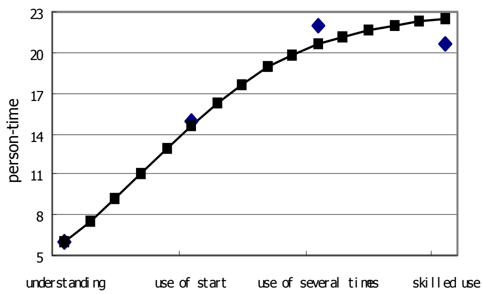

Fig. 6 The number of Teachers to "use of several times" slightly more than the quantity of "skilled use"

Proposals: The 4 schools, in which speed of development when adopting IT has emerged with some saturation tendency, so we must to try to find new incentive factor both inside and outside in order to breakthrough saturation tendency.

5 In CD School the Number of Teachers That "Use of Several Times" Are Far More Than Quantity of "Skilled Use"

In CD School, the numbers of teachers are adopting IT to "use of several times" are far more than the quantity of teachers, which "skilled use", shown in fig.7. In CD school the model of proficiency degree of adoption IT:

$$v_{CD} = \frac{70}{1+15.5\mathrm{e}^{-1.8n}} - \frac{70}{1+15.5\mathrm{e}^{-1.8(n-1)}}, n = 1,\ 2,\ 3$$

Proposals: In such school, the model of proficiency degree to adoption IT have significantly shaped single peak of a tendency, to do attribution analysis, looking for reasons to change the status.

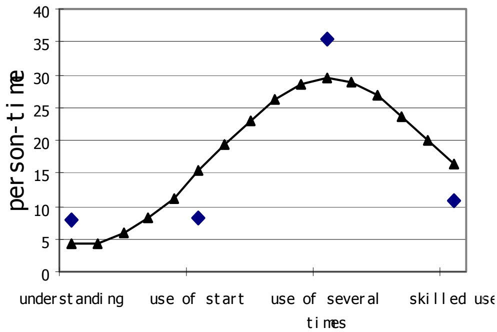

Fig. 7 The number of teachers of adoption the IT to " use of several times " is far more than the quantity of teachers, which "skilled use "

6 Sort Based on the Parameters of Verhulst Model for Each School

Based on the parameters of the degree model to adopt IT for teachers of 20 schools, we can sort descending, shown the Tab.2.

Table II The Sort Results with the Parameters of the Verhulst Model

MIDDLE	K	BK	PRIMARY	K	BK
SL	100	1.41	GL	100	1.62
JC	100	1.25	FS	100	0.95
DC	100	1.15	LS	100	0.92
YS	100	0.99	YX	100	0.8
JPS	100	0.89	JY	100	0.76
SN	100	0.8	LSE	100	0.65
JP	100	0.77	CY	100	0.42
CD	70		LX	41	1.91
			PN	38	1.62
			JX	32	1.5
			LQ	23	1.6
			JL	21	1.49

According with the first keyword to saturation value K in the degree model, with the second keyword to increase the speed value bK in the degree model, and primary and secondary schools were apart sorted. From table I, we can see that on these schools, the sort results are in accordance with the assessment indicator system, and the sort results with the parameters of the Verhulst Model have striking similarities.

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Part V
Grey Decision-Making

The Chain Structure Model of Evolutionary Game of Production-Study-Research Collaboration*

Hongzhuan Chen, Sifen Liu, and Zhenxin Jin

Some progress of economic activities can be intuitionally described and imitatively analyzed by the chain model of evolutionary game. To the evolutional law of combination of production, study and research which is based on the bounded rationality of human, the symmetric chain model of evolutionary game of combination of production, study and research and Dynamic Decision-making Equation have been established; the state of balance and equilibrium of co-evolutionary game has been discussed. Through the imitative analysis, the evolution of Chinese combination of production, study and research has been well explained and the profound conclusion of it has been drawn out, which offer reasons to Chinese managerial decision and mode selection to the combination of production, study and research.

1 Introduction

From 1992, a co-operation of a development work with the joint of industry, academia and research was organized and implemented by the former State Economic and Trade Commission. The Ministry of Education and the Chinese Academy of Sciences across the country has begun an organized, planned, systematic production

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* This work is sponsored by soft science of china funds(2008GXS5D115).

and research to promote the work of co-operation. A study of 767 companies in 10 provinces and cities including Beijing, Guangdong and Hubei and so on by Liu Yingqiu and other scholars shows that about 36% of enterprises take joint innovation with universities, research institutions or enterprises (Liu, 2008). According to statistics, in 2007, universities and enterprises in Zhejiang Province reached 8040 production and research co-operation projects, the co-operation funding reached 1.13337 billion Yuan. Now industry-university co-operation has achieved initial results with full of opportunities, but there are also a huge challenge. Industry-university cooperation involves a very wide scope, and the problems are also complex, with the biggest being pursue of "fashion". Some enterprises and scientific research institutions, co-blind half-way abandonment of production and research co-operation, scientific research and chain fracture.

As the main co-operation means of scientific research results' development and promotion, domestic and foreign scholars have begun to explore and research about co-operation model for years. There are more scholars abroad than domestic who study on research co-operation, such as David, etc. (1986) considered: the University - enterprise relation had both interest and risk to academic institutions, the university's challenge was to find ways to manage this relationship in order to retain the interest and minimize risk at the same time (David, Michael, et al., 1986); Rustum (1972) analyzed several co-operation models between University and enterprises (Ruston, 1972);

Since then, some scholars probed the research co-operation from the perspective of knowledge management, such as Elias (2000) believed that research co-operation as a cross-organizational phenomenon, and had the motivation of sharing knowledge, but trust and social capital had significant impact. Thus knowledge transactions and knowledge of a total of Frederick is the basement of trust and innovation. Domestic scholars also made research studies about it, such as: Wang Juanru(2002) etc. probed direct co-operation modes of industry, academia and research in micro-level, and classified co-operation modes into 3 categories: technical cooperation type, contract type and integration-type (Wang and Pan, 2002). Zhou Zhu (2004) considered that intellectual property rights conflict between all parties involved in research co-operation was an important factor, therefore our country should coordinate the intellectual property rights conflict through Science and Technology Council (Zhou and Huang, 2004); Ye Xiaoqing etc. (2003) researched on the base of the conditions of information asymmetry and used game models to analyze adverse selection problem of enterprises and scientific research institutions' co-operation and innovation It also established a non-symmetric information dynamic game model to discuss how the enterprise innovation and commercialization value impact the choice of innovative ways of co-operation and co-operation partners (Ye and Xu, 2003). Hu Enhua (2001) analyzed 5 questions such as technology supply, technology needs in the co-operation innovation between industry, academia and research (Hu, 2002). Zhu Guilong (2003) etc. integrated the implication of industry, academia and research cooperation, innovation and network organization, he also proposed the definition of industry, academia and research cooperation innovation network (Zhe and Peng, 2003). Luo Wei etc. (2002) analyzed the choice between co-operation way and co-operation partner in the universities and enterprises' process of co-operation and innovation (Luo and Tang, 2002).

Looking at home and abroad studies, mostly scholars abroad only studied general Business-University co-operation, few concerned with China's reality, operability being poorly (Zhang et al., 2007); and most of the domestic scholars focused their research on general co-operation and countermeasures therefore have not really studied the evolution of co-operation and innovation (Wang et al., 2005). From the point view of process game of co-operation and innovation between enterprises and research institutions, the strategy of large groups composed by similar members of slow learning repeated random matching game can be simulated by the "dynamic replication" in biological evolution of the game, such as using the strategy of "Selection strategy-Evolution-Choose a new strategy-Further evolution".

Table I Cooperation proceeds symmetric matrix

		Enterprise	
		Cooperation	Uncooperative
Partici-pation1	Cooperation A	$A(p^t), A(p^t)$	$B(p^t), C(p^t)$
	Uncooperative	$C(p^t), B(p^t)$	$D(p^t), D(p^t)$

This chapter will attempt to use the theory of evolutionary game, study the law of research co-operation and innovation under conditions of limited rationality, analyze the dynamic strategy of innovation and stability in a relatively stable environment of co-operation between enterprises and research institutions， and explain stable equilibrium problems between enterprises and scientific research institutions in the circumstances of continuously adjustment strategy.

2 Cooperative Innovation Model of Evolutionary Game

Evolutionary Game Theory to study the proposed economic and social phenomenon of the evolution and development provides an important tool. Its limited theoretical assumptions make the model better in describing the reality situation of economic man; and the chain structure model of evolutionary game dynamics described the characterization of the replication dynamics and learning mechanism (Ruan, et al., 2008). Therefore, this chapter studies combination of co-operation in China's production of innovative features, the establishment in a class of evolution with the evolutionary stage of the evolutionary game model, and discusses the evolutionary stable strategy model solution, and tries to do some research and discussion on the evolution of co-operation and innovation.

Evolutionary Game Theory was emerged during 1960s when the evolution of biological phenomena was explained. The evolutionary stable strategy (ESS) was made by Smith in 70s; it was more and more used by ecologists (Xie, 2004). In recent years, due to his great success in biology, the ESS was introduced into economics and it became a popular field of game theory in economics. The basic idea of evolutionary game is that the economy balanced thumbtack state cannot rightly know where the state of their own interests, limited the ability of economic agents (bounded rationality of economic agents)which had found the best course of action, imitated the most beneficial strategy gradually, and reached the final state. Evolutionary game theory holds that economic model was not designed, but for those new structures adapted by the environment, social changes have been found and are better preserved, that is, it is emerged in the process of so-called "adaptive evolution" as a result of the existence of "limited rationality"(Fang and Liu, 2003).

A. Model Assumptions

In order to discuss easily and maintain the practical significance of the model as far as possible, we make the assumptions as follows:(1) Studying the two research of co-operation, and assuming that the actual result of the game in each board is zero.(2)In this chapter, studying the entire period of research co-operation without distinguishing between technical trading and commercial collaboration. (3)Co-operation agencies are all from large groups of random pairing, the two sides to participate in the game are "rational" and the game they are acts of "rational behavior. Game strategy sets between the two sides are finite sets, and are common knowledge for both parties.

B. Profit and Loss of Matrix Game

Indicator responses to the evolution of the extent and the stage of development are multi-faceted, so we use a change proportion of participants as a measured parameter in this chapter. The proportion is an objective existence in the marketplace, and co-operators can only have subjective probability estimates based on their experience. Slow learning, limited low-level rational imitation participators heighten the profit through learning the game and adjust the strategy and tactics of the stability of dynamic replication.

Co-operation between the parties to co-operate in different stages have different strategies, and their income is different, if the earnings stage and evolution meet the income conditions of symmetric matrix, the matrix gains that can be used in table I, where P is the proportion of participants in time t. The profits in tables 1 and 2 are a function of co-operation, and the following table expresses that the income function contains grey parameter(s), for references on grey systems and information, please consult with (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). This evolutionary game model of the chain structure of the game can be used to describe the chain model, shown in Figure 1.

C. Cooperation and innovation chain structure of the evolutionary game

In the game process, business and science research groups in both games all has the respond to the current game situation (not necessarily best response). They either learn from each other, or choose the strategy by imitating a neighbor. Using the circle means the evolutionary game strategy1.2, and using the arrow means the game with the strategy of individuals in the transfer between the proportion $P^t_{i,12}$ (or $P^t_{i,12}$) and take the game strategy of the gains $u^t_{i,12}$ (or $u^t_{i,12}$) that the evolution of the strategy game between the situation. Supposing the science-based research side i = 1, enterprise square i = 2, then the evolutionary game chain model shown in Figure 1.

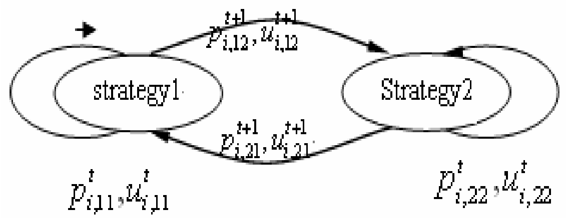

Fig. 1 Chain structure of cooperation in evolutionary game

Use the chain structure of evolutionary game to describe the whole process of evolutionary game of the equation symmetric partners (Liu and Lin, 2006), P is the certain proportion of participants in the strategy; u is the average revenue of one of the participant. Parameters superscript expresses the time, which is evolutionary stage; subscript is the changes in strategy selection.

Suppose at the time of t the proportional x-school research side choose the "co-operation" strategy and a proportion y of enterprises choose "co-operation" strategy, Then, at the t time of t co-operative learning strategies research side the ratio of expected return and learning research side groups, the average expected return, respectively, with equation (1), type (2), equation (3) to be described.

$$\begin{aligned} p^t_{1,11} &= x \\ p^t_{1,22} &= 1-x \end{aligned} \tag{1}$$

$$\begin{aligned} u^t_{1,11} &= y \cdot A(p^t) + (1-y) \cdot B(p^t) \\ u^t_{1,22} &= y \cdot C(p^t) + (1-y) \cdot D(p^t) \end{aligned} \tag{2}$$

$$\overline{u}^t_1 = x u^t_{1,11} + (1-x) u^t_{1,22} \tag{3}$$

At the t time of t enterprise learning strategies research side the ratio of expected return and learning research side groups, the average expected return, respectively, with equation (4), type (5), equation (6) to be described.

$$\begin{aligned} p^t_{2,11} &= y \\ p^t_{2,22} &= 1-y \end{aligned} \tag{4}$$

$$u_{2,11}^{t} = x \cdot A(p^{t}) + (1-x) \cdot B(p^{t})$$
$$u_{2,22}^{t} = x \cdot C(p^{t}) + (1-x) \cdot D(p^{t}) \tag{5}$$

$$\overline{u}_{2}^{t} = y u_{2,11}^{t} + (1-y) u_{2,22}^{t} \tag{6}$$

So, at the time of t+1, what kind of co-operation strategies than the limited rationality individual parties will be taken according to the situation to improve their earnings situation?

In the evolutionary game process, the dynamic change of the strategy adopted by the individual proportion is the core in the evolutionary game analysis. The key is the speed of dynamically change, the direction of velocity can be reflected by the positive and negative number, in this chapter, this dynamic pace of change that the performance of parameters in the non-arrow line from the ring.

According to the principle of biological evolution, we know that, the percentage rate of change depends on the dynamics of individual learning and imitation game speed. We assume that: at the t moment, school parties and corporate research groups in the use of a side game strategy, individual changes in the next moment t +1 using other strategies (imitation or learning strategies), the ratio value and t time game party groups and their average revenue expectations. The average income difference between the individual and the imitation or the learner is proportional to the number of individuals.

According to Figure 1, we can get t +1 moment, learning research side of the state change (to maintain the original policy or strategy, imitation and learning), such as equation (7) and (8) as shown.

$$p_{1,12}^{t+1} = p_{1,11}^{t} \frac{\overline{u}_{1}^{t} - u_{1,11}^{t}}{\overline{u}_{1}^{t} - u_{1\min}}$$
$$p_{1,11}^{t+1} = p_{1,11}^{t} + p_{1,21}^{t+1} \tag{7}$$

$$p_{1,21}^{t+1} = p_{1,22}^{t} \frac{u_{1}^{t} - u_{1,22}^{t}}{u_{1}^{t} - u_{1\min}}$$
$$p_{1,22}^{t+1} = p_{1,22}^{t} + p_{1,12}^{t+1} \tag{8}$$

Equation (7), equation (8) said: In the t time the use of a strategy for school research side, in the t +1 time to change and use other strategies, its benefits and its expected returns of imitation or learning are equal, and assumed the cost of imitation or learning is zero. $p_{1,12}^{t+1}$ is , at the time of T, using the strategy in the day-to-school research side, experienced its benefits and learn the average income gap between research groups, at the time of t+1,change other strategies, the number of parties of changes in the original strategy of academic research to use other strategies $p_{1,12}^{t+1}$ should be used with the original strategy of learning the number of research side $p_{1,11}^{t}$ and $\dfrac{\overline{u}_1^t - u_{1,11}^t}{\overline{u}_1^t - u_{1\min}}$ are proportional, which $u_{1\min} = \min\left\{A(p^t), B(p^t), 0\right\}$. We assume that the ratio of a factor is 1, so at the time of t+1, return parameters is as follows:

$$
\begin{aligned}
u_{1,11}^{t+1} &= p_{2,11}^{t+1}A(p^t) + p_{2,22}^{t+1}B(p^t) \\
u_{1,22}^{t+1} &= p_{2,11}^{t+1}C(p^t) + p_{2,22}^{t+1}D(p^t) \\
\overline{u}_1^{t+1} &= p_{1,11}^{t+1}u_{1,11}^{t+1} + p_{1,22}^{t+1}u_{1,22}^{t+1}
\end{aligned}
\tag{9}
$$

By the same token available in the t +1 moment, business operations (copy, imitate and learn from), the expression of various parameters, is type (10), (11) and (12) as shown.

$$
\begin{aligned}
p_{2,12}^{t+1} &= p_{2,11}^{t}\frac{\overline{u}_2^t - u_{2,11}^t}{\overline{u}_2^t - u_{2\min}} \\
p_{2,11}^{t+1} &= p_{2,11}^{t} + p_{2,21}^{t+1}
\end{aligned}
\tag{10}
$$

$$
\begin{aligned}
p_{2,21}^{t+1} &= p_{2,22}^{t}\frac{u_2^t - u_{2,22}^t}{u_2^t - u_{2\min}} \\
p_{2,22}^{t+1} &= p_{2,22}^{t} + p_{2,12}^{t+1}
\end{aligned}
\tag{11}
$$

$$
\begin{aligned}
u_{2,11}^{t+1} &= p_{1,11}^{t+1}A(p^t) + p_{1,22}^{t+1}B(p^t) \\
u_{2,22}^{t+1} &= p_{1,11}^{t+1}C(p^t) + p_{1,22}^{t+1}D(p^t) \\
\overline{u}_2^{t+1} &= p_{2,11}^{t+1}u_{2,11}^{t+1} + p_{2,22}^{t+1}u_{2,22}^{t+1}
\end{aligned}
\tag{12}
$$

And so on, in the next moment T +2, game two sides will make evolutionary game decision-making, accordance with its situation in the t +1 moment , so co-operation between the two sides continuously adjust their strategies, until the pursuit of personal interests and the interests of both sides reaches the maximize value and thus achieves the steady state.

3 Copy of Game Dynamics and Evolution of Production and Research Cooperation

In the production and research co-operation game, Only when a strategy is the evolutionary advantage of strategy, Individuals using this strategy will maintain the policy unchanged, the individual using other strategies will study and imitation of the dominant strategy; Then in the future the individual number (or proportion) using the dominant strategy is increasing. The number of individuals (ratio which using the non-dominant strategy is reducing; In the meantime, with the number of individual which using dominant strategy increasing, the advantages of the strategy are constantly disappearing. In other words, If in a certain evolutionary game there is no dominant strategy game Fong, then the individual would not exist imitation and learning; At this point, the game of all individuals Fang maintain its original strategy, in a by the evolutionary stable strategy ESS (Evolutionary Stable Sets) determined by the equilibrium (stable) state.

First of all ,analytics research side of game, as time goes on, learning research side choose a strategy remain unchanged, to achieve balance, making $p_{1,12}^{t+1} = 0$,then obtain the equilibrium (stable) points, such as the type (13).

$$p_{1,12}^{t+1} = p_{1,11}^{t} \frac{\overline{u}_1^t - u_{1,11}^t}{\overline{u}_1^t - u_{1\min}} = x \frac{(x-1)(u_{1,11}^t - u_{1,22}^t)}{\overline{u}_1^t - u_{1\min}} = 0, \qquad (13)$$
$$x_1 = 0, x_2 = 1, u_{1,11}^t = u_{1,22}^t$$

Similarly consider the business side of game, so that $p_{2,21}^{t+1} = 0$ may be appropriately balanced (stable) points, such as the type (14).

$$p_{2,21}^{t+1} = p_{2,22}^{t} \frac{u_2^t - u_{2,22}^t}{u_2^t - u_{2\min}} = (1-y) \frac{(y\ u_{2,11}^t - u_{2,22}^t)}{u_2^t - u_{2\min}} \qquad (14)$$
$$y_1 = 0, y_2 = 1, u_{2,11}^t = u_{2,22}^t$$

As the $p_{1,12}^{t+1}$ and $p_{2,21}^{t+1}$ is equivalent to the rate of increase the number of individuals $\frac{dx}{dt}$ and $\frac{dy}{dt}$ of Game Party and businesses which have adopted a certain strategy, Thus, equation (13) and equation (14) determines the evolutionary game of all possible equilibrium points, which, $u_{1,11}^t$, $u_{1,22}^t$, $u_{2,11}^t$ and $u_{2,22}^t$ is the function of $A(p^t), B(p^t), C(p^t), D(p^t)$ function of income. The equilibrium of the study -research side and business side is devised by its revenue function

4 Simulation

As of 2009, the Nanjing government or enterprises and 100 colleges and universities have signed co-operative agreements or build a co-production and research base, such as scientific research base in Nanjing in 2008 was named national technology transfer agencies, a number of successful transformations of research results. Nanjing University of Technology and Nanjing National research new models of production and build a production and research base. Nanjing University of Aeronautics and Astronautics and Wuxi, Suzhou Government signed a production and research co-operation agreement. According to statistics reported in 2008, Nanjing has more than 200 items of production and research successful docking, due to the increase in production and research has reached about 28 billion gross domestic product. And due to the partners or technical problems, it also has the typical 8 production and research co-operation fails, in co-operation drop out, or technology transfer unsuccessfully.

According to evolutionary game chain model of the formula (1) - formula (12) the recursive formula for the equilibrium point, accordance with the general rules when research questions, assume that S is a co-evolutionary stage in a linear function of time t, using Matlab simulation program, simulation and analysis of practical issues of production and research co-operation in Nanjing in 2008, the simulation results shown in Table 2.

From Table 2 and Figure 1, we can see that when the evolution of iterations to 400 times when P_{11}^t close to 1, P_{22}^t close to 0, that is, in the early stages of production and

Table 2 Simulation results of the evolution of production and research co-operation

Evolution algebra	P_{11}^t (The proportion of co-evolution)	P_{22}^t (The proportion of non-cooperation)
0	0.01	0.99
20	0.01157	0.9884297
40	0.013844	0.9861553
60	0.0174034	0.9828058
80	0.022583	0.97741606
100	0.0325438	0.9674561
120	0.0561061	0.9438939
140	0.1495061	0.8504938
160	0.629537	0.37046246
180	0.850888	0.1491120
200	0.895678	0.104322
220	0.9112192	0.08878076
240	0.9180374	0.08196258
260	0.9213592	0.07864082
280	0.92306234	0.076937
300	0.9239598	0.07604
320	0.9244387	0.0755613
340	0.92469637	0.0753036
360	0.9248355	0.07516448
380	0.92491	0.07509
400	0.92491	0.07509

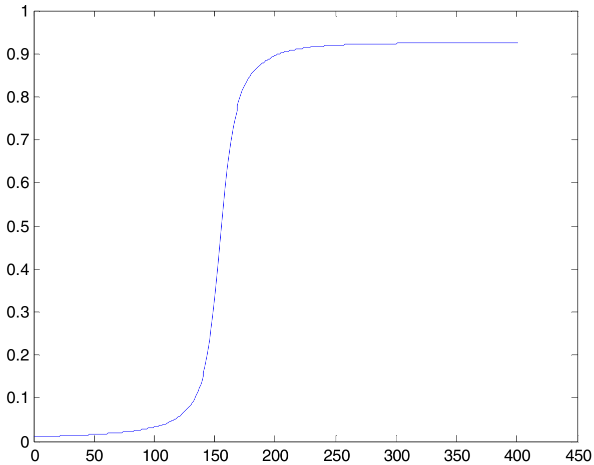

Fig. 2 Simulation results of production and research co-operative game

research, co-operation game is not strong sense of co-operation, select the co-ratio than is low; With the advance of production and research co-operation, cooperation, both sides realize that cooperation between the two contributions, gradually tend to be happy to co-operation, choose the sharp increase in the proportion of co-operation strategy; further co-operation over a period of time game, choose the cooperative strategy, the proportion becoming more and more stable until it reaches a steady state, that is, both partners tend to co-operation strategy. Of course, in the course of game, not everyone can be successful in co-operation, but after a long game, will increase the proportion of successful cooperation.

5 Conclusion

Combined with the co-operation problems of real life, the chapter analyses the laws of co-operation evolution of co-operation partners by using evolutionary game model. It constructs grey evolutionary game chain structure model under established cooperative income over time based on the logistic model, then reveals the laws of "Industry-University-Institute" Cooperation evolution.

(1) The chapter discusses the solution and balance of grey evolutionary game model under the conditions that the co-operation incomes are symmetrical and linear, and provides a better explanation of the process of co-operation of collaborators to adjust the cooperative measures, achieve co-operation balance to maximize the interests of both based on the partners' advantages and disadvantages.

(2) Industry, University, Institute are different interest main bodies in co-operation evolution where exist contradictions, conflicts and interests convergence. In order to have a successful completion of co-operation and innovation, we must establish a set of norms in co-operation mechanism, so that both sides of the

game reach a consensus on the basis of maximize the benefit in the pursuit of individual interests and achieve a mutual benefit and win-win situation.

(3)The establishment and maintenance of "Industry-University-Institute" Co-operation faces a "Prisoner's Dilemma" problem, no matter what the probability of the strategic choice is, the enterprises will choose some strategy to maximize long-term interests, and achieve a balance ultimately.

(4) The evolution and stability of production and research co-operation and evolutionary stages by strong revenue function related to the decision, production and research cooperation in technology research and development phase and commercialization stage, revenue function is different from its stability are also different, such as the revenue function from the symmetric to the non-symmetric, linear function to the sub-function, non-linear function and so on. These questions await further research.

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Development and Application of Computer Decision-Making System for Crop Grey Breeding (CDSCGB)*

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In this chapter, we introduce the theory basis of Computer Decision-making System for Crop Grey Breeding, development environment and procedure, main models and its functions and demonstrate its application living example. Based on this, we discuss the merits and demerits of the system and its wide application prospects.

1 Introduction

With the development of computer techniques, the development and research of crop breeding expert system have begun since the eighties of the 20th century. F. J .Muehlbauer et al. (1981) made the first computer simulation for the single seed descent and mass selection method: Mokinion. J .M (1985) took the breeding expert system as the potential domain of development of agricultural expert system; Chinese Academy of Agricultural Sciences (1990) developed breeding expert system for winter wheat and breeding expert system for corn hybrid respectively on the basis of the breeding experiences of Academician Zhuang Qiaosheng, a well-known expert in wheat genetic breeding, and Academician Li Jingxiong, a

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* Manuscript received on March 3, 2009. This work was supported in part by Nation Ministy of Science and Technology.

well-known expert in corn genetic breeding (Zhao et al., 1994; Cheng et al., 1996). Sun Qixing and Zhang Aiming et al. (1991) established the computer evaluation system for wheat parent selective breeding according to the system method of wheat yield breeding, the least two multiplication method of parent selective breeding, the method of combination expression index, and the method of forecasting strong superiority combination (Zhang, 1994). Liaoning Academy of Agricultural Sciences (1993) developed the breeding expert system for rice in accordance with the breeding of northern rice improved variety (Yue et al., 1993). The expert systems above-mentioned advance the crop breeding works to a certain degree, but they have limitations: either confine to a certain breeding link lacking integration, or do not have extensive adaptability owing to learning from the experiences of breeding expert to a certain specific stage. Thus, Ma Hongweng et al. (2002) and Guo Ruilin et al. (2003) developed the crop grey breeding computer decision-making system based on the Visual Basic 6.0 and PowerBuilder 6.0 separately taking the book Crop Grey Breeding Science as the original version (Guo, 1995; Ma et al., 2002; Guo et al., 2003).The two systems make up some deficiencies of expert systems above-mentioned, but their applications are limited because the former without succession, doesn't support multithread technique, and doesn't run cutting across the platform; the latter is incompatible with Windows XP and Vista. For this reason, we carried out the development of crop grey breeding computer decision-making system based on the Java technique in 2007, made considerable headway, and provided a convenient, swift and effective means for the breeding workers (Guo and Wang, 2008).

2 Theory Basis of Computer Decision-Making System for Crop Grey Breeding (CDSCGB)

Computer decision-making system for crop grey breeding (CDSCGB) is set up on the basis of crop grey breeding science which is a new interdisciplinary subject combing the theory of grey system with the theory of crop breeding. The birth of it indicated a revolutionary leap from traditional crop breeding to modernized, informational and quantitative breeding, thus making the crop breeding level climb to a quantitative stage from a qualitative one, and developing the crop breeding subject into a precise one from a qualitative and descriptive one. Adopting the theory and method during the course of the crop breeding, breeding workers can not only consider multi-factors comprehensively and supply exact effective decision-making methods for modern crop breeding, but also realize highly intelligence for crop breeding. Even breeding newcomers can also come up to the decision-making standards of a breeding expert. Consequently, developing the computer decision-making system for crop grey breeding (CDSCGB) based on the theory of crop grey breeding science is of momentous significance to promote the crop breeding.

3 Development Circumstances of Computer Decision-Making System for Crop Grey Breeding (CDSCGB) and Its Procedure

A. Development circumstances

Computer decision-making system for crop grey breeding (CDSCGB) adopts the MVC model, using the Java2 developed by Sun Corporation in America as technique support, using JBuilder 2006 as integrated development circumstances, and using Microsoft Access 2000 as background data base. JBuilder 2006 is a strong enterprise development platform of Java which can develop various application programs under the frame of J2EE, integrating all Java techniques and containing every process of soft life cycle. It can not only stride across platform, accomplish writing program once, running anywhere, and fit in with various computer operation system, but also program facing the object. Design of soft structure in JBuilder 2006 is distinct and obvious, strengthening its extension and duplication. It also provides 4 unitary interfaces which can make the system connect all current management systems of data base such as Oracle, Sybase, Microsoft SQL Server, IBM DB2, Informix, Access, Foxpro, Paradox and so on. It is special commendable that the soft is apt to bring about network. Thus it can be seen that the development circumstances of computer decision-making system for crop grey breeding (CDSCGB) is very advantageous.

B. Development procedure

The second innovation and development of computer decision-making system for crop grey breeding (CDSCGB) has been made based on the book Crop Grey Breeding Science combined with Guo Ruilin's study fruits in recent years. Its development procedures are as follows: system analysis of crop grey breeding →system design of crop grey breeding →set up application objects of crop grey breeding →generate user object, function and structure of crop grey breeding →establish windows and menu of crop grey breeding →create data window object of crop grey breeding →compile events of crop grey breeding →debugging and application →test system →product executable file.

4 Main Modules of Computer Decision-Making System for Crop Grey Breeding (CDSCGB) and Their Functions

A series of activities of crop breeding are a great deal of decision-making processes in essence. Multiple modules will be used during those processes which constitute core contents of computer decision-making system for crop grey breeding (CDSCGB).

C. Module and function of grey incidence analysis of breeding targets

Adopting the principle and method of grey relational analysis, the module is used to analyze influence of main characters on the yield and quality, to distinguish main characters and secondary ones, to make the relation among characters clear, and to provide scientific basis for ascertaining objective and reasonable breeding targets.

D. Module and function of parent grey classification

Adopting the principle and method of parent grey classification, the module is used to determine the genetic differences quantitatively, to classify parents from essence attribute by this relation, and to guide the formulating of cross combinations.

E. Module and function of grey evaluation of cross combinations

Using the principle and method of grey evaluation of cross combination, the module is used to evaluate F1 combinations comprehensively, thus determining key combinations.

F. Module and function of single-plant grey selection

Using the principle and method of single-plant grey selection, the module is used to select single-plant in segregation generations, thus deciding which to use.

G. Module and function of grey multi-target comprehensive evaluation of variety

Using the principle and method of grey multi-target comprehensive evaluation of variety, the module is used to evaluate varieties in regional variety test, thus providing scientific basis for examining and popularizing of variety.

H. Module and function of grey distribution of variety

Using the principle and method of grey distribution of variety, the module is used to analyze results in joint regional variety test and to propose appropriate varieties in various ecological areas.

I. Module and function of grey similarity cultivation of variety

Using the principle and method of grey similarity cultivation of variety, the module is used to determine similarity variety by the grey similarity degree between the new variety and the popularizing variety, thus realizing complete sets of good variety and good cultivation measures.

J. Module and function of grey forecasting of crop diseases and insect pests

Using the principle and method of grey forecasting of crop diseases and insect pests, the module is used to forecast crop diseases and insect pests, thus supplying prevention tactics to agricultural production.

5 Application Example of Computer Decision-Making System for Crop Grey Breeding (CDSCGB)

Let us illustrate application of computer decision-making system for crop grey breeding (CDSCGB) in crop breeding with example of wheat F_2 single-plant selection in Anyang Institute of Technology in 2008.

First, double click the icon of computer decision-making system for crop grey breeding (CDSCGB) with mouse in windows VDU, enter the system, and click the data base attachment in the menu of database management. Then, click the menu of Single-plant Selection, select the table F208, click the Determination button, and the interface Selecting Grey Characters Please appears (Figure 1).

Fig. 1 Interface Selecting Grey Characters Please

Choose characters to be evaluated, click the button Operation and Next respectively, and get into the interface Please Input Parameter of Grey Selection Degree 1(Figure 2).

Input the values of characters and submit them, click the button Next, and the interface Whited Function of Grey Selection Degree 1 for Characters appears (Figure 3).

Click the button Next, enter the interface Please Select Way Of Determining Weighted Value Of Characters (Figure 4), choose one way arbitrarily among Expert Determination, Grey Degree Computing Determination, Deviation Computing Determination, Information Entropy Computing Determination and Judgment Matrix Determination according to concrete conditions, and select the way Judgment Matrix Determination in the example. After inputting corresponding values, click the button Accomplishing Determination of Weighted Value and Next separately.

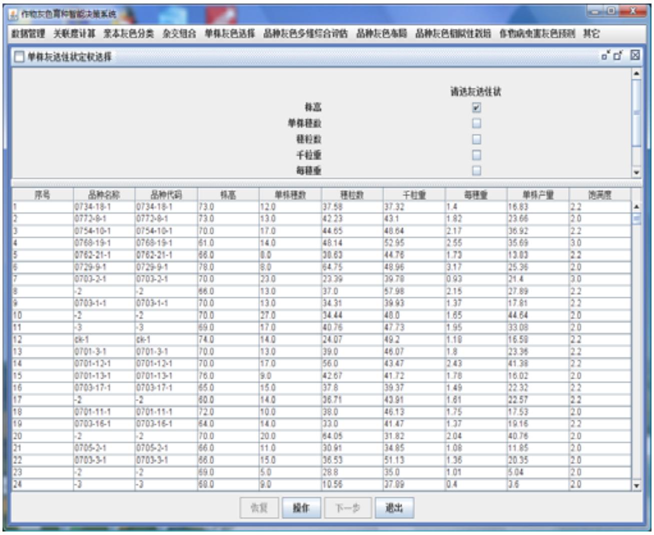

Fig. 2 Interface Please Input Parameter of Grey Selection Degree 1

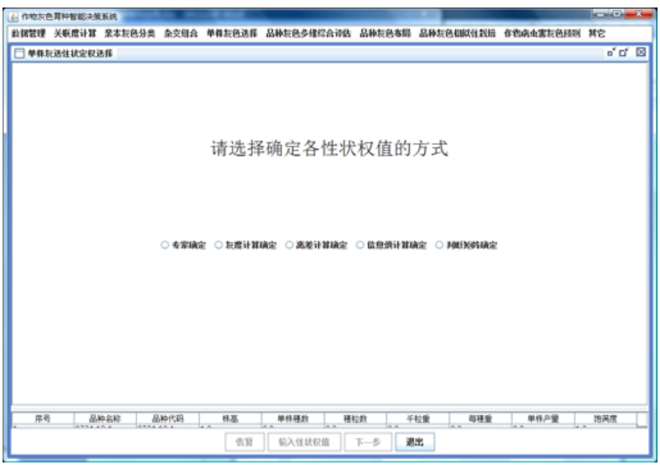

Fig. 3 Interface Whited Function of Grey Selection Degree 1 for Characters

The interface Please Input Parameter Of Grey Selection Degree 2 and Please Input Parameter Of Grey Selection Degree 3 emerges separately. Input corresponding values respectively and submit them. Then click the button Demonstration Of Coefficient Matrix, and, attain the results of single-plant degree evaluation as shown in Figure 5.

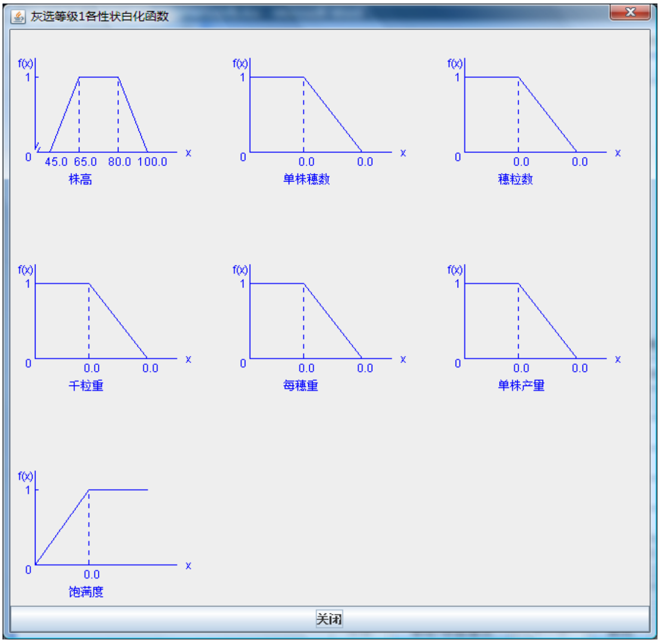

Fig. 4 Interface Please Select Way Of Determining Weighted Value Of Characters

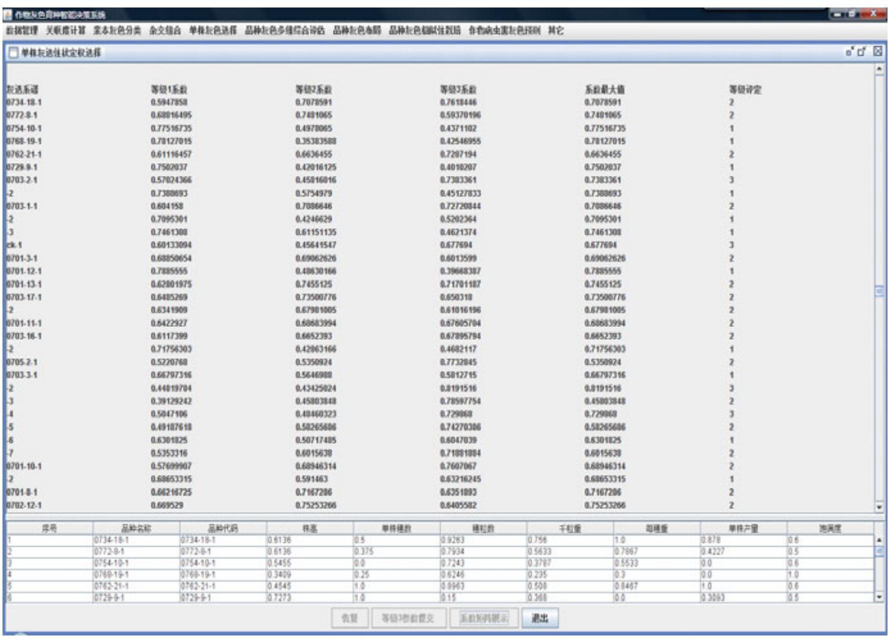

Fig. 5 Selection results of single-plant of F_2 in 2008

The results show that 635 single-plants are first degree single-plant, 1204 single-plants are second degree single-plant, and 192 single-plants are third degree single-plant. Among them, the growing scale of the first degree single-plant should be extended adequately according to concrete conditions next year, and be observed and selected as key plant lines; the second degree single-plant should be retained to grow, and be selected continuously; the third degree single-plant should be eliminated. The whole process above takes only 5 minutes, 100 times faster than the usual time required in accordance with the experiences of breeding expert, so a lot of time are spared, the work efficiency of breeding researchers and breeding selection effects are raised greatly.

6 Conclusion

For a long time, the selection of crop new variety has been at a qualitative experience stage. This is why only few breeding experts with rich experiences can achieve success. Undoubtedly, the breeding experiences include breeding art and skill which are not only the fruit of painstaking labor and wisdom of breeding expert's whole lifetime, but also valuable spiritual wealth of crop breeding area. However, only a few breeding experts have these experiences, others do not have. Let alone the breeding experiences which are only effective for a given period of time. For example, it is very difficult to apply the experiences of high yield breeding in guiding the high quality breeding. This status increases the mystery of breeding experiences, and becomes one of the difficult problems puzzled the breeding workers. The development of computer decision-making system for crop grey breeding (CDSCGB) based on the Java technique brings about hopes for getting rid of the difficult problem. Leaping from the traditional experience breeding to quantitative breeding has been realized because of introducing the grey math, even the breeding newcomer can also attain the level of breeding expert by the system, and the work efficiency can be increased extremely. This is the first significant feature of computer decision-making system for crop grey breeding (CDSCGB).

The second feature of computer decision-making system for crop grey breeding (CDSCGB) is that it can run on different platforms. As mentioned above, the system writes programs facing up to the object by using the Java technique in the development circumstances of JBuilder 2006, which can be transplanted conveniently, and can obtain writing once, running anywhere.

The third feature of computer decision-making system for crop grey breeding (CDSCGB) is that it has a complete range of functions and amiable interface, and can be learned and used easily. The system can realize all decision-making functions of various links during the process of crop breeding.

The fourth feature of computer decision-making system for crop grey breeding (CDSCGB) is that it has excellent robustness and security. As a kind of net language, the system can provide enough safeguard, and protect it from virus.

The fifth feature of computer decision-making system for crop grey breeding (CDSCGB) is that it supports multithread technique.

The features mentioned above promise that computer decision-making system for crop grey breeding (CDSCGB) has a wide application prospect. We believe that computer decision-making system for crop grey breeding (CDSCGB) will be an effective implement for breeding workers with the lapse of time. Certainly, there are some weaknesses in the system. For example, the establishment of tables, inputting and modifying of data and so on are not as convenient as Excel, which will be settled by further study and improvement.

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Positive Fractional Linear Systems

Tadeusz Kaczorek

1 Introduction

The main purpose of this chapter is to give an overview of some recent results on positive fractional continuous-time and discrete-time linear systems.

The set of real $n \times m$ matrices with nonnegative entries is denoted by $\Re_+^{n\times m}$ and $\Re_+^n := \Re_+^{n\times 1}$. A matrix $A = [a_{ij}] \in \Re_+^{n\times n}$ (a vector $x \in \Re_+^n$) is called strictly positive and denoted by $A > 0$ ($x > 0$) if $a_{ij} > 0$ for $i, j = 1, 2, ..., n.$ A matrix $A = [a_{ij}] = \Re^{n\times n}$ is called the Metzler matrix if its off-diagonal entries are nonnegative ($a_{ij} \geq 0,\ i \neq j$).The set of nonnegative integers is denoted by Z_+.

2 Positive Fractional Continuous-Time Linear System

The following Caputo definition of the fractional derivative will be used (Kaczorek, 2008a)

$$D^\alpha f(t) = \frac{d^\alpha}{dt^\alpha} f(t) = \frac{1}{\Gamma(k-\alpha)} \int_0^t \frac{f^{(k)}(\tau)}{(t-\tau)^{\alpha+1-k}} d\tau, \quad k-1 < \alpha \leq k \in N = \{1, 2, ...\} \tag{2.1}$$

where $\alpha \in \Re$ is the order of fractional derivative and $f^{(n)}(\tau) = \dfrac{d^k f(\tau)}{d\tau^k}$.

Consider the continuous-time fractional linear system described by the state equations

$$\frac{d^\alpha}{dt^\alpha} x(t) = Ax(t) + Bu(t), \quad 0 < \alpha \leq 1 \tag{2.2a}$$

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$$y(t) = Cx(t) + Du(t) \tag{2.2b}$$

where $x(t) \in \Re^n$, $u(t) \in \Re^m$, $y(t) \in \Re^p$ are the state, input and output vectors and $A \in \Re^{n \times n}$, $B \in \Re^{n \times m}$, $C \in \Re^{p \times n}$, $D \in \Re^{p \times m}$.

Theorem 2.1. The solution of equation (2.2a) is given by

$$x(t) = \Phi_0(t)x_0 + \int_0^t \Phi(t-\tau)Bu(\tau)d\tau, \quad x(0) = x_0 \tag{2.3}$$

where

$$\Phi_0(t) = E_\alpha(At^\alpha) = \sum_{k=0}^{\infty} \frac{A^k t^{k\alpha}}{\Gamma(k\alpha+1)} \tag{2.4}$$

$$\Phi(t) = \sum_{k=0}^{\infty} \frac{A^k t^{(k+1)\alpha-1}}{\Gamma[(k+1)\alpha]} \tag{2.5}$$

and $E_\alpha(At^\alpha)$ is the Mittag-Leffler matrix function, $\Gamma(x) = \int_0^\infty e^{-t} t^{x-1} dt$ is the gamma function.

Definition 2.1. The system (2.2) is called the internally positive fractional system if and only if $x(t) \in \Re_+^n$ and $y(t) \in \Re_+^p$ for $t \geq 0$ for any initial conditions $x_0 \in \Re_+^n$ and all inputs $u(t) \in \Re_+^m$, $t \geq 0$.

Theorem 2.2. The continuous-time fractional system (2.2) is internally positive if and only if the matrix A is a Metzler matrix and

$$A \in M_n, \quad B \in \Re_+^{n \times n}, \quad C \in \Re_+^{p \times n}, \quad D \in \Re_+^{p \times m} \tag{2.6}$$

where M_n is the set of the Metzler matrices.

These consideration can be extended for the cone fractional linear systems (Kaczorek, 2006; Kaczorek, 2007a).

Definition 2.2. The state $x_f \in R_+^n$ of the fractional system (2.2) is called reachable in time t_f if there exist an input $u(t) \in \Re_+^m$, $t \in [0, t_f]$ which steers the state of system (2.2) from zero initial state $x_0 = 0$ to the state x_f. If every state $x_f \in R_+^n$ is reachable in time t_f the system is called reachable in time t_f. If for every state $x_f \in R_+^n$ there exist a time t_f such that the state is reachable in time t_f then the system (2.2) is called reachable.

A real square matrix is called monomial if and only if each its row and column contains only one positive entry and the remaining entries are zero.

Theorem 2.3. (Kaczorek, 2009a) The continuous-time fractional system (2.2) is reachable in time t_f if the matrix

$$R(t_f) = \int_0^{t_f} \Phi(\tau) B B^T \Phi^T(\tau) d\tau \tag{2.7}$$

is a monomial matrix.

The input which steers the state of the system (2) from $x_0 = 0$ to x_f is given by the formula

$$u(t) = B^T \Phi^T(t_f - t) R^{-1}(t_f) x_f \tag{2.8}$$

where T denotes the transpose.

Definition 2.3. A state $x_f \in \mathcal{P}$ of the cone fractional system (2.2) is called reachable in time t_f if there exists an input $u(t) \in \Re_+^m$, $t \in [0, t_f]$ which steers the state of the system from zero initial state $x_0 = 0$ to the desired state x_f, i.e. $x(t_f) = x_f$. If every state $x_f \in \mathcal{P}$ is reachable in time t_f then the cone fractional system is called reachable in time t_f. If for every state $x_f \in \mathcal{P}$ there exists a time t_f then the cone fractional system is called reachable.

Theorem 2.4. (Kaczorek, 2009a) The cone fractional system (2.2) is reachable in time t_f if and only if the matrix

$$\bar{R}(t_f) = P \int_0^{t_f} \Phi(\tau) B Q^{-1} Q^{-T} B^T \Phi^T(\tau) d\tau P^T \quad (Q^{-T} = (Q^{-1})^T) \tag{2.9}$$

is a monomial matrix.

3 Positive Continuous-Time Systems with Delays

Consider the continuous-time linear system with q delays in state

$$\dot{x}(t) = A_0 x(t) + \sum_{k=1}^{q} A_k x(t - d_k) + Bu(t) \tag{3.1a}$$

$$y(t) = Cx(t) + Du(t) \tag{3.1b}$$

where $x(t)\in\Re^n$, $u(t)\in\Re^m$, $y(t)\in\Re^p$ are the state, input and output vectors, A_k, $k=0,1,...,q$; B, C, D are real matrices of appropriate dimensions and d_k, $k=1,2,...,q$ are delays $(d_k\geq 0)$.

The initial conditions for (1a) has the form

$$x(t)=x_0(t) \text{ for } t\in[-d,0], \quad d=\max_k d_k \tag{3.2}$$

where $x_0(t)$ is a given vector function.

Definition 3.1. The system (3.1) is called (internally) positive if and only if $x(t)\in\Re_+^n$, $y\in\Re_+^n$ for any $x_0(t)\in\Re_+^n$ and for all inputs $u(t)\in\Re_+^m$, $t\geq 0$.

Theorem 3.1. (Kaczorek, 2009b) The system (3.1) is (internally) positive if and only if

$$A_0\in M_n, \quad A_k\in\Re_+^{n\times n},\ k=1,...,q, \quad B\in\Re_+^{n\times m}, \quad C\in\Re_+^{p\times n}, \quad D\in\Re_+^{p\times m} \tag{3.3}$$

The positive system (3.1) is called asymptotically stable if and only if the solution of (3.1a) for $u(t)=0\in\Re_+^m$ satisfies the condition $\lim_{t\to\infty}x(t)=0$ for $x_0(t)\in\Re_+^n$, $t\in[-d,0]$.

Theorem 3.3. (Kaczorek, 2009b) The positive system (3.1) is asymptotically stable if and only if there exists a strictly positive vector $\lambda\in\Re_+^n$ satisfying the equality

$$A\lambda<0, \quad A=\sum_{k=0}^{q}A_k \tag{3.4}$$

Theorem 3.4. (Kaczorek, 2009b) The positive system with delays (3.1) is asymptotically stable if and only if the positive system without delays

$$\dot{x}=Ax, \quad A=\sum_{k=0}^{q}A_k\in M_n \tag{3.5}$$

is asymptotically stable.

From Theorem 3.4 it follows that the checking of the asymptotic stability of positive systems with delays (3.1) can be reduced to checking the asymptotic stability of corresponding positive systems without delays (3.10). To check the asymptotic stability of positive system (3.1) the following theorem can be used.

Theorem 3.5. The positive system with delays (3.1) is asymptotically stable if and only if one of the following equivalent conditions holds:

1) Eigenvalues $s_1, s_2, ..., s_n$ of the matrix A have negative real parts, $\operatorname{Re} s_k < 0, k = 1, ..., n$
2) All coefficients of the characteristic polynomial of the matrix A are positive
3) All leading principal minors of the matrix

$$-A = \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \dots & \vdots \\ a_{n1} & \dots & a_{nn} \end{bmatrix}$$

are positive.

Theorem 3.6. (Kaczorek, 2009b)**.** The positive system with delays (3.1) is unstable for any matrices A_k, $k = 1, ..., q$ if the positive system $\dot{x} = A_0 x$ is unstable.

These considerations can be extended to positive fractional continuous-time systems with delays.

4 Positive Fractional Discrete-Time Systems

In this chapter the following definition of the fractional difference (Kaczorek, 2008b)

$$\Delta^\alpha x_k = \sum_{j=0}^{k} (-1)^j \binom{\alpha}{j} x_{k-j}, \quad 0 < \alpha < 1 \tag{4.1}$$

will be used, where $\alpha \in \Re$ is the order of the fractional difference, and

$$\binom{\alpha}{j} = \begin{cases} 1 & \text{for } j = 0 \\ \dfrac{\alpha(\alpha-1)\cdots(\alpha-j+1)}{j!} & \text{for } j = 1, 2, ... \end{cases} \tag{4.2}$$

Consider the fractional discrete linear system, described by the state-space equations

$$\Delta^\alpha x_{k+1} = Ax_k + Bu_k, \quad u \in Z_+ \tag{4.3a}$$

$$y_k = Cx_k + Du_k \tag{4.3b}$$

where $x_k \in \Re^n$, $u_k \in \Re^m$, $y_k \in \Re^p$ are the state, input and output vectors and $A \in \Re^{n \times n}$, $B \in \Re^{n \times m}$, $C \in \Re^{p \times n}$, $D \in \Re^{p \times m}$.

Using the definition (4.1) we may write the equations (4.3) in the form

$$x_{k+1} + \sum_{j=1}^{k+1} (-1)^j \binom{\alpha}{j} x_{k-j+1} = Ax_k + Bu_k, \ k \in Z_+ \tag{4.4a}$$

$$y_k = Cx_k + Du_k \tag{4.4b}$$

Definition 4.1. The system (4.4) is called the (internally) positive fractional system if and only if $x_k \in \Re_+^n$ and $y_k \in \Re_+^p$, $k \in Z_+$ for any initial conditions $x_0 \in \Re_+^n$ and all input sequences $u_k \in \Re_+^m$, $k \in Z_+$.

Theorem 4.1. (Kaczorek, 2008b) The solution of equation (4.4a) is given by

$$x_k = \Phi_k x_0 + \sum_{i=0}^{k-1} \Phi_{k-i-1} Bu_i \tag{4.5}$$

where Φ_k is determined by the equation

$$\Phi_{k+1} = (A + I_n\alpha)\Phi_k + \sum_{i=2}^{k+1} (-1)^{i+1} \binom{\alpha}{i} \Phi_{k-i+1}, \quad \Phi_0 = I_n. \tag{4.6}$$

Theorem 4.2. (Kaczorek, 2008b) Let $0 < \alpha < 1$. Then the fractional system (4.4) is positive if and only if

$$A + I_n\alpha \in \Re_+^{n\times n}, \ B \in \Re_+^{n\times m}, \ C \in \Re_+^{p\times n}, \ D \in \Re_+^{p\times m} \tag{4.7}$$

From (4.2) it follows that the coefficients

$$c_j = c_j(\alpha) = (-1)^j \binom{\alpha}{j+1}, \quad j = 1, 2, ... \tag{4.8}$$

strongly decrease for increasing j and they are positive for $0 < \alpha < 1$. In practical problems it is assumed that j is bounded by some natural number h. In this case the equation (5.4a) takes the form

$$x_{k+1} = A_\alpha x_k + \sum_{j=1}^{h} c_j x_{k-j} + Bu_k, \quad k \in Z_+ \tag{4.9}$$

where $A_\alpha = A + I_n\alpha$.

Definition 4.2. The positive fractional system (4.4) is called practically stable if and only if the system (49), (4.4b) is asymptotically stable.

Defining the new state vector

$$\tilde{x}_k = \begin{bmatrix} x_k \\ x_{k-1} \\ \vdots \\ x_{k-h} \end{bmatrix} \tag{4.10}$$

we may write the equations (4.9) and (4.4b) in the form

$$\tilde{x}_{k+1} = \tilde{A}\tilde{x}_k + \tilde{B}u_k, \quad k \in Z_+ \tag{4.11a}$$

$$y_k = \tilde{C}x_k + \tilde{D}u_k \tag{4.11b}$$

where

$$\tilde{A} = \begin{bmatrix} A_\alpha & c_1 I_n & c_2 I_n & \dots & c_{h-1} I_n & c_h I_n \\ I_n & 0 & 0 & \dots & 0 & 0 \\ 0 & I_n & 0 & \dots & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & \dots & I_n & 0 \end{bmatrix} \in \Re_+^{\tilde{n}\times\tilde{n}}, \quad \tilde{B} = \begin{bmatrix} B \\ 0 \\ \vdots \\ 0 \end{bmatrix} \in \Re_+^{\tilde{n}\times m} \tag{4.11c}$$

$$\tilde{C} = \begin{bmatrix} C & 0 & \dots & 0 \end{bmatrix} \in \Re_+^{p\times\tilde{n}}, \quad \tilde{D} = D = \in \Re_+^{p\times m}, \quad \tilde{n} = (1+h)n$$

To test the practical stability of the positive fractional system (4.4) the well-known conditions for positive systems can be applied to the system (4.11).

Theorem 4.3. (Kaczorek, 2007b) The positive fractional system (4.4) is practically stable if and only if one of the following condition is satisfied

1) Eigenvalues $\tilde{z}_k$, $k = 1,\dots,\tilde{n}$ of the matrix $\tilde{A}$ have moduli less 1, i.e. $|\tilde{z}_k| < 1$ for $k = 1,\dots,\tilde{n}$
2) $\det[\tilde{A} - zI_{\tilde{n}}] \neq 0$ for $|z| < 1$
3) $\rho(\tilde{A}) < 1$

   where $\rho(\tilde{A})$ is the spectral radius defined by $\rho(\tilde{A}) = \max_{1\le k\le\tilde{n}}\{|\tilde{z}_k|\}$ of the matrix $\tilde{A}$
4) All coefficients $\tilde{a}_i$, $i = 0,1,\dots,\tilde{n}-1$ of the characteristic polynomial

$$p_{\tilde{A}}(z) = \det[I_{\tilde{n}}(z+1) - \tilde{A}] = z^{\tilde{n}} + \tilde{a}_{\tilde{n}-1}z^{\tilde{n}-1} + \dots + \tilde{a}_1 z + \tilde{a}_0 \tag{4.12}$$

   of the matrix $[\tilde{A} - I_{\tilde{n}}]$ are positive

5) All principal minors of the matrix

$$[\tilde{A}-I_{\tilde{n}}]=\begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & ... & \tilde{a}_{1\tilde{n}} \\ \tilde{a}_{21} & \tilde{a}_{21} & ... & \tilde{a}_{2\tilde{n}} \\ ... & ... & ... & ... \\ \tilde{a}_{\tilde{n}1} & \tilde{a}_{\tilde{n}1} & ... & \tilde{a}_{\tilde{n}\tilde{n}} \end{bmatrix} \tag{4.13}$$

are positive

Theorem 4.5. The positive fractional system (5.4) is practically unstable if at least one diagonal entry of the matrix A_α is greater than 1.

Reachability and controllability to zero of positive fractional discrete-time linear systems have been investigated in (Kaczorek, 2007b). LMI approaches to checking the practical stability of positive fractional discrete-time linear systems have been applied in (Kaczorek, 2009c).

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Integrated Method of Grey Multi-attribute Risk Group Decision-Making

Luo Dang and Zhou Ling

The problem of grey multi-attribute risk group decision-making is studied, when the attributive values are interval grey numbers and the attribute weights are unknown. Using grey incidence method of the grey system theory, Relative deviation degree based on the optimum alternative group and the worst alternative group, a new method is proposed. It establishes the integrated optimization model dealing the weights of index based on that the deviation of group members is minimum and the deviation between two groups is maximum. By using the model, the attribute weights can be gotten. Then, based on subjective preferences of decision-maker group, synthetically deviations of each alternative to the optimum alternative group and the worst alternative group are calculated to determine the ranking order of alternatives. Finally, an example is given to show the feasibility and availability of this method.

1 Introduction

Group decision–making is a very important research field of decision science and it has extensive practical background. Group decision–making problem is solved by the expert group by exerting their advantages, evaluating the alternative from different aspects and assembling different opinions so so as to sort and optimize the alternative. In the recent years, researches on group decision–making theory and

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* This work was Supported by the Science and Technology Attack Projects of Henan Province (072102340009); Supported by the Natural Science Foundation of Department of Henan Province (2009A110011); Supported by the Philosophy and Social Sciences Plan Project of Henan Province (2007BJJ014); Supported by Soft Science Foundation of Science and Technology Department of Henan Province (082400440100).

methods have made many achievements (Li and Liu, 2004; Liu et al., 2007b; Song and Zou, 2004; Liu et al., 2007a). The research of grey multi-attribute risk group decision-making is relatively new (Luo and Liu, 2004; Rao and Xiao, 2006; Luo et al., 2008). The characteristic of these questions is: The attribute value of the alternative is random variable, which can change along with the different natural state, the decision-maker will be unable to certain its future real state, but he will propose each kind of possibility of the natural state. Based on own knowledge, the experience and the preference and in view of different natural states, the decision-maker will be certain about different preference attribute value. Due to the complexity of objective things, uncertainty and ambiguity of human thinking, decision-makers often do not explicitly give the weight of the attribute information, and the attribute value is also in the form of interval gray number. This chapter investigates a problem for multi-attribute group decision making with unknown attribute weight. The attributes, expressed by interval grey number (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), are given to determine the objective weight of the integrated optimization model by using grey incidence method of the grey system theory. Relative deviation degree based on the best alternative group and the worst alternative group is proposed. At last, an example is given.

2 Problem Description of Grey Multi-attribute Group Decision-Making

Suppose that the alternative set of multi-attribute group decision making under risk is $A=\{A_1,A_2,\cdots,A_n\}$, decision-making group set is $E=\{e_1,e_2,\cdots e_q\}$ $(q\geq 2)$, where e_s denotes the s-th decision-maker, whose weight is λ_s, $0<\lambda_s<1$, $\sum_{s=1}^{q}\lambda_s=1$; $u=\{u_1,u_2,\cdots,u_m\}$ is the set of decision-making attribute, the weight of attribute u_j is w_j, $0\leq w_j\leq 1$, $\sum_{j=1}^{m}w_j=1$, where weight vector $w=(w_1,w_2,\cdots,w_m)$ is unknown. For every decision-making, attribute u_j has l possible states $\theta=(\theta_1,\theta_2,\cdots\theta_l)$. To decision-maker e_s, the probability of θ_t happening is under the attribute u_j, where $0\leq p_{tj}^s\leq 1$ $(0\leq t\leq 1)$ $\sum_{t=1}^{l}p_{tj}^s=1$.The attribute value of alternative A_i is $a_{ijt}^s(\otimes)\in[\underline{a}_{ijt}^s,\overline{a}_{ijt}^s]$.

Risk decision-making information under all kinds of states presented by Decision-maker e_s as shown in Table I.We should make comprehensive evaluation and sorting decision alternatives based on risk decision information table about decision-maker e_s $(s=1,2,\cdots,q)$.

Table I Risk decision-making table $E^s(\otimes)$ for decision-maker e_s

scheme	u_1				u_2				…	u_m			
	θ_1	θ_2	…	θ_l	θ_1	θ_2	…	θ_l	…	θ_1	θ_2	…	θ_l
	p_{11}^s	p_{21}^s	…	p_{l1}^s	p_{12}^s	p_{22}^s	…	p_{l2}^s	…	p_{1j}^s	p_{2j}^s	…	p_{lj}^s
A_1	$a_{111}^s(\otimes)$	$a_{112}^s(\otimes)$	…	$a_{11l}^s(\otimes)$	$a_{121}^s(\otimes)$	$a_{122}^s(\otimes)$	…	$a_{12l}^s(\otimes)$	…	$a_{1j1}^s(\otimes)$	$a_{1j2}^s(\otimes)$	…	$a_{1jl}^s(\otimes)$
A_2	$a_{211}^s(\otimes)$	$a_{212}^s(\otimes)$	…	$a_{21l}^s(\otimes)$	$a_{221}^s(\otimes)$	$a_{222}^s(\otimes)$	…	$a_{22l}^s(\otimes)$	…	$a_{2j1}^s(\otimes)$	$a_{2j2}^s(\otimes)$	…	$a_{2jl}^s(\otimes)$
…			…			…			…			…	
A_n	$a_{n11}^s(\otimes)$	$a_{n12}^s(\otimes)$	…	$a_{n1l}^s(\otimes)$	$a_{n21}^s(\otimes)$	$a_{n22}^s(\otimes)$	…	$a_{n2l}^s(\otimes)$	…	$a_{nj1}^s(\otimes)$	$a_{nj2}^s(\otimes)$	…	$a_{njl}^s(\otimes)$

3 Decision-Making Principle and Method

A. Data processing and concept

Definition 1. (Liu et al., 2004) Suppose that $\otimes_1 \in [a,b], a<b;\quad \otimes_2 \in [c,d], c<d$, then the sum of $\otimes_1$ and $\otimes_2$ is remarked by $\otimes_1 + \otimes_2$, $\otimes_1 + \otimes_2 \in [a+c, b+d]$

Definition 2. (Liu et al., 2004) Suppose that $\otimes \in [a,b]\ a<b, k$ is real number, then $k \cdot \otimes \in [ka, kb]$.

According to the above definitions we could get the expected value of the attribute under all kinds of states in risk decision table for decision-maker $e_s \quad (s=1,2,\ldots,q)$, and then we consider the expected revenue instead of natural revenue under different kinds of states and put several grey risk decision tables into one grey non- risk decision table. Finally, we obtain the non-risk decision matrix $X^s(\otimes) \quad (s=1,2,\ldots,q)$.

$$x_{ij}^s = \sum_{t=1}^{l} a_{ijt}^s(\otimes) p_{tj}^s$$

In order to dispel the impact of different physical dimension on the decision result, we need to normalize the decision matrix. The most common attribute is cost and benefit,

Table II Normalization Matrix $Y^s(\otimes)$

Schemes	u_1	u_2	...	u_m
A_1	$y_{11}^s(\otimes)$	$y_{12}^s(\otimes)$	...	$y_{1m}^s(\otimes)$
A_2	$y_{21}^s(\otimes)$	$y_{22}^s(\otimes)$	...	${}_{2m}^s(\otimes)$
...	...	...	...	...
A_n	$y_{n1}^s(\otimes)$	$y_{n2}^s(\otimes)$	...	$y_{nm}^s(\otimes)$

So we turn decision matrix $X^s(\otimes)$ into normalization matrix $Y^s(\otimes) = (y_{ij}^s(\otimes))_{n\times m}$ according to the method proposed in (Xu, 2004).

$$\begin{cases} \underline{y}_{ij} = \underline{x}_{ij} \Big/ \sum_{i=1}^{n} \overline{x}_{ij} \\ \overline{y}_{ij} = \overline{x}_{ij} \Big/ \sum_{i=1}^{n} \underline{x}_{ij} \end{cases} \quad \text{(benefit attribute)}$$

$$\begin{cases} \underline{y}_{ij} = 1/\overline{x}_{ij} \Big/ \sum_{i=1}^{n} (1/\underline{x}_{ij}) \\ \overline{y}_{ij} = 1/\underline{x}_{ij} \Big/ \sum_{i=1}^{n} (1/\overline{x}_{ij}) \end{cases} \quad \text{(cost attribute)}$$

Definition 3. Let evaluation vector of each normalized alternative be

$$y_i^s(\otimes) = (y_{i1}^s(\otimes), y_{i2}^3(\otimes), \cdots, y_{im}^s(\otimes)) \quad (i = 1,2,\cdots,n, s = 1,2,\cdots,q)$$

Let $\underline{y}_j^{s+} = \max_{1\le i\le n}\{\underline{y}_{ij}^s\}$; $\overline{y}_j^{s+} = \max_{1\le i\le n}\{\overline{y}_{ij}^s\}$; $\underline{y}_j^{s-} = \min_{1\le i\le n}\{\underline{y}_{ij}^s\}$; $\overline{y}_j^{s-} = \min_{1\le i\le n}\{\overline{y}_{ij}^s\}$, then $y^{s+}(\otimes) = (y_1^{s+}(\otimes), y_2^{s+}(\otimes), \ldots, y_m^{s+}(\otimes))$ is the optimum alternative evaluation vector for decision-maker e^s , and $y_j^{s+}(\otimes) \in [\underline{y}_j^{s+}, \overline{y}_j^{s+}]$; then $y^{s-}(\otimes) = (y_1^{s-}(\otimes), y_2^{s-}(\otimes), \ldots, y_m^{s-}(\otimes))$ is the worst alternative evaluation vector for decision-maker e^s, and $y_j^{s-}(\otimes) \in [\underline{y}_j^{s-}, \overline{y}_j^{s-}]$.

Considering the situation of the decision-makers, then

$$B=\begin{pmatrix} y^{1+}(\otimes) \\ y^{2+}(\otimes) \\ \vdots \\ y^{q+}(\otimes) \end{pmatrix}=\begin{pmatrix} y_1^{1+}(\otimes) & y_2^{1+}(\otimes) & \cdots & y_m^{1+}(\otimes) \\ y_1^{2+}(\otimes) & y_2^{2+}(\otimes) & \cdots & y_m^{2+}(\otimes) \\ \cdots & \cdots & \cdots & \cdots \\ y_1^{q+}(\otimes) & y_2^{q+}(\otimes) & \cdots & y_m^{q+}(\otimes) \end{pmatrix}$$

is the optimum alternative group matrix;

$$C=\begin{pmatrix} y^{1-}(\otimes) \\ y^{2-}(\otimes) \\ \vdots \\ y^{q-}(\otimes) \end{pmatrix}=\begin{pmatrix} y_1^{1-}(\otimes) & y_2^{1-}(\otimes) & \cdots & y_m^{1-}(\otimes) \\ y_1^{2-}(\otimes) & y_2^{2-}(\otimes) & \cdots & y_m^{2-}(\otimes) \\ \cdots & \cdots & \cdots & \cdots \\ y_1^{q-}(\otimes) & y_2^{q-}(\otimes) & \cdots & y_m^{q-}(\otimes) \end{pmatrix}$$

is the worst alternative group matrix.

Let $y_j^+(\otimes)\in[\underline{y}_j^+,\overline{y}_j^+]=\frac{1}{q}\sum_{s=1}^{q}y_j^{s+}(\otimes)$, $y_j^-(\otimes)\in[\underline{y}_j^-,\overline{y}_j^-]=\frac{1}{q}\sum_{s=1}^{q}y_j^{s-}(\otimes)$,

Then

$$y^+(\otimes)=(y_1^+(\otimes),y_2^+(\otimes),\cdots,y_m^+(\otimes))$$

is mean vector of the optimum alternative group;

$$y^-(\otimes)=(y_1^-(\otimes),y_2^-(\otimes),\cdots,y_m^-(\otimes))$$

is mean vector of the worst alternative group.

Definition 4. Suppose that system behavior interval grey series is

$$X_0(\otimes)=([\underline{x}_0(1),\overline{x}_0(1)],[\underline{x}_0(2),\overline{x}_0(2)],\cdots,[\underline{x}_0(m),\overline{x}_0(m)])$$
$$X_1(\otimes)=([\underline{x}_1(1),\overline{x}_1(1)],[\underline{x}_1(2),\overline{x}_1(2)],\cdots,[\underline{x}_1(m),\overline{x}_1(m)])$$
$$\vdots$$
$$X_n(\otimes)=([\underline{x}_n(1),\overline{x}_n(1)],[\underline{x}_n(2),\overline{x}_n(2)],\cdots,[\underline{x}_n(m),\overline{x}_n(m)])$$

$$r_{0i}(j)=\frac{\min\limits_{1\le i\le n}\min\limits_{1\le j\le m}\{l_{0i}(j)\}+\lambda\max\limits_{1\le i\le n}\max\limits_{1\le j\le m}\{l_{0i}(j)\}}{l_{0i}(j)+\lambda\max\limits_{1\le i\le n}\max\limits_{1\le j\le m}\{l_{0i}(j)\}}$$

is grey interval relation coefficient between $X_0(\otimes)$ and $X_i(\otimes)$ in place j, where $l_{0i}(j)=\sqrt{(\underline{x}_0(j)-\underline{x}_i(j))^2+(\overline{x}_0(j)-\overline{x}_i(j))^2}$ is deviation degree (distance) between $[\underline{x}_0(j),\overline{x}_0(j)]$ and $[\underline{x}_i(j),\overline{x}_i(j)]$, λ is identification coefficient, $\lambda\in[0,1]$; $\xi_{0i}=\frac{1}{m}\sum_{j=1}^{m}r_{0i}(j)$ is grey interval relation degree between series.

Theorem 1. $r_{0i}(j)$ satisfies the following properties:

(1) $0 \le r_{0i}(j) \le 1$;

(2) when $l_{0i}(j)$ is smaller, $r_{0i}(j)$ is bigger.

B. Modeling Principle

When people make decisions, the smaller the internal group deviation of the optimum alternation group and the worst group is the better. Because it indicates that the group opinions tend to coincide. Besides, under the attribute u_j, the smaller the difference in the evaluation value of all the optimum schemes (or the worst) within the group is, the smaller role this attribute plays in scheme decision and sorting. At the same time, we hope that the internal group deviation between the two groups is bigger. According to Definition 4

$$r_{tk}^{(1)}(j) = \frac{\min\limits_{1\le k\le q}\min\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{t+}-\underline{y}_j^{k+})^2+(\overline{y}_j^{t+}-\overline{y}_j^{k+})^2}+\lambda\max\limits_{1\le k\le q}\max\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{t+}-\underline{y}_j^{k+})+(\overline{y}_j^{t+}-\overline{y}_j^{k+})^2}}{\sqrt{(\underline{y}_j^{t+}-y_j^{k+})^2+(\overline{y}_j^{t+}-\overline{y}_j^{k+})^2}+\lambda\max\limits_{1\le k\le q}\max\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{t+}-\underline{y}_j^{k+})^2+(\overline{y}_j^{t+}-\overline{y}_j^{k+})^2}}$$

is the grey interval relation coefficient under the attribute u_j and the optimum alternative evaluation vector y^{k+} corresponding to alternative y^{t+}, $\lambda \in [0,1]$ is identification coefficient, $\lambda = 0.5$ in this chapter.

$v_{tj}^{(1)}(w)$ denotes the grey interval relation degree between the optimum alternative evaluation vector y^{k+} and others under attribute u_j, then

$$v_{tj}^{(1)}(w) = \sum_{k=1}^{q} r_{tk}^{(1)}(j) w_j$$

Let

$$v_j^{(1)}(w) = \sum_{t=1}^{q} v_{tj}^{(1)}(w) = \sum_{t=1}^{q}\sum_{k=1}^{q} r_{tk}^{(1)}(j) w_j \quad (j = 1,2,\cdots,m)$$

To attribute u_j, $v_j^{(1)}(w)$ denotes the total relation degree between all the optimum alternative evaluation vectors and others. According to the above, the selection of weight vector w should make the sum of total relational degree the largest.

To construct the following Model (I)

$$\begin{cases} \max v^{(1)}(w) = \sum_{j=1}^{m}\sum_{t=1}^{q}\sum_{k=1}^{q} r_{tk}^{(1)}(j) w_j \\ s.t. \sum_{j=1}^{m} w_j^2 = 1, \qquad w_j \ge 0 \qquad (j = 1,2,\cdots,m) \end{cases}$$

Similar to the above definition

$$r_{tk}^{(2)}(j)=\frac{\min\limits_{1\le k\le q}\min\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{t-}-\underline{y}_j^{k-})^2+(\overline{y}_j^{t-}-\overline{y}_j^{k-})^2}+\lambda\max\limits_{1\le k\le q}\max\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{t-}-\underline{y}_j^{k-})+(\overline{y}_j^{t-}-\overline{y}_j^{k-})^2}}{\sqrt{(\underline{y}_j^{t-}-y_j^{k-})^2+(\overline{y}_j^{t-}-\overline{y}_j^{k-})^2}+\lambda\max\limits_{1\le k\le q}\max\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{t-}-\underline{y}_j^{k-})^2+(\overline{y}_j^{t-}-\overline{y}_j^{k-})^2}}$$

is the grey interval relation coefficient under the attribute u_j and the worst alternative evaluation vector y^{k-} corresponding to alternative y^{t-}, $\lambda\in[0,1]$ is identification coefficient, $\lambda=0.5$ in this chapter.

The Symbol $v_{tj}^{(2)}(w)$ denotes the grey interval relation degree between the worst alternative evaluation vector y^{k-} and the others under attribute u_j, then

$$v_{tj}^{(2)}(w)=\sum_{k=1}^{q}r_{tk}^{(2)}(j)w_j$$

Let $v_j^{(2)}(w)=\sum_{t=1}^{q}v_{tj}^{(2)}(w)=\sum_{t=1}^{q}\sum_{k=1}^{q}r_{tk}^{(2)}(j)w_j$,($j=1,2,\cdots,m$). As u_j , $v_j^{(2)}(w)$ denotes the total relational degree between the entire worst alternative evaluation vector and others. Then the selection of weight vector w should make the sum of total relational degree the largest.

To construct the following Model (II)

$$\begin{cases}\max v^{(2)}(w)=\sum\limits_{j=1}^{m}\sum\limits_{t=1}^{q}\sum\limits_{k=1}^{q}r_{tk}^{(2)}(j)w_j\\ s.t.\sum\limits_{j=1}^{m}w_j^2=1,\qquad w_j\ge 0\qquad (j=1,2,\cdots,m)\end{cases}$$

Let

$$r(j)=\frac{\min\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{+}-\underline{y}_j^{-})^2+(\overline{y}_j^{+}-\overline{y}_j^{-})^2}+\lambda\max\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{+}-\underline{y}_j^{-})+(\overline{y}_j^{+}-\overline{y}_j^{-})^2}}{\sqrt{(\underline{y}_j^{+}-y_j^{-})^2+(\overline{y}_j^{+}-\overline{y}_j^{-})^2}+\lambda\max\limits_{1\le j\le m}\sqrt{(\underline{y}_j^{+}-\underline{y}_j^{-})^2+(\overline{y}_j^{+}-\overline{y}_j^{-})^2}}$$

be the grey interval relation coefficient under mean vector of the optimum alternative group y^+ corresponding to mean vector of the worst alternative group y^-. $\lambda\in[0,1]$ is identification coefficient, $\lambda=0.5$ in this chapter.

Let $v^{(3)}(w)$ denote the grey interval relation degree between mean vector of the optimum alternative y^+ corresponding to mean vector of the worst alternative group y^-, then

$$v^{(3)}(w)=\sum_{j=1}^{m}r(j)$$

According to the above, the selection of weight vector w should make the sum of total relational degree the smallest.

To construct Lagrange function (III).

$$\begin{cases} \min v^{(3)}(w) = \sum_{j=1}^{m} r(j) w_j \\ s.t. \sum_{j=1}^{m} w_j^2 = 1, \qquad w_j \ge 0 \quad (j = 1,2,\cdots,m) \end{cases}$$

We can get optimization decision-making model (IV) by considering the above three models.

$$\begin{cases} \max \sum_{j=1}^{m} \{ [\sum_{t=1}^{q} \sum_{k=1}^{q} (r_{tk}^{(1)} w_j + r_{tk}^{(2)} w_j)] - r(j) w_j \} \\ \qquad s.t. \sum_{j=1}^{m} w_j^2 = 1, \quad w_j > 0 \qquad\qquad (j = 1,2,\cdots,m) \end{cases}$$

To construct Lagrange function

$$F(w,\lambda) = \sum_{s=1}^{q} \sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{k=1}^{n} \lambda_s r_{ik}^{s}(j) w_j + \lambda \left(\sum_{j=1}^{m} w_j^2 - 1 \right);$$

To calculate the partial derivative to w_j and λ, let it be zero, so the optimal solution of the model is

$$w_j^* = \frac{[\sum_{t=1}^{q} \sum_{k=1}^{q} (r_{tk}^{(1)}(j) + r_{tk}^{(2)}(j))] - r(j)}{\sqrt{\sum_{j=1}^{m} \left[(\sum_{t=1}^{q} \sum_{k=1}^{q} r_{tk}^{(1)}(j) + r_{tk}^{(2)}(j)) - r(j) \right]^2}} \qquad (j = 1,2,\cdots m)$$

Because traditional weight vector usually satisfies normalization constrained condition, therefore we also can process w_j^* by normalization in order to be consistent with people's usage after getting unitization weight vector w_j^*.

Let $w_j = \frac{w_j^*}{\sum_{j=1}^{m} w_j^*}$ $(j = 1,2,\cdots m)$, we have

$$w_j = \frac{[\sum_{t=1}^{q} \sum_{k=1}^{q} (r_{tk}^{(1)}(j) + r_{tk}^{(2)}(j))] - r(j)}{\sum_{j=1}^{m} [(\sum_{t=1}^{q} \sum_{k=1}^{q} r_{tk}^{(1)}(j) + r_{tk}^{(2)}(j)) - r(j)]}.$$

C. Decision Algorithms

Step 1: By the counting formula of the expected value, getting the non- risk decision matrix and turning decision matrix $X^s(\otimes)$ into normalization matrix $y^s(\otimes)$ ($s=1,2,\cdots,q$) .

Step 2: Establishing the optimum alternative group matrix and the worst alternative group matrix.

Step 3: According to Model (IV), we get the attribute weight.

Step 4: According to the attribute weight and normalization matrix $y^s(\otimes)$, we get weighted normalization matrix $Y_w^s(\otimes)$.

Step 5: Calculating the distances, which are respectively

$$d_{is}^{(1)} = \sum_{j=1}^{m} w_j \left(\left| \underline{y}_{ij}^{s} - \underline{y}_{j}^{+} \right| + \left| \overline{y}_{ij}^{s} - \overline{y}_{j}^{+} \right| \right)$$

and

$$d_{is}^{(2)} = \sum_{j=1}^{m} w_j \left(\left| \underline{y}_{ij}^{s} - \underline{y}_{j}^{-} \right| + \left| \overline{y}_{ij}^{s} - \overline{y}_{j}^{-} \right| \right) (i=1,2,\cdots,n)$$

between the alternative A_i of every decision-maker e_s $(s=1,2,\cdots,q)$ and the optimum alternative group, as well as between A_i and the worst alternative group.

Step 6: Consider the distances

$$D_i^{+} = \sum_{s=1}^{q} \lambda_s d_{is}^{(1)} \text{ and } D_i^{-} = \sum_{s=1}^{q} \lambda_s d_{is}^{(2)}$$

respectively, between the alternative of all decision-makers and the optimum alternative group, as well as between the alternative A_i and the worst alternative group.

Step 7: Calculating closeness degree of each alternative to the optimum alternative group

$$C_i = \frac{D_i^{-}}{D_i^{-} + D_i^{+}} \quad (i=1,2,\cdots,n)$$

The bigger C_i is the more superior the alternative is.

4 Example

An enterprise decides to modify its products. Now there are 3 design alternatives $A_i (i=1,2,3)$. By studying the 3 main attributes: u_1—cost (unit: ten thousand Yuan), u_2—reliability (non-fault working time. unit: ten thousand hours) and

u_3—product life (unit: year). Three decision-makers $e_s (s = 1,2,3)$ give out the evaluation data of each alternative. Supposing the weight of each decision-maker is 1/3, then we try to decide which is the best alternative. Here we directly give out the formula of expectation calculation to get the Non-risk Decision Matrix of each decision-maker, as shown from Table III to Table V.

Table III Normalization Decision Table $X^1(\otimes)$ For Decision-Maker e_1

	u_1	u_2	u_3
A_1	[0.7, 0.85]	[1.8, 1.9]	[12, 14]
A_2	[0.8, 0.9]	[1.9, 2.3]	[14, 15]
A_3	[0.65, 0.72]	[0.9, 1.2]	[11, 13]

Table IV Normalization Decision Table $X^2(\otimes)$ For Decision-Maker e_2

	u_1	u_2	u_3
A_1	[0.8, 0.9]	[1.9, 2.1]	[13, 15]
A_2	[0.75, 0.85]	[1.8, 2]	[12, 14]
A_3	[0.7, 0.75]	[1.2, 1.5]	[12, 13]

Table V Normalization Decision Table $X^3(\otimes)$ For Decision-Maker e_3

	u_1	u_2	u_3
A_1	[0.8,0.9]	[2,2.1]	[14,15]
A_2	[0.7,0.8]	[1.5,1.8]	[13,15]
A_3	[0.6,0.7]	[0.9,1.1]	[10,12]

(1) Turning decision matrix $X^s(\otimes)$ into normalization matrix $y^s(\otimes)$, we can obtain the optimum alternative group matrix:

$$B = \begin{pmatrix} [0.3287, 0.4398] & [0.4, 0.4773] & [0.3333, 0.4054] \\ [0.3439, 0.4185] & [0.3519, 0.5] & [0.3415, 0.4054] \\ [0.3323, 0.3875] & [0.3393, 0.4286] & [0.25, 0.4054] \end{pmatrix}$$

and the worst alternative group matrix

$$C = \begin{pmatrix} [0.2557,0.3298] & [0.18,0.25] & [0.2381,0.3243] \\ [0.2751,0.34] & [0.1667,0.2609] & [0.2683,0.3514] \\ [0.2932,0.3391] & [0.2143,0.3061] & [0.2307,0.3514] \end{pmatrix}$$

(2) According to Model (IV), we get the attribute weight

$$w = (0.350,0.237,0.413)$$

(3) Calculate distance $d_{is}^{(1)}$ and $d_{is}^{(2)}$.

$d_{11}^{(1)} = 0.07867$; $d_{21}^{(1)} = 0.05972$; $d_{31}^{(1)} = 0.16860$; $d_{12}^{(1)} = 0.07960$; $d_{22}^{(1)} = 0.07127$; $d_{32}^{(1)} = 0.11667$; $d_{13}^{(1)} = 0.08067$; $d_{23}^{(1)} = 0.10090$; $d_{33}^{(1)} = 0.13895$; $d_{11}^{(2)} = 0.17019$; $d_{21}^{(2)} = 0.13779$; $d_{31}^{(2)} = 0.07368$; $d_{12}^{(2)} = 0.10935$; $d_{22}^{(2)} = 0.16003$; $d_{32}^{(2)} = 0.07355$; $d_{13}^{(2)} = 0.10839$; $d_{23}^{(2)} = 0.10051$; $d_{33}^{(2)} = 0.06242$

(4) Calculate closeness degree of each alternative with regard to the optimum alternative group.

$$C_1 = 0.62842; C_2 = 0.63205; C_3 = 0.32970$$

The sort of alternative is $A_2 \succ A_1 \succ A_3$, so A_2 is the best alternative.

5 Conclusion

This chapter investigates the problem of multi-attribute group decision making under risk, in which the attributes are interval grey numbers and the attribute weights are unknown.

A new method is proposed by determining relative degree based on the best alternative group and the worst alternative group. The attribute weight determination is objective and reliable in this method, which can obviously avoid the randomness of the subjective weight given by the decision-maker.

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Grey Relational Analysis Method of Linguistic Information and Its Application in Group Decision

Qiuping Wang, Daohong Zhang, and Haiqing Hu

Grey relational analysis based on grey relational degree is a very successful theory and method in grey system theory. On the basis of grey relational four axioms, this chapter extends general grey relational degree formula to the case of linguistic term sequence. This work may extend the application field of grey relational degree. This chapter puts forward a method for group multiple attribute decision making problems with linguistic information, in which the preference values take the form of linguistic variables. Then a procedure to group multiple attribute decision making is provided under linguistic environment. Finally, an example of risk investment problem is given to verify the proposed method, and practicality of the proposed method is shown by illustrative example.

1 Introduction

Grey relational analysis was pioneered by Deng Julong in 1984 (Deng, 1984; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). Grey relational analysis is an important part of grey system theory. It is a quantitative method of analyzing grey relational degree among each factor in grey system. Its basic idea is to judge the relational degree of the development situation during grey process based on the geometrical figure similar degree of the sequences curves. The application of grey relational analysis to practical problem, the key is to calculate relational degree.

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Therefore, how to define grey relational degree is very important. Over the recent twenty years, the study of grey relational degree has aroused maximum concern and many results have been achieved. Grey relational models of the real number sequence are as follows: classical relational models proposed by Deng Julong (Deng, 1985; Deng, 1989), grey B-mode relational degree and grey C-mode relational degree proposed by Wang Qingyin (Wang, 1989; Wang and Zhao, 1999), the generalized degree of grey incidence (including the absolute degree of grey incidence, the relative degree of grey incidence, and the synthetic degree of grey incidence proposed by S. F. Liu (Liu, 1992; Liu et al., 2004), grey absolute correlation degree proposed by Mei Zhenguo (Mei, 1992), T's correlation degree proposed by Tang Wuxiang (Tang, 1995), a kind of modified grey correlation degree proposed by Xiao Xinping (Xiao et al., 1995), Grey slope incidence degree and improved degree of grey slope incidence proposed by Dang Yaoguo (Dang, 1994; Dang et al., 2004a). Grey relational models of the interval number sequence are as follows: interval number incidence degree proposed by Dang Yaoguo (Dang et al., 2004b), interval number related degree proposed by ZHANG Jijun (Zhang, 2005), the incidence degree coefficient formula and relative incidence degree coefficient formula for interval grey numbers constructed by LUO Dang (Luo, 2005). Grey relational models of the triangular fuzzy number sequence are as follows: the grey incidence coefficient formula of triangular fuzzy number based on idea of grey system theory and expectation formula of triangular fuzzy number proposed by Qiu-Ping WANG et al (Wang et al., 2007), the method of grey relational analysis of triangular fuzzy number based on triangular fuzzy number distance formula (Chen, 2000) proposed by Wei Gui-Wu (Wei and Wang, 2008). Moreover, Xiong Hejin proposed grey vector relational degree and complex number relational degree (Xiong et al., 2000), etc. These relational degree models have been used widely in practice.

Qualitative evaluating information is often given directly when evaluating such as ideological moral character of human, performance of a car and so on(e.g., linguistic form like “excellent”, “good”, “poor” and so forth). Linguistic variable approach is an effective tool which deals with problem not to be assessed precisely in a quantitative form. Therefore, a study of linguistic term grey relational model has important theoretical and actual application value. At present, research achievement relating to the problem at home and abroad has been rare. In literature (Wei and Lin, 2008), semantic grey relational coefficient was given and a method for multiple attribute group decision making based on two-tuple linguistic setting was proposed. Motivated by the idea of Zeshui Xu (Ze, 2005), this chapter defines the distance of linguistic term. On this basis, this chapter proposes the computational method of linguistic term sequence grey relational degree according to grey relational analysis axioms, thus extending grey relational analysis theory from real number sequence to linguistic term sequence. We take further steps to research multiple attribute group decision making problems and establish grey relational model for multiple attribute group decision making with linguistic term.

The rest of this chapter is organized as follows. Section 2 introduces some basic notations and operational laws of linguistic variables. Section 3 proposes grey relational degree of linguistic terms. Section 4 gives a representation of group decision making problem with linguistic information, gives the method of grey relational analysis for group decision making with linguistic information. Section 5 gives an illustrative example. And finally, conclusion is made in Section 6.

2 Basic Notations and Operational Laws

The linguistic approach is an approximate technique, which represents qualitative aspects as linguistic values by means of linguistic variables (Zadeh, 1975; Herrera-Viedma and Verdegay, 1995; Herrera-Viedma and Martinez, 2000; Herrera and Herrera-Viedma, 2000; Torra, 2001).

Suppose that $S=\{s_\alpha \mid \alpha=-t,\cdots,-1,0,1,\cdots,t\}$ is a finite and totally ordered discrete term set whose cardinality value is an odd one, such as 7 and 9, where s_α represents a possible value for a linguistic variable. For example, a set of nine terms S could be given as follows (Ze, 2005):

$$S=\{s_{-4}=\text{extremely poor},\ s_{-3}=\text{very poor},\ s_{-2}=\text{poor},$$
$$s_{-1}=\text{slightly poor},\ s_0=\text{fair},\ s_1=\text{slightly good},$$
$$s_2=\text{good},\ s_3=\text{very good},\ s_4=\text{extremely good}\}.$$

In these cases, it usually requires that s_α and s_β satisfies the following additional characteristics (Herrera-Viedma and Martinez, 2000; Herrera and Herrera-Viedma, 2000).

(1) The set is ordered: $s_\alpha > s_\beta$ if and only if $\alpha > \beta$;

(2) There is the negation operator: $\text{neg}(s_\alpha)=s_{-\alpha}$, especially, $\text{neg}(s_0)=s_0$;

(3) Max operator: $\max(s_\alpha, s_\beta)=s_\alpha$, if $i \ge j$;

(4) Min operator: $\min(s_\alpha, s_\beta)=s_\alpha$, if $i \le j$.

The operation on two linguistic terms can be converted to the operation on subscript variables of the corresponding terms.

Definition 1. Let $s_\alpha, s_\beta \in S$ be two linguistic variables, we define the distance between s_α and s_β as follows:

$$d(s_\alpha, s_\beta)=|\alpha-\beta|.$$

We can prove $d(s_\alpha, s_\beta)$ to satisfy condition of distance measure axiom, and it has properties in the following:

(1) $s_\alpha = s_\beta$ if and only if $d(s_\alpha, s_\beta) = 0$;

(2) Let $s_\alpha, s_\beta, s_\gamma \in S$, s_β are closer to s_α than s_γ, if and only if $d(s_\alpha, s_\beta) < d(s_\alpha, s_\gamma)$.

3 Grey Relational Degree of Linguistic Terms

Let X be sequence set of linguistic terms, $x_0 \in X$ be reference sequence of linguistic terms, $x_i \in X$ be comparison sequences of linguistic terms ($i = 1, 2, \ldots, n$).

$$x_0 = (x_0(1), x_0(2), \ldots, x_0(m)),$$
$$x_i = (x_i(1), x_i(2), \ldots, x_i(m)),$$

where $x_0(j)$ and $x_i(j)$ are linguistic terms, $x_0(j) = s_{I(x_0(j))}$, $x_i(j) = s_{I(x_i(j))}$, $(j = 1, 2, \ldots, m)$.

Let $I(x_0(j))$ and $I(x(j))$ be the subscript variables of linguistic values of $s_{I(x_0(j))}$ and $s_{I(x(j))}$ respectively. For example, if $x_i(j) = s_4$, then $I(x_i(j)) = 4$. Let

$$\Delta_i(j) = \left| I(x_0(j)) - I(x_i(j)) \right|,$$
$$\Delta_{\min} = \min_i \min_j \left| I(x_0(j) - I(x_i(j)) \right|,$$
$$\Delta_{\max} = \max_i \max_j \left| I(x_0(j) - I(x_i(j)) \right|.$$

Definition 2. A nonnegative real number $\gamma(x_0(j), x_i(j))$ is called grey relational coefficient between x_0 and x_i at j, which is defined as

$$\gamma(x_0(j), x_i(j)) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_i + \rho\Delta_{\max}}. \tag{1}$$

where $\rho \in [0, 1]$ is the distinguishing coefficient, generally $\rho = 0.5$. And γ_i is called grey relational degree of x_i with respect to x_0, which is defined as

$$\gamma_i = \gamma(x_0, x_i) = \frac{1}{m} \sum_{j=1}^{m} \gamma(x_0(j), x_i(j)) \tag{2}$$

Theorem 1. The grey relational degree $\gamma(x_0, x_i)$ of x_i with respect to x_0 obtained from (1) and (2) satisfies the following four grey axioms.

(1) Norm property

$$0 < \gamma(x_0, x_i) \le 1, \text{for any } i; \quad x_0 = x_i \Rightarrow \gamma(x_0, x_i) = 1.$$

(2) Duality symmetric property

$$x_i, x_j \in X, \gamma(x_i, x_j) = \gamma(x_j, x_i), \quad \textit{iff} \quad X = \{x_i, x_j\}.$$

(3) Wholeness property

For $x_i, x_j \in X = \{x_t \mid t = 0,1,2,\cdots,n; n \ge 2\}$, $\gamma(x_i, x_j) \overset{\text{often}}{\ne} r(x_j, x_i),\ i \ne j$.

(4) Approachability property

The smaller $\Delta_i(j) = |I(x_0(j)) - I(x_i(j))|$ is, the larger $\gamma(x_0(j), x_i(j))$ is.

Proof. (1) Norm property. If $\Delta_i(j) = |I(x_0(j)) - I(x_i(j))| = \Delta_{\min}$, then

$$\gamma(x_0(j), x_i(j)) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_i(j) + \rho\Delta_{\max}} = 1,$$

If $\Delta_i(j) = |I(x_0(j)) - I(x_i(j))| \ne \Delta_{\min}$, then $\Delta_i(j) = |I(x_0(j)) - I(x_i(j))| > \Delta_{\min}$, thus $\Delta_{\min} + \rho\Delta_{\max} < \Delta_i + \rho\Delta_{\max}$, thereby $\gamma(x_0(j), x_i(j)) = \dfrac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_i(j) + \rho\Delta_{\max}} < 1$.

Obviously, for any *j*, $\gamma(x_0(j), x_i(j)) > 0$, therefore, $0 < \gamma(x_0, x_i) \le 1$.

(2) Duality symmetric property. If $X = \{x_0, x_1\}$, then

$$|I(x_0(j)) - I(x_1(j))| = |I(x_1(j)) - I(x_0(j))|$$

$$\max_i \max_j |I(x_0(j)) - I(x_i(j))| = \max_i \max_j |I(x_1(j)) - I(x_i(j))| \tag{3}$$

$$\min_i \min_j |I(x_0(j)) - I(x_i(j))| = \min_i \min_j |I(x_1(j)) - I(x_i(j))| \tag{4}$$

The left of equation (3), (4), $i = 1$, the right of equation (3), (4), $i = 0$, hence

$$\gamma(x_0, x_1) = \gamma(x_1, x_0)$$

(3) Wholeness property. If $X = \{x_t \mid t = 0,1,2,\cdots,n; n \ge 2\}$, for any x_{t_1}, $x_{t_2} \in X$, generally speaking, $\max_i \max_j |I(x_{t_1}(j)) - I(x_i(j))| \ne \max_i \max_j |I(x_{t_2}(j)) - I(x_i(j))|$. Therefore wholeness property holds true.

(4) Approachability property holds water evidently.

4 Method of Grey Relational Analysis for Group Decision Making with Linguistic Information

For simplicity, we let $N = \{1,2,\cdots,n\}$. Suppose the alternatives are known. Let $X = \{X_1, X_2, \cdots, X_n\}$ denote a discrete set of *n* ($n \ge 2$) potential alternatives. Attributes are predefined too, let $C=\{C_1, C_2, \cdots, C_m\}$ denote a set of m($m \geq 2$) criteria or attributes. The attribute weights are completely unknown. Let $D=\{d_1, d_2, \cdots, d_K\}$ be the set of decision makers (DMs for short, the same meaning for DM in the rest of this chapter) and the weight vector of DMs is also completely unknown. Suppose that $A^{(k)}=[a_{ij}^{(k)}]_{n\times m}$ is the linguistic assessment matrix given by the DM $d_k \in D$, where $a_{ij}^{(k)}$ is a linguistic terms in the set

$$S=\{s_\alpha \mid \alpha=-t, \cdots, -1, 0, 1, \cdots, t\}$$

for alternative X_i with respect to the attribute C_j.

Definition 3. Let $^{+}a_j^{(k)}=a_{\max\limits_{1\le i\le n} I(a_{ij}^{(k)})}$, $j \in M$, m-dimension vector $^{+}a^{(k)}=(^{+}a_1^{(k)}, {}^{+}a_2^{(k)}, \cdots, {}^{+}a_m^{(k)})$ is called ideal optimum alternative of decision maker $d_k \in D$.

In the following, we develop a practical approach based on grey relational analysis to group decision making with linguistic information.

Step1: To a group MADM (multiple attribute decision making) problem, construct the decision matrix $A^{(k)}=[a_{ij}^{(k)}]_{n\times m}$, where k represents the k^{th} DM and all the arguments are linguistic terms.

Step2: Compute $^{+}a^{(k)}$ ($k=1,2,\cdots,K$) (namely, ideal optimum alternative vector of each decision maker).

Step3: Using linguistic grey relational coefficient formula (1), calculate grey relational coefficient of all alternative with respect to ideal optimum alternative of each decision maker, then using formula (2), calculate linguistic grey relational degree of all alternatives with respect to ideal optimum alternative of each decision maker.

$\gamma_i^{(k)}=\gamma[^{+}a^{(k)}, a_i^{(k)}]$, $i=1, 2, \ldots, n$, $k=1,2,\cdots,K$, can be obtained from grey linguistic relational degree of each decision maker individual.

We can obtain score matrix γ of group grey relational degree from individual linguistic grey relational degree of K decision makers versus n alternatives with respect to individual ideal optimum alternative.

$$\gamma=\begin{bmatrix} \gamma_1^{(1)} & \gamma_2^{(1)} & \cdots & \gamma_n^{(1)} \\ \gamma_1^{(2)} & \gamma_2^{(2)} & \cdots & \gamma_n^{(2)} \\ \vdots & \vdots & \vdots & \vdots \\ \gamma_1^{(K)} & \gamma_2^{(K)} & \cdots & \gamma_n^{(K)} \end{bmatrix}$$

Step4: Compute matrix F. $F = \gamma^{\mathrm{T}}\gamma$.

Step5: Compute maximum eigenvalue corresponding to the eigenvector $z = (z_1, z_2, \cdots, z_n)^{\mathrm{T}}$ of matrix F by means of power method. $z = (z_1, z_2, \cdots, z_n)^{\mathrm{T}}$ is to be the optimal decision (Qiu, 1997).

Step6: Ranking all the alternatives X_i ($i \in N$) and select the best one(s) in accordance with the value of $z_i (i \in N)$ in the descending order.

Step7: End.

The algorithm of the power method is described as follows.

(1) Given precision requirement $\varepsilon > 0$.

(2) For any initial vector $z^{(0)}$, e.g., $z^{(0)} = (\frac{1}{n}, \frac{1}{n}, \cdots, \frac{1}{n})^{\mathrm{T}} \in R^n$.

For $k = 1, 2, \cdots$; doing

(a) Let $y^{(k)} = Fz^{(k)}$

(b) Compute length $m_k = \|y_k\|_2$ of vector $y^{(k)}$

(c) Let $z^{(k)} = y^{(k)} / m_k$

(d) If $\max\limits_{1 \le i \le n} \left| z_i^{(k)} - z_i^{(k-1)} \right| < \varepsilon$ ($z_i^{(k)}$ denotes the i^{th} component of $z^{(k)}$), then stop computation, else go to (a).

5 An Illustrative Example: A Risk Investment Problem

Let us suppose a risk investment company, which wants to invest a sum of money in the best option (adapted from (Wu and Chen, 2007) and (Xu, 2004, p. 165). This MADM problem involves the evaluation of four possible alternatives denoted as X_1, X_2, X_3, *and X4*. The investment company must make a decision according the following seven attributes: C_1—the ability of sale, C_2—the ability of management, C_3—the ability of production, C_4—the ability of technology, C_5— the ability of financing, C_6 —the ability to resist venture, C_7 — the consistency of corporation strategy. Three DMs are asked to evaluate each alternative using the linguistic term set in terms of their performance

$$S = \{s_{-4} = \text{extremely poor}, s_{-3} = \text{very poor}, s_{-2} = \text{poor}, \\ s_{-1} = \text{slightly poor}, s_0 = \text{fair}, s_1 = \text{slightly good}, \\ s_2 = \text{good}, s_3 = \text{very good}, s_4 = \text{extremely good}\}.$$

The decision matrices $A^{(k)} = (a_{ij}^k)_{n \times m}$ (k = 1, 2, 3) are listed in Tables I-III.

Table I Decision matrices $A^{(1)}$

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
X_1	s_1	s_3	s_3	s_0	s_1	s_2	s_2
X_2	s_3	s_2	s_0	s_2	s_3	s_1	s_{-1}
X_3	s_2	s_2	s_3	s_1	s_4	s_3	s_2
X_4	s_2	s_2	s_{-1}	s_1	s_3	s_1	s_1

Table II Decision matrices $A^{(2)}$

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
X_1	s_1	s_2	s_3	s_0	s_2	s_2	s_4
X_2	s_0	s_1	s_0	s_1	s_2	s_2	s_1
X_3	s_3	s_1	s_2	s_2	s_4	s_4	s_1
X_4	s_0	s_1	s_0	s_1	s_0	s_1	s_{-1}

Table III Decision matrices $A^{(3)}$

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
X_1	s_0	s_2	s_2	s_1	s_3	s_2	s_3
X_2	s_2	s_1	s_1	s_2	s_0	s_2	s_{-1}
X_3	s_2	s_1	s_2	s_2	s_2	s_3	s_2
X_4	s_0	s_1	s_{-1}	s_1	s_0	s_0	s_1

Step1: Calculate ideal optimum alternative vector ${}^{+}a^{(k)}$ of each decision maker.

$$ {}^{+}a^{(1)} = (s_3, s_3, s_3, s_2, s_4, s_3, s_2), $$

$$ {}^{+}a^{(2)} = (s_3, s_2, s_3, s_2, s_4, s_4, s_4), $$

$$ {}^{+}a^{(3)} = (s_2, s_2, s_2, s_2, s_3, s_3, s_3) $$

Step2: Let $\rho = 0.5$, using (1), calculate linguistic grey relational coefficient of all alternative with respect to ideal optimum alternative of each decision maker, then using formula (2), calculate linguistic grey relational degree of all alternatives with respect to ideal optimum alternative of each decision maker. Thereby, we can obtain matrix γ,

$$ \gamma = \begin{bmatrix} \gamma_1^{(1)} & \gamma_2^{(1)} & \gamma_3^{(1)} & \gamma_4^{(1)} \\ \gamma_1^{(2)} & \gamma_2^{(2)} & \gamma_3^{(2)} & \gamma_4^{(2)} \\ \gamma_1^{(3)} & \gamma_2^{(3)} & \gamma_3^{(3)} & \gamma_4^{(4)} \end{bmatrix} = \begin{bmatrix} 0.724 & 0.616 & 0.859 & 0.597 \\ 0.746 & 0.558 & 0.840 & 0.502 \\ 0.833 & 0.676 & 0.857 & 0.505 \end{bmatrix} $$

and

$$ \gamma^{\mathrm{T}} = \begin{bmatrix} \gamma_1^{(1)} & \gamma_1^{(2)} & \gamma_1^{(3)} \\ \gamma_2^{(1)} & \gamma_2^{(2)} & \gamma_2^{(3)} \\ \gamma_3^{(1)} & \gamma_3^{(2)} & \gamma_3^{(3)} \\ \gamma_4^{(1)} & \gamma_4^{(2)} & \gamma_4^{(3)} \end{bmatrix} = \begin{bmatrix} 0.724 & 0.746 & 0.833 \\ 0.616 & 0.558 & 0.676 \\ 0.859 & 0.840 & 0.857 \\ 0.597 & 0.502 & 0.505 \end{bmatrix} $$

Step3: Compute matrix F

$$F = \begin{bmatrix} 1.7446 & 1.4254 & 1.9624 & 1.2274 \\ 1.4254 & 1.1478 & 1.5772 & 0.9892 \\ 1.9624 & 1.5772 & 2.1779 & 1.3673 \\ 1.2274 & 0.9892 & 1.3673 & 0.8634 \end{bmatrix}$$

Step4: Compute maximum eigenvalue corresponding to the eigenvector $z = (z_1, z_2, \cdots, z_n)^{\mathrm{T}}$ of matrix F by means of power method.

Given $\varepsilon = 0.00001$, the results of iterative computation are listed in Table IV.

Table IV The results of iterative computation

$z^{(0)}$	$y^{(1)}$	$z^{(1)}$	$y^{(2)}$	$z^{(2)}$	$y^{(3)}$	$z^{(3)}$
0.2500	1.5974	0.5455	3.2463	0.5456	3.2463	0.5456
0.2500	1.2849	0.4388	2.6106	0.4387	2.6106	0.4387
0.2500	1.7712	0.6048	3.5988	0.6048	3.5988	0.6048
0.2500	1.1118	0.3797	2.2583	0.3795	2.2583	0.3795

Optimal decision is $z = z^{(3)} = (0.5456, 0.4387, 0.6048, 0.3795)^{\mathrm{T}}$. Namely:

$$z_1 = 0.5456,\ z_2 = 0.4387,\ z_3 = 0.6048,\ z_4 = 0.3795$$

Rank z_i (i = 1, 2, 3, 4) in descending order $z_3 > z_1 > z_2 > z_4$. The ranking order of all alternatives is $X_3 \succ X_1 \succ X_2 \succ X_4$. Thus the best alternative is X_3. The selection order of illustrative example by using our proposed approach is the same with that by using approach in (Wu and Chen, 2007) or (Xu, 2004).

6 Conclusion

In the real world, the decision maker may have vague knowledge about the preferences degree of one alternative over another. Furthermore, it is too complex or too ill-defined to be amenable for description in conventional quantitative expressions. Extend grey relational analysis to linguistic environment is highly beneficial when the performance values cannot be expressed by means of numerical values. This chapter extends general grey relational degree formula to the cases of linguistic term sequence. This work may extend the application field of grey relational degree. On the basis of grey relational degree of linguistic term, we have developed a group decision making method under linguistic environment. We have also applied the proposed approach to a group decision-making problem of choosing the best option for a risk investment company. The linguistic approach gives a more flexible framework to deal with decision problems using qualitative information. The linguistic grey relational analysis proposed in this chapter is also applicable to group decision making with multi-granularity linguistic assessment information. The grey relational analysis method of relating to group MADM problem with uncertain linguistic assessment information is the future work.

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The Relation between Grey Relational Decision Making and Grey Situation Decision Making under the Proper Condition*

Yong Wei and Xinhai Kong

The relation between grey relational decision making and grey situation decision making is pointed out in this chapter, which broadens the train of thought to define the incidence degree, effect measure, uniform measure and incidence coefficient. Furthermore, we analyze the substantial cause that the incidence order is changed with non-dimensionalization in grey incidence analysis. At the same time, we point out two kinds of common processing methods (unitization of initial values and zeroization of initial points for row vectors) both are unreasonable.

1 Introduction

From the angle of the research method, we can see that grey relational decision making (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006) is to seek the ideal decision-making scheme at first, but the ideal decision- making scheme does not exist truly in the known decision- making schemes for choosing, so we have to select the relatively satisfactory decision-making scheme in a series of non-ideal decision-making schemes. And the method of selecting the relatively satisfactory decision-making scheme is to discuss the relational degrees between each decision-making scheme and the ideal decision-making scheme, and select the biggest one as the satisfactory decision-making scheme. However, the concept of relational degree is by no means introduced in grey situation decision making from

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* This work was supported by scientific research fund of Sichuan Education Department (2006A007) and basic application research fund of Sichuan (2008JY0112).

beginning to end, thus we don't need to calculate the relational degrees and compare with each other, but directly carry out the following three steps:

1) Standardization and positive polarization of column vectors, and $r_i(k)$ is said to be the effect measure of the *i*-th scheme (row) and the *k*-th indicator.
2) The arithmetic average of all the effect measures in the *i*-th scheme $r_i = \frac{1}{m}\sum_{k=1}^{m} r_i(k)$ is said to be the uniform measure of the *i*-th scheme.
3) Select the scheme corresponding with the biggest uniform measure as the optimal situation.

Before an in-depth study, it is difficult to discover the intrinsic connection between them from the object of study or the method of study, so they are naturally considered as two kinds of different ways to choose the optimal decision making. The limitations of the traditional relational degree, effect measure, uniform measure and relational coefficient are broken in this chapter. We dig up the intrinsic and essential relation between the two, and come to the conclusion that grey relational decision making can be regarded as grey situation decision making derived from one new kind of effect measure, while grey situation decision making can be also regarded as grey relational decision making derived from some new kind of grey relational degree. These connections will undoubtedly contribute in opening up a new way to define the relational degree, effect measure, uniform measure and relational coefficient, and provide a new idea for the evaluation with optimization of grey decision making.

2 Grey Relational Decision Making Derived from the Relational Degree with the Property of Positive Definiteness Seen as Grey Situation Decision Making

For the sake of convenience, we first introduce the following concept.

Definition 1. If a relational degree satisfies: for all $x_1(k), x_2(k)$, such that $r(x_1(k), x_2(k)) \in (0,1]$, and $r(x_1(k),x_2(k))=1 \Leftrightarrow x_1(k)=x_2(k)$, then $r(x_1(k),x_2(k))$ is said to have the property of positive definitive.

The reasons why the grey relational decision making derived from the relational degree which has the property of positive definitive can be seen as the grey situation decision making are as follows: First of all, the sequences in every decision-making scheme can be regarded as the effect samples under the corresponding goal; secondly, in grey relational decision making, whether row vectors are non-dimensionalized or not, and whether column vectors are positive polarized or not, as long as the relational degree has the property of positive definitive, then the relational coefficient $r(x_0(k), x_i(k))$ between the *k*-th item of the *i*-th mode and the k-th item of the ideal mode can be always regarded as the effect measure $r_i(k)$ of the k-th item, which is regulated having the property of positive polarity and standardization in the i-th scheme, thus the relational degree between the i-th mode and the ideal mode

$$r(X_0, X_i) = \frac{1}{m}\sum_{k=1}^{m} r(x_0(k), x_i(k))$$

can be seen as regulating a special uniform measure r_i for the i-th scheme

$$M_{eff}(X_i) = \frac{1}{m}\sum_{k=1}^{m} r_i(k).$$

Selecting the mode corresponding with the biggest relational degree as the satisfactory mode, it can be also seen that selecting the one corresponding with the biggest uniform measure as the optimal situation.

Note 1: It is necessary to satisfy the property of positive definitive for grey relational degree, otherwise the regulated $M_{eff}(X_i) = \frac{1}{m}\sum_{k=1}^{m} r_i(k)$ doesn't necessarily satisfy the requirement of measure. Therefore, Xiao suggested that using the related coefficient in probability theory as grey relational degree in (Xiao, 1997), and the correlation relational degree defined in (Wei, 2006) can't also taken as the responsibility.

By means of the relational degree which doesn't reflect the property of closeness, even if it is non-negative, we can't also obtain grey situation decision making. For example, although grey slope relational degree is non-negative, from the proposition 4.5.3 of literature (Liu et al., 2004), we know that the grey slope relational coefficient is only related to the geometrical shape of original data, and has nothing to do with their relative position of space. So it is unable to reflect the property of closeness.

While making the grey relational decision making, we shouldn't do any data transformation for the mode vectors (row vectors), such as doing the unitization of initial values for the mode vectors (row vectors) (namely, the transformation $y_i(k) = \frac{x_i(k)}{x_i(1)}$). It is inadvisable to analyze y_i, because it will deny the substance differences between different modes, and then result in the loss of the reasonableness of evaluation. For example, two modes $(1,1,\cdots,1)$ and $(0.2,0.2,\cdots,0.2)$. Every item of the mode $(1,1,\cdots,1)$ reaches the perfect standard, and every item of the mode $(1,1,\cdots,1)$ never reaches the qualified standard, but through unitizing for the initial values, the two are transformed into the same mode $(1,1,\cdots,1)$.

In a similar way, when making the grey relational decision making, we do the zeroization of initial points for mode vectors (row vectors), namely let $y_i(k)=x_i(k)-x_i(1)$. It is also inadvisable to analyze y_i, because the above-mentioned two modes are transformed into $(0,0,\cdots,0)$. Especially, when calculating the relative relational degree, we needn't only do the unitized transformation, but also do the zeroized transformation (Mei, 1992), so it is much more unreasonable. In fact, the absolute degree of grey incidences (Yang, 2005), slope relational degree (Mei, 1992) and so on, involve the following operation:

$$a^{(1)}(x_i(k+1) = x_i(k+1) - x_i(k),\ i = 0,1,2,\cdots,n, k = 1,2,\cdots,m.$$

Therefore, there also exist similar problems in them.

Generally speaking, any operation between $x_i(k_1)$ and $x_i(k_2)$ in the same mode will bring about the above-mentioned similar confusion, which cannot have any practical significance. So we must be cautious.

3 Grey Situation Decision Making Seen as Grey Relational Decision Making

For the sake of illustrating the problem conveniently, we only discuss it with regard to a single case. The so-called grey situation decision making, there is nothing more than n countermeasures (scheme) and m indicators of each countermeasure. Might as well write as:

$$X_1 = (x_1(1), x_1(2), \cdots, x_1(k), \cdots, x_1(m))$$
$$X_2 = (x_2(1), x_2(2), \cdots, x_2(k), \cdots, x_2(m))$$
$$\cdots\ \cdots\ \cdots$$
$$X_i = (x_i(1), x_i(2), \cdots, x_i(k), \cdots, x_i(m))$$
$$\cdots\ \cdots\ \cdots$$
$$X_n = (x_n(1), x_n(2), \cdots, x_n(k), \cdots, x_n(m))$$

It's worth noting that the dimension, the meaning and the polarity of data among items in each row vector may be inconsistent, so there is no comparability in all senses. But the dimension, the meaning and the polarity of data among items in each column vector may be consistent, thus there exist the comparability.

The reason why grey situation decision making can be regarded as grey relational decision making is that standardizing and positive polarizing for the *i*-th column vector, and the value of $r_i(k)$ is said to be the effect measure of the *i*-th countermeasure (row) and the *k*-th indicator, actually, this can be seen as seeking a special relational degree. As a matter of fact, the effect measure $r_0(k)$ corresponding with the most satisfactory value $x_0(k)$ in the *i*-th column vector is always 1; therefore, the effect measure $r_i(k) = \dfrac{\min\{x_i(k), x_0(k)\}}{\max\{x_i(k), x_0(k)\}}$ can be regarded as one new kind of special incidence coefficient $r(x_0(k), x_i(k))$, defined by

$$r(x_i(k), x_j(k)) = \frac{\min\{x_i(k), x_j(k)\}}{\max\{x_i(k), x_j(k)\}} \tag{1}$$

And the uniform measure $M_{eff}(X_i) = \dfrac{1}{m}\sum_{k=1}^{m} r_i(k)$ is considered as one new kind of special and specific incidence degree $r(X_0, X_i)$, defined by

$$r(X_0, X_i) = \frac{1}{m}\sum_{k=1}^{m} r(x_0(k), r(x_i(k)) \tag{2}$$

Therefore, select the scheme corresponding to the biggest uniform measure as the optimal situation, that is to say, select the one corresponding to the biggest relational degree as the satisfactory mode in grey relational decision making.

Note2: For the indicator sequence (column vector), if the original series is a non-negative series with positive polarity or negative polarity, with the standardization and positive polarization, the sizes of relational coefficient and relational degree defined by (1) and (2) may be changed, but the order does not be changed. So this is reasonable to do it in this way.

If the polarity of original series (column vector) is medium, even if they are non-negative, as long as two numbers lie in the two sides of the medium value, then the incidence coefficient defined by (1) and (2) can only reflect the degree of closeness of their effect measures (or data after the non-dimensionalization), can't reflect the degree of closeness of original series. For example: suppose u_0 =20 is the medium value of the *k*-th indicator of original series, then the effect measures of u_1=10 and u_2 =40 respectively are calculated as follows:

$$r_1(k) = M_{eff}(u_1) = \frac{\min\{20,10\}}{\max\{20,10\}} = \frac{1}{2},\ r_2(k) = M_{eff}(u_2) = \frac{\min\{20,40\}}{\max\{20,40\}} = \frac{1}{2}.$$

And it follows from (1) that

$$r(x_1(k), x_2(k)) = \frac{\min\{\frac{1}{2}, \frac{1}{2}\}}{\max\{\frac{1}{2}, \frac{1}{2}\}} = 1.$$

That is to say, the closeness degree of effect measure between 10 and 40 reaches 100%. In fact, the distance between 10 and 40 is farther than that between 10 and 20, but also closer than that between 10 and 20, thus it is obviously unreasonable.

This is the essential cause that some articles complain about why some relational degrees have the ordinal effect after the treatment of non-dimensionalization or positive polarization (Xiao, 1997; Yi et al., 2006; Tang, 1994; Zhang and Zhang, 1996). In fact, any kind of relational degree cannot guarantee that the order of the size of relational degree still maintain unchanged after the data of medium polarity are transformed into the data of positive polarity. This is completely normal phenomenon.

4 Conclusion

Due to the diversity of existing grey relational coefficients and relational degrees, such as the absolute relational degree, the relative relational degree, the slope relational degree, the point relational degree, the improved absolute relational degree, the B-mode degree of grey incidence too, the T-mode relational degree and so on (Liu et al., 2004), it decides on the diversity of effect measures and uniform measures for one indicator through the method provided in this chapter. In particular, it's worth noting that it is likely for the effect measure defined by the relational coefficient in this chapter to break the mode that the effect measure is decided by only single target, and it may emerge the case that we need to use all the data of each indicator to obtain the effect measure, such as the effect measure defined by the traditional relational coefficient (Deng, 1995). Therefore, with regard to the concept of effect measure, its connotation is greatly enriched and its extension is expanded.

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Use of Grey System for Assessment of Drinking Water Quality: A Case Study of Jiaozuo City, China*

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In this chapter, the water standard is interval rather than point, so a new analysis method which proposed from the grey system theory—Grey Relational Analysis (GRA) based on the distance of a point to the interval is used for assessment of drinking water quality in Jiaozuo city China; This method is simple with good operability, and the physics significance was clear. Good results are achieved. The assessment results provide a scientific reference for the integrated planning, management and rational use of drinking water source in Jiaozuo city.

1 Introduction

The water environment quality issue is a subject of ongoing concerned with the development of economy, especially, since the reform and open-up in China. The water resources problems related to environmental degradation have been serious, due to the rapid industrialization and urban sprawl. The China State Environmental Protection Administration investigated the protection status of drinking water sources in major cities in 1989 and 1996 (Han et al., 2000), then evaluated the water quality and management status with the environmental protection planning being carried out in 2006 (China State Environmental Protection, 2006). The China Ministry of Water Resources evaluated the quantity and quality of national city drinking water sources and a national drinking water source protection planning was carried out in 2005 (China Ministry of Water Resources, 2005).

Aquatic ecosystems are subject to a wide variety of pollutants as well as destructive land-use or water-management practices around the world. Drinking water is obtained from two basic sources: surface water and groundwater. All water

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* This work was supported in part by National Science Foundation of The Education Department of Henan Province in 2009(NO.2009A57009).

contains natural contaminants, particularly inorganic contaminants that arise from the geological strata through which the water flows and to a varying extent, anthropogenic pollution by both microorganisms and chemicals (Fung, 2003). The assessment of drinking water quality is a very important content of the assessment of drinking water sources (Wang et al., 2007). Its main task is to analyze the space-time distribution of drinking water quality, and to provide a scientific basic reference for the development and utilization planning of drinking water sources, which is based on the main material components of drinking water and is given water quality standard.

Generally, there are many methods and opinions about the evaluation of the water quality. For example, single index method (Han et al., 2000; Pan et al., 2007), analytic hierarchy process method (AHP) (Ren et al., 2007; Pang et al., 2007), pollution index method (Yu and Wang, 2003; Zhou et al., 2007; Zhang et al., 2009), fuzzy evaluation method (Singh et al., 2008; Zhu and Wu, 2005), matter-element analysis method (Xu and Shang, 1996; Men and Liang, 2003), artificial neural network method (Sun et al., 2004; Ma et al., 2007), set pair analysis method (Li and Chen, 2003; Qiu et al., 2007; Qiu et al., 2008; Li et al., 2004), and Grey evaluation method (Zheng andYu, 1989; Wang et al., 2007; Moran et al., 2006; Wong et al., 2006; Ding, 1995). Besides these, the method using Geographical Information System (GIS) in assessment for water quality is widely used at present (Babiker et al., 2007; Zhou and Zheng, 2008; Xiang et al., 2003). The methods mentioned above have their own scope of application and limitations. Of which single index method is over strict and pessimistic, analytic hierarchy process (AHP) method exits subjectivity when fixing weighting coefficient and leads to flying away from the objectivity of evaluating result. Pollution index method can not reflect the order relation of different water quality categories of different sections although it is easy, and fuzzy evaluation method can avoid the disadvantages, but it is very complicated and not intuitive in concept, while artificial neural network method can equalization the evaluation results when the sample is poor coordination. However, Grey relational analysis method with characteristics of simple in principle and calculation, can make the most of data and do not lose information, whose results can reflect the significant differences of different water quality categories of different sections (Li et al., 2004). Using GIS is a new good method, but it is restricted by the conditions and technical matters.

In this work, given the water quality monitoring data of 13 drinking water sources in Jiaozuo city Henan province China in 2004, grey relational analysis method based on the distance of a point to the interval (Shen and Xie, 1997; Xiao et al., 2005) applied to the drinking water quality assessment has been studied. And the results can provide scientific reference for decision-making by the government.

2 Methodology

A. Grey System theory

Grey incidence analysis is part of grey system theory, which is suitable for solving the complicated interrelationships between multiple factors and variables. A grey system is defined as a system containing unknown information presented by grey numbers and grey variables. In Grey theory, black represents a system devoid of information, while white stands for complete information. Thus, the information that is either incomplete or undetermined is called grey. Grey systems theory was initiated by Deng in 1982 (Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006), and has been widely applied in the last decade in China in several research fields (Deng, 1985; Deng, 1999). The system has three approaches such as Grey relational analysis, Grey clustering, Grey decision-making (Song and Deng, 2004; Zhang and Lei, 2005).

Grey relational analysis method has several advantages. The major advantage of Grey theory is that it can handle both incomplete information and unclear problems very precisely. It serves as an analysis tool especially in cases when there is insufficient data. Its concept is intuitive and simple, and no matter what the number of water quality parameters is it can analyze completely; there is no technical problems and it is easy to be promoted (Xu et al., 2006). In the evaluation process, it can make full use of environmental monitoring data, and will not lose information. The results of the evaluation not only reflect the differences between the different levels of water quality samples significantly, but also reflect the differences between different samples of the water environment quality which are at the same level (Li et al., 2004). It has a combined effect which can reflect the various water quality parameters fully (Xu et al., 2006).

It was recognized that the Grey relational analysis in Grey theory had been largely applied to project selection, prediction analysis, performance evaluation, and factor effect evaluation due to Grey relational analysis software development, such as auto control design, water resource development, hydroelectric generation scheduling and environmental management (Fung, 2003; Yeh and Chen, 2004; Liang, 1999; Chang and Lin, 1999). In terms of water quality evaluation, take water environmental monitoring data as reference sequence and water environmental quality standards as comparative sequence. More than one gray relational degree can be obtained according to grade water quality standards, and the grade corresponding with reference sequence which has the largest gray relational degree relative to comparative sequence is the grade of the water sample to be evaluated.

B. Grey Relational Analysis method based on the distance of a point to the interval

According to the differences of calculating method of gray relational coefficient, there are two kinds of method about the application of gray relational analysis for water quality evaluation; calculating the distance based on a point to a point and based on a point to the interval. To the traditional grey relational analysis method, distance based on a point to a point is used to calculate relational coefficient. Thus, typical value must be chosen from the water quality standard, subjectivity must be exited when choosing typical value, and as a result, the objectivity of evaluating result may be deviated. Optimal method which based on the basic application of Monte Carlo stochastic simulation method, relational degree according to the practice requirement is taken as the optimization object was proposed by (Du et al., 2008). Although this method would solve the problem in some degree, its optimization procedure is very complicate. Another gray relational analysis method for water quality in which distance based on a point to a point used to calculate relational coefficient, which is an improvement of traditional method that can fit the characteristic of water quality standard better. A method of calculating gray relational coefficient was defined by (Shen and Xie, 1997), in which the distance of a point to the interval is zero when the point is in the interval. This method leads to the effect is always the same when a point is in the interval and neglects the variations within the interval. Based on the operational method of gray intervals, the distance of a point to the interval is defined from another angle; the traditional gray relational analysis method is broadening (Xiao et al., 2005). This method is scientific and innovative in some degree, when the interval becomes into a point, it is identical with the absolute difference between two points of traditional gray relational analysis method.

(1) Determine the reference sequence and comparative sequence for a Grey system

Suppose the monitoring data $\{x_0(k)\},(k=1,2,3...n)$ for assessment of water quality as the reference sequence, which is the mother sequence; supposes the water quality standards $\{[\underline{x}_i(k),\overline{x}_i(k)]\}=\{[\underline{x}_i(1),\overline{x}_i(1)],[\underline{x}_i(2),\overline{x}_i(2)]...\}(i=1,2,3...;k=1,2,3...)$ as the comparative sequence, which is the sub sequence;

(2) Calculating the incidence coefficient

(i) Based on operation rule of Grey interval, define the distance of a point to the interval as (Xiao et al., 2005):

$$D_{0,\ i}=D(x_0(k),[\underline{x}_i(k),\overline{x}_i(k)])=\frac{\sqrt{2}}{2}\sqrt{(x_0(k)-\underline{x}_i(k))^2+(x_0(k)-\overline{x}_i(k))^2} \tag{1}$$

By (1)-type can be seen that $D_{0i}=|x_0(k)-x_i(k)|$ is the same as the absolute distance between two points compute by Grey relational analysis with the traditional method, when the interval $[\underline{x}_i(k),\overline{x}_i(k)]$ becomes a point $x_i(k)$.

(ii) Calculating the correlation coefficient

The correlation coefficient between the comparative sequence $\{[\underline{x}_i(k),\overline{x}_i(k)]\}=\{[\underline{x}_i(1),\overline{x}_i(1)],[\underline{x}_i(2),\overline{x}_i(2)]...\}(i=1,2,3...;k=1,2,3...)$ and the reference sequence $\{x_0(k)\}$ is defined as (Fung, 2003; Yeh and Chen, 2004; Deng, 1989):

$$\gamma(x_0(k),[\underline{x}_i(k),\overline{x}_i(k)])=\frac{D_{\min}+\rho D_{\max}}{D_{0,\ i}+\rho D_{\max}} \tag{2}$$

Where $D_{\max}=\max\limits_i\max\limits_k D_{0,\ i}(k)$, $D_{\min}=\min\limits_i\min\limits_k D_{0,\ i}(k)$; ρ is a resolution coefficient, $\rho\in(0,1)$, usually $\rho=0.5$ (Deng, 1989).

(3) Calculating the grey relation grade

Generally takes mean value, namely $\omega_k=\frac{1}{n}$, the grey relation grade is defined as (Deng, 1989):

$$\gamma(x_0, x_i) = \sum_{k=1}^{n} \omega_k \gamma(x_0(k), [\underline{x}_i(k), \overline{x}_i(k)]) \quad (i = 1, 2, 3 \ldots) \tag{3}$$

(4) Sort correlation order and determine the water quality categories

According to the size of correlation degree which calculated as mentioned above, we sort correlation order and find out the largest one, and then we can determine the water quality level.

Herein, the grey relation grade represents the degree of correlation between the reference sequence and the sequence for comparison. If a particular sequence for comparison is more important to the reference sequence than other comparative sequences, then the grey relation grade between that comparative sequence and reference sequence exceed the other grey relation grades. If the comparative sequence is consistent with the reference sequence, then the grey relation grade is close to unity. Grey relational analysis measures the absolute differences between sequences, and so can be used to measure the approximate correlation of sequences (Fung, 2003).

3 Case Study

C. Study area

Jiaozuo city is located in the Yellow River Valley, Taihang Mountains, northwestern Henan Province, China (Figure 1), including five city areas, namely Jiefang area, Zhongzhan area, Macun area, Shanyang area, New city area, with two county-level cities, namely Qinyang, Mengzhou, as well as four counties, namely Wen County, Bo'ai County, Xiuwu County and Wuzhi County. It is located between Latitudes 34°48’55”–35°29’59” N and Longitudes 112°33’40” 113°38’42”E, 120 km long from east to west, 77 km wide from north to south, and covers an area of 4071 km^2. The climate of the Jiaozou city is subtropics and temperate, and the average annual precipitation and temperature are 650 mm and 14.1°C. More than 70% precipitation occurs particularly between June and October period. It has a total amount of 3,455,000 people, of which 1,155,000 are urban population. There are 13 centralized drinking water sources (excluding self-drilled wells); including 2 reservoir water sources and 11 groundwater sources. Water of good quality is crucial to sustainable social and economic development, and an adequate supply of safe drinking water is one of the main requirements for a healthy life. Therefore, selecting a method for assessment of the water quality scientifically and making a real objective evaluation of the drinking water quality which is in the evaluation regional are particularly important, for protecting, rationally exploiting and utilizing the drinking water sources.

D. Water quality data

In this study, the water quality samples were collected from 13 centralized drinking water sources in 2004. The selected parameters for the estimation of surface water quality characteristics are: Total nitrogen, Potassium permanganate index, Chemical oxygen demand(COD), Ammonia nitrogen, Total phosphorus(TP), Cu^{2+}, Zn^{2+}, Fluoride, Arsenic, Mercury, Cr^{6+}, Cyanide, Anionic surfactant, Fecal coli-form group. The selected parameters for the estimation of ground water quality characteristics are: Chroma, turbidity , Total hardness, Total dissolved solids, sulfate, chloride, Fe, Mn, Cu^{2+}, Zn^{2+}, Volatile phenols , Permanganate index, Ammonia nitrogen, Total coli-form, Total bacteria, nitrate(NO^{3-}), nitrite(NO^{2-}), Fluoride, Cyanide, Mercury , Arsenic , Selenium , Chromium , Lead. Environmental Quality Standard for Surface Water (GB3838-2002) and Ground water quality standards (GBT 14848-93) are taken as the assessment level.

E. Results and discussions

First, treat the monitoring data and water quality standards for the Maximum then they will be non-dimensional and comparable. Secondly, the distance from the monitoring point to the water quality standards interval is calculated by (1)-type.

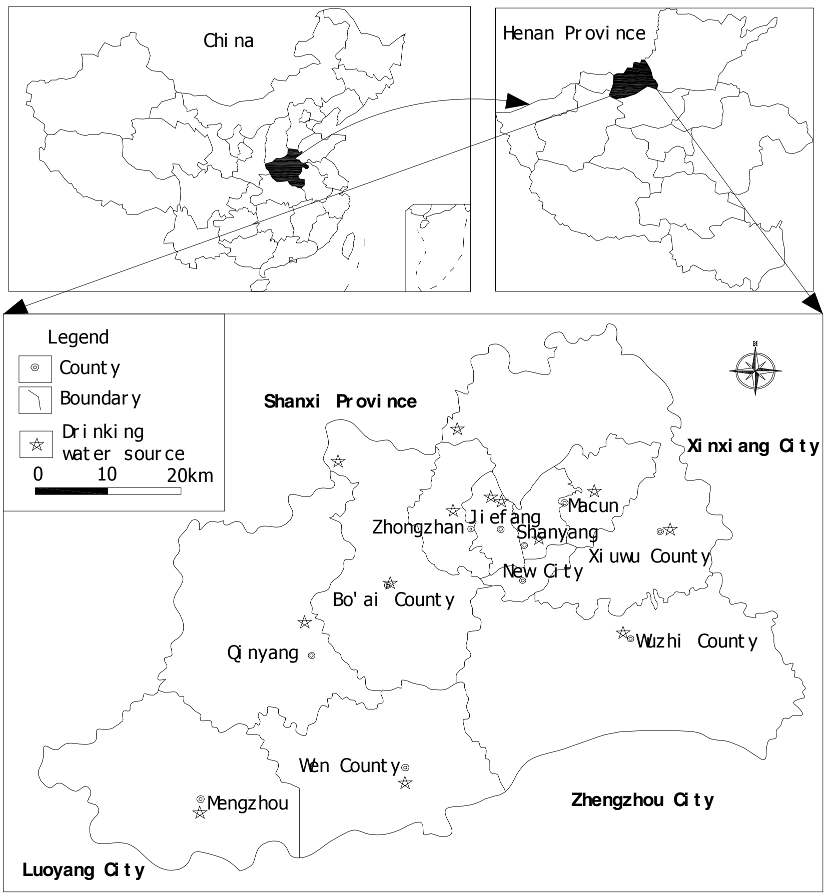

Fig. 1 Geographical location of study area

Thirdly, the correlation coefficient was calculated by (2)-type. Finally, the correlation degree was calculated by (3)-type and we can determine the water quality assessment level of different water resource. The water quality evaluation results of surface sources are shown in table I, and that of ground water sources are shown in table II.

Table I The evaluation results of reservoir water quality

Water sources name	Flood season	Non-flood season	Normal water season
Qunying reservoir	I	I	I
Qingtian Rive reservoir	I	I	I

Table II The evaluation results of ground water quality

Urban name	Water sources name	Evaluation result	Urban name	water sources name	Evaluation result
Jiaozuo city zone	Taihang sources	II	Bo'ai County	Bo'ai waterworks	I
	Fenglin sources	II	Wuzhi County	Nanjia sources	II
	Zhongma sources	I	Wen County	Wen county waterworks	II
	Zhongzhan sources	II	Qinyang City	Qinbei sources	II
	New city sources	II	Mengzhou City	Mengzhou waterworks	I
Xiuwu County	Original haizheng waterworks	II			

As shown in table I, the water qualities of the Qunying Reservoir and the Qingtian River Reservoir are all I category no matter when is the flood season and non-flood season or Normal water season. As can be seen from table II, the water qualities of Zhongma sources in Jiaozuo City, Bo'ai waterworks and Mengzhou waterworks are I category, and that of some other sources are II category, such as Taihang sources, Fenglin sources, Zhongzhan sources, New city sources in the Jiaozuo City, Original Haizheng waterworks in Xiuwu County, Nanjia sources in Wuzhi County, Wen County waterworks in Wen County and Qinbei sources in Qinyang City. So the drinking water quality of Jiaozuo city is I or II category, which is good enough to meet the requirement as an origin for drinking water. All the above assessment results provide a scientific theoretical basis for integrated planning of the drinking water resource and the management of water quality in Jiaozuo City.

However, there are still some disadvantages or problems. For example, when $x_{0h}(k)$ is located at the interval endpoint, namely $x_{0h}(k)=\overline{x}_i(k)=\underline{x}_{i+1}(k)$, which category should it attributed to while evaluating the water quality.

4 Conclusions

The water environmental system is a multi-factor, multi-level complex system, in which the information provided by water environmental monitoring data is incomplete and not specific because it is obtained within the scope of the limited time and space, and the circumscription of the evaluation criteria is not absolute, with a certain degree of ambiguity. The gray relational analysis method with characteristics of simple in principle and calculation, and no special requirements about data type and variable distribution, breakthroughs the limit that the precise bound ambiguous can't be allowed in traditional mathematic. So the gray relational analysis has great value and broad application prospects in water quality evaluation.

In this chapter, given the water quality monitoring data of 13 drinking water sources of Jiaozuo City in 2004, grey correlation evaluation method, which is based on interval arithmetic rules of Grey, is used to do the water quality evaluation. This new method put forward a formula to calculate the distance from a point to the interval, and then calculate the correlation coefficient and correlation degree.

This study shows that this method is well adapted to the characteristics of water quality evaluation. Besides, it had a clear physical meaning and is a useful tool for understanding of complex nature of water quality issues. As any method is not perfect, though there are some disadvantages, it is believed to assist decision makers assessing drinking water quality and determining priorities in pollution prevention efforts.

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Part VI
Grey Cybernetics and Intelligent Services

Research on the Support System of Dual-Use Core Technologies Integration Based on Open Innovation*

Jianmin Fan, Guangming Hou, and Xinwen He

Dual-use core technology can be integrated along the entire life cycle of technology because of its value extensibility, while integration of this technology requires a corresponding support system for its success. Owing to problems with China's policy, this support system is a closed type. A support system based on open innovation should be constructed in China in order to deal with the problems of its backward economy and defense, its low efficiency of resource allocation and the rate of success in dual-use core technology integration. This support system should be divided into a software platform subsystem, a hardware platform subsystem, and an organization and coordination subsystem. Sustained efforts countermeasures should be done by the Chinese government in order to build it, such as forming efficient organization and management systems, establishing and improving policies and regulations, building hardware supportive platforms and doing well with matching management measures for the operation of this support system and so on.

1 Introduction

Since Marco Ianisiti (1993, 1997) studied systematically the issue of technology integration, academic research on technology integration has been ascendant. The current technology integration theory is to study how certain technologies can be

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* This work was supported in part by the National Natural Science Foundation of China (70873008), the Science and Research Plan on Technology Foundation of the Military Industry of China (C172008C001), and the Fund for Research on Doctoral Programs in Institutions of Higher Learning (20060007034).

transformed into a product or industry and the release of technology to maximize productivity so as to realize the technology value. The integration of core technologies is the most difficult one in all kinds of technical integrations, but it has a very important practical significance for all countries. Since more than 80% of the key technologies are shared by the military and civilians in the current worldwide high-tech areas, dual-use core technologies integration (to be referred as DCTI hereinafter) can save resources and reduce waste so as to maximize the value of technology. Therefore, the study of the integration law of dual-use core technologies is of greater value. Since it is related to national security, most of China's DCTI is still carried out under the closed status. It is difficult to obtain a large number of dual-use critical technology achievements because it does no help to break the closed state of resources and management, or to absorb more external high-level innovation resources. Therefore, it is necessary for China to build a support system of DCTI based on open innovation. In fact, the United States, Japan, France, Britain and other developed countries have set up DCTI support systems based on open innovation and had successful experiences. To this end, it is an important issue to be settled urgently for home scholars to study how to build an open support system of DCTI by using the theory of open innovation and DCTI and to combine China's actual situation with experiences at home and abroad. At present, since domestic and foreign scholars pay little attention on this research issue, there are almost no research results. In response to this question, this chapter will put forth an open support system model of DCTI and countermeasures to build this support system briefly.

2 Relevant Theoretical Research on Open Innovation and DCTI

A. Research on open innovation

The "open innovation" concept was first proposed in May 2003 by Henry W. Chesbrough, a professor at Harvard Business School. It refers to enterprises in the balanced coordination of internal and external resources that generate innovative ideas and the comprehensive utilization of corporate internal and external marketing channels for the innovation activities of services. Under this innovative model, enterprises should not put a goal on innovating products at the mercy of the traditional operators, but should look for actively external technical licensing, technology partnerships, strategic alliances or risk investments and other suitable business models to make the commercialization of innovative ideas a reality (Chesbrough, 2003). Because it overcomes some defects of the closed-end innovation model, such as a huge money input, a too long research cycle, the large risk of investment, etc., high-tech enterprises can make use of limited resources to acquire the needed technology so as to quickly gain a competitive edge. As a new resource allocation way of innovation, open innovation is not perfect. There are some limitations for it, such as the difficulty to manage and control the innovation process, increasing the uncertainty of successful innovation, creative loss brought by key staff turnover, huge loss caused probably by missing intellectual property for

R&D enterprises or institutions, etc. (Chen and Chen, 2008). Since open innovation research is still in a stage of infancy, many issues need be studied in depth. Some areas of the research were almost empty; for example, fields in the defense industry sector are so sensitive to the introduction of open innovation that few scholars have studied them with the theory of open innovation. Zhou Hua, Miao Hong (2007) from China have written an article about open innovation strategy explored in national defense research (Zhou and Miao, 2007), but their paper hardly concerns the issue of open support system of technology integration, similar to other scholars.

B. Research about dual-use core technology Integration

(1) Research on technology integration

The earliest scholar to systematically research integration technology is Marco Ianisiti (1993, 1997), a Professor at Harvard Business School. In his view, for industries with rapid development while their technological advances are interrupted, such as those in the semiconductor field, the real competitive advantage does not belong to those who are high-tech but to those who are best at the selection and application of these technologies (Iansiti and West, 1997). By combining the categories of knowledge and multi-categories of technology with the related concept of reasonable business, an effective program of product manufacturing and manufacturing processes forms, so as to achieve volume production (Yan, 2003).

Technology integration is extremely difficult. As the study indicated, 80% of the introduction projects of technology in companies have problems, and most of them considered a basic failure (Rob, 2002). So, this study is necessary. Research on technology integration includes: technology integration for new product development, mass production-oriented technology integration and other broader technology integration (Deng and Lei, 2006). At present, the integration of technology is also still in its infancy, and the research results are very limited. Moreover, research on an open support system of DCTI is difficult to find.

(2) Research on dual-use core technology integration

Dual-use technology is a kind of technology with military value, commercial uses and potential for industrial development. Conversion technologies from military to civilian or from civilian to military and technologies for both the military and civilians are in the scope of dual-use technology (Wang and Tong, 2006). Their application areas include aerospace, communications, materials, ship, nuclear, biology, photovoltaic and other industries, and their use is more and more wide.

Core technology is a part of technologies that play a decisive role in the course of enterprise production and operations. It is not only a core component of the essential capabilities, but also a key factor to translate a competitive advantage into core competency (Yu and Fan, 2003). DCTI is the process of convert dual-use core technology into key products or industries, so as to maximize the value of key technologies. As the study in this field is weak at present, it also should be strengthened.

3 Relation between DCTI and the Open Support System to Integrate Core Technologies

A. The path of DCTI

Due to the notable effect of the dual-use technology bilateral spillovers, which show the scalability of this technical value, we can integrate it at for the entire technology life.

As shown in figure 1, for a single project of DCTI, its integration pathway is very complex and involves many integrations of resources elements, but it also involves the use of lots of the integration strategy. Whether it succeeds or not is decided by not only enterprise power of obtaining dual-use core technology and the ability to integrate its internal resources, but also enterprise capacity access to resources from externally. While the external environment, such as macroscopic systems and mechanisms, policy, the availability of funds, manpower supply, technical supply, access to information channels, competitive situation, etc. have a direct influence on enterprise capacity access to resources from externally. Moreover, it also has an indirect impact on enterprise power for obtaining dual-use core technology. Since the support system of DCTI is a multiple integration of the enterprise external environment, its state of growth has a critical impact on the success or failure of enterprise DCTI.

Within the whole chain of dual-use core technology value includes technology integration process value finding, acquisition of value, cash of value and continuity of value etc. We can integrate them by selecting one or several integration procedures (Fan et al., 2008). This pathway of the whole integration process is shown in figure 1.

B Analysis of the necessity and feasibility of building an open support system for DCTI

(1) Necessity for China to construct an open support system for DCTI

(i) It is determined by a special state situation in China. Table 1 shows us support system states of DCTI in the United State, Japan and China. Accompanied by that of United States and Japan, China's support system of DCTI belongs to a closed type. It is small and short of a defense investment, with many management problems needed to be resolved, so as to lead to a smaller output of DCTI.

Hence, it is necessary for China to construct the support system based on innovation.

(ii) It is practical and required for China to solve the problem of lacking key resources for the development of dual-use technology. Although China's R & D investment has accounted for 1.49 percent of the current GDP and its annual military spending continuously goes up, the contradiction between the supply and demand of doing research has not been resolved (Zhang and Zhang, 2003). This also applies to civilian industries. One of the main reasons is that the support system for China's R & D and technology integration are both closed. Due to the military

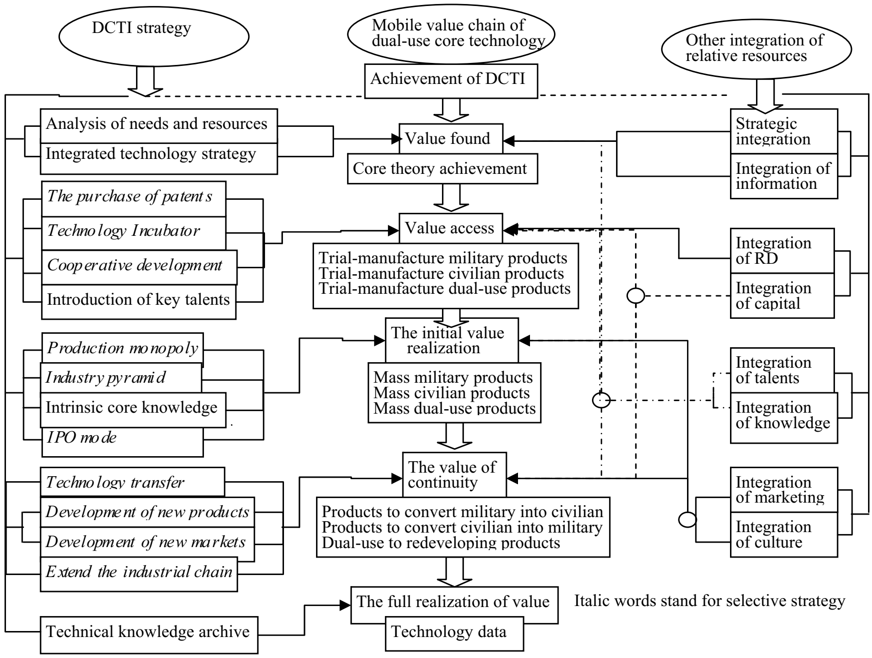

Fig. 1 The path of DCTI Based on the technology life cycle

industry and civilian-use industries developing products, enormous resources are wasted in R & D, and technical integration is brought by the duplication of research and production, so that investment on the development of DTCI is quite small. Therefore, a support system based on open innovation for DTCI must be set up in China, so as to solve the problem of insufficient funds in the development of dual-use core technologies

(iii) It is key for investors to successfully integrate dual-use core technology. As a complicated systematic project, DTCI can succeed only when some related resource integrations are involved. These resource include senior management and technology talents, venture investors, matching technology enterprises, the demander of technology, a supporting facilities manufacturer (Deng, 2008), suppliers of information and money, and other resources and participants. There are not adequate resources for DTCI without a policy-type software platform and a resources-type hardware platform based on open innovation. Moreover, due to the lack of effective organization for DTCI, it is difficult to successfully promote these projects, even bringing in adverse affection to national defense. Therefore, support system based on innovation is key to successfully integrating dual-use core technology.

(2) Possibility for China to set up an open support system of DCTI

(i) This support system can easily been taken because it has been included in China's national strategies for the combination of military and civilians;

(ii) China has a lot of exploration and practical experience in the implementation of military and civilian integration strategies, as well as open innovation;

(iii) There are some successful experiences that promote ways in developed countries, such as the USA, Japan, Britain, France, Israel, etc., which can be used for reference by the Chinese government.

Table 1 Key factors of support system for DCTI among the United State, Japan and China

country	openness	robustness	defense fee (2005)	problem of management	technical standard	security regulations	quantity of dual-use core products
America	higher	soundest	1	few	relative consolidated	rigid and moderate	most
Japan	high	sounder	0.0917	few	compatible	rigid and flexible	more
China	low	not sound	0.0619	many	few compatible	total rigid	not many

4 Open Support System and Its Content of DCTI

A Model of DCTI based on open innovation

Because the inverted U-shaped relationship exists between the degree of openness and economics performance (Fan and Hou, 2008) and because dual-use core technology is under the restrictions for the special requirements of security, the degree of openness for the open support system of DCTI should be appropriate for the core elements of technology integration. The degrees of openness among the different elements in this support system of DCTI are also different. The process and path of DCTI is available from the following to a brief description of Figure 2.

As Figure 2 below indicates, the support system is to support DCTI running based on open innovation, which has an impact directly on the project efficiency of DCTI and even determines its success or failure. It includes three subsystems. The subsystem of organization and coordination ensures the whole open DCTI system operates effectively, whereas the software platform one and hardware platform one are both the prerequisites for the success of the DCTI project. These three subsystems should be built by the Chinese central government.

B Support system content of DCTI based on open innovation

(1)Subsystem of organization and coordination

(i) Agencies of organization and coordination for DTCI: They include institutions of core leadership, handling affairs, and expert support, which are built by the central and provincial-level government, respectively. Their responsibilities include organizing and promoting the foundation of software and hardware platform subsystems in non-profits and carrying out the national plan of DTCI through effective operations.

(ii) Sound service networks: In addition to the establishment of a military and civilian information network for national technology supply and demand, a number of services networks on DTCI should be built in the provincial region. At the same time, the operation of these networks will be standardized by effective management

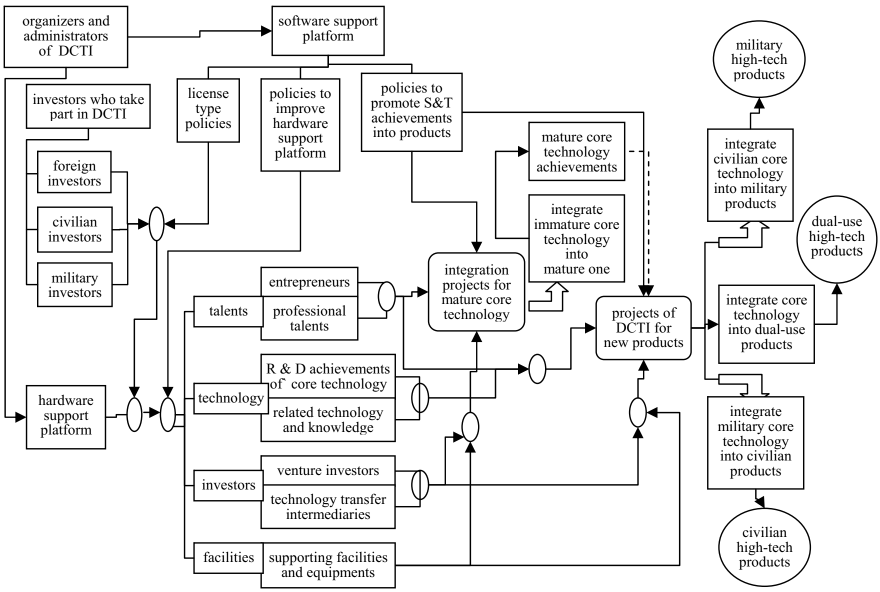

Fig. 2 Path of DCTI based on open innovation

and service regulation, so as to ensure that the DTCI is carried out continuously and effectively.

(iii) A large quantity of service teams with some highly skilled experts: A staff subsystem of organization and coordination is mainly composed of three parts: leaders with expert skills, experts, and quasi-experts. Leaders with expert skills are in charge of decision-making and management on one or some fields of DTCI work, while experts and quasi-experts are responsible for examining and guiding some major operations and carrying out the implementation of specific operations of the DTCI, respectively.

(2) Subsystem of the software support platform

It includes mainly three aspects:

(i) Licensing policy category: It includes policy measures involved in the flow of core technologies, such as that of encouraging civilian sectors to participate in development of high-tech weapons, converting the defense industry into a civilian production, cooperating with international technology of the military industry from advanced countries, developing international markets for the Chinese military enterprises, etc.

(ii) Policies to improve the hardware support platform: They include policy measures to encourage the development of senior talents, core technical knowledge and information, venture investors and a support facility, which are key factors to support the running of the DCTI . Examples include accelerating national defense innovation of science and technology, intellectual property management of core technology in national defense, increasing the supply of dual-use technologies, stinging development of venture investment, dual-use technology intermediary organizations, the pool of entrepreneurs, speeding up high-tech enterprise listings on the stock market, and so on.

(iii) Policies to promote dual-use scientific research achievements into products: They include policies and regulations promoting the technology transfer between military and civilian industries, such as that of opening up information, relatively unified technology standards, and policies to standardize the operation of DCTI projects, such as reasonable governance rules, an income distribution system, innovation culture, security measures and other policy measures to aid the success of the DCTI project.

(3) Subsystem of hardware support platform

It includes mainly four aspects , as follows:

(i) A national talent net system should be built to optimize entrepreneurs and professionals allocation for DCTI. Large quantities of senior talents are listed on the net system by the scientific mechanism of selection, use, exchange and elimination to ensure a sufficient supply of outstanding innovative talents in scientific research and management for DCTI projects.

(ii) A large quantity of dual use core technology achievements are provided by some excellent research and development teams, which are not lots of pure theoretical and valueless research results but advanced and practical achievements of dual-use technology.

(iii) Many service institutions of technology transfer intermediary are high-performing, highly reputed and well-functioning, such as military and civilian technology transfer centers, dual-use scientific and technological information networks, operation management agents for DCTI projects, etc.

(iv) Advanced system of venture capital participators: It contains well-developed capital markets, especially securities markets, an adequate supply of experienced venture capitalists, an adequate market supply of start-up money in research and innovation, experimental facilities and experimental equipment that can be shared by others.

5 Countermeasures for China to Establish and Improve the Open Support System of DCTI

A. A highly efficient subsystem of organization and coordination on DTCI should be formed.

(i) The establishment of corresponding organizational institutions: The institution of organization and management of DTCI should be established by the central government. This institution takes charge of strategic planning, policies and regulations, information management, coordinating national DTCI between military and civilian industries, and so on. Correspondingly, this institution should be established by every provincial government, so as to organize and supervise local operations of the DTCI. Meanwhile, several professional service sectors should also be set up by some famous scientific research institutes in support by state but as a non-profit operation, which will bear guiding and set an example for national investors for DTCI project in their respective areas of expertise.

(ii) Accurate positioning functions of this organization and coordination subsystem: Its specific functions at least include: to formulate and release policies and regulations, to long-term and medium-term plan the DTCI, and to supervise their implementation; to organize a demonstration on keeping or removing the confidentiality of national defense core technology projects; to be responsible for the construction and management of DTCI platforms; to set up the anti-risk mechanism of DTCI, and so on.

(iii) Select correctly and make good use of all expert members: On the one hand, every expert should be correctly selected so that they are more with the true operational capacity than the "image ambassador" to represent their sector of interest, and the participation of the experts of the time should be devoted to investment work rather than merely being a "nominal leader". On the other hand, the mechanism of assessment, rewards and punishments of these experts should also be established correspondingly so that staff exert their full capacity and energy into their work concerning DTCI. (Fan and Hou, 2008).

B. Policies and regulations promoting DTCI should be established and improved

(i) In order to relax restrictions on policies and regulations for civilian-use enterprises taking part in DTCI, the permit-type policies and regulations category should be amended and improved by the central government, such as the "confidentiality regulations on defense," "People's Republic of China Interim Regulations on Private Enterprises", technical standards system of national defense, and so on. (Chen and Liu, 2008).

(ii) Some policies and regulations about building the platform of DTCI should be formulated and improved so as to absorb more resources and investors to DTCI projects, such as "Regulations on reasonable flow of senior talents", the "law of entrusting enterprises management to others", the “law on venture investment in China ", regulations on standardizing participants of DTCI, etc.

(iii) In order to speed up national DTCI, policies and regulations about transforming dual-use core technology achievements into products or industry should also be formulated and improved, such as the "law on promoting scientific and technological achievements of national defense", "the Law to promote dual-use technology " and other laws and regulations.

(iv) Policies and regulations on risk prevention should be rigidly drawn. On one hand, a reasonable security threshold should be set, such as to review the contractor's security qualifications level and restrictions on trading with foreign businessmen and treatment of classified information by means of secrecy for items of independent research and development to prevent the risk of technology leaks because of the relaxation threshold. On the other hand, major losses should be avoided by a system of accountability and a heavy crackdown on those who neglect duty.

C. The hardware support platform of DTCI based on open innovation should be constructed

(i) The establishment of a senior talent pool for the DTCI: In order to afford sufficient talent for DTCI, the senior talent pool of management and technology should follow efficient methods, such as widening the scope of talent selection, scientific and reasonable selection procedure, and so on. Meanwhile, a scientific and effective talent management system should be built for this talent pool, such as establishing an expert agency mechanism to resolve the management of misconduct and the "moral hazard" problem coming from a number of experts, so that the twisted relationship between experts and their working members is readjusted, and the basic system of performance tracking and contact information with various enterprises, with which the effective usage of the personnel is closely followed and unqualified personnel or the dark side of human resources in some units are revealed so as to promote more proper usage of available talents.

(ii) The development of direct participants in the DTCI: In addition to increasing direct supporters concerning the DTCI, such as core technology providers, technical supporters, and material resources available, the technology users, intermediary service organizations, providers of technology information, providers of DTCI services, etc. should be developed so as to promote the development of the DTCI business.

(iii) Supply of adequate funding: The state should take some effective measures to financially support the development of DTCI, such as setting up a special fund, focusing on a financial support or incentives policy for the development projects of DTCI, procuring by the government on home enterprise products of core technologies, introduction of venture investors, etc. Meanwhile, effective venture contract management and the withdrawal mechanism from venture investments should be established by a central government so as to encourage more investors to participate in the DTCI (Ma, 2007).

D. Matching management measures for the operation of this support system should be done well

(i) Deepen reform on resource allocation of the military industry so as to build strategy for military and civilian integration: Firstly, measures that promote and uncover resources for the national defense to advance should be developed, such as the establishing relatively uniform technical standards among military and civilian industries, compressing unnecessary confidentiality restrictions, expanding the scope of civilian-use enterprises to join weapons research and production, establishing unified military and civilian strategy of high-tech R & D and technology integration should be established, etc., so as to break the closed state of resources. Secondly, in order to avoid similar problems of quality, cost and scheduling when weapons are researched and produced, resulting from unreasonable weapon pricing, the state should encourage pricing policies on dual-use core technology products. (Wang, 2008).

(ii) Deal well with the relationship between participants and members of the organization subsystem: The correct positioning of organizing members is that they are makers of policies, regulations and planning, advocates to promote the project operation, coordinators of issues and service of the DTCI work. And they have equal status with participants, correctly guiding participants through the DTCI projects. Moreover, participants and organizers should mutually supervise, so as to prevent corruption of the organizers and participants.

(iii) Correct the twisted relationship between major participants: There are two vexing problems between the major participants of DTCI, one of which is that participants cheat on others; the other is the distortion of the principal-agent relationship coming from a multiple principal-agent way. Due to the lack of effective incentives and restraint mechanisms, it results in the failure of the project commissioned. For the first one, those who break credibility by policy of strict norms and regulations need to be punished; for the second one, comprehensive management measures should be done, such as to reasonably select experts, to streamline the entrustment way, to strengthen incentives and restraint of team members, etc.

6 Conclusions

The DCTI should be laid on as one of first important works for nearly any country in the world. But it is very difficult to do in that, as it involves many aspects for its integration of resources and strategy selection, the external environment having an important impact on it, even directly deciding its success or failure. Due to China's special conditions and restriction of policy, the support system for the DCTI based on innovation has not been built. It is essential and feasible for China to set up this support system. In addition to the management software platform and hardware platform, the organization of administrators is also included in this support system.

In order to build this support system, some countermeasures should be done, such as forming efficient organization and management systems, establishing and improving policies and regulations, building hardware supportive platforms and matching management measures well for the operation of this support system and so on. This initial conclusion still needs to be replenished and bettered further in future.

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Operational Risk Measurement via the Loss Distribution Approach*

Jichuang Feng, Jianming Chen, and Jianping Li**

In the Basel II Accord, banks are encouraged to use the Advanced Measurement Approach (AMA), which is suitable for banks to assess operational risk capital, but banks are required to demonstrate their ability to capture severe tail loss events. In this chapter, based on 860 operational risk loss data of Chinese commercial banks collected from public reports from 1995 to 2006, we found that the sample data set is characterized as having a heavier tail than a normal distribution. Then we use the loss distribution approach (LDA) to measure the operational risk and operational risk capital of Chinese commercial banks after a brief introduction to LDA. At last, we compare the operational risk economic capital of Chinese commercial banks with the operational risk economic capital (EC) of other major banks. We discover that the operational risk of Chinese commercial banks is larger than that of some foreign major commercial banks.

1 Introduction

Operational risk is one of the most important risks of Chinese commercial banks, and it brings huge losses to Chinese commercial banks. In recent years, the frequency and severity of operational risk have become increasingly high. We realized

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* The work was supported in part by a grant from the National Science Foundation of China (#70701033, #90718042, and #70531040).

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that we should use quantitative methods to better understand our operational risk profiles and to estimate the economic capital for operational risk. Operational risk, the BCBS (2004) defines it as "the risk arising from inadequate or failed internal processes, people and systems or from external events" (De Fontnouvelle et al., 2005). This definition, which is based on the underlying causes of operational risk, includes legal risk but excludes business and reputational risk.

Unlike the modeling of market and credit risk, the measurement of operational risk faces the challenge of limited data availability. Furthermore, due to the sensitive nature of operational loss data, banks are not likely to freely share their operational loss data. The Basel II Accord suggests three methods for calculating operational risk capital charges: (i) the basic indicators approach (BIA), (ii) the standardized approach (STA), and (iii) the advanced measurement approach (AMA). As banks become more sophisticated, they are encouraged to move along the spectrum of available approaches. The underlying hypothesis here is that the use of sophisticated approaches to calculate the regulatory capital by a bank that has an appropriate risk management framework should result in a lower operational risk minimum regulatory capital. This means that the prospects of lower regulatory capital induce banks to use sophisticated risk management practices and modeling approaches.

Only for recently years do we have the measurements of operational risk moving towards a data-driven loss distribution approach (LDA). Therefore, many financial institutions have begun collecting operational loss data, as they are trying to move towards an LDA to measure their operational risk. And several researchers have experimented with operational loss data over the past few years (Aue and Kalkbrenner, 2006/2007; De Fontnouvelle et al., 2003; Dutta and Perry, unpublished; Embrechts et al., 2004; Moscadelli, 2004).

One approach for calibrating operational losses is to fit a parametric family of distributions, such as a log-normal, weibull, and exponential. An alternative approach, pioneered in several works by P. Embrechts, uses the extreme value theory (EVT) to fit a generalized pareto distribution (GPD) to extreme losses exceeding a high pre-specified threshold (Embrechts et al., 2003; 2004; 1997; 2005).

In this chapter, we aim to develop a process for Chinese commercial banks to measure their operational risk and enhance their operational risk management. In this chapter, first, 860 pieces of publicly reported operational risk loss data of Chinese commercial banks were collected, which is from 1995 to 2006. We find that the sample data set is characterized as having a heavier tail than a normal distribution. Later, we introduce the framework of the loss distribution approach, which is used in the chapter. Then we use the loss distribution approach to measure the operational risk and operational risk capital of Chinese commercial banks. At last, we compare the operational risk capital of Chinese commercial banks with the operational risk economic capital of other banks. We discover that the operational risk of Chinese commercial banks is larger than that of foreign commercial banks.

The chapter is organized as follows: Section 2 describes the risk measurement framework. In Section 3, we outline the characteristics of the data we collected. In Section 4, we estimate the operational risk of Chinese commercial banks by using the traditional LDA, and then we compare the operational risk capital of Chinese commercial banks with the operational risk economic capital of other banks. Finally, Section 5 concludes the chapter and summarizes the findings.

2 Loss Distribution Approach

We describe some basic techniques and concepts used in this chapter in this section, and introduce the framework of the loss distribution approach, which is used in the chapter.

In this chapter, we define the amount of risk as the value at risk (VaR) and the expected shortfall (ES). Unlike VaR, ES satisfies the properties of a coherent risk measurement and enables a better capture of the tail events (Artzner et al., 1999). We assume an operational risk measurement period of one year and choose 99%, 99.9% and 99.98% as confidence intervals. We use the Monte Carlo Simulation to estimate the loss distribution.

LDA combines the loss frequency distribution and the loss severity distribution, where the loss frequency distribution is the probability distribution of the number of times loss occurs during the risk measurement period; meanwhile, the loss severity distribution means the probability distribution of the amount of losses incurred per occurrence. Two assumptions are used in the LDA model: (i) the frequency and severity are independent and (ii) two different losses in the same class are independently and identically distributed.

The amount of operational risk is estimated by the following process:

1) Estimating the Loss Frequency Distribution

The distribution of N, which is the number of losses during the risk measurement for one year, is estimated. We assume that N follows a Poisson distribution, and the probability function of the Poisson distribution is $f(x) = \frac{e^{-\lambda} \lambda^{-x}}{x!}$. The expected value is λ, which is estimated by equating this with the annual average number of loss events.

2) Estimating the Loss Severity Distribution

The loss severity distribution means the probability distribution of the amount of losses incurred per occurrence. Based on the estimation of the loss severity distribution, we estimate the amount of losses per occurrence of the operational risk loss events. There are two methods to estimate the severity distribution; one is the parametric method, in which a particular severity distribution is assumed, and the other is the nonparametric method. In this chapter, we use the parametric method.

3) Calculating the Loss Amount

We use loss frequency distribution estimated in 1) above, and the number of annual losses N is derived. Then the severity of losses of N occurrences X_i (i=1, 2, …, N) is derived from the severity distribution estimated in 2) above. The total amount S of operational risk losses of one year equals to:

$$S = \sum_{i=1}^{N} X_i$$

4) Calculating the VaR and ES by Monte Carlo Simulation

Repeat step 3 K times and arrange the results in ascending order as S_j. The amount of risk is:

$$VaR(\alpha) = S_i\,,\ \frac{i-1}{K} \le \alpha < \frac{i}{K}, i = 1, 2, \cdots, K\ .$$

And,

$$ES(\alpha) = \frac{\sum_{i=j}^{N} S_j}{K - j - 1}, \frac{j-1}{K} \le \alpha < \frac{j}{K}, j = 1, 2, \cdots, K\ .$$

3 Description of Operational Risk Data

Measurement and management of operational risk has been impeded by the lack of internal or external data on operational losses, and as far as we know, no available, reliable public data source on operational risk exists in China. We consider newly available data collected from public information sources; 860 pieces of operational risk loss data from Chinese commercial banks from 1995 to 2006 are obtained. According to the definition of operational risk in Basel II accord, we use the direct loss data as our operational risk data. To determine the characteristic of the sample data set used for operational risk measurement, we evaluate the tail heaviness of the sample distribution. As shown in the figure 1, the distribution of the sample data set exhibits a much heavier tail than a normal distribution.

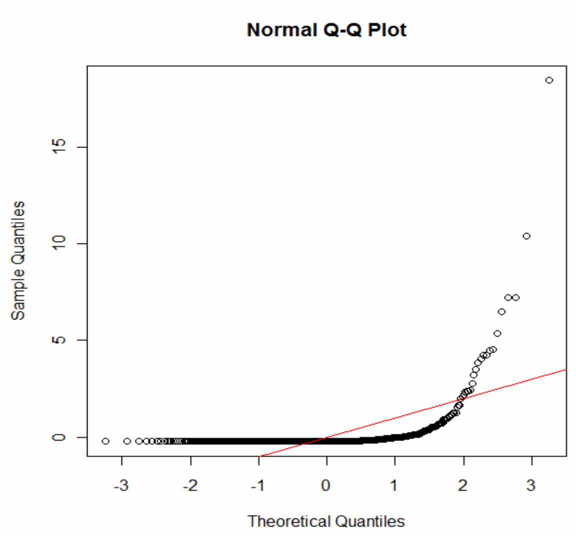


Fig. 1 Q-Q Normal plot for data sample

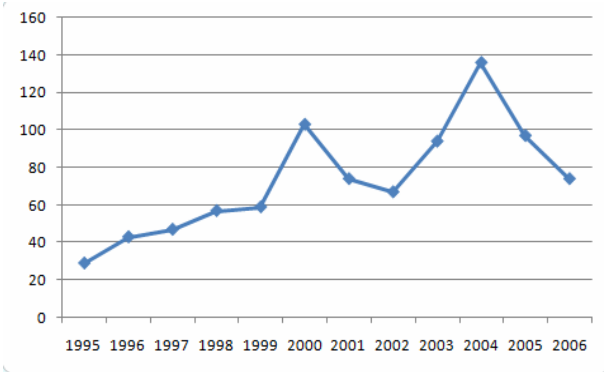


Fig. 2 Occurrence times of operational risk loss per year

Table I Statistical Characteristic Of The Sample Data Set

Mean	Median	*skewness*	kurtosis.
1.200e+04	4.390e+02	10.72768	156.8218

From Figure 2, we can see the occurrence times of the operational risk loss per year from 1995 to 2006 in the sample data set, and we can find that occurrence times after 2000 are more than occurrence times before 2000. The reason for this phenomenon may be that few people understood operational risk before 2000 in China, as operational risk is one of the most crucial risks that has not been realized. We choose the occurrence times of operational risk loss per year from 1996 to 2006 as our useful data in estimating the parameter of the loss frequency distribution. In estimating the parameter of the loss severity distribution, all loss data was used. The statistical characteristic of the sample data set used for operational risk measurement is shown in Table I.

4 Operational Risk of Chinese Commercial Banks and Analysis of the Results

In this section, operational risk and the capital of Chinese commercial banks are calculated using the techniques described in Section 2 and based on the sample data discussed in Section 3. We evaluate the result of measuring the operational risk.

In subsection *A*, we estimate the parameter of operational risk frequency distribution. In subsection *B*, we calculate and analyze the amount of risk by LAD. In subsection *C* and *D*, we compare the operational risk capital of Chinese commercial banks with the operational risk EC of other banks.

A. Estimating the Parameter of the Operational Risk Frequency Distribution

If we want to simulate the operational risk, the parameter estimation of the operational risk frequency distribution is needed, so first we estimate the parameter of the operational risk frequency distribution. In Section 2, we have assumed that the occurrence times of the operational risk follow a Poisson distribution. Using occurrence times of the operational risk loss per year from 2000 to 2006, we adopt the Maximum likelihood Method (MLE). We can get the parameter of operational risk frequency distribution λ=73.

Table II Results of parameter estimation

	EXPONENTIAL	WEIBULL		LOG-NORMAL	
MLE	Rate	Shape	Scale	Mean-log	SD-log
	8.331405e-05	3.650340e-01	1.874324e+03	6.17817323	2.84692718

B. Estimating the Parameter of the Operational Risk Severity Distribution

We apply three different severity distributions to all the data and use MLE to quantify the amount of risk. The exponential distribution, the weibull distribution and the log-normal distribution are used. The estimated parameters are shown in Table II.

Before we test the hypothesis, QQ-plots of the empirical distribution with the log-normal, exponential and weibull distribution are shown in Figure 3.

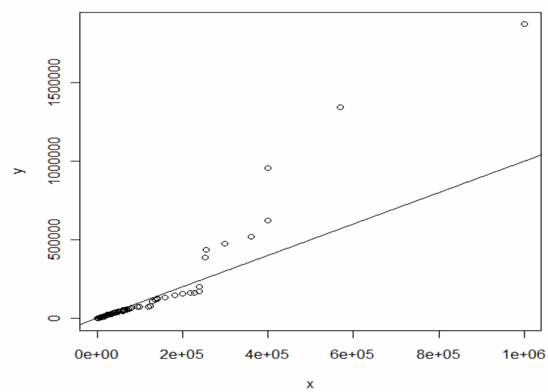
From Figure 3, we could find that the Log-normal distribution fits the data set better than the others.

In Table III, the chi-square test and K-S test for log-normal, weibull and exponential distributions fitting the loss data are given.

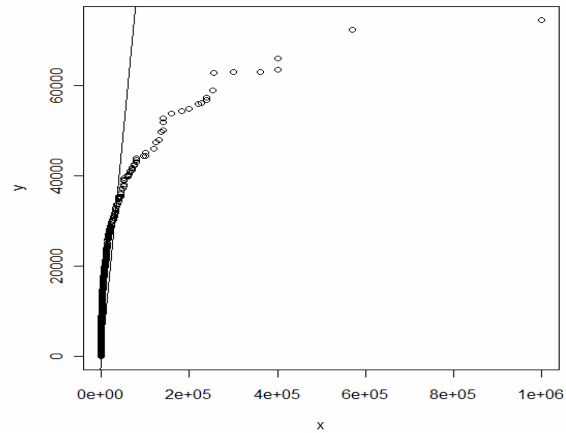
From Table III, we find that only the Chi-Square test P-value is over 5%, so we can conclude that the data follows a log-normal distribution with a Mean-log=6.17817323, and SD-log=2.84692718 is accepted, as the p-value is greater than the significance level fixed at least in 5%. Meanwhile, we accept the null hypothesis that the data follow a Log-normal distribution, because the K-S p-value is higher enough than the significance levels usually referred to in statistical literature. All in all, we suppose the log-normal distribution fits the operational risk severity distribution well.

C. Results and Results Analysis

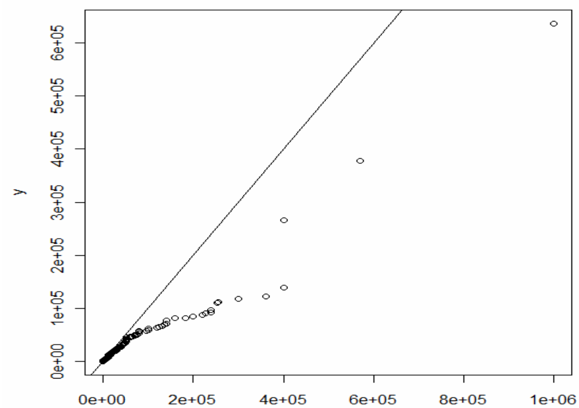
Using the method in Section 2, for the distribution we choose and the parameters we estimate, we simulate the situation 1,000,000 times so that we can get the VaR, mean, EC and ES at different confidence intervals. The results are shown in Table IV.



a. Log-norm



b. Exponential



c. Weibull

Fig. 3 QQ-plots of data sample (x denotes sample quantiles and y denotes theoretical quantiles)

Table III P-value of hypothesis test

distribution	P-value(chi-square test)	P-value (K-S test)
Exponential	0	2.2e-16
Weibull	6.467809e-05	0.001209
Log-normal	0.051	0.2673

Table IV Amount of operational risk

	VaR	Mean	EC	ES
99%	170083	19931	150151	422934
99.9%	723061		703130	1527688
99.98%	1679917		1659986	3339510

Unit: million

Table V Detailed data of the different banks

Name of bank	Total assets	Total regulatory capital: Basel II approach	Total economic capital	Operational risk economic capital:Basel II AMA	Operational risk regulatory capital: Basel II BIA	Name of bank
Citigroup	\$1,484,101	\$100,899	\$52,200	\$8,100	\$10,621	\$1,484,101
Bank of America Corp.	\$1,044,660	\$92,266	\$69300	NA	\$6,065	\$1,044,660
JP Morgan	\$1,157,248	\$96,807	\$34,900	\$4,500	\$4,305	\$1,157,248
AIG	\$1,157,248	\$73,317	\$40,000	\$5,388	\$4,875	\$1,157,248
Deutsche Bank	€1,126,000	NA	€11,693	€3,323	NA	€1,126,000
Chinese commercial banks	￥43,949,970	NA	NA	￥703,130	NA	￥43,949,970

Unit: million

According to the requirement of Basel II under the 99.9% confidence interval, it is easy to find that the overall operational risk of Chinese commercial banks is 7.23×10^{11} yuan, the overall operational risk regulatory capital of Chinese commercial banks is 7.03×10^{11} yuan each year, and the ES under the 99.9% confidence interval is 1.53×10^{12} yuan. If all commercial banks in China want to get the AA rate, 1.66×10^{12} yuan operational risk regulatory capital is needed each year; meanwhile, the ES under the 99.98% confidence interval is 3.34×10^{12} yuan.

D. Comparing Results of LDA of Chinese Commercial Banks with Foreign Banks

In subsection *C,* we measured the operational risk of Chinese national commercial banks. In this subsection, we compare the results with the operational risk of foreign banks. The detail data is shown in Table V.

From Table V, we can see the total assets of China as a nation is larger than foreign banks. Meanwhile, we also find that the operational risk is larger than that of any others. From column 4 and 5, we can discover that the ratio of the operational risk economic capital to the total economic capital is from 12.9% to 28.4%, but we believe that the ratio of Chinese banks is higher than this. The ratio of the operational risk regulatory capital to total regulatory capital is from 4.4% to 10.5%. So we get a large operational risk of Chinese commercial banks using the LDA. We suppose that the operational risk of our banks is so large because of two possible reasons: first, the data samples contain a disproportionate number of very large losses. In the present case, the disproportionate number of large losses can lead to an estimate that overstates a bank's exposure to operational risk. Second, the operational risk management in our banks is poor. So our commercial bank should intensify operational risk management to improve our banks' competitiveness in financial globalization.

5 Conclusion

Despite many headlines having reported operational losses that occurred over the past decade in China, banks have made limited progress in quantifying their operational risk. Instead, qualitative approaches have been emphasized in operational risk management; take enhancing the firm's control environment and monitoring "key risk" indicators as an example. This qualitative emphasis has been driven by the lack of reliable operational losses. This chapter analyzes recent available publicly disclosed data, and we implement LDA to measure the commercial banks' annual operational risk and operational capital. We find that the Chinese commercial banks' annual operational risk is 7.03×10^{11} yuan, which is larger than foreign international commercial banks. So our commercial banks should intensify operational risk management to improve our banks competitiveness in financial globalization.

At last, we emphasize that this chapter has to be primarily taken for its methodological aspects. Even though our data is real data, it is biased data. Only when banks have completely collected operational data, the full potential of this very promising area of research will find a practical achievement. If more extensive and robust data is available, the results will make sense.

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Research on Greedy Simulated Annealing Algorithm for Irregular Flight Schedule Recovery Model

Qiang Gao, Xiaowei Tang, and Jinfu Zhu

To release the severe influence caused by irregular flight, this chapter puts forth a new model and its optimization algorithm based on the existing model, the focus of which is to design a Greedy Simulated Annealing Algorithm. The new algorithm, which integrates the characteristics of GRASP and the simulated annealing algorithm, improves the efficiency of neighborhood selection and reduces the probability of falling into a local optimal solution. An example proves that this algorithm is capable of solving large-scale irregular flight schedule recovery, with the time cost suitable to the outcome quality.

1 Introduction

Irregular flights refer to flights that are delayed or cancelled or that land at an alternate airport due to bad weather, mechanical failures, traffic control or some other reason. Problems raised by irregular flights cause passengers great inconvenience, as well as tremendous financial losses to airlines. Irregular fight issues have played a core role in operating efficiency and service quality of the air transport system. The recovery of an irregular flight schedule consists of aircraft schedule recovery, crew recovery and passenger flow recovery. Aircraft schedule recovery has the

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greatest influence on revenue management, so it's the key step. Irregular flight schedule recovery discussed in this chapter refers to aircraft schedule recovery.

To improve market competitiveness and to maximize the utility of aircraft resources, airlines carry out much research on flight schedule (including aircraft schedule and crew schedule) optimization. There is virtually not enough slack time (Etschmaier and Mathaisei, 1985) in response to the unexpected changes in the flight schedule. Due to the high backup cost of aircraft resources, airlines are not willing to allow any aircraft to standby, in case of changes to the flight schedule, which is one of the major reasons that the capacity deployment is difficult under irregular circumstances. In addition, the operating environment of the flight schedule is uncertain, e.g. aircraft availability, crew feasibility and maintenance constraints increase the complexity of schedule adjustment, as well as airport runway conditions, flight conditions of plateau regions, air route restrictions, etc.

To exactly describe an irregular flight schedule recovery and search for an optimization algorithm has always been the central issue in aviation OR research. In order to solve the resource optimization problem that may occur anytime for airlines, finding a rapid and effective algorithm would result in enormous economic benefits. Studies on aircraft recovery can be traced back to the 1960s. Until the mid-1990s, the study has mainly been focused on the recovery of a single-fleet, small-scale delay (Teodorovic and Guberinic, 1984; Teodorovic, 1988; Teodorovic and Stojkovic, 1995). However, the single-fleet model doesn't work well for airlines, because rarely do airlines have a single fleet, and even if it does, aircrafts of the same type are different in airworthiness. In essence, they are multi-type. Since the mid-and-latter-1990s, multi-fleet, multi-type and large-scale delays have gradually been the focus of the study in the field. In model construction, the resource assignment model and the multi-commodity flow model emerged one after another (Cao and Kanafani, 1997; Yan and Young, 1996; Yan and Tu, 1997; Michael and Jonathan, 1997; Thengvall, 1999). Whether the fleet type is single or multiple, a common problem is algorithm complexity. Irregular flight schedule recovery is a real-time network optimization problem with multiple and complicated constraints, the solution space of which increases exponentially with the number of aircrafts and flights, that is, a NP-hard problem with multiple parameters and multiple constraints. At present, GRASP, a time-space network algorithm, etc. have been maturely applied. As a heuristic algorithm, GRASP is most applicable on large-scale problems. However, for large-scale problems, it has poor convergence and more easily falls into a local optimal solution. The time-space network algorithm tries to reduce the delayed time by reconstructing new routes, which makes the problem difficult to solve. When the scale reaches more than 20 aircrafts and 80 flights, the computing time required by the time-space network algorithm extends beyond 30 minutes, which is difficult for meeting the real-time control requirement of the airlines.

First, this chapter appropriately improves the irregular flight schedule optimization model raised in Reference (Michael and Jonathan, 1997), focusing on bringing forward the Greedy Simulated Annealing Algorithm. The new algorithm includes the greedy and random ideas in GRASP and improves the convergence of GRASP by designing an alternative pool with neighborhood solutions in it. Also, it incorporates the characteristics of simulated annealing, reducing the probability of falling into a local optimal solution.

2 Optimization Model of Irregular Flight Schedule Recovery

Existing optimization model (Michael and Jonathan, 1997) could describe irregular flight schedule recovery issues well. However, the required constraints for the recovery haven't been discussed in detail, including flight connecting constraint, turn-time constraint, airport curfew constraint, etc. In this chapter, the model is properly improved. Variables used in the model are defined as follows:

O : set of aircraft routes in the original flight schedule

A : set of implemented aircraft routes

C : set of cancelled aircraft routes

F : set of flights

S : set of overnight airports

P : set of airports covered by flights

O_i : aircraft route *i* of the original flight schedule

A_i : implemented aircraft route *i*

C_i : cancelled aircraft route *i*

F_{ij}^{K} : flight *K* is No. *j* on aircraft route *i*. The last flight in aircraft *i* is called the tail flight, denoted as F_{itail}^{K}.

$F_{ij,departure}^{K}$: departure airport of flight *j* on aircraft route *i* with flight No. *K*

$F_{ij,arrival}^{K}$: arrival airport of flight *j* on aircraft route *i* with flight No. *K*

p^K : number of passengers in flight *K*

$F_{itail,arrival}^{K}(s)$: the arrival airport of tail flight *K* on aircraft route *i* is *S*

N_s : number of overnight aircrafts required in airport *s*

$F_{ij,ETD}^{K}$: estimated departure time of flight *K*, $F_{ij,STD}^{K}$: scheduled departure time of flight *K*, $F_{ij,ETA}^{K}$: estimated arrival time of flight *K*, $F_{ij,STA}^{K}$: scheduled arrival time of flight *K*

d^K : delayed time of flight *K*, determined by the difference between F_{ETD}^{K} and F_{STD}^{K}

CD : delayed cost per passenger if the flight is cancelled. In accordance with international practice, cancellations could be seen as delays, and the delayed time of cancelled passengers is 480 minutes.

TR_i : turnaround time of an aircraft on route i

$F^K_{departure}(curfew)$: curfew time in the departure airport of flight K, $F^K_{arrival}(curfew)$: curfew time for the arrival airport of flight K

The objective is to minimize the total passenger delayed time as follows:

$$\min \sum_A p^K d^K + \sum_C p^K \times CD \tag{1}$$

$$F^K_{ij,arrival} = F^Q_{ij+1,departure},\ i \in A \tag{2}$$

$$F^K_{ij,ETA} + TR_i \le F^Q_{ij+1,ETD},\ i \in A \tag{3}$$

$$\sum_A F^K_{itail,arrival}(s) = N_s,\ s \in S \tag{4}$$

$$\sum_A F^K + \sum_C F^Q = \sum_O F \tag{5}$$

$$F^K_{ij,ETD} < F^K_{departure}(curfew),\ F^K_{ij,ETA} < F^K_{arrival}(curfew),\ i \in A \tag{6}$$

where $F^K_{ij,arrival}, F^Q_{ij+1,departure}, F^K_{ij,ETD}, F^K_{ij,ETA}, F^K_{itail,arrival}(s)$ are integers.

Formula (1) is the objective function, in which the total passenger delayed time consists of delayed time for delayed and cancelled passengers, respectively; Formula (2) delivers that implemented flights in the same aircraft route should meet the space connecting requirement, that is, the arrival airport of the previous flight remains the same as the departure airport of the following flight; Formula (3) indicates that the implemented flights on the same aircraft route should meet the time connecting requirement, that is, the ETA of the previous flight plus the turnaround time should be earlier than the ETD of the following flight; Formula (4) requires that the implemented aircraft route should meet the aircraft flow balance, e.g. the number of overnight flights (in each airport) in the recovery plan should be equal to that in flight schedule; Formula (5) embraces the flight cover principle, where all flights in schedule should be contained in the recovery plan, in implemented routes or cancelled routes; Formula (6) requires that the ETD/ETA of all flights shouldn't go beyond the curfew of the departure/arrival airport.

3 Analysis of Grasp

Before analyzing GRASP, four definitions are required: flights circuit, flight string, implemented aircraft routes, cancelled aircraft routes.

Definition 1. Flight circuit refers to a both linked aircraft route where the first flight originates and the last flight terminates at the same airport;

Definition 2. Flight string refers to a both linked aircraft route where the first flight originates and the last flight terminates at different airports;

Definition 3. Implemented aircraft routes: aircraft routes that are operated with the aircraft No (four numbers) in the original flight schedule.

Definition 4. Cancelled aircraft routes: aircraft routes that are operated with a virtual aircraft No (begin with V). A virtual aircraft that just is assumed for operator is not actually possessed by airlines. Flights in this aircraft route will be cancelled.

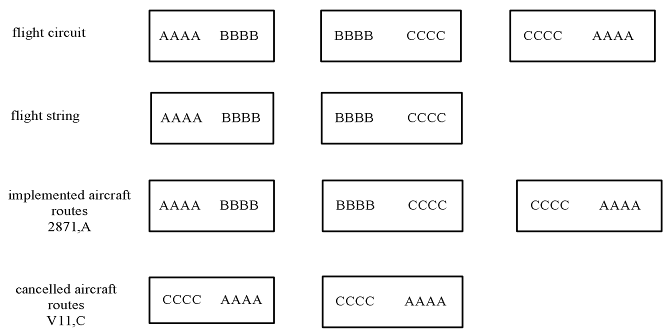

Fig. 1 Flight Circuit, Flight String, Implemented Aircraft Route, Cancelled Aircraft Route

GRASP consists of circulating three stages: beginning with initial feasible solutions and constructging neighborhood solutions; then, putting better neighborhood solutions into the RCL; finally, randomly choosing one from the RCL to construct feasible solutions. The specific operations are based on the flight circuit and flight string, including 7 types: the flight circuit prefix, flight circuit infix, flight circuit suffix, flight circuit cancelled, rear connect flight string, swap flight strings with the same departure airport and swap flight strings with the same departure and arrival airport. The deficiencies of GRASP are as follows:

1) Three of the foregoing seven operations could be merged.

2) The length of the RCL list is not easily determined. Even worse, the sequencing operation applied to inserting neighborhood solutions into the RCL results have worse time efficiency.

3) GRASP only allows the feasible solutions to iterate on the cost-reduced direction, which could cause the algorithm to fall into a local optimal solution.

4 Greedy Simulated Annealing Algorithm

A. Construction of neighborhood solutions in the new algorithm

The model in this chapter is based on aircraft routes, so in essence the optimization process is to construct new routes to replace the ones with the same flight No in previous solutions. To ensure the generation process is not against Formula

(2)(4)(5), it should be in accordance with operations raised by GRASP. It was analyzed that the flight circuit prefix, infix and suffix could be combined as the flight circuit insertion. Thus, the seven operations can be simplified as five. The five operations are equivalent to constructing neighborhood solutions to create new aircraft routes. Newly-generated routes can meet the constraint (3) by re-scheduling the ETD and ETA of flights. Re-scheduling methods are as follows:

1) Set the ready time of a certain aircraft as the ETD of its first flight in the implemented route if the STD is earlier than the ready time.

2) The ETA of the first flight equals the ETD plus the flight span (STA of the first flight minus STD). STA refers to Scheduled Time of Arrival and STD for Scheduled Time of departure.

3) The ETD of the following flight equals the ETA of the previous flight plus the turn-time of this aircraft.

4) The ETA of the following flight equals the ETD plus the previous flight span (STA of this flight minus STD)

Choosing any two aircraft routes by the five operations would result in many neighborhood solutions, over ten under normal circumstances. If there are many routes in the flight schedule, the number of generated neighborhood solutions is very large; thus, the construction of the new feasible solutions requires special treatment.

B. Alternative Pool of Neighborhood Solutions

One feasible solution is a flight recovery scenario. Generate neighborhood solutions by choosing two aircraft routes from a recovery scenario and then replace the aircraft routes with the same aircraft No in a current solution, and new feasible solution emerges. However, choosing a pair of routes from the previous solution could generate many neighborhood solutions.

To ensure the feasibility of the algorithm, an evaluation should be made to choose the optimal neighborhood solution from the generated ones. If the total delayed cost of its neighborhood solution is less than the previous two routes, we put it in an alternative pool for cost-reducing solutions; otherwise, it is put into an alternative pool for cost-increasing solution. The two pools are collectively referred to as alternative pools of the neighborhood solutions.

The new algorithm does not store the superior solutions into an RCL list but directly puts the optimal neighborhood solution into the alternative pool, which could better control the scale of the neighborhood solutions, remove the sequencing operation and improve time efficiency. But it increases the probability of falling into a local optimal solution. So in the new algorithm, we bring forward a search strategy based on the simulated annealing algorithm to settle it.

C. Construction of a feasible solution in the new algorithm

By combining any two aircraft routes, we could obtain neighborhood solutions and put them into cost-reducing and cost-increasing alternative pools, then randomly choosing only one from the pools to construct a feasible solution from the pools. The details are as follows:

1) To ensure Formula (6), aircraft routes that are beyond curfew require assigning a considerable delayed cost. First, check whether there are aircraft routes that violate curfew in the incumbent solution. If there are, prioritize choosing the neighborhood solution to replace the ultra-curfew routes. Through this method, infeasible solutions can be turned into feasible ones by finite iterations.

2) If there are no aircraft routes beyond curfew in the current solution and the cost-reducing alternative pool is not empty, choose a neighborhood solution randomly from it.

3) If there are no ultra-curfew aircraft routes in the current solution and the cost-reducing alternative pool is empty, it indicates that the current solution doesn't have a cost-reducing direction. To avoid falling into a local optimal solution, the current solution is allowed to deteriorate temporarily in accordance with the simulated annealing algorithm, so choose a neighborhood solution from the cost-increasing alternative pool. Since the cost-increasing direction always exists and the number of neighborhood solutions is large, judge the number of neighborhood solutions that meet Formula (7) and its percentage in the cost-increasing alternative pool. If the percentage is over 5%, randomly choose one; otherwise, the algorithm terminates.

$$\exp(-\Delta / K_t) > random(0,1) \tag{7}$$

Of which: Δ is the increased delayed cost of the neighborhood solution; K_t is current temperature; $random(0,1)$ is a uniform random number between 0 and 1.

After choosing a neighborhood solution, we may improve the current solution to get a new solution for the next iteration. If there is no neighborhood solution that meets all the constraints, the algorithm exits automatically. Irregular flight schedule recovery is of a high level in time efficiency, so the function for controlling time is set in the algorithm. When the operating time reaches the limit, it is forced to exit. The overall flow diagram is as follows (See Figure 2).

5 Example Analysis

One day, an airline's flight schedule has not yet been operated when some irregularities occur, the causes of which are shown in Table 1. The original schedule consists of 149 flights, carried out by 30 aircrafts. Due to limited space, here lists only 5 aircraft routes in table 2. The curfew time of some airports is shown in Table 3. The delayed cost for airline passengers is 1 RMB / (minutes * person).

When the causes of the flight irregularities appear, if the flight operators don't adopt a positive strategy and implement the flights as scheduled—postponing the flights—it will result in the cancellation of the light GH9538 flown by aircraft 2875 because the departure time is beyond the curfew time. This does not only influence itself but also the implementation of the flight schedule the next day. This method will cause a total delayed cost of 503,730 RMB.

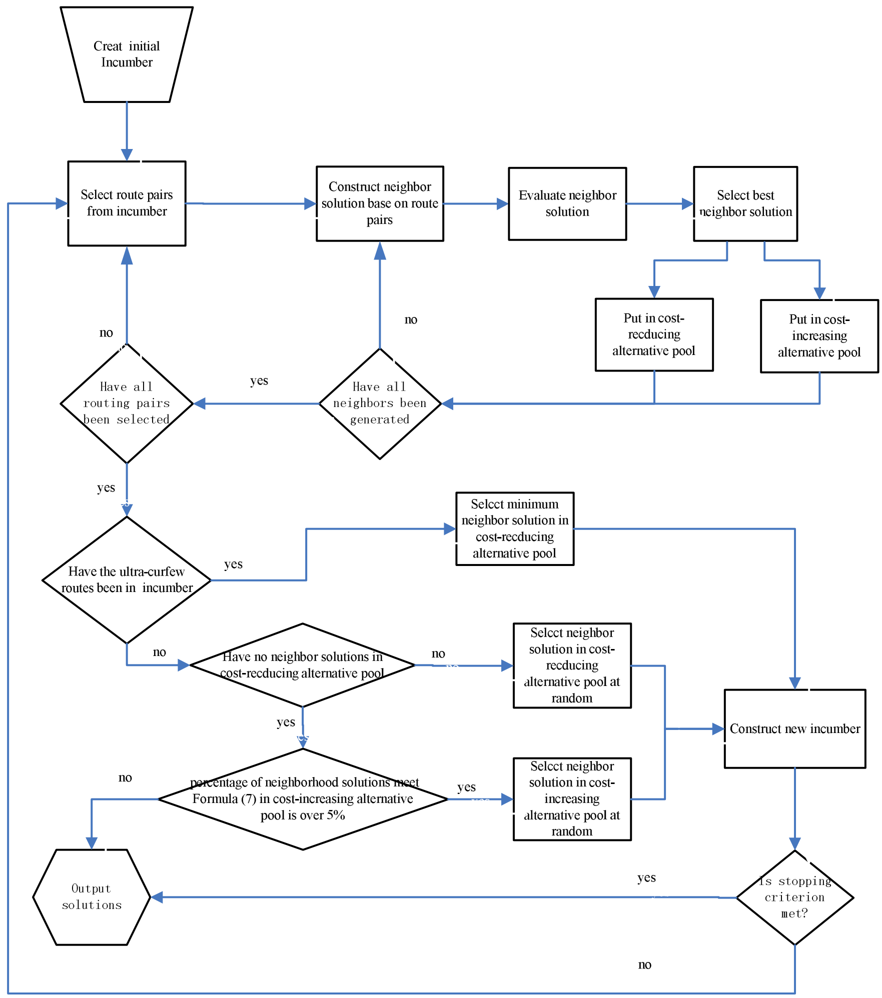

Fig. 2 Flow diagram of the greedy randomized simulated annealing algorithm

However, if the model and algorithm described in this chapter are implemented, the optimal recovery scenario only costs 359,820 RMB, reducing the ratio up to 28.65%. The comparison between the two methods is detailed in Table 4.

Through the analysis, some adjustments on aircraft routes 2875 and 3020 result in the optimal solution, as Figure 3 shows. The simple adjustment turns the flight schedule from infeasible to feasible and leads to a significant reduction in the delayed cost. However, the simple adjustment couldn't be achieved as easily. If the number of aircrafts and flights is large, it is difficult to manually discover. In fact, flight operators in airlines cancel flights GH9183 and GH 9184 of aircraft 2875, or flights GH9537 and GH9137. Obviously, it's far from the optimal solution.

Table I Reasons for Irregular Flights

Irregular Reason	Tail No.	Estimated Ready Time	Scheduled Ready Time	Airport Name	Start Time of Closing	End Time of Closing
Mechanical Problem	2153	1000	830			
Mechanical Problem	2833	1100	700			
Mechanical Problem	2875	1030	830			
Mechanical Problem	5088	840	740			
Mechanical Problem	5142	900	810			
Mechanical Problem	5148	1105	805			
Weather				ZGGG	800	1000
Weather				ZSPD	1800	2000

Table II Original Flight Schedule (A)

Tail No.	Seats	Ready Time	Turn Around Time	Flight No.	Depart Airport	STD	ETD	Arrival Airport	STA	ETA	Pax
2153	171	1000	40	GH9521	ZSSS	830	1000	ZSFZ	940	1100	47
				GH9129	ZSFZ	1255	1255	ZBTJ	1500	1500	12
				GH9130	ZBTJ	1545	1545	ZSSS	1730	1730	72
				GH9115	ZSSS	1935	1935	ZBAA	2155	2155	37
2833	200	1100	40	GH2833	ZSPD	700	1100	ZSSS	720	1120	165
				GH9117	ZSSS	845	1200	ZBAA	1055	1410	96
				GH9118	ZBAA	1155	1450	ZSSS	1355	1650	15
				GH823	ZSSS	1530	1730	RKSS	1720	1920	171
				GH824	RKSS	1820	2000	ZSSS	2005	2145	11
				GH9379	ZSSS	2110	2225	ZGSZ	2345	2500	102
2875	200	1030	40	GH9466	ZUUU	830	1030	ZSPD	1100	1300	130
				GH9183	ZSPD	1205	1340	ZYTX	1400	1535	53
				GH9184	ZYTX	1455	1755	ZSPD	1700	2000	149
				GH9537	ZSPD	1805	2040	ZJSY	2055	2330	140
				GH9538	ZJSY	2155	2410	ZSPD	2445	2700	63
3020	50	800	35	GH9275	ZSPD	800	800	ZSAQ	920	920	34
				GH9276	ZSAQ	1000	1000	ZSPD	1120	1120	17
				GH9221	ZSPD	1240	1240	ZLYA	1520	1520	28
				GH9222	ZLYA	1600	1740	ZSPD	1820	2000	8
…											

The running time of applying the algorithm on a P4 2.6G, 512 M memory desktop for a solution is 57 seconds, far lower than the time required for a manual recovery scenario. This wins time for plan approval, resource preparation and crew arrangement. Through a large number of experiments, it shows that the model and optimized algorithm have the following advantages:

1) The model is of good readability. It gives a detailed description of the space and time connecting constraint and airport curfew constraint.

Table III Curfew time of airports covered by flights

Airport	Curfew Time	Airport	Curfew Time	Airport	Curfew Time	Airport	Curfew Time	Airport	Curfew Time
RJNT	2400	VMMC	2400	ZBTJ	2400	ZGSZ	0	ZPJH	2400
RJTT	2400	VTSP	2400	ZBYN	2400	ZGZJ	2400	ZPPP	2400
RKPK	2400	VVTS	0	ZGDY	2400	ZHHH	2400	ZSAM	2400
RKSI	2400	WADD	2400	ZGGG	2400	ZHYC	2400	ZSAQ	2400
RKSS	2400	ZBAA	2400	ZGKL	2400	ZJSY	2400	ZSFZ	2400
ZYTL	2400	ZYTX	2400	ZYYJ	2400	ZLYA	2400	ZWWW	2400
ZSNJ	2400	ZSPD	0	ZSQD	2400	ZSSS	0	ZSTX	2400
ZWTN	2400	ZUCK	2400	ZUMY	2400	ZUUU	2400		

"0" means no curfew.

Table IV Comparison between postponed scenario and optimization scenario

	Total Aircraft	Cancelled Flights	Delayed Flights	Delayed Cost	Delays In 0.5h	Delays In 1h	Delays In 2h	Delays In 3h	Delays In 4h	Delays Over 4h
Postponed	30	0	39	503730	2	6	15	12	3	1
Optimization	30	0	38	359820	2	6	15	10	2	3

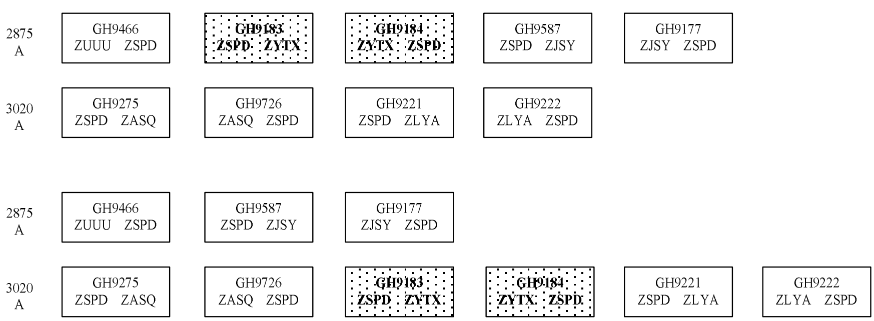

Fig. 3 Illustration of the aircraft route changes in the optimal solution

2) It has a high running efficiency. For an irregular case within 50 aircrafts and 200 flights, the general solving time is less than 2 minutes, and it's capable of meeting the actual requirement. Also, it may significantly reduce the established time for the recovery scenario and win time for organizing work.

3) It has a good effect on optimization. For an irregular case with 50 aircrafts and 200 flights, it may reduce the total delayed cost up to 14-19%. For a medium-sized airline, 90 million RMB per year could be saved accordingly.

4) The algorithm has practicality. The recovery scenario obtained through this algorithm has a small disturbance on the original flight schedule, so it is easy for airlines to deploy aircraft supporting resources.

6 Conclusion

This chapter modifies the original irregular flight schedule optimization model and presents a new algorithm based on GRASP and the simulated annealing algorithm. The new algorithm may improve the time efficiency by applying an alternative pool of neighborhood solutions (including cost-reducing and cost-increasing alternative pools) to replace the RCL linked list in GRASP. Moreover, it incorporates the ideas of the simulated annealing algorithm to effectively reduce the probability of falling into a local optimal solution. The major deficiencies of this algorithm are that the objective function doesn't contain all the costs required for an irregular flight schedule recovery, including the cost of ferrying and fleet substitution. These will direction improvement in the next step.

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Network Externality, Call Externality and Price Policy: A Consumer Development Analysis of China's 3G Mobile Data Services*

Yonghua Gong and Bangyi Li

The key to 3G data service development in the primary period is to expand the firm's number of subscribers and market share. However, price strategy is an important weapon for popularizing 3G data services to some extent. This chapter studies the price of 3G data services and market development under network externalities and call externalities. Consumer "self-selection" is induced in models of bundling tariffs and two-part tariffs. Then the optimal pricing strategies of the two pricing models are analyzed, and then the corresponding market development strategies are dropped from the optimal pricing strategy. The result shows that the optimal consumer development strategy is to draw high-demand consumers to becoming the firm's subscribers with a precedent in both pricing systems because of the effects of network externalities. Following the increase of the proportion of the firm's subscribers, the firm's development of low-demand consumers spreads out. Moreover, call externalities will reduce the firm's activity to serve low-demand consumers.

1 Introduction

The market structure has changed from a duopoly to a triopoly in China's 3G mobile communication market. The competition for mobile communication service firms is becoming fiercer, where 3G tariffs are becoming one of the most important focuses. Compared to 2G, 3G can provide more new services, such as Network

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* This work was supported by the Scientific and Technical Innovation Project of the Jiangsu Provincial Department of Education under Grant CX08B_040R.

Access, Mobile Electronic Business, Location Services (LCS), File Transfering, Conference Bridge and Video on Demand multimedia and Broadband Data Services et al., besides Mobile Voice and Short Messaging Service (SMS). The variety of 3G services, especially the data services, makes the tariff problem even more complicated. The detailed tariff pattern includes the flat-rate, the number of uses, and usage-based and content-based accounting. However, China's 3G firms can still adopt the existing tariff strategy-bundling tariff and two-part tariff, according to the operation experiences of foreign 3G firms and Fu Gang's study (2007). In fact, no matter what tariff policy the firm chooses, attracting more consumers, rapidly opening the market, and improving the market share are the most important things firms need to consider during the early period of 3G services entering the market. However, we know the communication service industry has obvious network effects, and which firm consumers choose will be affected by network externalities, and they will anticipate the net scale and growth prospect. Moreover, interactive services, Point to Point (P2P) and Point to Multi-Point (P2MP) services increase a lot in the 3G age, so under the condition of a one-way charge, the consumers' choice will also be affected by call externalities. With those two externalities, adding a network increases the surplus of other subscribers who are able to call and be called by the new customer, and therefore affects not only consumers' demand for the service but also their demand for a subscription.

If we investigate the market development problem for 3G mobile communication services in the market introduction phase from externalities (network and call externalities) and pricing strategy, then the content that we will study is very clear.

This chapter includes four parts. In the first part, we preview correspondent literature. In the second part, we make some assumptions. In the third part, we first propose a pricing model with network externalities and call externalities. It includes two pricing models-bundling tariffs and two-part tariffs. Then, we solve the pricing models and give the optimal price strategies. Finally, we analyze the relevant market development strategy. In the last part, we draw the conclusions.

2 Literature Review

In this section, we mainly review literature concerning the tariffs model building with network and call externalities. Economists have been quite active in analyzing the effect of network externalities on firms' pricing policies in telecommunications. The main focus has been on how Ramsey pricing should be adjusted in order to internalize network externalities. Efficient pricing with network externalities typically involves a lower price mark-up for uniform pricing (Willing, 1979) and a lower fixed fee for two-part tariffs (Littlechild, 1975), compared to ordinary markets without network externalities. Einhorn (1993) emphasized the importance of the identity of the marginal customer in determining the welfare-maximizing two-part tariff with network externalities. Blonski (2002) found that there's a tendency for conformity that is established by network externalities that may in some sense be overcome by sufficient differentiation in price structures. Call externalities, however, have been given little attention in literature, which is somewhat surprising, considering that roughly half of the benefits of using a telephone service is from receiving calls. To our knowledge, Squire (1973) is the first economist who analyzed incorporating call externalities into telecommunication pricing. He derived the best two-part tariff with call and network externalities, and the result is that a per-call price is less than the marginal cost, which reflects the effect of call externalities. However, it is not implementable without subsidizing the firm using public funds. Willing (1979) argued that call externalities are hard to deal with if they are not easily related to other variables. Hahn (2003) extended previous work on telecommunication pricing to a more general environment where consumers benefit not only from network externalities but also from call externalities. He related the call externalities to variables like outgoing calls and the subscription rate, and he then gave the consumers' utility function.

This chapter will adopt Hahn's dealing method of introducing network externalities and call externalities in a consumer utility function. Since the consumers' utility function consists of the subscription rate, we can use it to analyze a firm's consumer development according to the pricing policy, which is important and new for China's 3G data services during the introduction period. Shuai and Chen (2003) researched China's mobile communication market competition for 2G/1G and 2.5G; they also used network externalities to analyze consumers' choice of services. Pan and Chen (2006) built a two-period model with network externalities to analyze the monopolist's pricing strategy. Xu and Chen (2006) found that network effects can relax the equilibrium condition to engage in price discrimination. Teng and Tang (2008) analyzed the price and social welfare in a duopoly market when the firms both engage in third-degree price discrimination, where the consumers are divided into two types: low-demand and high-demand. The consumer segment is the base for the firm to engage in discrimination. Two-part tariffs and bundling tariffs always divide consumers into different types, depending on the consumption preference. Kolay (2003) builds the two-part tariffs and bundling pricing model just on that consumer segment. So, in our pricing models, we also will focus on two consumer types that differ in their quantity demanded of a product of a fixed quality.

3 Hypothesis and Variables

Consider a monopolistic firm selling a two-way telecommunications service with a marginal cost c. We make the following assumptions for analytical simplicity:

(1) *Uniform communicating pattern*: Every subscriber equally distributes his/her outgoing communications across all subscribers in the network.

(2) *Indifference to communication partners*: Subscribers gain the same benefit from an outgoing or incoming communication regardless of who the recipient (caller) is.

(3) *No charge for incoming calls*: The recipient is free from charge.

(4) *Two types of subscribers*: Subscribers differ in their consumption preference according to taste parameter θ, the low-demand group has taste parameter θ_1 and the high- demand group has taste parameter θ_2, where $\theta_2 > \theta_1$.

(5) The firm's subscriber number is $n \in [0,1]$, the low- demand group occurs in the proportion $\lambda \in [0,1]$, and the high- demand group occurs in the proportion 1-λ.

Network effects make subscribers' value received from connecting to a network depend on the number of subscribers connecting to the network. Subscribers also can get value from call externalities when receiving calls is free. So the subscriber utility consists two parts, from calling and receiving calls. On the basis of the hypothesis mentioned above and the achievement of Hahn (2003), we can define the utility function as $U(q,\tilde{q},\theta,n) = nu(q,\theta) + \alpha(\theta)n\tilde{q}$. q is the number of calls a subscriber makes to each of the other subscribers in the network. $\tilde{q}$ is the average number of incoming calls the customer receives from other subscribers in the network. Here, n reflects the effects of network externalities, and $\alpha(\theta)$ reflects the effect of call externalities. We assume $\alpha \geq 0$, $\alpha'(\cdot) > 0$, $\alpha''(\cdot) \geq 0$. When call externalities do not exist, $\alpha = 0$. The following restrictions are imposed on $U(q,\tilde{q},\theta,n)$:

$$\text{(a)} \quad \frac{\partial U(q,\tilde{q},\theta,n)}{\partial q} > 0, \quad \frac{\partial^2 U(q,\tilde{q},\theta,n)}{\partial q^2} < 0$$

$$\text{(b)} \quad \frac{\partial U(q,\tilde{q},\theta,n)}{\partial \theta} > 0, \quad \frac{\partial^2 U(q,\tilde{q},\theta,n)}{\partial q \partial \theta} > 0$$

With the subscription rate n, the subscriber's total number of outgoing calls is simply given by nq , and then the utility $U(nq,\tilde{q},\theta,n) = nu(nq,\theta) + \alpha(\theta)n\tilde{q}$. We further assume that $u(nq,\theta) = nu(q,\theta)$, then $U(nq,\tilde{q},\theta,n) = n^2u(q,\theta) + \alpha(\theta)n\tilde{q}$.

4 Consumer Development Strategy in a Two Pricing Policy

1. Bundling Tariff Model

Now suppose the monopolist offers a menu of bundles ((nq_1, T_1), (nq_2, T_2)), where nq_i denotes the bundled quantity of services and T_i is its price, with (nq_1, T_1) meant for the low-demand consumer and (nq_2, T_2) meant for the high-demand consumer. Then the monopolist's problem is

$$\max_{q_1,q_2,T_1,T_2} \pi^B = n\lambda(T_1 - cnq_1) + n(1-\lambda)(T_2 - cnq_2) \tag{1}$$

Subject to the low-demand consumer purchasing a positive quantity,

$$n^2u(q_1,\theta_1) + \alpha(\theta_1)n\tilde{q} - T_1 \geq 0 \tag{2}$$

And the high-demand consumer choosing the bundle nq_2 at price T_2 , rather than nq_1 at price T_1,

$$n^2 u(q_2,\theta_2) - T_2 \geq n^2 u(q_1,\theta_2) - T_1 \tag{3}$$

Because the maximand in (1) is increasing in T_1 and T_2, it follows that T_1 will be chosen to satisfy (2) with equality and that, given T_1, T_2 will be chosen to satisfy (3) with equality. To determine the profit-maximizing quantities, we can substitute the T_1 and T_2 obtained in this way into the maximand in (1) and differentiate to obtain the first-order conditions:

$$\lambda\left(n\frac{\partial u(q_1,\theta_1)}{\partial q_1} - c\right) + n(1-\lambda)\left(\frac{\partial u(q_1,\theta_1)}{\partial q_1} - \frac{\partial u(q_1,\theta_2)}{\partial q_1}\right) = 0 \tag{4}$$

$$n(1-\lambda)\left(n\frac{\partial u(q_2,\theta_2)}{\partial q_2} - c\right) = 0 \tag{5}$$

Let $((n\hat{q}_1,\hat{T}_1),(n\hat{q}_2,\hat{T}_2))$ solve the monopolist's problem in (1)-(3). Then the monopolist's maximized profit, given the optimal menu of the price-quantity bundle, is

$$\pi^B = n\lambda(\hat{T}_1 - cn\hat{q}_1) + n(1-\lambda)(\hat{T}_2 - cn\hat{q}_2) \tag{6}$$

Let nq_1^c denote the quantity that satisfies $n\partial u(q_1,\theta_1)/\partial q_1 = c$, and let nq_2^c denote the quantity that satisfies $n\partial u(q_2,\theta_2)/\partial q_2 = c$. Since a high-demand consumer is assumed to have a higher utility at any given quantity than a low-demand consumer, we have that $\frac{\partial u(q_1,\theta_2)}{\partial q_1} - \frac{\partial u(q_1,\theta_1)}{\partial q_1} > 0$. So the first term of the left-hand side in (4) $n\frac{\partial u(q_1,\theta_1)}{\partial q_1} > c$, which implies that the profit-maximizing quantity to the low-demand consumers is less than the efficient quantity nq_1^c. From (4), we know $n\cdot\frac{\partial u(q_1,\theta_1)}{\partial q_1} = \lambda c + n(1-\lambda)\frac{\partial u(q_1,\theta_2)}{\partial q_1}$, so we find that $n\partial u(q_1,\theta_1)/\partial q_1$ is increasing in n, and the profit-maximizing quantity for low-demand consumers is near nq_1^c. This means that in the market introduction period, low-demand consumers are not the key consumer for the firm. Only when the subscriber number n reaches some level, the firm begins to consider increasing the number of the low-demand consumers. The expression in (5) implies that the profit-maximizing quantity for the high-demand consumers is the efficient quantity nq_2^c. Then we can see that the high-demand consumers are the important potential consumers.

Proposition 1. In the bundling tariff mechanism, the firm will first attract high-demand consumers to become its subscribers during the 3G market introduction period, while the number of the low-demand consumers is increasing in n.

We know $T_1 = n^2u(q_1,\theta_1)+\alpha(\theta_1)n\tilde{q}$, and $T_2 = n^2u(q_2,\theta_2) \ -n^2u(q_1,\theta_2)+T_1$, so the effects of call externalities will make both low-demand and high-demand consumers pay more for the same quantity compared to non-existing call externalities. It will affect the low-demand consumers' purchases of the services because they are usually more sensitive to price. In the firm's perspective, the effects of call externalities will weaken the firm's incentive to provide services to low-demand consumers, who only receive incoming calls without making any outgoing call, while it is difficult for the firm to further gain a consumer surplus.

Proposition 2. Call externalities will reduce the firm's incentive to sell services to low-demand consumers.

2. Two-part Tariff Model

Suppose the monopolist offers a menu of two-part tariffs $((p_1, F_1),(p_2, F_2))$, where p_i denotes the per-unit price and F_i is the fixed fee, i=1,2, with (p_1, F_1) meant for the low-demand consumer and (p_2, F_2) meant for the high-demand consumer. Let $q_1(p_1)$ denote the low-demand consumer's quantity choice when facing a per-unit price of p_1, and $q_2(p_2)$ is defined analogously. Then the monopolist's problem is

$$\max_{p_1,p_2,F_1,F_2} \pi^{2PT} = n^2\lambda(p_1-c)q_1(p_1)+n^2(1-\lambda)(p_2-c)q_2(p_2) + n\lambda F_1 + n(1-\lambda)F_2 \tag{7}$$

Subject to the low-demand consumer purchasing a positive quantity,

$$n^2u(q_1(p_1),\theta_1)+\alpha(\theta_1)n\tilde{q}-np_1q_1(p_1)-F_1 \geq 0 \tag{8}$$

And subject to the high-demand consumer choosing to purchase under (p_2, F_2) rather than (p_1, F_1),

$$\begin{aligned} &n^2u(q_2(p_2),\theta_2)+\alpha(\theta_2)n\tilde{q}-np_2q_2(p_2)-F_2 \\ &\geq n^2u(q_2(p_1),\theta_2)+\alpha(\theta_2)n\tilde{q}-np_1q_2(p_1)-F_1 \end{aligned} \tag{9}$$

Because the maximand in (7) is increasing in F_1 and F_2,

$$F_1 = n^2u(q_1(p_1),\theta_1)+\alpha(\theta_1)n\tilde{q}-np_1q_1(p_1) \tag{10}$$

$$\begin{aligned} F_2 = {} & n^2u(q_2(p_2),\theta_2)-np_2q_2(p_2)-n^2u(q_2(p_1),\theta_2) \\ & + np_1q_2(p_1)+F_1 \end{aligned} \tag{11}$$

The first-order conditions for (7) maximization:

$$n\lambda(p_1-c)\frac{\partial q_1(p_1)}{\partial p_1}+(1-\lambda)q_2(p_1)-(1-n\lambda)q_1(p_1)=0 \tag{12}$$

$$n(p_2 - c)\frac{\partial q_2(p_2)}{\partial p_2} + (n-1)q_2(p_2) = 0 \tag{13}$$

Let F_1^c, F_2^c be the fixed fees when $p_1^* = c, p_2^* = c$ and (p_1^*, F_1^*), (p_2^*, F_2^*) solve the monopolist's problem in (7)-(9), and let $T_1^* = np_1^* q_1^*(p_1^*) + F_1^*$ denote the amount paid to the monopolist by a low-demand consumer. And similarly $T_2^* = np_2^* q_2^*(p_2^*) + F_2^*$ .Then the monopolist's maximized profit, given the optimal menu of two-part tariffs, is

$$\pi^{2PT} = n\lambda(T_1^* - cnq_1^*(p_1^*)) + n(1-\lambda)(T_2^* - cnq_2^*(p_2^*)) \tag{14}$$

Given n, the optimal price in a two-part tariff model can be shown as in Fig.1. From (10), we have that F_1^* equals the shaded area A, and from (11), we have that F_2^* equals the shaded area A+B+C. Obviously, F_1^* is decreasing in p_1^* and F_2^* is decreasing in p_2^*. From (12), $p_1^* < c, F_1^* > F_1^c$ when $0 \le n < \frac{1}{\lambda} - \frac{(1-\lambda)q_2(p_1^*)}{\lambda q_1(p_1^*)}$, which implies that under the subscriber number, the activity the firm provides the low-demand consumers is weak, because the fixed fee is high. And $p_1^* \ge c$, $F_1^* \le F_1^c$ when $\frac{1}{\lambda} - \frac{(1-\lambda)q_2(p_1^*)}{\lambda q_1(p_1^*)} \le n \le 1$. Moverover, from (10) we see that call externalities make F_1^* increase, and then it is unfavorable to low-demand consumers.

Proposition 3. In the two-part tariffs mechanism, the price for low-demand consumers is related to the firm's subscriber number in the 3G data services market

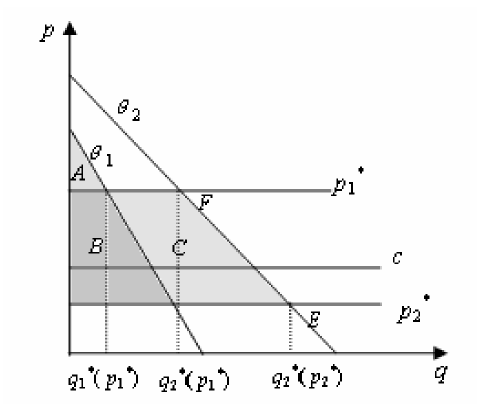

Fig. 1 Optimal Menu of Two-part Tariffs

introduction period. When $0 \le n < \frac{1}{\lambda} - \frac{(1-\lambda)q_2(p_1^*)}{\lambda q_1(p_1^*)}$, the mixed fee is higher, which satisfies $F_1^* > F_1^c$. When $\frac{1}{\lambda} - \frac{(1-\lambda)q_2(p_1^*)}{\lambda q_1(p_1^*)} \le n \le 1$, the fixed fee is lower, which satisfies $F_1^* \le F_1^c$.

From (13), we gain $p_2^* = c - \frac{n-1}{n} \cdot \frac{q_2(p_2^*)}{\partial q_2(p_2^*)/\partial p_2^*}$. Because $(n-1)q_2(p_2^*) \le 0$, $\partial q_2(p_2^*)/\partial p_2^* < 0$,then $p_2^* \le c$ and $F_2^* \ge F_2^c$, which implies that the per-unit price is lower and the fixed fee is higher for high-demand consumers.

Proposition 4. In the two-part tariffs mechanism, the firm's strategy is to charge a low fixed fee from high-demand consumers during the 3G data services market introduction period.

In the two-part tariff mechanism, the fixed fee generally affects the consumer's purchasing decision, and the per-unit price generally affects the purchasing quantity. So a lower fixed fee for low-demand consumers is more effective, even though the per-unit price is higher because their purchasing quantity usually is small. A lower per-unit price is more effective for high-demand consumers because they usually purchase more. Proposition 3 and 4 show that high-demand consumers have a higher value for the firm, and they will first attract them to become the subscribers. The strategy is that the per-unit price for them is lower than the marginal cost. When *n* is small, the mixed fee is higher for low-demand consumers to purchase the service during the primary period. This result is consistent to the experience in foreign 3G market development.

3. *Examples*

To illustrate the second condition of the propositions, suppose $u(q,\theta) = aq - q^2/2\theta$, $a=9$, $\theta_1 = 2$, $\theta_2 = 4$, $c=4$, $\tilde{q}=9$, $\alpha(\theta)=\theta^2$. We begin with the case of bundling tariffs. Substitute in (4), and solving gives $n\hat{q}_1 = \frac{\lambda(16-36n)}{1-3\lambda}$. In Fig.2, we find that *n*=4/9 is the turning point, and the firm begins to attract more low-demand consumers to be subscribers when $n \in (9/4, 1]$.

For the case of two-part tariffs, substitute in (12) and (13), and solving gives $p_1^* = \frac{9n^2\lambda - 14n\lambda + 2\lambda - 2}{2n\lambda - 1}$, $p_2^* = \frac{9n^2 - 5n}{2n-1}$.

In Fig.3, the curve of λ=1/4 shows that $p_1^* < 4, F_1^* > F_1^c$ when $n \in (0, 0.6]$, and $p_1^* \ge 4$, $F_1^* \le F_1^c$ when $n \in (0.6, 1]$. Because the low-demand consumer's purchasing quantity is small and sensitive to price, so they are usually not regarded as a

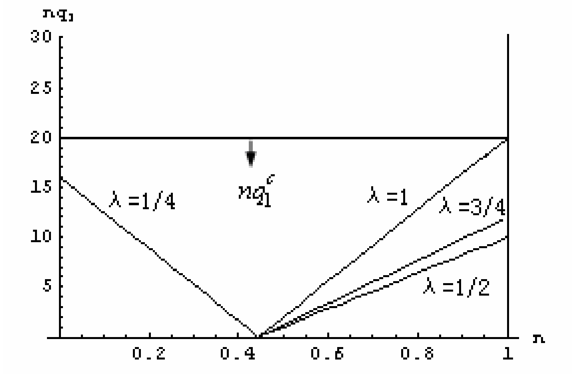

Fig. 2 Optimal Price of Bundling Tariffs for Low-Demand Consumers

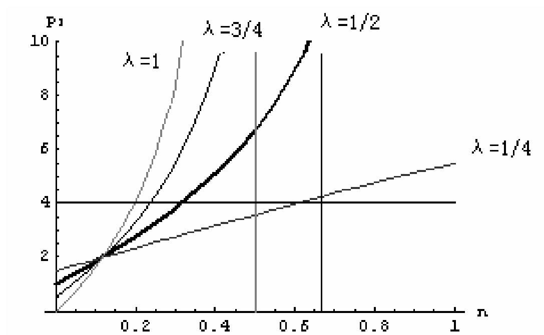

Fig. 3 Optimal Price of Two-Part Tariffs for Low-Demand Consumers

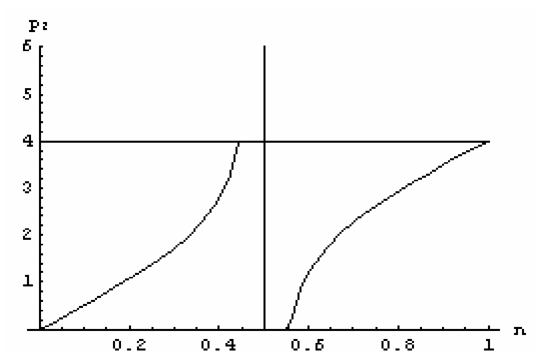

Fig. 4 Optimal Price of Two-Part Tariffs for High-Demand Consumers

good transaction from potential consumer to subscriber. During the key market development period, the tariffs do not have enough benefit for them.

In Fig.4, we can see that p_2^* is increasing in subscriber number n when $n \in (0, 4/9]$ and reaches the top value c, and it keeps the value until n=5/9. When the firm's subscriber number n>5/9, the firm has to reduce the per-unit price for more high-demand consumers. It is a market penetration strategy through which much more consumers can be attracted, and the market share will be increased rapidly during the market introduction period.

5 Conclusion

This chapter has investigated the firm's consumer development strategy under network externalities, call externalities and price policy during China's 3G data services introduction period, where consumers are divided into the two types of low-demand and high-demand. It has been shown that attracting high-demand consumers to be the firm's subscribers through providing favorable tariffs is the optimal strategy for both of the bundling tariffs and two-part tariffs policy. When the firm's subscriber number is small, all the the firm's efforts are for high-demand consumers. Also, the presence of call externalities weakens the firm's incentive to sell services to low-demand consumers. A high fixed fee is provided to the low-demand consumers for a two-part tariffs and a low quantity experiencing bundle in bundling tariffs, which are unfavorable to low-demand consumers. However, the development of 3G will lack vitality if the firm only aims for high-demand consumers. So the firm will attract the low-demand consumers when the firm's subscriber number increases to some level.

The great advantage of this chapter is to connect the 3G data services consumers development strategy with network externalities, call externalities and price policy because the consumer subscribes to a network not only decided by the price but also the probability to be reached by others, which is a problem of network externalities. So we can introduce network and call externalities in bundling tariffs and two-part tariffs pricing models and let the subscriber number represent the effects of network externalities. Then, the consumer development strategy can be gained when analyzing the relationship between the firm's profit-maximizing quantity and the price with the subscriber number.

Obviously, consumers are divided into two types in this chapter, according to their consumption preference; however, they can be divided with even more detail. The bundling tariffs model is based on one service; two or more different services bundled together are for further research (Gong, Li, 2009).

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Coordinating an Online Dual-Channel Supply Chain with Asymmetrical Information*

Liu Bin, Zhang Rong, and Bai Hongyuan

Mixed channels are attracting more and more channels firms. This chapter investigates an online dual channels supply chain system, and deals with its coordination with a menu of contract under information asymmetry. First, according to the centralized system, the optimal production and pricing strategies are depicted. Then, for the decentralized system, we consider two kinds of contracts, a single contract and a menu of contracts, to coordinate the channel system, and depict their production and pricing decisions with principle-agent method under the asymmetrical information on traditional channel. Finally, some interesting insights are found out.

1 Introduction

It is known that there are several channel modes in our present marketing system, and they are traditional channels, direct-selling channels with the Internet (abbreviated as on-line channels), and dual channels combined with the above two-type channels. In a traditional channel, retailers who confront uncertain settings take on full risk by buying products from suppliers at a wholesale price and selling them to the end customers. In a direct-selling channel, such as the Dell channel, suppliers sell their products to consumers directly through the Internet, and suppliers often

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* This work is partly supported by the National Nature and Science Fund of China (grant number 70871035), the Nature Science Fund of Henan Education Committee (grant number 2008A630020 and 2009A630022), and the Financial Program for Core Teachers of Henan University.

adopt the made-to-order production mode. Recently, with the rapid growth of science and technology and the improvement of people's standards of life, consumers want higher quality and services for products, and they want the supplier to provide a flexible selling mode. For example, more and more people are starting to gain enthusiasm over Internet shopping, while some people continue physically shopping through stores.

This chapter studies this on-line dual channel system and considers a supply chain with one manufacture who sells products through two selling channels. One selling channel is the traditional brick-and-mortar retail store while the other is an e-channel in which the customers place orders through the Internet. The traditional channel may or may not be owned by the manufacturer. When the manufacturer operates dual channels, we aim to see the optimal production and pricing strategies under centralized control. If the traditional channel is a franchise outlet, it is quite common that the manufacturer and the retailer process asymmetrical information on the market condition. Under such a scenario, the manufacturer not only needs to decide the total production quantity and selling price at the e-channel but also the contract terms to the retailer so that he can maximize his own profits. In this chapter, we will investigate the above scenarios under price-dependent stochastic demand and asymmetrical information and analyze this setting under asymmetrical information for a traditional channel with a principle-agent method.

2 Related Literature

The foundation of supply chain coordination is the newsboy problem. M. Khouja (1999) reviewed related literature on some extensions of the newsboy problem in depth, and (Petruzzi and Dada, 1999) reviewed literature on the joint decision for ordering and pricing and depicted a joint decision for ordering and pricing under a stochastic additive demand, multiple demand, and united stochastic demand, respectively. Like the above literature, this chapter investigates the decision problem under stochastic price-dependent demand, but there are two competing channels to be considered.

On dual channels, (Paralar and Wang, 1993) developed a two-firm competitive newsboy model, where the firms faced independent random demands. In a paper closely related to Parlar's, Karjalainen (1992) also analyzed cases where independent firm demands are aggregated to form industry demand. (Lippmand and Macardle, 1997) considered a competitive version of the classical newsboy problem in which a firm must choose an inventory or production level for a perishable good with random demand, where the optimal solution is a fractal of the demand distribution, and investigate the impact of competition on industry inventory. Note that the logic underlying our model is distinctly different from that used by Parlar, Karjalainen, or Lippman: in their models, firm demands are independent, whereas in our model, it is dependent on selling prices, and the channels' demand is correlated with each other.

Information is very important for all members of the supply chain, especially for the manufacturers who almost do not directly contact the end customer. Researchers were therefore motivated to explore supply chain models under information asymmetry, such as asymmetry in cost information and asymmetry in demand information. (Corbett, 2001), for instance, compared quantity discount mechanisms with symmetric and asymmetric downstream cost information in a decentralized supply chain consisting of one supplier and multiple buyers who may not share their cost information. (Ha, 2001) considered the asymmetrical cost information problem of determining an optimal coordinated contract in a two-echelon newsboy model. (Lau, 2003) explored two-echelon newsboy models with asymmetrical demand information, in which the retailer has better market information than the manufacturer, and analyzed the effects of improving the retailer's and the manufacturer's market knowledge of their profits and the system profit. As for the rationality of two-echelon supply chain gaming models, (Chen, 2005) studied Gonik's scheme and compared it with a menu of linear contracts – a solution often used in the agency literature – in a model where the market information possessed by the sales force is important for the firm's production and inventory-planning decisions.

Based on the above literature, this chapter will investigate the joint decision of production and pricing and coordinate the system with asymmetrical information. Other than the above literature, we address a new type of market setting, on-line dual channels with different operation modes, and study how to make a joint decision for the production and pricing of a centralized system and a decentralized system with asymmetrical information, respectively. Further, we will investigate how to measure the information value when making use of private information and which coordination mechanism is optimal for a decentralized system under franchise outlet mechanisms.

3 Denotations and Assumptions for Modeling

A. Modeling denotations

In this chapter, c is for the production cost per unit, and c_s is for the salvage value of unsold products at the end of the selling period. e is additional payment for a shortage. s_1 is the selling cost per unit in an e-channel, s_2 is the selling cost per production in a traditional channel operated by the manufacturer, and s_{2r} is the selling cost per production in a traditional channel operated by a retailer.

For the decision variables, p_1 is the selling price of a product sold in the e-channel, while p_2 is the selling price in a traditional channel. Furthermore, Q is for the ordering/production quantity made before the beginning of the selling period.

For stochastic customer demand, $D_1(p_1, p_2, x)$ is the demand function in the e-channel, and its form is $x - b_1 p_1 + \beta p_2$, while $D_2(p_1, p_2, x)$ is the demand function in a traditional channel, with the form $x - b_2 p_2 + \beta p_1$, where b_1 is the price-demand elasticity of the e-channel, b_2 is the price-demand elasticity of a traditional channel (especially b_2^H with a higher probability ρ and b_2^L with a lower probability $1-\rho$), and β is the price elasticity on another channel. The market scale x is a random variable, its probability distribution function is $F(\cdot)$, and the density function is $f(\cdot)$ with the mean μ.

Additionally, we denote the expected profit of a centralized and a decentralized system with $\prod^{C}(\cdot)$ and $\prod^{DC}(\cdot)$, respectively, and use *S* and *M* to denote the mechanism single contract and menu of contracts, respectively. *S* and *M* will be denoted in superscript. The superscripts * on some variables are used to denote optimization, such as the optimal selling prices, and the optimal ordering quantity. We use *R* and *M* in subscript to denote the retailer and manufacturer of this supply chain.

B. Assumptions

For simplicity, the following assumptions are made according to the marketing setting and its practical operation mode.

1) $e > c > c_s$, which implies that the emergent production will occur more costs than the normal one if there is a shortage, and at the same, all unsold products will be sold with the salvage value c_s.

2) $b_1 > b_2 > \beta$, which implies that the customers in the e-channel are more sensitive to the selling price than those in the traditional channel because of the rapid transfer of information on the Internet. At the same time, the customers are more sensitive to local selling prices than another's prices because of the time effect.

3) $s_2 > s_{2r} > s_1$, which shows that the selling cost in a traditional channel operated by the manufacturer is more than that in a traditional channel operated by a retailer and much more than that in an e-channel because there are more selling locations and more salesmen.

4) The production plan must be made and be one-off before the selling period, and all of members of the supply chain are risk-neutered.

5) It is the most important that we assume all customer demand will be met and that the manufacturer can ensure the supply with emergence production or transportation from other stores. Interestedly, this assumption is different from that of the newsboy problem, which assumes that these are in shortage during the selling period. Certainly, some scholars have adopted a simliar assumption in their research, such as literature (Chen, 2005). Additionally, all of the above parameters are more than zero, and the initial inventory of the whole system is zero.

4 Joint Decision on Production and Pricing for a Centralized System

Under a centralized system, the expected profit is

$$\begin{aligned}\prod{}^{C}(p_1,p_2,Q) &= E\{(p_1-s_1)D_1(p_1,p_2)+(p_2-s_2)D_2(p_1,p_2)-cQ \\ &-e\left[D_1(p_1,p_2)+D_2(p_1,p_2)-Q\right]^+ + c_s\left[Q-D_1(p_1,p_2)-D_2(p_1,p_2)\right]^+\}\end{aligned} \quad (1)$$

where $[\bullet]^+ = Max\{\bullet, 0\}$.

Lemma 1: The expected profit of the whole system $\prod^{C}(p_1,p_2,z)$ is concave on the decision vector (p_1, p_2, z), where $Q=(z-b_1p_1+\beta\, p_2)+(z-b_2p_2+\beta\, p_1)$.

Proof: Omitted.

Proposition 1: The optimal joint decision of production and pricing for a centralized supply chain with on-line dual channels is determined by

$$\begin{cases} z^{C*} = F^{-1}\left(\dfrac{e-c}{e-c_s}\right) \\ p_1^{C*} = \dfrac{s_1}{2}+\dfrac{c}{2}+\dfrac{(\beta+b_2)\mu}{2(b_1b_2-\beta^2)} \\ p_2^{C*} = \dfrac{s_2}{2}+\dfrac{c}{2}+\dfrac{(\beta+b_1)\mu}{2(b_1b_2-\beta^2)} \end{cases} \quad (2)$$

Correspondingly, the optimal ordering quantity is

$$Q^{C*} = 2F^{-1}\left(\frac{e-c}{e-c_s}\right)-\frac{(b_1-\beta)(c+s_1)+(b_2-\beta)(c+s_2)}{2}-\mu\,. \quad (3)$$

Proof: Omitted.

5 Joint Decision on Production and Pricing for a Decentralized System under Asymmetrical Information

Asymmetrical information in our chapter means the manufacturer does not know the demand information b_2 of the traditional channel held by the retailer. For this information, there are two attitudes of the manufacturer for dealing with it: one is to ignore it, and the other is to reveal it with a feasible mechanism. Here we suppose that the manufacture, as the leader of the Stackelberg game, will design a contract (a,d) to inspire the retailer. The contract (a,d) means that the retailer in a traditional channel should pay a fixed franchise fee d to the manufacturer for selling permission rights, and the manufacturer will return the a proportion of the selling revenue to inspire the retailer. We will consider inventory control and pricing decisions under two kinds of contracts: a single contract and a menu of several contracts. With these inventory decision models, we will investigate whether or not the manufacturer encourages the retailer in a traditional channel and depict the information value and the welfare value of private information held by the retailer.

C. *Joint Decision on Production and Pricing for a Decentralized System with a single contract*

Here we will consider the single contract (a,d) for inspiring the retailer, which implies that the manufacturer will ignore the private information on a traditional channel held by the retailer and make her inventory decision based only on the channel information held by herself. Then, the expected profit of manufacturer is

$$\prod_M^{DC-S}(p_1,p_2,Q,a,d) = \sum_{j=H,L}\Big\{\rho^j_{b_2^j}\cdot\{(p_1-s_1)D_1(p_1,p_2)+(1-a)p_2D_2(p_1,p_2\,|\,b_2^j)-cQ+d$$

$$-e[D_1(p_1,p_2)+D_2(p_1,p_2\,|\,b_2^j)-Q]^+ + c_s[Q-D_1(p_1,p_2)-D_2(p_1,p_2\,|\,b_2^j)]^+\}\Big\} \qquad (4)$$

where $\rho^j_{b_2^j}=\rho$ if $j=H$, otherwise $\rho^j_{b_2^j}=1-\rho$, and the first expression is the selling revenue of an on-line channel, and the second is the selling amount of a traditional channel, which subtracts the part belonging to the retailer. Furthermore, the third expression is the product cost, and the forth is the franchise fee charged by the manufacturer. The fifth is the added cost when the quantity supplied is less than the real demand, while the sixth is the salvage value of unsold products when the supply is more than the real demand.

The expected profit of a retailer in a traditional channel is

$$\prod_R^{DC-S}(a,d\,|\,b_2^j)=E\{(a\cdot p_2-s_{2r})D_2(p_1,p_2\,|\,b_2^j)-d\} \qquad (5)$$

Correspondingly, the principle-agent problem is depicted by

$$Max_{(p_1,p_2,Q)}\prod_M^{DC-S}(p_1,p_2,Q,a,d) \qquad (6)$$

s.t.

$$(a\cdot p_2-s_{2r})(\mu-b_2^H p_2+\beta p_1)-d\ge 0 \qquad \text{(IR-H)}$$

$$(a\cdot p_2-s_{2r})(\mu-b_2^L p_2+\beta p_1)-d\ge 0 \qquad \text{(IR-L)}$$

Through the consequences, we can get the following problem equivalent to (6).

$$Max_{(p_1,p_2,Q)}E\Big\{\sum_{j=H,L}\rho^j_{b_2^j}\cdot\{(p_1-s_1)D_1(p_1,p_2)-cQ+(p_2-s_{2r})(\mu-b_2^H p_2+\beta p_1)$$

$$-e[Q-D_1(p_1,p_2)-D_2(p_1,p_2\,|\,b_2^j)]^+ + c_s[D_1(p_1,p_2)+D_2(p_1,p_2\,|\,b_2^j)-Q]^+\}\Big\} \quad (7)$$

Lemma 2: The expected profit of a decentralized system, $\prod_M^{DC-S}(p_1,p_2,z)$, is concave on the decision vector (p_1,p_2,z) , where $Q=(z-b_1p_1+\beta p_2)+(z-\overline{b}_2p_2+\beta p_1)$, and $\overline{b}_2=\rho b_2^H+(1-\rho)b_2^L$.

Proof: Omitted.

Proposition 2: Under asymmetrical information, when a single contact (a,d) is covenanted between the manufacturer with an on-line channel and the retailer with a traditional channel, the optimal joint decision for production and pricing is

$$\begin{cases} z^{j*} = F^{-1}\left(\dfrac{e-c}{e-c_s}\right), \quad j = H, L. \\ p_1^{DC-S*} = \dfrac{s_1}{2} + \dfrac{c}{2} + \dfrac{(\beta + b_2^H)\mu}{2(b_1 b_2^H - \beta^2)} \\ p_2^{DC-S*} = \dfrac{s_{2r}}{2} + \dfrac{c}{2} + \dfrac{(\beta + b_1)\mu}{2(b_1 b_2^H - \beta^2)} \end{cases} \tag{8}$$

Correspondingly, the optimal ordering quantity is

$$Q^{C*} = 2F^{-1}\left(\frac{e-c}{e-c_s}\right) - \frac{(b_1 - \beta)(c + s_1) + (\overline{b}_2 - \beta)(c + s_{2r})}{2} - \mu \tag{9}$$

Proof: Omitted.

Additionally, it is important for the manufacturer and retailer to determine their proportion of the selling revenue, a. In general, we think that bargaining power will determine it, and the higher the status of the traditional retailer in the supply chain channel, the larger the proportion of the selling revenue charged by the retailer. Certainly, the retailer should get some profit from the contract between the manufacturer and the retailer, otherwise the retailer need not this trade.

D. Joint Decision on Production and Pricing for a Decentralized System with a Menu of Contracts

Here we will consider a menu of contracts (a^j, d^j), where $j = H, L$, to inspire the retailer, which implies that the manufacturer will pay attention to the private information of the traditional channel held by retailer and make her inventory decision according to the channel information held by herself. Then, the expected profit of manufacturer is

$$\prod_M^{DC-M}(p_1^j, p_2^j, Q^j, a^j, d^j) = \sum_{j=H,L} \rho_{b_2^j}^j \cdot \{(p_1^j - s_1) D_1(p_1^j, p_2^j) + (1-a^j) p_2^j D_2(p_1^j, p_2^j \mid b_2^j) - cQ^j + d^j$$

$$-e[D_1(p_1, p_2) + D_2(p_1, p_2 \mid b_2^j) - Q]^+ + c_s[Q - D_1(p_1, p_2) - D_2(p_1, p_2 \mid b_2^j)]^+\} \tag{10}$$

While the expected profit of the retailer in a traditional channel is

$$\prod_R^{DC-M}(d \mid a^j, b_2^j) = E\{(a^j \cdot p_2^j - s_{2r}) D_2(p_1^j, p_2^j \mid b_2^j) - d^j\} \tag{11}$$

Correspondingly, the Principle-Agent problem is depicted by

$$Max_{(p_1^j, p_2^j, Q^j)} \prod_M^{DC-M} (p_1^j, p_2^j, Q, a^j, d^j) \tag{12}$$

s.t.

$$(a^H p_2 - s_{2r})(\mu - b_2^H p_2 + \beta p_1) - d^H \geq 0 \qquad \text{(IR-H)}$$
$$(a^L p_2 - s_{2r})(\mu - b_2^L p_2 + \beta p_1) - d^L \geq 0 \qquad \text{(IR-L)}$$
$$\begin{aligned}&(a^H p_2^H - s_{2r})(\mu - b_2^H p_2^H + \beta p_1^H) - d^H \\ &\geq (a^L p_2^L - s_{2r})(\mu - b_2^H p_2^L + \beta p_1^L) - d^L\end{aligned} \qquad \text{(IC-HL)}$$
$$\begin{aligned}&(a^L p_2^L - s_{2r})(\mu - b_2^L p_2^L + \beta p_1^L) - d^L \\ &\geq (a^H p_2^H - s_{2r})(\mu - b_2^L p_2^H + \beta p_1^H) - d^H\end{aligned} \qquad \text{(IC-LH)}$$

where it is supposed that the minimized expected profit of a traditional retailer is not less than 0, which also implies that the retailer in a traditional channel will receive the contract only if his profit is more than 0. So, conditions (IR-H) and (IR-L) mean that the Individual Rationality of retailer and this constraint condition often occur in the principle-agent model.

With similar consequences to that of a single contract, we can get the problem equivalent to (12),

$$\begin{aligned}&Max_{(p_1, p_2, Q)} E\Big\{ \sum_{j=H,L} \rho_{b_2^j}^j \cdot \big\{ (p_1^j - s_1) D_1(p_1^j, p_2^j) - cQ^j + (p_2^j - s_{2r})(\mu - b_2^j p_2^j + \beta p_1^j) \\ &- e[Q^j - D_1(p_1^j, p_2^j) - D_2(p_1^j, p_2^j \mid b_2^j)]^+ + c_s[D_1(p_1^j, p_2^j) + D_2(p_1^j, p_2^j \mid b_2^j) - Q^j]^+ \big\}\Big\} \\ &- (1-\rho)\big\{ (b_2^H - b_2^L)(a^H p_2^H - s_{2r}) p_2^H \big\}\end{aligned} \tag{13}$$

Lemma 3: The expected profit of a decentralized system, $\prod_M^{DC-M}(p_1^j, p_2^j, z^j)$, is concave for the decision vector (p_1^j, p_2^j, z^j), where $Q^j = (z^j - b_1 p_1^j + \beta p_2^j) + (z^j - b_2^j p_2^j + \beta p_1^j)$.

Proof: Omitted.

Proposition 3: When the manufacturer and retailer in a traditional channel subscribe to a menu of contracts (a^j, d^j), where $j = H, L$, under asymmetrical information, the optimal joint decision on production and pricing is as follows:

$$
\begin{cases}
z^{j*} = F^{-1}\left(\dfrac{e-c}{e-c_s}\right), \quad j = H, L. \\
p_1^{DC-M\_L*} = \dfrac{s_1}{2} + \dfrac{c}{2} + \dfrac{(\beta + b_2^L)\mu}{2(b_1 b_2^L - \beta^2)} \\
p_2^{DC-M\_L*} = \dfrac{s_{2r}}{2} + \dfrac{c}{2} + \dfrac{(\beta + b_1)\mu}{2(b_1 b_2^L - \beta^2)} \\
p_1^{DC-M-H*} = \dfrac{s_1}{2} + \dfrac{[(b_1 - \beta)(b_2^H + \frac{1-\rho}{\rho}(b_2^H - b_2^L)a^H] \cdot c}{2[(b_1 b_2^H - \beta^2) + \frac{1-\rho}{\rho} a^H b_1 (b_2^H - b_2^L)]} \\
\qquad - \dfrac{[\frac{1-\rho}{\rho} a^H \beta (b_2^H - b_2^L)] \cdot s_{2r}}{2[(b_1 b_2^H - \beta^2) + \frac{1-\rho}{\rho} a^H b_1 (b_2^H - b_2^L)]} \\
\qquad + \dfrac{[\beta + b_2^H + \frac{1-\rho}{\rho}(b_2^H - b_2^L)a^H] \cdot \mu}{2[(b_1 b_2^H - \beta^2) + \frac{1-\rho}{\rho} a^H b_1 (b_2^H - b_2^L)]} \\
p_2^{DC-M-H*} = \dfrac{[(b_1 b_2^H - \beta^2) + \frac{1-\rho}{\rho}(b_2^H - b_2^L)b_1] \cdot s_{2r}}{2[(b_1 b_2^H - \beta^2) + \frac{1-\rho}{\rho} a^H b_1 (b_2^H - b_2^L)]} \\
\qquad + \dfrac{(b_1 b_2^H - \beta^2) \cdot c}{2[(b_1 b_2^H - \beta^2) + \frac{1-\rho}{\rho} a^H b_1 (b_2^H - b_2^L)]} \\
\qquad + \dfrac{(\beta + b_1) \cdot \mu}{2[(b_1 b_2^H - \beta^2) + \frac{1-\rho}{\rho} a^H b_1 (b_2^H - b_2^L)]}
\end{cases}
\tag{14}
$$

Proof: Omitted.

Interestingly, the proportions of selling revenue a^j are critical for channel coordination. Certainly, they are the profit balance between the manufacturer and the retailer in the traditional channel, and their bargaining power and channel status determine these proportions. Generally, because the retailer should get the more profit than 0, the feasible region of a^H is

$$
\left[\frac{2(b_1 b_2^H - \beta^2) s_{2r}}{(s_{2r} + c)(b_1 b_2^H - \beta^2) + (\beta + b_1)\mu - \frac{1-\rho}{\rho} b_1 (b_2^H - b_2^L)}, \quad 1 \right] \tag{15}
$$

and the feasible region of a^L is

$$
\left[\frac{2(b_1 b_2^L - \beta^2) s_{2r}}{(s_{2r} + c)(b_1 b_2^L - \beta^2) + (\beta + b_1)\mu}, \ 1 \right] \tag{16}
$$

Now we compare the optimal selling prices of a decentralized system with a single contract to that with a menu of contracts, and we get several deductions, as follows.

Deduction: $p_1^{DC-M-L*} \geq p_1^{DC-S*} \geq p_1^{DC-M-H*}$ and $p_2^{DC-M-L*} \geq p_2^{DC-S*} \geq p_2^{DC-M-H*}$.

Proof: Omitted.

This deduction implies that the optimal selling prices are in between the optimal selling prices of an optimistic market setting and that of a pessimistic one. That is, the more optimistic the market setting is, higher the optimal selling prices are. Otherwise, the more pessimistic the market setting is, the lower the optimal selling prices are.

6 Numerical Examples

In this numerical study, based on our previous analysis, we aim to provide key managerial insight by answering the following questions: What is the value of channel information for a firm? What is the value of the menu of contracts? What is the best operation mode for a dual on-line channel system with asymmetrical information, a centralized system, a decentralized system with a single contract, and a decentralized system with a menu of contracts?

We use the following parameters as benchmarks for the coming numerical studies:

$b_1 = 12.5$, $b_2^H = 12$, $b_2^L = 8$, $\beta = 7.5$, $c = 4$, $c_s = 3$, $e = 4.5$ $s_1 = 0.5$, $s_2 = 2$, $s_{2r} = 1$, $\rho = 0.75$

and we assume that x is normally distributed with a mean of 100 and a variance of 30, i.e., $x \sim N(100,30)$.

Additionally, in the coming numerical examples, channel coordination is not our focus, so we only consider the final expected profits of members in the supply chain under the conditions to average the coordination profit.

From table I, we find that whether there is a single contract or a menu of contracts, the expected profit of the manufacturer will decrease with the deterioration in the channel setting (namely, ρ increases), while the information welfare of the traditional retailer will be constant under a single contract but will increase under a menu of contracts. Furthermore, with the increase of the uncertainty of channel information b_2^j , the expected profit of the manufacturer under a single contract will decrease, while the information welfare of a traditional retailer will increase. On the contrary, the expected profit of the manufacturer will increase while the information welfare of the traditional retailer will decrease under the menu of contracts. This shows that when the uncertainty in traditional channel information is higher, the manufacturer would more likely design the menu of contracts to cope with different channel settings and then get more expected profits. When the uncertainty of the traditional channel is lower, the manufacturer would be likely to adopt the single contract, rather than the menu of contracts. At the same time, it is interesting that the higher the uncertainty of the traditional channel is, the more information welfare traditional retailer gains.

Table I The performances of members in a supply chain with different channel information b_2^j

ρ	b_2^j	$\prod_M^{DC-S}(\cdot)$	$\prod_R^{DC-S}(\cdot \mid b_2^L)$	$\prod_M^{DC-M}(\cdot)$	$\prod_R^{DC-M}(\cdot \mid b_2^L)$
0.25	(8,12)	922.221	640.778	1092.042	209.787
0.50	(8,12)	814.693	640.778	827.315	407.465
0.75	(8,12)	707.166	640.778	664.049	544.080
0.25	(9,11)	942.514	408.920	855.851	197.400
0.50	(9,11)	869.900	408.920	751.139	310.336
0.75	(9,11)	797.284	408.920	704.090	371.280

Table II The performances of members in supply chain with different selling cost s_{2r}

ρ	s_{2r}	b_{2j}	$\prod^C(\cdot \mid b_2^H)$	$\prod^C(\cdot \mid b_2^L)$	$\prod^{DC-S}(\cdot \mid b_2^H)$	$\prod^{DC-S}(\cdot \mid b_2^L)$	$\prod^{DC-M}(\cdot \mid b_2^H)$	$\prod^{DC-M}(\cdot \mid b_2^L)$
0.25	1	(8,12)	565.763	1505.001	599.638	1670.527	479.472	1549.876
0.75	1	(8,12)					553.369	1549.876
0.25	1	(9,11)	688.045	1107.652	724.670	1424.049	643.888	1149.777
0.75	1	(9,11)					680.097	1149.777
0.25	1.4	(8,12)	565.763	1505.001	585.368	1651.137	466.465	1531.446
0.75	1.4	(8,12)					538.358	1531.446
0.25	1.4	(9,11)	688.045	1107.652	709.360	1406.179	627.892	1132.387
0.75	1.4	(9,11)					664.319	1132.387
0.25	1.8	(8,12)	565.763	1505.001	572.058	1632.067	453.884	1513.656
0.75	1.8	(8,12)					524.288	1513.656
0.25	1.8	(9,11)	688.045	1107.652	694.930	981.068	612.425	1115.717
0.75	1.8	(9,11)					649.415	1115.717

From table II, it is unlikely that the centralized system is better than the decentralized system with a feasible contract if the traditional and professional retailer has the advantage of selling cost. Furthermore, the difference between a centralized system and decentralized system is more obvious when the selling cost of a traditional channel is much less than that of a centralized system. Comparing the performance of a decentralized system with a single contract with a menu of contracts, we find that the decentralized system with a menu of contracts does not outperform that with a single contract, and their difference in performance is more when the uncertainty of the traditional channel information is less. In fact, with a single contract, the manufacturer makes her decision according to only the mean of the traditional channel, and this decision mode integrates the optimistic and pessimistic market setting well. Undoubtedly, the variance of this system performance should be greater. Differing from the results of Chen's similar problem, the system performance under a single contract is better than that under a menu of contracts because this chapter deals with the joint decision of an on-line dual channel and there exists competition between dual channels.

7 Conclusions

In this chapter, we investigate a supply chain with one manufacturer who sells products through two selling channels. One selling channel is the traditional brick-and-mortar retail store, while the other is an e-channel in which customers place orders through the Internet. The traditional channel may or may not be owned by the manufacturer. According to the centralized system, namely, the market setting where the manufacturer operates dual channels, the optimal production and pricing strategies are depicted. According to the decentralized system, we consider two kinds of franchise outlets to coordinate the channel system: one is a single contract and the other is a menu of contracts. We depict their production and pricing decisions with a principle-agent method under asymmetrical information of the traditional channel. Some interesting management insights are found.

1) It is unlikely that the centralized system is better than the decentralized system with a feasible contract if the traditional and professional retailer has an advantage in selling cost.

2) The more optimistic the market setting is, the higher the optimal selling prices are; otherwise, the more pessimistic the market setting is, the lower the optimal selling prices are.

3) When uncertainty in the traditional channel information is higher, the manufacturer would be more likely to design the menu of contracts to cope with the different channel setting, then getting more expected profits. When the uncertainty of the traditional channel is lower, the manufacturer would be more likely to adopt the single contract rather than the menu of contracts.

4) The higher the uncertainty of the traditional channel, the more the information welfare of the traditional retailer gains.

5) The decentralized system with a menu of contracts does not outperform that with a single contract, which integrates the optimistic and pessimistic market setting well, and their difference in performance is more when the uncertainty of the traditional channel information is less.

In this chapter, we only consider the decision setting where the manufacturer holds the pricing power for a traditional channel and the retailer does not make a pricing decision according to his private channel information. For future research, we will investigate scenarios similar to this chapter, but the retailer will make the pricing decision on the traditional channel.

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The Optimization of Supply Chain Components' Quality Characteristics Based on the Structural Equation Model

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Aiming to quality character management under the "Main Manufacturer-Supplies" model, the structural equation model and programming model are set up to evaluate and optimize the supply chain components' quality characteristics. This chapter can be divided into 4 parts: (1) The quality loss function: We design the quality loss functions according to 3 quality types as input for the model; (2) The structural equation model: We establish the two-order factor model to illustrate the production model and evaluate the quality contribution weight for the product's quality; (3) The programming model: we set up the programming model to optimize the quality performance based on the evaluation results; (4) A case study: An automobile production case is researched to show the effectiveness of the method. This chapter provides a new way to evaluate and improve the supply chain components' quality characters.

1 Introduction

Because of labor division and specification, the "Main Manufacturer–Supplies" (M-S) production model has become the foremost manufacturing pattern around the

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world. As the core of the M-S structure, the Main Manufacturer plays an important role as the “production organizer” and “system integrator”, designing the whole product’s structure and setting up the quality requirements of the components to his suppliers. Furthermore, the Main Manufacturer demands that the supplies provide the qualified components that must be in accordance with his quality requirements. If not, he won’t order and purchase the supply’s components and will choose another one. After getting all the essential components needed, the Main Manufacture will assemble all the components the suppliers submitted into a large and complete product, such as an automobile, a plane, or a rocket.

According to the quality engineering theory, the quality of the whole product greatly relies on the quality of all the components. The quality competition among the products is just a quality competition among their supply chains. Consequently, the main manufacturer, who expects to maintain its market share and occupy an advantageous state in the intense market competition, should monitor the components’ quality strictly. The quality factors of different components don’t play the same effect in the whole product’s performance and quality competition. Consequently, under the premise that maintains the product’s quality, the main manufacturer should set up stricter quality requirements and less qualified biases to those components’ quality factors that relate more closely to the products’ quality competition. On the other hand, for those quality components that are not related much, the main manufacturer could design less strict quality requirements and more qualified biases to reduce the purchase cost of the components and quality factors. Take the Airbus A380's supplier network as an example (as shown in figure 1). The suppliers come from 5 continents and 480countries. The quality of the complete plane greatly relies on the components’ quality from these suppliers. Therefore, the components’ quality factors must be evaluated and optimized to maintain and raise the products’ quality competition as well as distribute the components’ quality requirements more properly is a valuable subject both in quality management theory and practical management work.

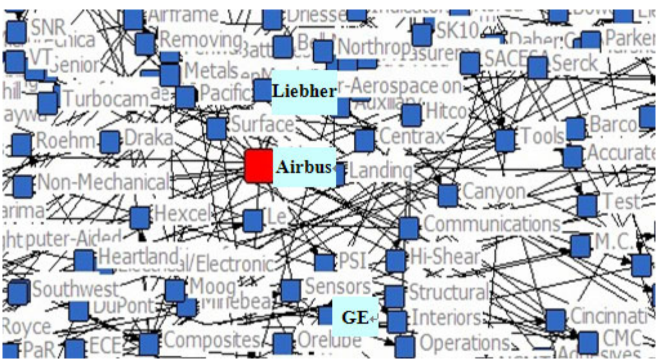

Fig. 1 The supply net of the Airbus A380 (part)
Data resource**:** www.airframer.com/aircraft_detail.html?model=A380

Looking over the relevant literature of recent years that we could find in this field, some scholars and management practitioners have done a series of related studies and research. Some representative views are as follows:

Nien-Lin Hsueh, Peng-Hua Chu and William Chu discussed a quantitative method for evaluating the quality design patterns, which was planned to calculate the effectiveness of quality improvement in a design pattern where pattern users could determine which design patterns were applicable to satisfy their functional and quality requirements (Hsueh et al., 2008). In (Fynes and De Búrca, 2005), a new path model was set up to incorporate the design quality, conformance quality, external quality-in-use, product cost, time-to-market and customer satisfaction that was conformed to data gathered from 351 production companies in the Republic of Ireland. Ful-Chiang Wu presented a measure to optimize the nonlinear multiple dynamic quality characteristics on the base of the double-exponential desirability function (Wu, 2008). E. Ertugrul Karsak designed a fuzzy multiple-objective programming measure to determine the design requirements under the "Quality Function Deployment" model with imprecise and subjective information (Karsak, 2004). Furthermore, many other researchers made considerable contributions in the quantity characteristics designing and management field (Liu and Fang, 2007; Han and Xiong, 2002; Powell and Pyke, 1996).

Throughout related literature of recent years, we can find that research in the quality characteristic designing, evaluating and optimizing fields are mainly limited to one enterprise, which concentrates on the product lever. But in the M-S production model that widely exists, because of various supply chains, kinds of components, numerous enterprises and complex relationships among them, the quality management of products and components under the M-S production model is more difficult and worthy of analysis and research. But the research on this subject and field wasn't mature and didn't form a scientific theory system. In main manufacturer enterprises, such as Boeing, Airbus, Toyota, and Volkswagen, a proper and effective management measure to design and evaluate the component quality characteristics in the whole product wasn't found, nor can it be optimized and improved.

Based on the above considerations, this chapter applies the "Structural Equation Model" theory to the M-S production model to get the evaluation of components' quality and affective factor loading. A programming model is established to calculate the components' quality performance under a series of constraints to confirm the quality characteristics' optimal value. The chapter is aimed to set up and establish a new method for product quality management under the M-S production model.

The chapter mainly solves the problems above:

(1) Improve Artiles-Leon's quality loss function (nominal type) and design 2 kinds of quality loss functions towards the larger-the-better type and smaller-the-better type to measure the quality characters' performance completely and properly .

(2) Set up the high-order factor model to describe the M-S production model and input the quality characters' performance of components to calculate the affective factor loading from quality characters to the final product's quality.

(3) Based on the factor loading weight, establish the programming model to calculate and optimize the quality characters' objective performance in order to design the quality characters' requirements and allocate the management resources scientifically and probably.

2 The Improved Quality Loss Functions

A. The Quality Loss Function of Product Characteristics

The generalized quality loss of product characteristics was firstly introduced by Taguchi. He argued that a product's quality fluctuation was a kind of objective reality. If the quality character deviates from the expected value designed, quality loss has happened.

In order to describe the quality loss of product characteristics, people designed the quality loss function to show the distance between a realistic value and an expected value. According to the meanings of an expected quality value, the quality loss function can be divided into the nominal type, the larger-the-better type and the smaller-the-better type.

B. The Nominal Type Quality Loss Function

Nominal type characteristics are called N-type for short and means refers to when the quality is better because the realistic value is closer to the expected value. In the quality engineering theory, when the realistic value is just equal to the expected value, the quality loss is 0, the smallest; when the realistic value reaches the upper or lower limit, the quality loss is 1, the largest. If the realistic value is beyond the upper or lower limit, the product is wasteful and isn't accepted. Consequently, if the nominal type characteristics (N-type) $Y_i \sim (\mu, USL, LSL)$, under standardized and dimensionless procedures, its quality loss function can be defined as follows:

$$L(Y_i) = 4(\frac{Y_i - \mu}{USL - LSL})^2 \tag{1}$$

In formula (1), μ is Y_i's expected value, and USL, LSL are Y_i's upper and lower limits.

C. The Larger-the-better Type Quality Loss Function

The larger-the-better type characteristic is called the L-type for short and refers to when the quality is better because the realistic value is higher. Similarly, if larger-the-better type characteristics (L-type) $Y_j \sim (Y_U, Y_L)$, its quality loss function can be defined as follows:

$$L(Y_j) = (\frac{Y_j - Y_U}{Y_U - Y_L})^2 \tag{2}$$

In formula (2), Y_u is Y_j 's Max-satisfied value, and Y_L is Y_j 's Min-acceptable value.

D. The Smaller-the-Better Type Quality Loss Function

The smaller-the-better type characteristic is called the S-type for short and refers to when the quality is better because the realistic value is lower. Similarly, if smaller-the-better type characteristics (S-type) $Y_k \sim (Y_{U'}, Y_{L'})$, its quality loss function can be defined as follows:

$$L(Y_k) = (\frac{Y_k - Y_{U'}}{Y_{U'} - Y_{L'}})^2 \tag{3}$$

In formula (3), $Y_{L'}$ is Y_k 's Min-satisfied value and $Y_{U'}$ is Y_k 's Max-acceptable value.

3 The Evaluation of M-S Quality Characteristics Based on the Structural Equation Model

E. The Structural Equation Model of the M-S System

Structural equation model (SEM) is a multivariate statistical analysis model and method that deals with complex data operating and researching. SEM is composed of two parts, the observable indicates (that can be measured or calculated directly and accurately) and the latent indicates (that can't be describe and shown immediately and exactly). SEM is an effective tool to establish a structure model consisting of the complex relationships between the observable indicates and latent indicates, or between a latent indicate and another.

According to function relations among the product structure and logistic goods flow directions among enterprises, we design the quality characters' performance (described as quality loss) as observable indicates that can be measured by quality loss functions. The quality lever of the components and whole product are devised as latent indicates connecting to observable indicates (which belong to the component) and each other. δ_i is character 1's measuring error. We create the path diagram of a structural equation model under the M-S production system, as shown in figure 2.

F. Data Collection and Adjustment

The SEM requires a strict demand for the size of sample, which reaches at least 100-200. We should collect 200 samples of each quality character realistic value to satisfy the requirement. For example, there are 12 types of quality characters, and each quality character needs to be measured 200 times. The sample size is 200, the indicator number is 12, and the data points are 12*200, or 2400, in total. SEM needs

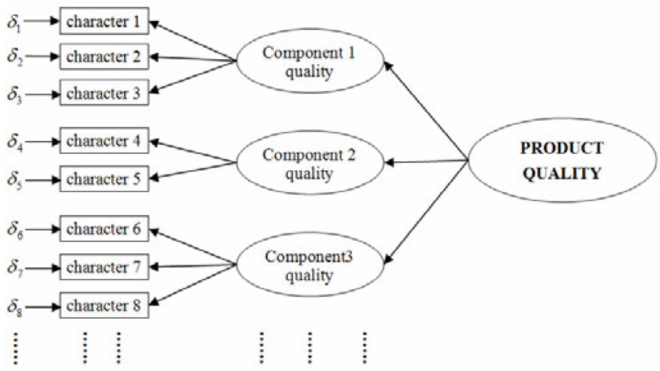

Fig. 2 The path diagram under M-S production system

an inputting number satisfying the normal distribution. The 12 types data are needed for changing the normal distribution. Apply formula (1), (2), and (3) and transform the 12 types of quality performance data into 12 groups of quality loss data, which are treated as input parameters.

In order to avoid a spurious regression due to the data's non-stationarity, we should examine and adjust the data through a stationarity test and a normal test. For the process of the stationarity test, an ADF (Augmented Dickey-Fuller) or PP (Projection Pursnit) test is recommended. For the process of the normal test, an ML (Maximum Likelihood) test is the most commonly applied method. Detailed test procedures can be found in (Hou et al., 2006).

G. Operating Procedures and Algorithm

Suppose there exists m groups of quality characters' performance, processed by quality loss functions, and we get the quality loss series $X=\{x_1,x_2,\cdots,x_m\}$, treated as observable indicates. Suppose there exists n kinds of components' quality level $Y=\{y_1,y_2,\cdots,y_n\}$ and the whole product's quality level Z, and both of them are treated as latent indicates. The quality loss values $x_1,\cdots,x_{m_1}$ belong to component 1, whose quality level is Y_1; the quality loss values $x_{m_{i-1}+1},\cdots,x_{m_i}$ belong to component i, whose quality level is y_i ($i=2,3,\cdots,n$). According to the path diagram under the M-S production system, we can set up the two-order factor model as follows.

Aimed at component i, suppose the triangle covariance matrix of X is S, the relation load of y_i and x_j is r_{ij}, and the x_j's error is δ_j. We get the relationship equation $x_j=r_{ij}y_i+\delta_j$, described as matrix $X=RY+\delta$.

According to the y_i and Z, support of the relation load is μ_i and the y_i's error is ε. The relation between y_i and Z is $y_i = \mu_i Z + \varepsilon_i$, described as matrix $Y = UZ + \varepsilon$.

The covariance of x_m and x_n is $\mathrm{cov}(x_m, x_n) = \mathrm{cov}(r_{im} y_i + \delta_m, r_{in} y_j + \delta_n) = r_{im} r_{in} \phi_i \phi_j$. So the triangle covariance matrix S can transfer to $\sum(\phi)$. If the model is effective, the maximum likelihood estimation of S is $\sum(\phi)$, which means $S = \sum(\phi)$ and each part of the matrix is equal. Solving the equation group, we can get the evaluation of parameters R, U and δ as the quality characters' load between X and Y, as well as Y and Z.

H. The Testing of Model

After getting the model's parameters, we should test the model's effectiveness and fitness. The main test indicators are χ^2, the RMSEA (Root Mean Square Error of Approximation), the NNFI (Non-Normed Fit Index) and the CFI (Comparative Fit Index). For detailed test methods and standards, refer to professional statistics books.

4 The Optimization of Quality Characteristics Based on the Programming Model

I. The Relative Contribution Weight of Quality Characters

From the output of SEM, we can calculate the relative contribution weight of each quality character to the whole product's quality. Suppose the quality load between Y_i and X_j is r_{ij} and the quality load between Z and Y_i is κ_i. According to the logic relationship among the nodes, we can get the quality load between Z and X_j as follows: $\lambda_j = \kappa_i r_{ij}$. After normalizing the λ, we can get the quality characters' contribution weight of $A = \{a_1, a_2, \cdots, a_m\}$, $a_i = \dfrac{\lambda_i}{\sum_{j=1}^{m} \lambda_j}$.

J. The Changing Rate of Quality Characters

We set up the changing rate t to judge the quality's improvement and optimization. For N-type quality characters, $Y_i \sim (\mu, USL, LSL)$. Suppose the expected quality performance is $Y_i^* \sim (\mu^*, USL^*, LSL^*)$, so the changing rate of Y_i is

$$t_i = \frac{USL + LSL}{USL^* + LSL*} \quad (4)$$

For L-type quality characters Y_j whose existing quality performance is μ_j and expected quality performance is μ_j^*, the changing rate of Y_j is

$$t_j = \frac{\mu_j^*}{\mu_j} \quad (5)$$

For the S-type quality characters Y_k, whose existing quality performance is μ_k and expected quality performance is μ_k^*, the changing rate of Y_j is

$$t_k = \frac{\mu_k}{\mu_k^*} \quad (6)$$

K. The Programming Model for Optimating

We set up a programming model to conform and calculate the quality characters' optimal value. For one quality character, the optimal target is the improved effect that is reaching the maximum, which means the product of the changing rate t and its quality contribution weigh a, $w = t \cdot a$, reaches the maximum. For the quality character series, the optimal target is maximizing the composite quality changing effort, which means $W = AT$.

There are mainly 2 kinds of constraints, changing rate constraints and resource constraints. For changing rate constraints, $Min \le T \le Max$ is represented. For resource constraints, $CT \le M$ is represented, C is the resources required matrix and M is total resources matrix.

Consequently, we set up the programming model as follows:

$$opt.\max W = AT$$
$$s.t.\begin{cases} Min \le T \le Max \\ CT \le M \end{cases} \quad (7)$$

Solving the programming model above, we can get the optimal solutions T^*, putting T^* into (6)(7)(8) to get the optimal quality performance.

5 Case Study

An automobile enterprise applies the above method to improve the quality performance of a pattern car. The car consists of 4 components: the engine, the chassis, the body and electrical equipment. The engine component has 3 quality characters: effective torque (unit: N.m), effective power (unit: Kw) and specific fuel consumption (unit: g/Kw). The chassis component has 3 quality characters: chassis rigidity (measured by top speed, unit: km/h), chassis weight (unit: Kg) and Max-load (unit: Kg). The body component has 3 quality characters: body deformation (measured by energy absorption, unit: %), body weight (unit: Kg) and body strength (measured by C-NCAP score, unit: point). The electrical equipments component has 2 quality characters: sensibility (unit: ms) and failure rate (unit: Km^{-1}).

L. *The Evaluation of Quality Characters*

Select 200 samples from each component randomly and measure the performance of the each quality. Input the realistic value into each quality loss function according to quality types. We get 11 groups of series data and 2,200 data points. Suppose the quality loss series is $X = \{x_1, x_2, \cdots, x_{11}\}$, the component quality level series is $Y = \{y_1, y_2, y_3\}$, and the whole product quality level is Z. We can get the triangle covariance matrix of the quality loss series X as follows:

$$S = \begin{bmatrix} 1 \\ 0.34 & 1 \\ 0.38 & 0.35 & 1 \\ 0.02 & 0.03 & 0.04 & 1 \\ 0.15 & 0.19 & 0.14 & 0.02 & 1 \\ 0.17 & 0.15 & 0.20 & 0.01 & 0.42 & 1 \\ 0.20 & 0.13 & 0.12 & 0.00 & 0.40 & 0.21 & 1 \\ 0.32 & 0.32 & 0.21 & 0.03 & 0.10 & 0.10 & 0.07 & 1 \\ 0.10 & 0.17 & 0.12 & 0.02 & 0.15 & 0.18 & 0.23 & 0.13 & 1 \\ 0.14 & 0.16 & 0.15 & 0.03 & 0.14 & 0.19 & 0.18 & 0.18 & 0.37 & 1 \\ 0.18 & 0.16 & 0.19 & 0.02 & 0.14 & 0.21 & 0.22 & 0.22 & 0.06 & 0.23 & 1 \end{bmatrix}$$

Input the model structure and covariance matrix S into software LISREL, and we get the two-order model as shown in figure 3.

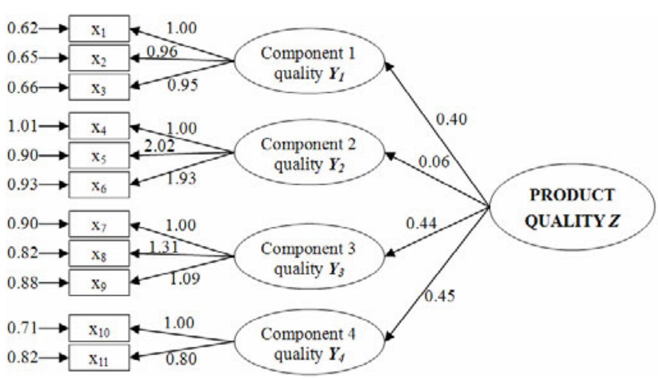

Fig. 3 The automobile quality path diagram

Suppose the quality load between Y_i and X_j is r_{ij} and the quality load between Z and Y_i is η_i. According to the logic relationship among nodes, we can get the quality load between Z and X_j as follows: $\lambda_j = \mu_i r_{ij}$. After normalization, we can get the relative contribution weight of each quality character as follows:

Table I The relative contribution weight of each quality character

quality character	x_1	x_2	x_3	x_4	x_5	x_6
weight	0.106	0.102	0.101	0.016	0.032	0.031
quality character	x_7	x_8	x_9	x_{10}	x_{11}	
weight	0.117	0.153	0.127	0.119	0.096	

From table I, we easily find that the maximum is 0.153, which means quality character x_8 influences the quality of the whole product most. x_8 is the bottleneck of the system quality and needs to improve immediately.

M. The Optimization of Quality Characters

Based on the evaluation results, gather the quality characters' changing information and the resources needed (just as table II illustrated). Suppose the total changing fee is $5,000, and then we set up a programming model to ensure maximum quality satisfaction under a series of constraints.

Improved target: the product's quality satisfaction reaches the maximum:

$$\max W = 0.106t_1 + 0.102t_2 + 0.101t_3 + 0.016t_4 + 0.032t_5$$
$$+0.031t_6 + 0.117t_7 + 0.153t_8 + 0.127t_9 + 0.119t_{10} + 0.096t_{11}$$

The improvement rate constraints:

$$95.59\% \le t_1 \le 102.94\%, 95.94\% \le t_2 \le 103.13\%,$$
$$90.00\% \le t_3 \le 108.00\%, 94.74\% \le t_4 \le 105.26\%,$$
$$92.86\% \le t_5 \le 108.33\%, 83.33\% \le t_6 \le 111.11\%,$$
$$83.33\% \le t_7 \le 108.33\%, 94.00\% \le t_8 \le 104.44\%,$$
$$88.89\% \le t_9 \le 106.67\%, 65.0\% \le t_{10} \le 130.0\%,$$
$$85.71\% \le t_{11} \le 114.29\%$$

The improved cost constraint:

$$1000 * [30(t_1 - 1) + 25(t_2 - 1) + 40(t_3 - 1) + 46(t_4 - 1)$$
$$+20(t_5 - 1) + 40(t_6 - 1) + 30(t_7 - 1) + 18(t_8 - 1)$$
$$+60(t_9 - 1) + 15(t_{10} - 1) + 22(t_{11} - 1)] \le 5000$$

Table II The improved information of the quality characters

quality character	x_1	x_2	x_3	x_4	x_5	x_6
character type	L	L	S	L	S	L
unit	N.m	Kw	g/Kw	km/h	Kg	Kg
current situation	680	320	270	190	260	3600
change rate(max)	102.94 %	103.13 %	108.00 %	105.26 %	108.33 %	111.11 %
change rate(min)	95.59 %	95.94 %	90.00 %	94.74 %	92.86 %	83.33 %
improved cost (k$/%)	30	25	40	46	20	40

Table II (*continued*)
The improved information of the quality characters

quality character	x_7	x_8	x_9	x_{10}	x_{11}
character type	L	S	L	S	L
unit	%	Kg	point	ms	Km^{-1}
current situation	0.6	940	45	130	3500
improvement rate(max)	108.33 %	104.44 %	106.67 %	130.00 %	114.29 %
improvement rate(min)	83.33 %	94.00 %	88.89 %	65.00 %	85.71 %
improved cost (k$/%)	30	18	60	15	22

Table III The optimal performance of the quality characters

quality character	x_1	x_2	x_3	x_4	x_5	x_6
improvement rate (%)	102. 94	103. 13	108. 00	94. 47	92. 86	83. 33
optimal performance	700	330	250	180	280	3000
unit	N.m	Kw	g/Kw	km/h	Kg	Kg
quality character	x_7	x_8	x_9	x_{10}	x_{11}	
improvement rate(%)	108. 33	104. 44	99. 51	130. 00	114. 29	
optimal performance	0.65	900	44.78	100	4000	
unit	%	Kg	point	ms	Km^{-1}	

Solving the above programming model with software Lingo, we get the quality characters' optimal performance (as shown in table III).

From table III, we find that the optimal result doesn't averagely distribute the improve fee but allocates the money according to the contribution of each character.

While all the quality characters' performance is improving, some are weakening, such as x_4, x_5, x_6, x_9. Under the optimal schedule, the quality competition of the product can rise 7.14%, the maximum improvement.

6 Conclusion

Because of various supply chains, kinds of components, numerous enterprises and complex relationships, the quality management for products and components under the M-S production model is more difficult and worthy of analysis and research, but in theory, research and the practical fields, there are few mature and effective methods to handle it. This chapter applies the structural equation model to this field to evaluate the quality characters. The programming model is set up to optimize based on the output of SEM. Lastly, the case study shows the effectiveness of the method, getting a good result.

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The Gap Prediction for the Sci-tech Innovative Talent of Jiangsu Province*

Jianling Wang, Sifeng Liu, and Yun Wang

Sci-tech innovative talent have been the most important source for Jiangsu province, and prominent achievements of the sci-tech jog have been made. In this chapter, the definition of sci-tech innovative talent is first explored, and the gap between the demand and supply of Jiangsu sci-tech innovative talent is predicted based on GM(1,1). Lastly, some policy suggestions are proposed.

1 Introduction

Sci-tech innovative talent (STIT) are special groups of talent, and their quantity and quality promote scientific and technological progress to a great extent, and they have gradually been attached to great importance by most countries in recent years (Song, 2006). As an eastern coast province, Jiangsu province has an important position in China's development, and great expectations have been taken by the Party Central Committee. While building a well-off society, it has been fully realized that sci-tech innovations are based on talented persons, and STIT has been the most important source for Jiangsu province. Technology jobs of Jiangsu having made remarkable achievements, the team of Jiangsu STIT grows gradually, and it has formed a hierarchy of innovative talent, which provides a new impetus and the intellectual support necessary for sustainable development in Jiangsu (Jiangsu Province Science and Technology Agency, 2008). The rules of economic development also determined that STIT is the primary resource for the development of Jiangsu during the new era, so it's of great significance to build the STIT team. In addition, it will be a useful implication to other provinces.

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* This work was supported in part by the Soft Science of Jiangsu Province under grant SBR200950.

At present, there are no commonly accepted concepts of innovative talent and STIT. Generally, it's agreed that to judge whether a person belongs to the innovative talent, the standard does not lie in his career nor in high or low positions and qualifications, but it lies in whether he is innovative in what he is assigned to do, and studious with research and practice, and if he achieved outstanding innovations (Liu, 2008; Wang et al., 2006; Mm , and Tan, 2002). We believe that STIT has a high scientific and technological innovation capacity, as well as a long-term sustainability to engage in scientific discovery and research and development activities. Their performance is mainly reflected in certain scientific and technological achievements. They promote scientific and technological progress and social development.

In China, statistical significant terms for STIT have not yet been made. As for the "[China's] Statistical Yearbook" and the "Statistical Yearbook of Science & Technology of China," 3 relevant groups correspond to the group of STIT: staff of scientific and technological activities (T&S S), staff of research and experimental development (R&D S), and staff of scientists and engineers (S&E S). T&S S are those who are engaged in or participate in scientific and technological activities directly, as well as scientific and technological management and service providing staff. S&E S are those who graduate from universities with high academic qualifications or above or are with a senior primary professional title. They are the core of science and technology staff. R&D S are those who are engaged in innovative scientific research. In short, T&S S, R&D S and S&E S are the mainstays of STIT, reflecting the structure and hierarchy of STIT.

In this chapter, the STIT Status Quo of Jiangsu is analyzed thoroughly based on the definition of STIT, and the future status is predicted by GM (1, 1). At last, the conclusion and a suggestion are given.

2 The Status Quo pf Jiangsu STIT

Jiangsu has made remarkable achievements on the cultivation of STIT, with a dramatic increase of both the quantity and quality. According to "The Monitoring Results of Jiangsu Province of Scientific and Technological Progress and Technology Statistics Statistical Bulletin" and the "Jiangsu Statistical Yearbook" (Jiangsu Province Science and Technology Agency, 2002-2007; Tan and Luo, 2003; Pu and Xi, 2007), it's found that Jiangsu STIT show the following characteristics:

A. The quantity and quality of Jiangsu STIT rank at the top among ones in China

In recent years, the sci-tech jobs of Jiangsu have achieved remarkable results, and the comprehensive assessment has ranked second nationwide in China. Not only is the STIT quantity of Jiangsu among the most of the provinces, but it also has cultivated groups of leading STIT in different areas. At present, there are 3413 thousand professional technical personnel and 395 thousand T&S S, which rank in the top two in China. Among those, there are 140 thousand R&D S and 240 thousand S&E S, which rank in the top three in China. While the scale of Jiangsu STIT is gradually growing, the talent reservation is substantial.

B. The concentration effect of talent introduction is appearing

Talent introduction has great achievements, and the concentration effect is appearing. Take leading STIT for example: a multi-level STIT introducing system has been jointly built by Jiangsu province and its respective cities, such as the Jiangsu high-level STIT introducing plans, Changzhou's "One Thousand Overseas Talent Gathering Project" and Suzhou's "Gusu Innovation Leader of [the] Talent Scheme" . A large number of scientific and technological talent is concentrating in Jiangsu and has important impacts at home and abroad.

C. The Innovative ability is sharply improving

During the period 2000-2006, the innovative ability of Jiangsu STIT improved sharply, the proportion of invention patents increased 11.28% annually, and utility model patents and design patents increase steadily. As for 2007, the patent applications ranked in the top two in China. The number of national science and technology awards ranked third, the international papers published ranked third, and the domestic papers published ranked second.

D. The Research cooperation is deepening

Jiangsu Province has signed cooperation agreements with the Chinese Academy of Sciences, the Chinese Academy of Engineering, Beijing University, Tsinghua University, and so on. Until now, there have been 275 cooperated organizations.

In recent years, Jiangsu has actively promoted more than 1700 innovation and entrepreneurial talent platforms and has built an innovation carrier by interaction among the research platform, incubator, venture investment and industry.

3 The Gap Prediction Model of Jiangsu STIT

A. The historical data of Jiangsu STIT

The supply prediction of STIT requires statistic data regarding T&S S, R&D S and S&E S. According to the "Jiangsu Technological Progress Monitoring Statistics Results and Statistical Bulletin" and the "Jiangsu Statistical Yearbook", statistics on Jiangsu STIT during the year of 2002 to 2007 are shown in table 1.

B. The modeling principle for STIT supply prediction

Supply prediction is a prediction of the volume of STIT at the end of the forecast period. The natural growth and flow of STIT have led to changes in STIT (Liu et al., 2004; Liu and Lin, 2006; Lin et al., 2004; Lin and Liu, 2006). Natural growth here refers to the changes of STIT in quantity that were caused by the cultivation of local schools, enterprises and society. Therefore, the capacity of STIT that are at the end of the forecast period depends on three factors: first, the total STIT at the beginning of the forecast period; second, the talent cultivation capacity of local schools,

Table 1 2002-2007 Jiangsu STIT

Year	T&S S (10 thousand)	S&E S (10 thousand)	R&D S (10 thousand)
2000	28.74	15.96	5.86
2001	29.52	16.94	6.60
2002	30.73	19.34	7.44
2003	33.18	20.89	10.50
2004	33.55	19.87	11.55
2005	38.17	23.08	10.05
2006	38.11	23.89	10.50
2007	39.50	24.00	14.00

businesses and the community; and third, the net inflow of IT professionals volume during the forecast period, net inflow here referring to the balance of the inflow and outflow of talent in STIT.

Because of regional economic development, personnel policies, as well as technological advances and other factors, the volume of the net inflow of IT professionals is somewhat uncertain, so a prediction from this perspective will have greater inaccuracy (Liu et al., 2004). In addition, the history statistics of STIT are relatively inadequate; it is difficult to reflect the rules of data changes, so it is a great challenge to predict the supply with a time-series prediction method.

Gray system theory study objects, characteristic of “poor information” and “small samples” with uncertainty, correctly describe and effectively control the system by generating valuable information through some information, and GM(1,1) has been applied in various areas of practical applications of the gray theory (Liu et al., 2004). In this chapter, we take the supply system of STIT as a gray system and use the model of the gray system GM (1, 1) to predict the supply of Jiangsu STIT in 2008-2020.

The time response sequence of GM(1,1) for S&E S is as formula(1), and the average error is 3.894145%; the time response sequence of GM(1,1) for R&D S is as formula(2), and the average error of the weakened sequence is 2.656121%; the time response sequence of GM(1,1) for T&S S in a large-medium industrial enterprise is as formula(3), and the average error is 1.795312%.

$$x(k+1)=321.392133\exp(0.054111*k)-305.432133 \tag{1}$$

$$x(k+1)=93.803114*\exp(0.066638*k)-87.943114 \tag{2}$$

$$x(k+1)=567.148646\exp(0.050893*k)-538.408646 \tag{3}$$

C. The modeling principle for STIT demand prediction

It’s shown that there is a positive relation between sci-tech talent and the economy. According to the above statistical data, a correlation analysis shows that there is remarkable positive correlation between the Jiangsu GDP and S&E S, R&D S and

T&S S, respectively (r=0.917, 0.872, 0.963, P<0.01), and the demand prediction models are as follows:

$$Y_{1t}=13.4937303+0.0004585X_t \quad (4)$$

$$Y_{2t}=-24.0997099+0.004046X_t \quad (5)$$

$$Y_{3t}=23.8347616+0.0006615X_t \quad (6)$$

where X_t is the Jiangsu province GDP of the year t, Y_{1t} is Jiangsu S&E S demand for year t; Y_{2t} is Jiangsu R&D S demand for year t; and Y_{3t} is Jiangsu T&S S demand for year t.

4 Analysis of a Gap Prediction and Suggestions for Jiangsu STIT

According to forum (1) ~ (6), the gap prediction of Jiangsu STIT during 2008 to 2020 is shown in figure 1: first, Jiangsu STIT are going to grow with a high speed but lag behind Jiangsu's economy; second, R&D S will grow at the highest rate among the STIT, which is inseparable from the development of Jiangsu's economy and education. From above, it's shown that though the job of Jiangsu STIT have been ahead in recent years, the dynamical adjustment of STIT structure should be adapted to the development of the society and economy. The suggestions for Jiangsu STIT are as follows:

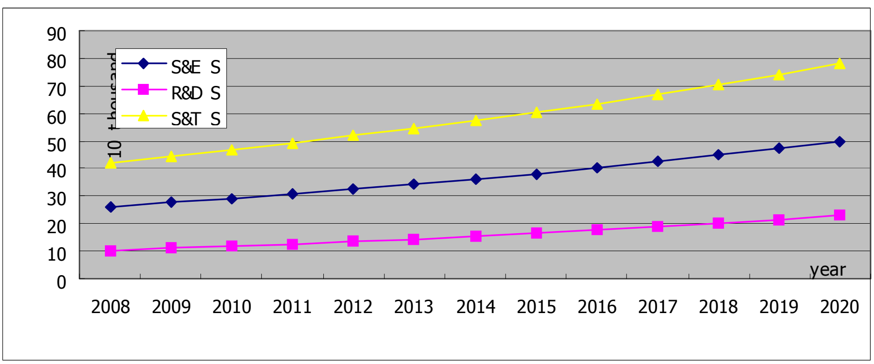

Fig. I Gap Prediction Of Jiangsu Stif

A. Cultivating STIT with multiple channels

The roles of multiple channels should be fully played, such as important talent cultivating plans, important scientific research projects, important scientific research bases, academic exchanges and international cooperation. The government should actively push forward team or group building, putting more effort in fostering an academic leader and key technology staff, and perfecting the rules and system of training and selecting high-level innovation talent.

B. Encouraging independent innovation

The whole society is not very confident for producing indigenous local innovative products, so the opportunity is uncertain for them to be chosen in government and enterprise procurement. Under these circumstances, even if some independent innovations are proven to be a technological breakthrough, enterprise profit is still hard. Therefore, the government should enhance supporting independent innovating products, recommend these products to be listed in the export catalog of new high technology products, invest more in introducing technology and equipments, and encourage the exportation of re-innovation enterprises by using economical instruments like taxation and the exchange rate.

C. Perfecting the achievements transformation platform

The incubator, science and technology parks play important roles in STIT constructing, venture capitalism, the infrastructure and service system to directly promote the job, which cannot be ignored, so the hardware building of STIT should first be strengthen. Accompanied with these strategies, the innovation service quality should be enhanced, and the interaction mechanisms should be explored deeply.

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Community Degree, Clustering Coefficient and Knowledge Propagation Efficiency in Complex Networks*

Wenping Wang, Qiuying Shen, and Yuqing Chen

The impact of complex network structure on knowledge propagation is currently one of the hotspots in complex network research. Based on the SIR epidemic model and mean-field theory of dynamical physics, this chapter conducts the research into the law of how the community degree and clustering coefficient influence the knowledge propagation efficiency in complex networks. The research discovered that when the clustering coefficient is below a certain value, there exists a network community degree threshold; when the network community degree is lower than the threshold, the knowledge propagation efficiency decreases as the community degree increases; when the network community degree is higher than the threshold, the knowledge propagation efficiency increases as the community degree increases, meaning the relationship between the two follows a "U-type" curve; when the clustering coefficient is higher than a certain value, the relationship between them monotonically increases.

1 Introduction

Knowledge and ability are the roots of organizational competitive advantage (Zahra et al., 1999), and knowledge propagation is the premise of organizational knowledge integration and ability building. The behavior of economic subjects is embedded in concrete and real-time complex networks (Granovetter, 1985), and knowledge is also contained in the network and community (Landry et al., 2002). The network is the structural basis for knowledge propagation among subjects. Therefore, to study the influence relationship between complex networks, structural characteristics and knowledge propagation is of great significance. Knowledge propagation is achieved through the connection among nodes, but then, what is the

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* This work was sponsored by the National Science Fund (70571013, 70973017) and the New Century Excellent Talent of Education Ministry (NECT-06-0471).

influence of the network structure on knowledge propagation? The current studies are: 1) Study knowledge propagation from the social capital, which the relationships are embedded in, such as trust dimension (Lane, 1998; Boiral, 2002); 2) Study knowledge propagation and the resulting innovation from the embedding structure dimension (Tsai and Ghoshal, 1998; Maskell, 2000; Zhang, 2006). As representatives, the small-world properties found in literature (Watts and Strogatz, 1998; Watts, 1999) and the scale-free network found in literature (Barabasi and Albert, 1999; Barabasi et al., 1999) set off the upsurge of studying the effects of complex network structure on knowledge propagation, in which Cowan's research results are the most prominent (Cowan and Jonard, 2004).

In recent research on the complex system's structure, apart from the small world and scale-free properties, scholars also lately found a new statistical feature of complex networks: community structure. Scholars have observed that there will be some node collections that are constituted by nodes in the networks, and the links among the nodes within a collection are much tighter than the links to the outside nodes, which means the number of edges among the nodes in the collection is more than those on the outside (according to Figure 1). Though literature (Cowan and Jonard, 2004; Cowan et al., 2004) have made useful discussion on the network structure, knowledge propagation and innovation, the model basically follows the physical model of Watts, and it does not put the community features into the network structure. Therefore, this chapter will use the network building model in literature (Liu and Hu, 2005) to build the network of the community features structure. Furthermore, it will conduct research on the influence of the community degree and clustering coefficient on the knowledge propagation efficiency in complex networks, according to the experience of the SIR model.

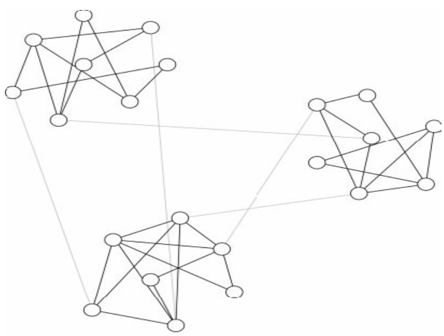


Fig. 1 Schematic diagram of the network community structure

2 Model Construction

2.1 The Network Building Model of an Adjustable Community Structure

The community structure is an important feature of complex networks. This chapter defines that a network community degree = the number of connections among inter-community nodes / the number of connections among nodes within the community (Liu and Hu, 2005), which is denoted by p . This chapter makes use of the network building model in literature (Liu and Hu, 2005), which can adjust the size of community identity p dynamically, and the degree distribution function is $P(k) = 2^{\frac{m}{2-p}} \frac{m}{2-p} k^{-\frac{m}{2-p}-1}$ (m denotes that the new joining node is connected to m nodes in the community), so the degree distribution $P(k)$ is controlled by p ($0 < p < 1$) (Liu and Hu, 2005) and the clustering coefficient of complex networks is $C = (1/N) * \sum_i C_i$, in which $C_i = 2E_i / (k_i(k_i - 1))$, E_i is the total connection number of node i's k_i neighbor nodes, the clustering coefficient is the probability that the two nodes connected to the same node are also connected in the network (Liu, 2004). The network building model can adjust the network structure parameter q at the same time, because E_i and q are directly proportional (Liu and Hu, 2005), so $C \sim q$ and the network structure parameter q indirectly determines the network clustering coefficient C ($0 < q < 1$).

2.2 SIR Model for Knowledge Propagation

This chapter assumes that knowledge of network nodes only propagates through the connection among nodes. It does not take into account the impact of the distance between nodes on knowledge propagation, nor does it take into account the impact of propagation time. We refer to the SIR epidemic model (Anderson and May, 1991), which assumes that for a certain knowledge, each node in the network has three states (A_1, A_2, A_3), in which: state A_1 (does not have that kind of knowledge); State A_2 (temporarily receives the knowledge through the propagation path); and State A_3 (perpetually owns the knowledge through digestion and absorption). β is the probability of the node knowledge's propagation to the connected other. Depending on the encoded degree of knowledge, knowledge can be divided into explicit knowledge and tacit knowledge. The explicit knowledge can be encoded for transmission, while tacit knowledge can not. Because the tacit knowledge is of high embedded nature, the explicit knowledge can be propagated more easily in the network than the tacit knowledge, so the propagation probability of explicit knowledge in the network is greater than the probability of tacit knowledge.

Without the loss of generality, assume that the propagation probability of explicit knowledge in the network β = 0.9, and the propagation probability of tacit knowledge β = 0.5. Suppose that there's only one node in the network initially owning certain knowledge. The node will propagate its knowledge to the connected nodes with probability β. With the propagation of knowledge, the nodes in the network that have temporarily received the knowledge are gradually increasing (state A_2). If the knowledge is not digested, absorbed and applied, it will be forgotten, and the state of the node will switch to state A_1; if the node perpetually owns the knowledge through digestion and absorption, the state of the node will switch to state A_3. Suppose that the probability of a node's state switching from state A_2 to A_3 is γ, that the probability of the node's state switching from state A_2 to state A_1 is $1-\gamma$, and that the node switching from state A_2 to state A_1 will no longer receive the knowledge again. So, in the initial propagation, the nodes in state A_2 will gradually increase until there is no node in state A_2 at the moment τ. At this time, the knowledge propagation process is completed.

In an average k degree and C clustering coefficient network, assuming that $\beta = 1$, the node owning the knowledge propagates it to k nodes at the first step, and then these nodes propagate it to $k(k-1-\frac{2E}{k})$ nodes at the second step (E is the number of the edges among these k nodes). Also, $C = \frac{2E}{k(k-1)}$, so $k(k-1-\frac{2E}{k}) = k(k-1)(1-C)$. When C=1, the knowledge propagation process is completed at the first step ($t = 1$). Therefore, assume that $f(C)$ is the influence function of the clustering coefficient on knowledge propagation, $0 < f(C) < 1$, and $df(C)/dC < 0$ (Liu and Hu, 2005). Because the knowledge propagation abilities of the nodes of different degrees are different, assume that $A_1^k(t), A_2^k(t), A_3^k(t)$ are the proportions of different states nodes number to the k degree nodes total number. When knowledge is being propagated in the network, the state of the nodes in the network is dynamic. Adopting the mean-field theory in dynamical physics (Pastor-Satorras and Vespignani, 2001), we set the following equations:

$$\frac{dA_1^k(t)}{dt} = -\beta k A_1^k(t) f(C) \cdot \Theta(t) \tag{1}$$

$$\frac{dA_2^K(t)}{dt} = \beta k A_1^k(t) f(C) \Theta(t) - \gamma A_2^k(t) \tag{2}$$

$$\frac{dA_3^k(t)}{dt} = \gamma A_2^k(t) \tag{3}$$

In the above equations, $\Theta(t) = \frac{\sum_k kP(k)A_3^k(t)}{\sum_s sP(s)}$ denotes the probability of any node in the network's connections to the node that owns the knowledge. Marking the average degree of the nodes in the network with $\sum_s sP(s) = <k>$, $\Theta(t) = \frac{\sum_k kP(k)C_k(t)}{<k>}$. The initial state: $A_3^k(0) = 0; A_2^k(0) = \frac{1}{N}P(k) \to 0; A_1^k(0) = 1 - A_3^k(0) - A_2^k(0) \to 1$. Therefore, by (1), we have

$$A_1^k(t) = e^{-\beta k A_1^k(t) f(C)\cdot\Theta(t)}$$

and

$$\frac{d\Theta(t)}{dt} = \frac{\sum_k kP(k)\gamma(1 - A_1^k(t) - A_3^k(t))}{<k>} = \gamma * (1 - \Theta(t) - \frac{\sum_k kP(k)e^{-\beta k A_1^k(t) f(C)\cdot\Theta(t)}}{<k>}).$$

When $t = \tau$, the knowledge propagation progress is completed, $\frac{d\Theta(t)}{dt} = 0$, meaning:

$$\Theta(t) = 1 - \frac{\sum_k kP(k)e^{-\beta k A_1^k(t) f(C)\cdot\Theta(t)}}{<k>}$$

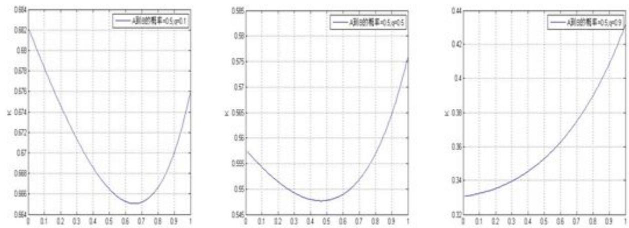
Eventually, the knowledge propagation efficiency

$$R \equiv \sum P(k)C_k(\tau) = 1 - \sum P(k)e^{-\beta k f(C)\cdot\Theta(\tau)} \tag{4}$$

3 Model Simulation and the Results

3.1 Model Simulation

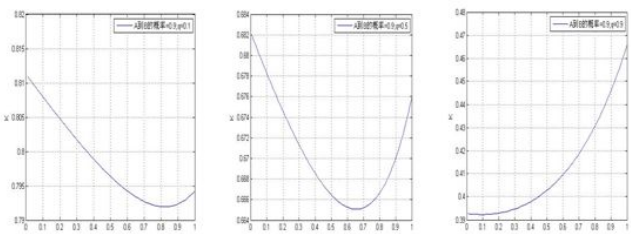
Using the network building model in 2.1 and MATLAB tools, build the networks of q = 0.1, 0.5, 0.9, respectively; simulate the propagation process of tacit knowledge (β = 0.5) and explicit knowledge (β = 0.9) in different networks; and study the relationship between knowledge propagation efficiency and community degree p. By calculating the simulation and analysis, we find that the network community degree p, the network structure parameter q and the probability of knowledge propagation β all have impacts on the propagation of knowledge in the network, as shown in Figure 2 and Figure 3, specifically. As $p << 1$, the network community structure is significant, the network is divided into several communities, the node links within the community are very tight, and the node links across communities are very sparse, which shows the node "bunching" phenomenon.



(a) (b) (c)

Chart 2 The relationship chart of R and p when β=0.5, q =0.1, 0.5, 0.9 respectively

(a) β=0.5, q =0.1; (b) β=0.5, q =0.5 ;(c) β=0.5, q =0.9



(d) (e) (f)

Chart 3 The relationship chart of R and p when β=0.9, q =0.1, 0.5, 0.9 respectively

(d) β=0.9, q =0.1; (e) β=0.9, q =0.5; (f) β=0.9, q =0.9

3.2 Simulation Results

(1) When knowledge is propagated in the network of network structure parameter q =0.1, 0.5, with the probability of β= 0.5, 0.9, respectively, the relationship between the knowledge propagation efficiency R and the network community degree p follows a "U-type" change curve (as shown in (a) and (b) of Figure 2, and (d) and (e) of Figure 3). Specifically, there is a community degree threshold value p^* . When $p \leq p^*$, R decreases with the increase of p . When $p \geq p^*$, R increases with the increase of p .

(2) When the network structure parameter q = 0.9, because the network clustering coefficient C is proportional to q , the network clustering coefficient C is also great at this time, and the knowledge propagation efficiency in the network is

an increasing function of the community degree p (as shown in (c) of Figure 2 and (f) of Figure 3).

(3) When the network structure parameter q is set, the tacit knowledge and explicit knowledge are propagated in the network with the probability of 0.5 and 0.9, respectively. Compare Figure 2 (a) to Figure 3 (d) and Figure 2 (b) to Figure 3 (e), and we find that the community degree threshold value p^* corresponding to the lowest point of the knowledge propagation efficiency curve shifts to the right with an increase of the knowledge propagation probability. When knowledge (tacit knowledge or explicit knowledge) is propagated in different networks (q =0.1 and q =0.5), compare Figure 2 (a) to (b), or Figure 3 (d) to (e), and we find that with the increase of q , because the clustering coefficient C is proportional to parameter q , C also increases, and the community degree threshold value p^* corresponding to the minimum of knowledge propagation efficiency in the network shifts to the left.

4 Conclusions and Future Research

With the above model and the simulation results, we can obtain the following conclusions:

1) The network clustering coefficient impacts the relationship between knowledge propagation efficiency and the network community degree. When the clustering coefficient is below a certain value, the relationship follows a "U-type" curve, and there exists a community degree threshold value at this time. As the network community degree is lower than the threshold value, the knowledge propagation efficiency decreases with the increase of the community degree. As the network community degree is higher than the threshold value, the knowledge propagation efficiency increases with the increase of the community degree. When the clustering coefficient is higher than a certain value, the relationship between knowledge propagation efficiency and the network community degree monotonically increases, meaning the knowledge propagation efficiency increases monotonically with an increase in the network community degree.

As the network clustering coefficient increases, the probability of the connection of the two nodes that are connected to the same node in the network is high. At this time, as the network community degree increases, the network becomes more akin to the regular network, so the knowledge propagation efficiency in the network becomes higher. For example, in the World Wide Web, which is approximate to the regular network, when a message appears on a website, it is quickly reproduced on other sites as the result of the network structure of the World Wide Web, and it becomes common news. The high propagation efficient makes people "breathtaking."

2) In the knowledge propagation process, the size of the network clustering coefficient impacts the community degree threshold value in the above conclusions. As the network clustering coefficient increases, the community degree threshold

value in the relationship between the knowledge propagation efficiency and the network community degree decreases.

3) The knowledge characteristics of the network (knowledge explicit degree) impact the community degree threshold value in the relationship between the knowledge propagation efficiency and the network community degree. As the knowledge explicit degree increases, the knowledge propagation probability increases, and the community degree threshold value in the above conclusions increases.

The above conclusions indicate that the network structure impacts knowledge propagation, and specific network architecture helps to improve the knowledge propagation efficiency. This research can provide the theoretical basis for enterprises to build and optimize their network structure and thus improve their knowledge propagation efficiency. In addition, this chapter conducts research on the impact of network structure on knowledge propagation on the basis of a static network. In fact, with the interaction of network nodes, the interactive history will make the nodes have different degrees of trust with the other nodes, thus resulting in different effects of different network connections on knowledge propagation, namely, the heterogeneity of network relationships. Researching into laws between the community degree and knowledge propagation efficiency is still an issue for further study. In addition, adjusting and optimizing the network structure to improve the knowledge propagation efficiency based on the above findings is also for future research.

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A Study on E-Government Information Sharing*

Zhijun Yan, Baowen Sun, and Tianmei Wang

Information sharing is of vital importance in cross-organizational collaboration. It can help achieve many important public benefits. From the integrated view of the technology system and trust, this chapter analyzes the influential factors of e-government information sharing. Derived from the DeLone & McLean model and Technology Acceptance Model (TAM), information quality, information use, perceived benefit, trust, perceived usefulness and perceived ease of use are proposed as antecedents of the users' intention to share information. Then, the research model is given and the research hypotheses are derived.

1 Introduction

Information is one of the most important resources in the public and private sectors. It is asserted that information needs to be well regulated to improve organizational efficiency. For public government agencies, information sharing is a crucial factor to achieving important public benefits: increased productivity, improved policymaking and integrated public services (Dawes, 1996). Fundamentally, sharing information reduces the "paperwork burden" on citizens, streamlines work processes, and enriches the formulation, implementation, and evaluation of policy (Landsbergen, Jr. and Wolken, Jr., 2001). Although there are many obvious advantages for information sharing, the existing barriers significantly impede the information sharing process across organizational boundaries. For example, the perceived risk is recognized as one major barrier that decreases user involvement with information sharing. Many scholars have studied the factors that affect

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* This work was supported in part by the Humanities & Social Sciences Key Project of the Ministry of Education of China (Grant No. 07JZD0019) and the National Science Foundation of China (Grant No.70872119).

information sharing from many distinct aspects, such as organizational culture (Drake et al., 2004), employee belief (Kolekofski and Heminger, 2003) and trust scheme (Peng Liu, 2005). Different from previous research, this chapter analyzes the influential factors of information sharing from the integrated view of the technology system and trust, and it proposes the hypothesis research model based on the updated DeLone & McLean information systems success model.

The chapter is organized as follows: Section 2 gives a literature review on information sharing in the e-government. The theory base of our research work is presented in section 3. Then, section 4 introduces the research model, and the research hypotheses are derived. The conclusions and further works are described in section 5.

2 Literature Review

Information sharing is a hot topic in e-government research and receives more attention from many scholars. This section only sheds light on some of such scholars' literature.

As one of the most cited references, Dawes's article states that information sharing is often limited by technical, organizational, and political barriers. The attitudes and opinions of state government managers on information sharing were analyzed. The result showed that more than 8 in 10 judge information sharing to be moderately to highly beneficial. Based on the survey results, a theoretical model for understanding how policy, practice, and attitudes interact was proposed. And the model also suggested two policy principles, stewardship and usefulness, to promote the benefits and mitigate the risks of information sharing (Dawes, 1996).

Extending from the research result of Dawes, Landsbergen analyzed the benefits and barriers of interoperability, which means the talking and sharing of information. Differing from Dawes' model, Landsbergen gave a three-stage theoretical model. The first stage is the theoretical model of individual agency-to-agency information sharing. The second stage concerns the infrastructure to support information sharing. The last stage focuses on the synthesis of legal, managerial and policy approaches to interoperability sharing (Landsbergen, Jr. and Wolken, Jr., 2001).

Seung investigated the influence of cultural factors on information sharing in China. They postulated that social network structures such as guanxi, Confucian dynamism,and collectivism could explain the degree to which information sharing took place between people in China. Then they administrated a survey to 140 high-level managers, general managers, and deputy general mangers in Chinese enterprises. The data analysis results confirmed their research hypothesis, which was that guanxi, Confucian dynamism and collectivism both have a significant influence on information sharing in China (Shin et al., 2007).

Based upon the theory of reasoned action (TRA), Keith proposed a model that defines the influential factors of one's intent to share information in a governmental organization. The research model was tested by surveying the workers in a unit of a large governmental organization that often fails to reap the benefits. The study suggests that stewardship attitude, instrumentality of sharing information and interpersonal feelings are three key factors that managers should address when striving to encourage wider sharing of organizational information (Kolekofski and Heminger, 2003).

J. Ramon Gil-Garcia proposed that expected benefits are an important reason for starting information sharing among government organizations and that potential impediments will limit the attainment of information-sharing projects' benefits, jeopardizing the project's business case and even the project itself. Using data from six public sector information-sharing projects, they revealed how some managerial and cultural impediments limit the perceptions of expected benefits. The three major managerial and cultural impediments are the controlled-oriented management style, lack of agreement on goals and the perception of management impatience (Gil-Garcia et al., 2007).

Theresa reported a comparative examination of knowledge sharing in two separate networks of public sector organizations participating in information technology innovation projects in the state of New York. Using interviews, observations and the document analysis method, the case studies follow knowledge sharing and other interactions in the inter-organizational networks of these two distinct settings. Their results confirm the difficulty of sharing knowledge across agencies and further reveals the influence of several relevant factors—incentives, risks and barriers for sharing, and trust—on the effectiveness of knowledge sharing (Pardo et al., 2006).

Soonhee Kim discussed the impact of organizational context and IT on employees' perceptions of knowledge-sharing capabilities. He proposed that three dimensions—organizational culture, organizational structure and information technology—are related to employee knowledge-sharing capabilities. Through the survey of 322 employees in five public sector and five private sector organizations in South Korea, the research found that social networks, centralization, performance-based reward systems, employee usage of IT applications, and user-friendly IT systems significantly affect employee knowledge-sharing capabilities in the organizations studied (Soonhee Kim, 2006).

Based on an interview with local government leaders, a literature review in a related field and the innovation diffusion theory, Hu put forth three main factors that influence information sharing among departments of the local government in China, including the resources, drives and cognitions of information sharing. Then, Hu investigated 50 government departments in a medium city in China and validated the effect of these three influential factors of information sharing (Hu et al., 2007).

3 Theoretical Framework

A. DeLone & McLean Information Systems Success Model

The DeLone & McLean information systems success model is a framework and model for measuring the complex-dependent variable in IS research (DeLone and McLean, 1992). DeLone and McLean first conceptualize their model in three hierarchical levels: a technical level, a semantic level, and an effectiveness level. The technical level concerns how well the system transfers the symbols of communication, the semantic level concerns the interpretation of meaning by the receiver compared to the intended meaning of the sender, and the effectiveness level relates to how well the meaning conveyed to the receiver affects the actual behavior. In terms of DeLone and McLean's taxonomy, System Quality belongs to the technical level and Information Quality belongs to the semantic level. IS Use, User Satisfaction, Individual Impact and Organizational Impact belong to the effectiveness-influence level. The hierarchy of levels provide a basis for modeling System Quality and Information Quality as antecedents of IS Use, User Satisfaction, Individual Impact and Organizational Impact.

System Quality measures the processing system itself and is proved by many researchers as one of the key indicators in IS success. Information Quality focuses on the quality of the information that the system produces, including the form of information and its usefulness. A core aspect of the DeLone & McLean model is that IS Use is considered an IS success variable and is labeled as the consumption of an IS output. User Satisfaction describes the user's response to the use of the information system. Lastly, Individual Impact and Organizational Impact evaluate the effect of the information on the behavior of the recipient and the organizational performance, respectively.

In 2003, DeLone & McLean proposed the updated success model (Fig.1), which includes the new construct "Service Quality" and incorporates the "Individual Impact" and "Organizational Impact" into one construct "Net Benefit" (William and Ephraim, 2003). Service Quality describes the extent an IS employee promptly provides service to users. Net Benefit is a simple and parsimonious indicator that measures the impact an information system engenders in the personal and organizational context.

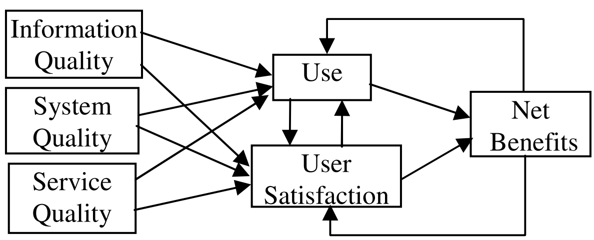

Fig. 1 Updated DeLone&McLean Model

The System Quality, Information Quality, and Net Benefit are accepted as antecedents of information sharing in the e-government. IS use is the measure of behavior, and User Satisfaction evaluates the usage of information systems from a subjective perception view. All of these two measures highlight the user of the information system. Thus, we combine these two constructs into "Information Use" in our work. Service Quality concerns the information system service, which is not related to information sharing and not included in our model.

B. TAM Model

At present, the Technology Acceptance Model (TAM) is generally referred to as a preeminent theory of technology acceptance in IS research. It is considered a parsimonious and robust model of technology acceptance behavior for a wide variety of IT, across both levels of expertise and countries (Gefen et al., 2003).

The origins of TAM can be traced to the Theory of Reasoned Action (TRA). TRA requires that salient beliefs about one's attitude toward a particular behavior (e.g., buying on the web) be elicited in order to be relevant to the specific behavior being studied (Benbasat and Barki, 2007). TAM can be assumed as a simple version of TRA.

According to TAM, the intention of a user wanting to accept a new IT system is determined by two beliefs: Perceived Usefulness (PU) of the new IT system and the Perceived Ease of Use (PEOU) of the new IT system. PU and PEOU are two measures of the individual's subjective assessment of the impact engendered by the new IT system. While PU is for the perception of the benefit offered by the new IT system in a specific context, PEOU is an indicator of the individual's cognition of the effort and time needed to learn and utilize the new IT system.

In essence, PU and PEOU are two measures used to evaluate the quality of information systems. Thus, they can be incorporated into the DeLone & McLean model.

C. Trust

Trust is a deeply studied concept in information systems and e-commerce. As defined by Mayer, trust is the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or confront that other party (Mayer et al., 1995).

Inspired by the TRA, McKnight integrated some trust constructs within the broad framework of the TRA. It was proposed that trusting beliefs will relate positively to trusting intentions and that the trusting intentions will affect the user's engagement in the trust-related behaviors (McKnight et al., 2002). Gefen identifies a number of trust antecedents: knowledge-based trust, institution-based trust, calculative-based trust, cognition-based trust, and personality-based trust (Gefen et al., 2003). These types of trust antecedents will affect user's trust formation of web systems and the intention to share personal information and conduct transactions with web vendors.

Trust has been conceptualized and scrutinized by previous research in a variety of ways, both theoretically and practically. It is definitely a pivotal concept in information sharing, and trust beliefs will also positively relate to information sharing intentions and behaviors in the e-government context. As a result, the trust notion will be integrated in the research model.

4 Research Model Development

In context of the e-government, information sharing is accomplished through specific kinds of information systems. Thus, technology-based and trust-based

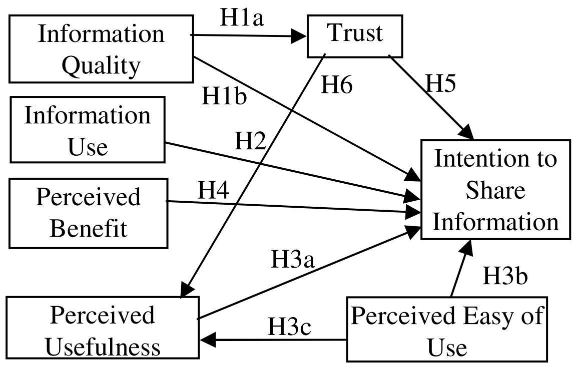

Fig. 2 Research Model

antecedents should work together to influence the decision to share information with other public agencies and employees. This section derives the research hypotheses of information sharing. The research model is depicted in Fig.2.

Information Quality measures the sharing information provided by other agencies and employees. The content of the information quality includes information accuracy, timeliness, usefulness, completeness and customized information presentation. Information quality has a positive influence on the user's intentions and behaviors of adopting and sharing information (Hsiu-Fen and Gwo-Guang, 2006). People definitely want to adopt accurate and useful information from other parties. Moreover, we argue that information users seem to enter into an implied agreement with the information providers and delegate the task of collecting and organizing information services to the providers. In order to counterbalance the information asymmetry between information providers and users, the information providers should make clearly visible, high-quality, and irreversible investments (Zahedi and Song, 2008). In the case of information sharing, information quality is the most important visible, high-quality, and irreversible investment. Information quality serves as one of the most important antecedents of consumers' beliefs in information providers' trustworthiness (Zahedi and Song, 2008). On the other hand, in return for the benefit brought by information sharing, information users like to share high quality information with providers. Thus a stable mutual information sharing relationship will be built based on the accruing benefits. Hence, the information quality will affect the user's intention to use the information sharing system and share information.

Hypothesis 1a: Sharing information quality is positively associated with trust in other agencies and employees.

Hypothesis 1b: Sharing information quality is positively associated with the users' intention to share information.

If the user needs to accomplish the organizational goal with the help of information sharing systems, he/she will have a high dependence on information sharing. Information Use measures the extent of a user's work dependent on the sharing information from other parties and is the corresponding construct of IS Use and User Satisfaction in the DeLone & McLean model. Information use is actually a behavior and describes the user's dependence on the information sharing system (Rai et al., 2002). A high information use means the user will adopt the sharing information in a high frequency and use that in management actions. Then, the employee will increase benefits from the information sharing activity. In the adoption process of the sharing information, a user among different government departments will establish the communication channel and share information for gradual mutual benefits. Thus, the higher dependence the user has in the sharing information, the higher the intention the user has to be involved in information sharing activities.

Hypothesis 2: The information use is positively associated with the users' intention to share information.

The information system is the basic technological infrastructure of information sharing in the public sector. It proffers a fundamental sharing platform for information in different public sector organizations. As such, information sharing intentions should be explained in part by the technology acceptance model, TAM, which contains the two basic constructs PU and PEOU.

The DeLone & McLean model doesn't include PU and PEOU, which are also important to IS success. Some notions in the DeLone & McLean taxonomy are closely associated to PU and PEOU. Information Quality in the semantic level of the DeLone & McLean model can make users perceive the IT system's usefulness. PEOU and PU are two salient indicators of System Quality.

Thus, the proposed research model takes the PU and PEOU into account, and we hypothesize that paths predicted by TAM apply also to information sharing. The more useful the information sharing system is for enabling users to accomplish their tasks, the more involved it will be. The easier the information sharing system is to use in enabling the users to accomplish their tasks, the more it will be provided.

Hypothesis 3a: PU is positively associated with the users' intention to share information.

Hypothesis 3b: PEOU is positively associated with the users' intention to share information.

Hypothesis 3c: PEOU is positively associated with PU.

Perceived benefits are defined as advantages offered by information sharing to policy makers, agencies, and the public. It is the analog of the net benefits construct in the DeLone & McLean model. Proponents of information sharing can enumerate an extensive list of potential benefits. First of all, information sharing will streamline the data management and contribute to the information infrastructure. From the organizational view, information sharing will support collaborative problem solving and broaden the professional network. At last, information sharing will improve public accountability and foster program and service coordination (Dawes, 1996). It is obvious that the perceived benefit will positively affect the users' intention to share information across organizational boundaries.

Hypothesis 4: Perceived benefits are positively associated with the users' intention to share information.

In context of e-government information sharing, trust also has been scrutinized by previous researchers in a variety of ways. Theresa pointed out that trust building is both a key factor for developing cross-boundary information sharing and, in a much broader sense, is an important element of the social capital needed for any type of successful cooperation or collaboration within and across social networks (Pardo et al., 2006).

Peng stated that the primary reason for hesitation and reluctance of agencies to share sensitive information with one another is that they simply don't trust each other, and trust-based information sharing schemes can easily lead to effective information sharing among government agencies (Peng Liu, 2005). One of the major reasons for distrust is that conflicts of interest usually exist between agencies. Thus having agency A share some information with agency B may actually compromise the interests of agency A. Another major reason for the lack of trust is that shared information may be improperly processed by an agency.

As shown in previous research, trust is a pivotal element in the cross-organizational collaboration. Trust is a useful assurance to mitigate the perceived risks and social uncertainty. If mutual trust has been built, the trustor will establish the truthful belief on the trustee's ability, benevolence and integrity. The trustor will believe that the trustee will not misuse the sharing information of the trustor and jeopardize the trustor's interests. Thus, the trustor will have more incentives to share information.

Hypothesis 5: Trust in other agencies and employees is positively associated with the users' intention to share information.

Trust should also increase certain aspects of the perceived usefulness of information sharing systems and sharing information. As Gefen stated, the usefulness of an information system depends on both the effectiveness of its relevant technological properties, such as advanced search engines, and on the extent of the human services behind the IT, which make the non-technological aspects of the IT effective (Gefen et al., 2003). One integral part of the human services behind the IT is the information sharing service offered by other agencies and employees. Viewed from this non-technological manner, trust will increase the perceived usefulness of information systems. Once mutual trust is built, information users can believe in the information the system produces and perceive the high quality of information systems. Thus, the benefits of sharing information will be maximized.

Hypothesis 6: Trusting other agencies and employees is positively associated with PU.

5 Conclusions

Information sharing is important in inter-organizational collaboration. Based on the DeLone & McLean model and TAM, this chapter integrates technology-based and trust-based antecedents to depict users' intentions for information sharing. Having a critical analysis of the previous theory, the corresponding information sharing influential factor research model is proposed and the corresponding hypotheses are derived. Information quality, information use, perceived benefit, trust, perceived usefulness and perceived ease of use are proposed as antecedents of the users' intention to share information. The research model provides a new research angle for information sharing, based on classic information system critical success factors. For our next research work, we will collect data from government agencies and validate the proposed research model.

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Research on Situations and Development Trends of Emergency Logistics at Home and Abroad

Xiufeng Zuo, Qian Ran, and Wenzhuo Gu

This chapter describes the features of emergency logistics and the role it plays in emergency management under the cognition of characteristics of public emergency. It elaborates on the three phases of foreign research and the situation of domestic research. The current emergency logistics research focuses on aspects of the organization, operation and control, the technical support, as well as policies and legislation. Finally, the chapter points out the trends of emergency logistics research.

1 Introduction

In 2008, snowstorms, frost, earthquakes, landslides, air crashes and mine disasters reminded us that human beings are sometimes faced with paroxysmal natural and man-made disaster. The unexpected occurrences disrupt the normal procedures of our daily work and life if we do not prepare for them. Therefore, it is an important research task to understand the principles and features of all kinds of disasters, to set up a system to deal with such incidents, and to optimize a rescue and emergency resources dispatch scheme so that we are active in dealing with emergencies.

With the development of human civilization, high-rise buildings, pipelines, efficient communications and traffic make comfortable living and working conditions for people. But, when we face disasters, the community becomes increasingly fragile. With GDP growth, the effect of emergencies is increasing. It is a strong national need to strengthen public security, and integrated emergency management is the core issue of public security (Fan, 2007).

Based on the principles of disaster and crisis, integrated emergency management covers disaster prevention, monitoring, forecasting, identification, measuring,

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rescue control, emergency preplans, rapid reactions, after-action reviews, reconstruction and so on (Cao et al., 2007). It also includes scientific management, dispatching and coordinating personnel and financial, material and informational resources during emergencies (Cao et al., 2007). At present, due to the lack of national-level research on integrated emergency management, it is still difficult to develop the storage of national emergency resources reasonably and build national and local monitoring networks and an emergency resource system to satisfy the demand of emergency handling and reconstruction (Cao et al., 2007).

The occurrence and development of public emergencies are non-reversible and non-experimental, so simulation experiments are an important method for studying the reasoning and principles of various kinds of emergencies and to take emergency management (Cao et al., 2007). Because Integrated Emergency Management is a complicated system, it is necessary to carry out the simulation research based on the rules of the evolution of emergencies. But research in this area both at home and abroad are still inadequate. Therefore, employing modern complex system modeling and simulation technology to study Integrated Emergency Management is a difficult task and has significant meaning.

A sudden, unexpected incident can cause serious damage. Emergency logistics is a special logistic activity that satisfies the demand of materials, personnel, information and finances during various kinds of emergencies. The basic features of emergency logistics are unpredictability, urgency and diversity in demands, as well as emergency mobilization of the army and local participation. The logistics disorder in the relief process of the massive earthquake in Wenchuan has been noted (Xu and Huang, 2008). Comprehensive arrangements for different resources and reducing waste are important elements in emergency management.

Emergency logistics research studies how to make use of technology to quickly identify the disaster’s state and the demands of disaster relief resources (the location and quantity of the needed resources) and how to use an appropriate means of transportation and routes to transport the materials efficiently and accessibly from the resource point to the rescue point, reducing the impact of the disaster and achieving the best disaster relief results.

2 Foreign Research on Emergency Logistics

There are three phases of research on emergency logistics abroad: before the mid-1990s, from mid-1990s to the start of the 21st century, and since the start of the 21st century.

In the first phase, before the mid-1990s, the difference between emergency logistics and general logistics was not much, and a few limiting factors were considered. In 1985, Aikens gave a location model based on linear programming, integer programming and dynamic programming (Aikens, 1985). Ray, in 1987, studied a transportation problem on emergency relief resources with different constraints to minimize transportation costs (Ray, 2003). Haghani and Oh, in 1996, developed a space-time network flow model (Haghani and Oh, 1996). At the same time, Gutierrez provided an optimization network design under uncertainty (Gutierrez et al., 1979).

In the second phase, from the mid-1990s to the start of the 21st century, researchers focused on the reality of emergency management, though the study range was still not wide, and they built more complex models under the consideration of more practical constraints and goals, and they employed the simulation method to study logistic problems. In 1997, Ahmed S. Zakit and Hsing Kenneth Cheng established a simulation analysis and management system of emergency services, which was designated by a mobile unit in a certain region, in order to respond to unexpected incidents occurring in different parts of a megalopolis (Zakit and Cheng, 1997). Wybo Jean Luc, et al. (1998) used the decision-making tools of GIS, simulator, information systems, as well as multimedia systems to build models (Luc et al., 1992). Owen and Daskin (1998) studied the problem of facilities location under uncertainty (Owen and Daskin, 1998). In 1998, Paulm and Needham studied an emergency transport problem using the simulation method and verified the effectiveness of the simulation used in emergency management (Needham, 1998). In 1999, Subramanian, in his doctoral dissertation, studied the transportation, emergency response, risk management and planning and location issues using the methods of the location of the supply center, path selection, resource allocation, etc. (Subramanian, 1999) Taniguchi (1999) used two-level programming to solve the location problem of public logistics transfer stations (Taniguchi, 1999). Holmberg K (1999) considered the location problem of non-linear freight costs. In order to minimize the number of deaths, Fiedrich (2000) studied an optimization model of resource distribution and transportation for the number of scenes after an earthquake under limited time and resources (Fiedrich et al., 2000a). Fiedich (2000) studied the heuristic arithmetic of the optimization of resource distribution after an earthquake, and proposed a dynamic portfolio optimization model to minimum the number of facilities during the rescue (Fiedich et al., 2000b).

In the third phase, since the beginning of this century, the research range of the emergency logistics was widening, using the system method to analyze and integrate a number of models. Especially after "9-11 incident", researchers laid emphasis on information, emergency response, emergency decision-making theories and the group decision support system. Yoshitaka Kuwata, et al. (2002) discussed a new simulation methodology and an approach assessing, designing and evaluating the emergency decision support system, which can quantitatively evaluate the effectiveness of the decision support system of an emergency response (Kuwata et al., 2002). Michael J. Kevany (2003) described the emergency maps, data center, and operational process, and he analyzed the function of GIS in emergency response through the "9-11 incident" (Kevany, 2003). In 2004, Eytan Pollak and Mark Falash gave an integrated analysis framework of emergency management (Pollak and Falash, 2004). Mei-Po Kwan and Jiyeong Lee (2005) further analyzed the structure of the GIS-based intelligent emergency response system (Kwan and Lee, 2005). Trevor Hale and Christopher R. Moberg (2005) studied the choice of the emergency logistics supply points (Hale and Moberg, 2005). For the number of emergency supply storages on the points, a quantitative model had been established. Groothedde B (2005) studied the coordinative HUB network, which can reduce the logistics costs and keep the level of service

(Groothedde et al., 2005). Yufei Yuan (2005) introduced an intelligent mobile emergency response system as well as its structure and functions (Yuan and Detlor, 2005). David Mendonca (2006) assessed a group decision support system of emergency response by game simulation (Mendonca et al., 2006). Yi W, et al. (2007) established a dynamic logistics coordination model for evacuation and rescue-injured personnel by studying FLP and VRP problems in emergency logistics as well as coordination between emergency delivery and people evacuation after disasters (Yi and Zdamar, 2007; Yi and Kumar, 2007). Jiuh-Biing Sheu (2005) thought that the core of the framework of emergency logistics was made of the following aspects: the forecast of the demand of the distributing materials, the emergency logistics network plan and design, the distribution of emergency materials, the rapid response of emergency material distribution, and the international emergency logistics cooperation (Sheu, 2005). Jiuh-Biing Sheu (2007) established a distribution system against the variability of the emergency materials demand. After obtaining the disaster information, the system first classified the grade stricken by the disaster in a different place with the fuzzy classification method, assessed the relational priority of the distribution, and then handled the distribution.

3 Domestic Research on Emergency Logistics

After SARS in 2003, Chinese scholars started to pay attention to the research of emergency logistics. Ou Zhongwen, et al. (2003) proposed to establish a support mechanism against the problems in present emergency logistics (Ou et al., 2004). Zhang Jing, using a utility function with a preference-order, solved the problem of resource allocation when multiple emergencies occurred simultaneously (Zhang et al., 2007). Xie Ruhe and Zong Yan (2005) discussed the establishment of a emergency response logistics system (ERL) by setting up an ERL Center, a public information platform and a distribution system (Xie and Zong, 2005). Li Lefei (2008) discussed the framework of the artificial emergency- logistics- planning system (Li, 2008). Hu Jiaxiang and Zhao Lindu established a framework for the logistics management system based on a multi-agent, including a communication support layer, a data layer, an accident find layer, an emergency operation layer, and a user layer (Hu and Zhao, 2008). Wang Dading and Chen Yuefeng, counting the complexity of equipment and logistics demands at war, provided a multi-agent framework of equipment and logistics systems based on a swarm platform to adapt different states, styles and environments of war. Liao Guangxuan proposed an assistant decision support system for urban emergency response, which integrated many areas of theories and technologies, including expertise, modern technologies and calculation models (Liao et al., 2005). Han Xiaomei and Han Jingti (2007) studied the emergency logistics intelligent decision support system under case-based reasoning technology and the intelligent decision-making method (Han and Han, 2007). Ji Lei, Chi Hong, Chen An, et al. (2006) described the concept of emergency management, essential contents and methods from the macro, middle, and micro aspects. Wang Feng, Jiang Yuhong and Wang Jin (2007) discussed essential contents of emergency logistics. Yu Jinju (2008) carried out an agent-based simulation research on natural disasters in airdrome management.

Domestic research has just started, but domestic researchers are no less aware of emergency logistics than those abroad. Both domestic and foreign research focus on operational control, technical support, and policies and legislation. The focal points of the study include: (1) research on emergency logistics information systems and technology; (2) research on rescue resource allocation and resource storage; (3) research on multi-supplier, multi-depot location routing problems; (4) research on the emergency logistics decision support system, integrating the above three aspects; (5) Based on the research above, discussion of the organization of emergency logistics, the effectiveness of relevant policies and the rationality of the emergency plan.

4 Trends of Future Research on Emergency Logistics

Emergency logistics are carried out under the interaction of emergency incident occurrence and its evolution and emergency handling. It is a complex process, composed of many departments and uncertainties. To reveal the real rules and mechanisms of the process, multidisciplinary research must be carried out.

Therefore, there are three aspects of future research: multidisciplinary research, the simulation method, and empirical study for different emergencies.

First, emergency logistics involves the disaster from the emergency, personnel reaction to the emergency, damage prediction or evaluation, information technology, decision-making methods, logistics, etc (Fan, 2007; Cao et al., 2007). Only under the ground of recognizing the damage of disasters, such as an earthquake, can we know the reactions of humans and predict injuries. According to the disaster information, it can organize an emergency rescue and material dispatch. Then, according to the disaster process, it can adjust the decision goals and produce a rescue plan of different levels.

Second, due to the emergency's uncertainty, serious damage and non-experimental research on emergency management are difficult. The effectiveness of emergency decision-making and the rationality of the emergency plan should not be measured by the heavy loss after such incidents. The simulations that have been currently conducted quickly have become an effective tool. Orienting continuous variation, discrete events and multi-agents, various kinds of simulation platforms are emerging. A simulation method is adapted to the variability of dynamic change of emergency logistics, involving multiple participants and complex relationships existing in emergency logistics. It can also integrate the multidisciplinary research results and embed these results in a simulation model. Through the operations of the simulation mode, we can study the process and the rules of emergency logistics. Therefore, the experiment method of simulation is an effective way to study emergency logistics.

Third, different kinds of emergencies have different principles of evolution, so they should be studied separately. This way, results are of pertinence and direction. It also facilitates testing and estimating the results. At the same time, it gives evidence to making an emergency plan and related policies.

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