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Zofia Wilimowska
Leszek Borzemski
Jerzy Świątek *Editors*

Information Systems Architecture and Technology: Proceedings of 38th International Conference on Information Systems Architecture and Technology – ISAT 2017

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Preface

This three volume set of books includes the proceedings of the 2017 38th International Conference on Information Systems Architecture and Technology (ISAT), or ISAT 2017 for short, which will be held on September 17–19, 2017, in Szklarska Poręba, Poland. The conference was organized by the Department of Computer Science and Department of Management Systems, Faculty of Computer Science and Management, Wrocław University of Technology, Poland.

The International Conference on Information Systems Architecture has been organized by the Wrocław University of Technology from the seventies of the last century. The purpose of the ISAT is to discuss a state of the art of information systems concepts and applications as well as architectures and technologies supporting contemporary information systems. The aim is also to consider an impact of knowledge, information, computing and communication technologies on managing the organization scope of functionality as well as on enterprise information systems design, implementation, and maintenance processes taking into account various methodological, technological, and technical aspects. It is also devoted to information systems concepts and applications supporting the exchange of goods and services by using different business models and exploiting opportunities offered by Internet-based electronic business and commerce solutions.

ISAT is a forum for specific disciplinary research, as well as for multi-disciplinary studies to present original contributions and to discuss different subjects of today's information systems planning, designing, development, and implementation. The event is addressed to the scientific community, people involved in a variety of topics related to information, management, computer and communication systems, and people involved in the development of business information systems and business computer applications.

This year, we received 180 papers. The papers included in the three proceedings volumes published by Springer have been subject to a thoroughgoing review process by highly qualified peer reviewers. At least two members of Program Committee or Board of Reviewers reviewed each paper. The final acceptance rate was 56%. Program Chairs selected 101 best papers for oral presentation and publication in the 38th International Conference on Information Systems Architecture and Technology 2017 proceedings.

The papers have been grouped into three volumes:

Part I—discoursing about topics including, but not limited to, Artificial Intelligence Methods, Knowledge Discovery and Data Mining, Big Data, Knowledge Discovery and Data Mining, Knowledge Based Management, Internet of Things, Cloud Computing and High Performance Computing, Distributed Computer Systems, Content Delivery Networks, Service Oriented Computing, and E-Business Systems, Web Design, Mobile and Multimedia Systems.

Part II—addressing topics including, but not limited to, System Modelling for Control, Recognition and Decision Support, Mathematical Modeling in Computer System Design, Service Oriented Systems and Cloud Computing and Complex process modelling.

Part III—dealing with topics including, but not limited to, Modeling of Manufacturing Processes, Modeling an Investment Decision Process, Management of Innovation, Management of Organization.

We would like to thank the Program Committee and external reviewers, essential for reviewing the papers to ensure a high standard of the ISAT 2017 conference and the proceedings. We thank the authors, presenters, and participants of ISAT 2017; without them, the conference could not have taken place. Finally, we thank the organizing team for the efforts in bringing the conference to a successful scientific event.

We devote ISAT 2017 to our friend and former ISAT Chair, Professor Adam Grzech.

September 2017

Leszek Borzemski
Jerzy Świątek
Zofia Wilimowska

In Memory of Our Friend and Past ISAT Chair

Professor Adam Grzech

November 2016

Professor DSc. Adam Grzech was born in 1954 in Dębica (Poland). He was graduated at the Wroclaw University of Technology 1977—M.Sc. Electronic Engineering. He did his PhD at the Institute of Technical Cybernetics in 1979 and D.Sc. in technical sciences in the field of computer science in 1989 and received the title of full Professor in 2003 from Wroclaw University of Technology.

He was an Assistant Professor at the Institute of Technical Cybernetics (1979–1982), an Assistant Professor at the Institute of Control and Systems Engineering (1982–1989), Associate Professor at the Institute of Control and Systems Engineering (1989–1993), a Professor at the Institute for Technical Informatics (1993–2006), and a Full Professor at the Institute of Computer Science, Faculty of Computer Science and Management at Wroclaw University of Technology (since 2006).

He was an author and co-author of over 350 published research works. His areas of research were as follows: analysis, modeling, and design information and communication systems and networks. Since 2002, he was a Chief of Telecommunication Department. He was a leader of Scientific School on Information and Communication Systems and Networks. He was a promoter of the 10 completed Ph.D. theses.

During the years 1991–1993 and 1999–2002, he was a Director of the Institute of Control and Systems Engineering. Since 2002, he was a delegate of the Rector for Information Technology, and then during the years 2003–2005, he was a Vice President for Development at the Wroclaw University of Technology and in 2002–2008 a member of the Senate of the Wroclaw University of Technology. During the years 2005–2012, he was a Vice Dean of Computer Science and Management Faculty.

He was active in the work at the national, international committees of conferences and scientific journals. He was Co-chair of Information Systems Architecture and Technology (ISAT) and Systems Science International Conferences. Since 1982, he served as Scientific Secretary, and since 2006 Editor-in-Chief of the Science Systems journal published quarterly.

Professor Adam Grzech was a member of the Wroclaw Scientific Society, the Polish Informatics Society, the Council of Information Technology, the Committee on Informatics of the Polish Academy of Sciences, and Technical Committee TC6 (Communication Systems) IFIP.

Leszek Borzemski
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ISAT 2017 Szklarska Poręba, September 17–19, 2017

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ISAT 2017 Special Session

Modeling of Manufacturing Processes
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Contents

Modeling an Investment Decision Process

Intelligent ALMM System for Discrete Optimization Problems – The Idea of Knowledge Base Application

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Abstract. The paper introduces the concept of intelligent information system for solving discrete optimization problems, named Intelligent ALMM System. The system is a new version of the software tool named ALMM Solver [8, 13]. The paper propose new idea of functioning the solver and its new, essentially extended structure. Presented in the paper Intelligent ALMM System not only solves discrete optimization problems, but also: assists its users in the selection of an appropriate solving method, helps configure algorithms and helps the development of problem model software representations. In order to implement this new idea the author proposes the use of a Knowledge Base linked with the Intelligent User Interface. Both ALMM Solver and Intelligent ALMM System utilize a modeling paradigm named Algebraic-Logical Meta-Model of Multistage Decision Processes (ALMM) and its theory both developed by Dudek-Dyduch E. ALMM enables a unified approach to creating discrete optimization problem models, representing knowledge about these problems and presenting solving methods and algorithms.

Keywords: Intelligent solver · Optimizer · Intelligent decision technology · Knowledge base · Algebraic-logical meta-model · ALMM · Discrete optimization problems · Intelligent software tool · Artificial intelligence tool · Intelligent User Interface · ALMM technology

1 Introduction

The paper introduces the concept of intelligent information system for solving discrete optimization problems (including NP-hard ones). The system is based on modeling paradigm named Algebraic- Logical Meta-Model of Multistage Decision Processes (ALMM) [6, 7], hence its name ALMM System. Using ALMM paradigm, it is possible to develop so called algebraic logical (AL) models for a large class of discrete optimization problems as well as combinatorial ones [5–7, 9, 11, 14]. Methods and algorithms used for solving as well as various problem properties can be presented in a uniform, ALMM based terminology too. This fact is of key importance. What is more, relationships between problem properties and the suitability (and feasibility) of

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applying certain methods can be recorded in the knowledge base. This particular fact was used for development of the Intelligent ALMM System.

The very first idea of the ALMM based software tool for solving discrete optimization problems, named ALMM Solver, was described in [8, 16]. Then the idea of functioning and the architecture of solver was developed by introducing a new module Problem Model Library [3, 13]. The solution methods provided in the all former versions [3, 8, 13], however, were only limited to those based on state graph searches. This paper introduces a new idea of the solver functioning together with its essentially modified and extended structure. The relatively simple software tool is replaced by extended information system. The tasks of the system, called Intelligent ALMM System by the author, are much more extensive. The ALMM System is not only supposed to solve discrete optimization problems utilizing a broader spectrum of methods than merely those based on state graph searches, but it is also supposed to:

- assist its users in the selection of an appropriate solving method,
- help configure algorithms based on the method selected,
- help and to a certain extent automate the development of software models of problems to be solved by the Solver.

In order to implement this new idea, the author proposes the use of a Knowledge Base (KB) linked with the Intelligent User Interface (IUI). Thanks to these two new modules, the Intelligent ALMM System will not only solve discrete optimizations problems, but also perform certain expert and creative functions to date reserved for humans [10].

The idea of developing software tools capable of solving certain classes of problems is not new. The most popular such tools are based on CLP approach [17]. The problems are modeled there by a finite, predetermined number of variables, their domains and relations between them. The models are introduced with the use of declarative languages [2]. There are also software tools based on agent approach and the ones dedicated to some chosen methods e.g. evolutionary programming [18] as well as discrete programming. None of these applications, however, according to the author, have sufficient intelligence to be able to tackle Intelligent ALMM System tasks.

The paper is organized as follows. Section 2 presents an ALMM based modeling paradigm. The structure of Intelligent ALMM Solver, proposed by the author, is described in Sect. 3 together with its functional background. Section 4 presents the idea and general structure of the proposed KB or more specifically the Knowledge Base of Problems. It describes the Library of Problem Models and the Problem Properties Knowledge Base with definitions of criteria important for automated procedure configuration and intelligent support of solving method selection included therein. Examples of such properties used for automated configuration of criteria' procedures are provided as well.

2 Algebraic-Logical Meta-Model

ALMM is the general model development paradigm for deterministic problems for which the solutions can be presented as a sequence or a set of complex decisions. The idea of system modelling, that uses both algebraic and logical formulas, comes from Z.

Bubnicki. The author of herein has adopted this general idea for create Algebraic Logical Meta Model of Multistage Decision Processes.

ALMM paradigm was proposed and developed by Dudek-Dyduch in [6, 7, 9] and recalled in many papers among others [3, 4, 13, 14]. It is also put to use in multiple cases [5, 7, 12, 14]. Based on ALMM the formal AL models may be established for a very broad class of discrete optimization problems from a variety of application areas (especially for modeling and control of discrete manufacturing processes) [4–6, 9–12, 14], thus yielding to the meta-model designation. ALMM provides a structured way of recording knowledge of the goal and all relevant restrictions that exist within the problems modeled. Using this paradigm, the author has provided, i.e. in [6] and recall in [3, 4] the definitions of two base types of multistage decision processes: a common process (cMDP) and a dynamic process (MDDP). Both types imply two basic classes of AL models and may frequently determine divergent solving methods (and algorithms). The definition of MDDP quoted below refers to processes wherein both the constraints and the transition depend on time. Therefore, the concept of the so called "generalized state" has been introduced, defined as a pair containing both the state and the time instant.

Definition 1. "**Multistage dynamic decision process is a process** that is specified by the sextuple $MDDP = (U, S, s_0, f, S_N, S_G)$ where U is a set of decisions, $S = X \times T$ is a set named a set of generalized states, X is a set of proper states, $T \subset \Re + \cup \{0\}$ is a subset of non-negative real numbers representing the time instants, $f : U \times S \rightarrow S$ is a partial function called a transition function, (it does not have to be determined for all elements of the set $U \times S$), $s_0 = (x_0, t_0)$, $S_N \subset S$, $S_G \subset S$ are respectively: an initial generalized state, a set of not admissible generalized states, and a set of goal generalized states, i.e. the states in which we want the process to take place at the end. Subsets S_G and S_N are disjoint i.e. $S_G \cap S_N = \emptyset$.

The transition function is defined by means of two functions, $f = (f_x, f_t)$ where f_x, f_t determine the next state and the next time instant respectively."

The cMDP is obtained by reducing a generalized state to a proper state with a transition function $f = f_x$. For both defined types of the multistage decision processes, in the most general case, sets U and X may be presented as a Cartesian product $U = U^1 \times U^2 \times \ldots \times U^m$, $X = X^1 \times X^2 \times \ldots \times X^n$ i.e. $u = (u^1, u^2, \ldots, u^m)$, $x = (x^1, x^2, \ldots, x^n)$. In particular, u^i, $i = 1,2..m$ represent separate decisions that must or may be taken simultaneously and relate to particular objects. Values of particular coordinates of a state or a decision may be names of elements (symbols) as well as some objects (e.g. finite set, sequence etc.). A sequence of consecutive states from the initial state to a final state (goal, nonadmissible or blind one), computed by transition function form a process trajectory. One can define a large class of constructive algorithms by means of proper control over the generation of particular trajectories or their parts, as the trajectories are defined with use of AL model. The concept of ALMM Solver is based on this noticing. AL model of optimization problem is denoted as a $(\boldsymbol{P}, \boldsymbol{Q})$ pair where $\boldsymbol{P}$ is a suitable multistage decision process and $\boldsymbol{Q}$, is a criterion. An optimization task is denoted as a (P, Q), where P, Q are the individual process and individual criterion respectively.

3 Structure of Intelligent ALMM System

Intelligent ALMM System is to provide solutions (exact or approximate) for combinatorial and discrete optimization problems or indicate that no solution has been found. A solution has form of a sequence (or set) of decisions (very often the complex ones). As mentioned, the initial structure of ALMM Solver [8, 16] has been modified essentially in [3], where then new Library of Problem Models module was introduced and described. Figure 1 presents quite new, extended architecture. The new modules are: Intelligent User Interface (IUI), Knowledge Base, Solution Creator module and Solution Creator Control module.

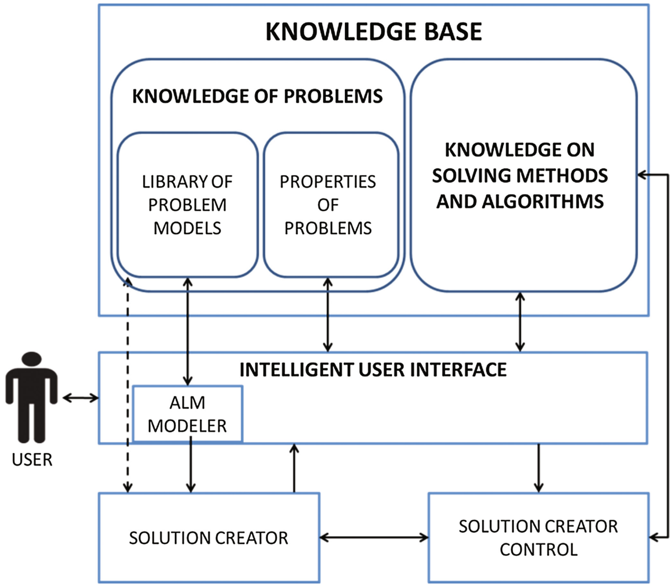

Fig. 1. Architecture of intelligent ALMM system

The main computation module is Solution Creator carrying out operations aimed at finding solutions for problem instances. In the current solver version, the Solution Creator consists of a few parallel submodules called Solving Method Engines (SME). The functioning of each SME is based on a strictly defined solving method (or class of algorithms). These methods, both well established and newly developed ones [4, 7], are defined by the so called ALMM technology, i.e. ALMM based modelling paradigm and terminology. The methods will be implemented in a component based technology. Each Solving Method Engine implements an algorithm class based on its own method. The Control of Solution Creator module launches and configures the appropriate Solution Method Engine so that the appropriate algorithm is executed.

In earlier papers [3, 8, 13] only one module named SimOpt was used instead of the Solution Creator. The SimOpt module was designed for implementation of a class of constructive algorithms based on state tree searches and specially developed local optimization tasks (see [4]). The SimOpt module task is to intelligently construct the state transition tree (either in its entirety, or only a part of it) by generating one or more trajectories (parts of trajectories). The structure of the SimOpt module and its detailed description is given in [3, 8]. (Due to limited length of the article, the description cannot be included herein.) From this point the module (following appropriate modifications) will constitute a part of the Solution Creator module as one of its Solving Method Engines. The Solution Creator operating paradigm and architecture will be laid out in a separate paper.

The role of the **Intelligent User Interface (IUI)** is threefold.

Its first task is to initiate and forward information about the problem model and its instance to the Solution Creator module. The model needs to take a form understandable to the Solution Creator module and other modules, i.e. it should have a software form called the software representation of the AL model (software model). There are three base manners of creating AL models and their software representations, proposed in [3]. A user can download a ready model from Problem Model Library or build a model from Problem Model Library components. Obviously, a user can develop a new model from scratch and implement it in a proper programming language. IUI processes the first task together with the Problem Library module and for the last two cases it can also use its submodule ALM Modeler.

The second task consists of intelligent method selection (supported by ALMM System) and configuration of its solving algorithm. In this task, the IUI works together with the Knowledge Base parts: Problem Properties (located in the Knowledge Base of Problems) and the Knowledge Base on Solving Methods & Algorithms.

The third task consists in returning a solution (one or many) or information that no solution was found. Additional information on the solution and solving processes may be also presented.

4 Knowledge Base

The Knowledge Base consists of two main mutually joined parts. First part contains the knowledge of problems while second part contains knowledge on solving methods and algorithms (see Fig. 1). This paper presents the idea and general structure of the first part, named Knowledge Base of Problems. This part consists of two further parts: Library of Problem Models and Properties of Problems.

4.1 Library of Problem Models

Library of Problem Models provides software models to various Solver modules and is supposed to serve two objectives. The first of these is storage of AL models together with their software representations. Models of problems belonging to specific, well-known areas such as scheduling, graph problems etc. will be stored in matching subareas of the library. The second objective is storage of components that can be used to develop new AL models and their software representations. For that reason, the library has a component based structure. The library must be designed the way it enables to easily seek out appropriate models and necessary components. Moreover, its structure must be flexible in order to enable its gradually extension. The library is implemented with the use of C# because of its object-oriented character, capacities, ease of use and availability of multiple class libraries for various purposes, as well as its reliability.

The most important issue is to adopt an appropriate way for implementing the problem models, that is to design a software representation of AL models. As mentioned earlier, process ***P*** represents all problem constraints and is the formal model of admissibility problem, while a ***(P, Q)*** correspond to optimization problem. The software model of process ***P*** is implemented as a class named cProblem. Problem instances are represented by objects from that class. The AL model indicates and defines elements of the process that need to be implemented in the cProblem class.

Both the idea and basic structure of the Problem Model Library and the software representation of AL models concept have been proposed and presented in [3]. Then, the extended and detailed description of process ***P*** implementation is given in [13]. The library also contains the components used for creating the procedures for the criteria. The paper gives basic rules of creating these procedures for the classes of most popular criteria.

4.2 Knowledge Base of Problem Properties

The knowledge of problems' properties stored in the Knowledge Base part referred to as Problem Properties will be used directly by the Intelligent User Interface. On the current stage, this part of the Knowledge Base is established with two basic objectives in mind. The first is related to model searches carried out in the Library of Problem Models and developing new models using existing components. The verification of whether a model or its components is already included in the Library of Problem Models is an important task. Such check may be carried out based on the problem name, but in case of ambiguous names it can also be executed based on certain selected properties of elements defining the model (e.g. properties of state or decision structures or others). The second objective is related to the Solution Creator Control module performance, touching on the issues of method selection and configuration of algorithm based on that method. Problems tackled by the Solver have certain common properties enabling the use of a relevant method and/or the determination of which out of interchangeable procedures (within that method) should be applied. They also have certain specific properties significant for an algorithm based on a selected solving method. The Intelligent User Interface supports method selection and communicates information regarding such choice (executed by an appropriate Solution Method Engine) to the Solution Creator Control module. Furthermore, it communicates information enabling the configuration of an algorithm based on the selected method by setting appropriate subroutines for execution. The interchangeable procedures contained in the procedure library are determined depending on the model as well as problem properties. Obviously, the interchangeable procedures can also be developed on purpose and input by the user. Properties stored in the knowledge base will be divided into groups related to:

- multistage process type that is a base for the given model (MDDP or cMDP),
- properties of individual elements defining the P process,
- properties of the P process trajectories,
- properties of individual criteria,
- other properties.

4.2.1 Properties of Criteria

The example below presents cooperation of the Intelligent User Interface with the Knowledge Base of Problem Properties, aimed at selection and configuration of an algorithm calculating any criterion. The example utilizes criteria properties given in Definitions 2–4. The Problem Model Library will contain, alongside software representation of processes ***P***, certain procedures enabling the computation of various criteria occurring frequently in some problem domain [1]. A broad class of criteria can be defined by recurrence and computed in parallel to the calculations of trajectories. The author named the said class as "separable criterions" (see Definition 2) [6, 9]. It is worth remembering, though, that these are not the only criterion class that may be used.

Vast majority of methods and algorithms described in literature use (with or without overt declaration) some properties of criteria that facilitate the solving process. Some of these, defined by Dudek-Dyduch and based on ALMM paradigm in [6, 7, 9] and then recalled in [14], are presented below. Let us denote: P – a fixed multistage decision process, S^P – set of all states of trajectory of the process, $d(\tilde{s})$ – number of the last state of a finite trajectory $\tilde{s}$, $\tilde{U}$ – set of all decision sequences of the process P, $\Re$ – set of real numbers.

Definition 2. "Criterion Q is a separable for the process P, iff for every decision sequence $\tilde{u} \in \tilde{U}$ can be recursively calculated as follows:

Q_0 = const., in particular $Q_0 = 0$

$$Q_{i+1} = f_Q(Q_i, u_i, s_i) \quad \text{for} \quad i = 0, 1, \ldots, d(\tilde{s}) - 1 \tag{1}$$

where: Q_i for $i > 0$ denotes partial value of criterion Q calculated for i–th state of the considered trajectory, defined as follows:

$Q_i = Q(\tilde{u}')$, where $\tilde{u}' = (u_0, u_2 \ldots u_{i-1})$ is the initial part of the sequence $\tilde{u}$, f_O is some partial function $f_Q : \Re \times U \times S \rightarrow \Re$ such that: $Dom f_Q = \{(a, u, s) \in \Re \times U \times S : \quad s \in S^P,\ u \in U_P(s), \quad a \in \Re\}$".

Separability is a property of an algorithm which calculates quality criterion for a sequence of decisions $\tilde{u}$, and thus for designated by it the trajectory $\tilde{s}$. Criterion is separable if we can calculate its value for the next state of trajectory knowing its value in the previous state and the decision taken at that time. Particularly useful are the property of additive separability of criterion. Let Q be separable criterion and a function $\Delta Q(u, s)$ denotes the increase (decrease) of criterion in the s state (of a fixed trajectory of the process P) as a result of decision u.

Definition 3. "Separable criterion Q is additive iff for each trajectory $\tilde{s}$ of process P:

$$f_Q(Q_i, u_i, s_i) = Q_i + \Delta Q(u_i, s_i) \quad for \quad i = 0, 1, \ldots, d(\tilde{s}) - 1 \tag{2}$$

($\Delta Q(u_i, s_i)$ is usually denoted as ΔQ_i)".

Definition 4. Separable criterion Q changes multiplicatively iff for each trajectory $\tilde{s}$ of process P:

$$f_Q(Q_i, u_i, s_i) = Q_i \cdot q(u_i, s_i) \quad for \quad i = 0, 1, \ldots, d(\tilde{s}) - 1 \tag{3}$$

where $q(u,s)$ is a certain function depending on the decision and the state (in particular $q(u,s)$ = const.).

Taking into account the widespread use of separable criterion class, its computation pattern will be implemented in the Solution Creator module. The Solution Creator module will execute various criterion calculation procedures depending on properties the individual criteria will meet. The ΔQ and q procedures may be stored in the Library of Problem Models or be entered by the user.

The Intelligent User Interface asks a series of question (see Fig. 2). The first of these concerns criterion separability. For affirmative answer it executes a default procedure compliant with Definition 2 (formula (1)) and checks in sequence if the criterion

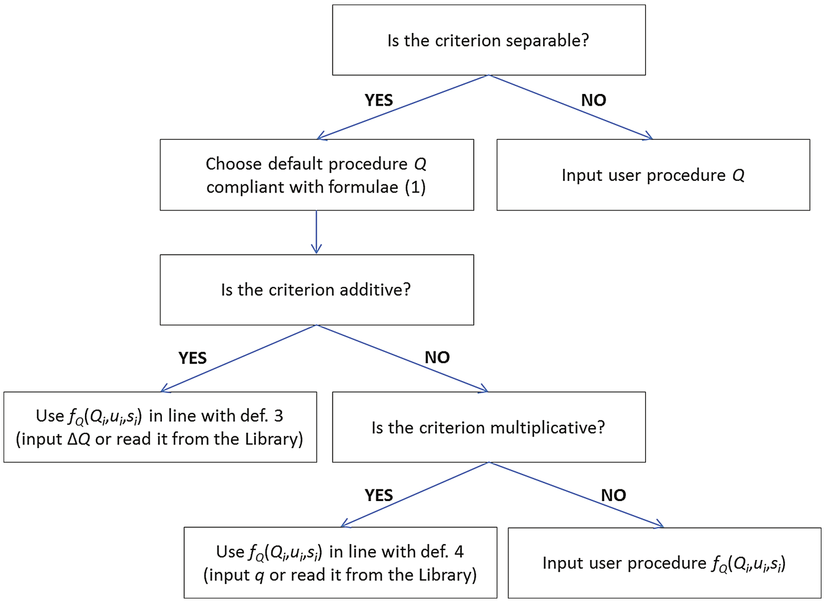

Fig. 2. Criterion algorithm configuration diagram

is additive or multiplicative, using functions $f_Q(Q_i,u_i,si)$ with formulas given in Definition 3 or 4, respectively, depending on the user's answer. The relevant part of the $f_Q(Q_i,u_i,s_i)$ formula (that is ΔQ or q) can be read from the library or input by the user. For nonseparable criterion, the Interface requests definition of the criterion calculation algorithm from the user.

The next, very valuable criterion properties is monotonicity. It is use in many method and individual algorithms, thus it is verified by IUI too.

Definition 5. "Separable criterion Q is monotonically ascending along each trajectory of the process P if $Q_{i+1} \geq Q_i$ for each decision sequence $\tilde{u} \in \tilde{U}$. If $Q_{i+1} \leq Q_i$ for each $\tilde{u} \in \tilde{U}$ we say that Q is monotonically descending."

The criterion properties provided above are used in branch & bound (or pruning) method, dynamic programming, reinforcement learning, A* algorithms and the construction algorithm class based on the so called three stage method and in particular learning method based on ALMM [4, 6, 9]. Thus IJI may offer possible solution methods to a user's problem based on criterion properties and the ***P*** process. Once a method is selected by the user, the Intelligent ALMM Solver uses more detailed problem properties and its software model to configure individual algorithm components.

5 Conclusion

The paper introduces concept of Intelligent ALMM System for solving large class of discrete optimization problems. The system is a new, essentially changed and developed version of the software tool named ALMM Solver. The author proposes the new idea of functioning and the new, extended structure. Intelligent ALMM System is supposed not only to solve discrete optimization problems, but also: assist its users in selection of an appropriate solving method, help configure algorithms and aid the development of problem model software representations. In order to implement this new idea, the author proposes the use of a Knowledge Base linked with the Intelligent User Interface. The paper presents the first part of the knowledge base, namely the Knowledge Base of Problems. Its next part, the Knowledge on Solving Methods linked with Solution Creator Control module will be covered in another paper to follow. The team under the supervision of Dudek-Dyduch E. is currently working on the implementation project of Knowledge Base.

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The Inversion Test of the Investment Funds Efficiency Measures

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Abstract. The purpose of this article is to present the use of the inverse test in investment funds based on historical data. Kendall's coefficient is the known factor used to test rank correlations. As a measure of dependency is used at any sample size. Its distribution (except asymptotic distribution) is rarely used because of the rather difficult analytical form of the statistics used to test the hypotheses. This work will use the inversion test, which is a variant of the test based on correlation Kendall rank. In the case of a moderate sample, it is more convenient to consider the amount of inversion. It is equal to the number of incompatible pairs (in the sense described below) for variables with a continuous distribution (binding pairs are not possible). It turns out that the language of inversion is often more comfortable. This is particularly noticeable in case of second type error analysis. In the paper are presented the results of the test of the Sharpe and Treynor measures ability for investment rate of return prediction of Polish investment funds.

Keywords: Investment funds · Inversion test · Efficiency · Predictability

1 Introduction

Investing in the capital market allows individual and institutional investors to make money without contributing the work by investing their previously earned cash surplus. However, the risk is an inherent part of investing. According to the definition of investment, today are incurred expenditures, for future benefits. The future in a changing environment creates uncertainty for future benefits, and uncertainty creates risk. Investor makes an investment decision and expects that future cash flows generated by the investment will earn money. All investors like the idea of achieving high returns on the investment, most tend to dislike the high risks that are associated with anticipated high returns. The investor in the decision-making process must constantly make choices (trade off) between the rate of return and risk. Understanding the trade-off that have to be made between investment risk and expected rate of return is a base to investment decision making. Uncertainty and risk which are associated with capital investment require a special instrument supporting process of the investor's decision making.

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Risk understood as uncertainty, possibility that expected benefits will not be achieved, that benefits deviate from expected benefits follows the decision making process. Managers recognize that the expected return from risky activity tends to be higher than the expected return from less risky activities.

Investment funds allow reduce the risk of investment in the financial market by risk diversification building the portfolio of financial instruments. The individual investor must devote a lot of effort, and when he has small amount of capital simply is not able to effectively diversify his portfolio. The investment fund deposit gathering many participants may choose securities such a way that potential large drops, or even bankruptcy of one of the issuers, it was compensated by increases in the prices of shares in other companies, thus reducing the investment risks and giving it greater stability.

Evaluation of the efficiency of investment is always carried out in relation to the accepted reference point (benchmark). As a criterion for assessing the effectiveness of the funds shall be the rate of return, which is determined on the basis of changes in the value of shares, the level of risk incurred and the additional profits that it compensate. The most commonly used indicators to evaluate investment funds are indicators: Sharpe (Sp), Treynor (Tr) and Jensen (Je) [10]. These measures are risk-adjusted capital, as their design takes into account both the rate of return reached by the investment fund as well as the accompanying investment risk. These indicators are calculated based on the results of the estimation model (CML) Capital Market Line and the Capital Asset Pricing Model (CAPM).

Sharpe ratio is the ratio of the average additional rate of return, which is the surplus profit that comes from the fund over a risk-free rate to the standard deviation of the additional rate of return which is a derivative of total risk. A positive index value indicates the profit worked out by the fund is higher than the benchmark, which lets you choose a fund with the highest rate of return with minimal risk. If the index value is negative, it means that the profit of the fund is lower than the market risk-free rate for which is usually assumed profitability of T-bills.

$$Sp = \frac{R_p - R_f}{\sigma_p}$$

where:

R_p - the average rate of return of the investment fund at time t
R_f - the average rate of return on risk-free instruments at time t
σ_p - standard deviation of the returns of the investment fund at time t

The counter of this expression is the so-called risk premium, a kind of reward for the investor, that is additional income above the risk-free rate. The higher the Sharpe ratio, the higher is the efficiency of the tested fund.

Construction of Treynor's Ratio is similar to Sharpe ratio, Treynor ratio, however, takes into account two types of risks. One result of the general situation on the whole market and is called systematic risk (coefficient β), and the second, the specific risk is characteristic of the assets in the portfolio. Through appropriate diversification of assets portfolio, reducing the risk unsystematic it manages to reduce the total risk to the level of systematic risk.

$$Tp = \frac{R_p - R_f}{\beta_p}$$

where:

Rp - the average rate of return of the investment fund at time t
Rf - the average rate of return on risk-free instruments at time t
βp - systematic risk (coefficient β) of investment fund at time t

This indicator reflects the sensitivity to changes in the value of the instrument to changes in benchmark.

2 The Inversion Test

The coefficient τ-Kendall (Magiera R. 2002) is used to describe the correlation between order variables. In order to calculate τ-Kendall, the observations in the sample should be compiled into all possible pairs and classified into three categories.

Compatible pairs – either variable or in the first observation both are larger than the second or both smaller, the number of such pairs will be marked as P_z.

Incompatible pairs – the variables change in the opposite direction, one of them is greater for the observation in pair for which the second one is smaller, the number of such pairs is marked as P_n.

Bonded pair – in both observations one variable has the same value, the number of such pairs – P_w.

Estimator of τ-Kendalla can be calculated from the formula

$$\tau = \frac{P_z - P_n}{P_z + P_n + P_w}$$

This coefficient is contained in the interval (−1, 1).

Because

$$P_z + P_n + P_w = \binom{n}{2} = \frac{n(n-1)}{2}$$

then

$$\tau = 2\frac{P_z - P_n}{n(n-1)}$$

where:
n – sample size.
P_z – number of compatible pairs.
P_n – number of incompatible pairs.

A permutation tool is a convenient tool for analyzing variables in the order scale.

Permutation is a function that transforms the set of natural numbers {1, 2,…, n} into oneself. Observations of any real random variable can be ordered according to the natural order if there are no equal ones. This happens if the assumed random variable is assumed to be continuous.

Let

$$N_n = \frac{n(n-1)}{2}$$

will be the maximum number of inversions in permutation with n arguments

Let $\left\{ \begin{matrix} N_n \\ k \end{matrix} \right\}$ will be the number of permutations having exactly k inversion.

If $N_1 = 1$, then from definition $\left\{ \begin{matrix} N_1 \\ 0 \end{matrix} \right\} = 0$

For $N_2 = 2$, is $\left\{ \begin{matrix} N_2 \\ 0 \end{matrix} \right\} = 1$ i $\left\{ \begin{matrix} N_2 \\ 1 \end{matrix} \right\} = 1$.

For $N_3 = 3$ is $\left\{ \begin{matrix} N_3 \\ 0 \end{matrix} \right\} = \left\{ \begin{matrix} 3 \\ 0 \end{matrix} \right\} = 1, \left\{ \begin{matrix} 3 \\ 1 \end{matrix} \right\} = 2, \left\{ \begin{matrix} 3 \\ 2 \end{matrix} \right\} = 2, \left\{ \begin{matrix} 3 \\ 3 \end{matrix} \right\} = 1$

Similary for $N_4 = 6$:

$$\left\{ \begin{matrix} N_4 \\ 0 \end{matrix} \right\} = 1, \left\{ \begin{matrix} N_4 \\ 1 \end{matrix} \right\} = 3, \left\{ \begin{matrix} N_4 \\ 2 \end{matrix} \right\} = 5, \left\{ \begin{matrix} N_4 \\ 3 \end{matrix} \right\} = 6,$$

$$\left\{ \begin{matrix} N_4 \\ 4 \end{matrix} \right\} = 5, \left\{ \begin{matrix} N_4 \\ 5 \end{matrix} \right\} = 3, \left\{ \begin{matrix} N_4 \\ 6 \end{matrix} \right\} = 1$$

In the general case:

$$\left\{ \begin{matrix} N_n \\ k \end{matrix} \right\} = \sum\nolimits_{i=\max(0,k-n+1)}^{k} \left\{ \begin{matrix} N_{n-1} \\ i \end{matrix} \right\} \tag{1}$$

3 Inversion Test for Investment Funds

The study was conducted for 36 investment funds with legal form of mutual funds or expertly open, operating on the Polish market. These are different types of funds: Money Funds, Debt Funds, Mixed Funds and Stock Funds, Table 1. The study period covers the years 2012–2016.

The following theorem [1] will be used to test hypotheses about inversions.

Theorem

Let p be a probability of inversion and

$$P(I_n = k) = \left(\left\{ \begin{matrix} N_n \\ k \end{matrix} \right\} p^k q^{N_n - k}\right) / \sum\nolimits_{k=0}^{N_n} \left\{ \begin{matrix} N_n \\ k \end{matrix} \right\} p^k q^{N_n - k} = \left(p_{n,k} \cdot p^k q^{N_n - k}\right) / \sum\nolimits_{k=0}^{N_n} p_{n,k} \cdot p^k q^{N_n - k} \tag{2}$$

Table 1. Tested investment funds

Type	Investment fund (TFI)
Money funds	INVESTOR Gotówkowy SFIO (Investors TFI)
	KBC Pieniężny (KBC TFI)
	MetLife Pieniężny (MetLife TFI)
	NN Lokacyjny Plus FIO (NN Investment Partners TFI)
	UniKorona Pieniężny FIO (Union Investment TFI)
Debt funds	Aviva Investors Obligacji Dynamiczny FIO (Aviva Investors Poland TFI)
	ALLIANZ Obligacji Plus FIO (Allianz Polska S.A. TFI)
	KBC Papierów Dłużnych FIO (KBC TFI)
	NN Obligacji FIO (NN Investment Partners TFI)
	PZU Ochrony Majątku FIO (PZU S.A. TFI)
	PZU Papierów Dłużnych POLONEZ FIO (PZU S.A. TFI)
	Skarbiec Depozytowy DPW FIO (Skarbiec TFI)
Mixed funds	ALLIANZ Aktywnej Alokacji FIO (Allianz Polska S.A.)
	Investor Zabezpieczenia Emerytalnego FIO (Investors TFI)
	Investor Zrównoważony FIO (Investors TFI)
	KBC Stabilny FIO (KBC TFI)
	MetLife Ochrony Wzrostu SFIO (MetLife TFI)
	MILLENNIUM Cyklu Koniunkturalnego FIO (Millennium TFI)
	NN Zrównoważony FIO (NN Investment Partners TFI)
	Noble Fund Mieszany FIO (Noble Funds TFI)
	Noble Fund Timingowy FIO (Noble Funds TFI)
	PKO Stabilnego Wzrostu FIO (PKO TFI)
	UniKorona Zrównoważony FIO (Union Investment TFI)
Stock funds	AVIVA Nowoczesnych Technologii FIO (Aviva Investors Poland TFI)
	BPH Akcji FIO (BPH TFI)
	KBC Akcji Małych i Średnich Spółek FIO (KBC TFI)
	KBC Akcyjny FIO {KBC TFI)
	Millennium Dynamicznych Spółek FIO (Millennium TFI)
	NN Akcji FIO (NN Investment Partners TFI)
	NN Średnich i Małych Spółek FIO (NN Investment Partners TFI)
	Noble Fund Akcji FIO (Noble Funds TFI)
	NOBLE FUND Akcji Małych i Średnich Spółek FIO (Noble Funds TFI)
	Novo Akcji FIO (Opera TFI)
	PKO Akcji Małych i Średnich Spółek FIO (PKO TFI)
	PZU Akcji Małych i Średnich Spółek FIO (PZU S.A. TFI)

Source: [11]

For selected funds were calculated: the expected rate of return, standard deviation, coefficient of variation, coefficient β and the efficiency measures of Sharpe and Treynor. In Table 2 there are shown expected value of rate of return, standard deviation, β coefficient, Sharpe and Traynor's coefficients for selected investment funds.

Table 2. Statistic for selected funds

Fund type	Selected fund	Date	2012	2013	2014	2015	2016
Money	MetLife Pieniężny	R*	0.093	0.023	0.038	0.018	0.012
		σ	0.048	0.057	0.015	0.010	0.018
		β	0.009	0.042	0.015	0.001	0.002
		Sharpe	1.936	0.395	2.454	1.685	0.508
		Treynor	10.490	0.539	2.545	11.622	3.923
Debt	Aviva Investors Obligacji Dynamiczny	R*	0.151	0.053	0.101	0.022	0.025
		σ	0.098	0.221	0.103	0.115	0.087
		β	0.080	0.105	0.127	0.045	0.002
		Sharpe	1.531	0.236	0.974	0.190	0.261
		Treynor	1.889	0.495	0.794	0.482	9.302
Mixed	MetLife Ochrony Wzrostu	R*	0.144	−0.070	−0.044	−0.076	−0.027
		σ	0.224	0.287	0.193	0.140	0.076
		β	0.325	0.462	0.467	0.318	0.113
		Sharpe	0.641	−0.246	−0.231	−0.542	−0.393
		Treynor	0.441	−0.153	−0.095	−0.239	−0.264
Stock	AVIVA Nowoczesnych Technologii	R*	0.112	0.247	−0.026	0.029	0.103
		σ	0.442	0.415	0.222	0.292	0.339
		β	0.569	0.523	0.416	0.272	0.285
		Sharpe	0.252	0.595	−0.120	0.100	0.297
		Treynor	0.196	0.471	−0.064	0.107	0.353

Source: own work

The basis for the fund's ranking is the Sharpe and Traynor's measure [10]. This is a commonly used methods for evaluating the quality of investment for investment funds, Table 3.

Calculating the number of inversions requires several comparisons of rankings from two consecutive years. In the penultimate line of the No. 4 table, the number of inversions was calculated, and in the last line the probability of inversion was estimated by frequency (Table 4).

The size of sample is 36. Value of p is the frequency of inversion. Maximal value of inversions equals $630 = (36 \cdot 35)/2$. NI- is the number of inversions. Thus $p = NI/630$.

In Table 5 chosen values of distribution function are presented. They are calculated using formulas (1) and (2). In Table 5, the values used for testing are bolded.

Table 3. Ranking by Sharpe and Treynor's measure

Ranking by Sharpe's measure						Ranking by Treynor's measure					
Rank	2012	2013	2014	2015	2016	Rank	2012	2013	2014	2015	2016
1	31	10	1	1	16	1	1	31	1	30	4
2	34	31	16	16	5	2	35	10	35	1	1
3	1	25	35	31	35	3	16	16	16	18	5
4	10	28	10	35	9	4	31	35	10	31	16
5	13	22	31	10	1	5	10	25	31	16	35
6	4	35	4	26	8	6	34	22	4	10	9
7	18	20	34	25	15	7	30	28	30	4	8
8	30	32	30	22	14	8	18	1	18	35	15
9	16	3	18	18	32	9	4	4	15	34	34
10	5	14	15	23	3	10	13	20	34	25	10
11	17	9	5	15	10	11	5	3	13	23	14
12	26	8	13	30	22	12	15	32	5	22	22
13	27	23	27	8	36	13	17	14	27	26	13
14	9	16	9	28	28	14	26	15	9	8	3
15	23	15	12	9	4	15	23	9	12	9	25
16	2	1	17	4	12	16	27	8	17	15	32
17	12	4	8	32	34	17	9	23	8	28	20
18	15	27	36	34	25	18	2	34	36	3	28
19	36	19	33	14	26	19	20	5	33	32	26
20	35	24	11	20	27	20	12	27	11	14	36
21	11	17	14	3	11	21	36	13	14	20	12
22	24	26	19	13	29	22	25	24	19	13	17
23	8	29	21	17	20	23	24	19	21	17	27
24	20	7	28	5	19	24	32	17	7	24	29
25	19	11	7	24	17	25	8	26	28	5	19
26	21	12	20	27	13	26	11	29	20	27	11
27	32	36	3	12	24	27	28	7	3	11	24
28	25	34	6	19	7	28	22	11	6	12	7
29	29	5	2	11	21	29	19	12	2	19	18
30	22	13	24	7	18	30	21	36	24	7	21
31	28	21	22	29	33	31	29	30	29	6	33
32	7	30	23	6	6	32	7	21	23	29	6
33	3	18	26	21	31	33	3	18	25	21	23
34	33	33	29	36	23	34	14	33	26	36	31
35	14	6	25	33	30	35	33	6	22	33	2
36	6	2	32	2	2	36	6	2	32	2	30

Source: own work

Table 4. Comparisons of ranking

Rank 2012	2013	Rank 2013	2014	Rank 2014	2015	Rank 2015	2016
1	2	1	4	1	1	1	5
2	28	2	5	2	2	2	1
3	16	3	35	3	4	3	33
4	1	4	24	4	5	4	3
5	30	5	31	5	3	5	11
6	17	6	3	6	16	6	19
7	33	7	26	7	18	7	18
8	32	8	36	8	12	8	12
9	14	9	27	9	9	9	30
10	29	10	21	10	11	10	34
11	21	11	14	11	24	11	7
12	22	12	17	12	22	12	35
13	18	13	32	13	26	13	6
14	11	14	2	14	15	14	14
15	13	15	10	15	27	15	4
16	36	16	1	16	23	16	15
17	26	17	6	17	13	17	9
18	15	18	13	18	34	18	17
19	27	19	22	19	35	19	8
20	6	20	30	20	29	20	23
21	25	21	16	21	19	21	10
22	20	22	33	22	28	22	26
23	12	23	34	23	33	23	25
24	7	24	25	24	14	24	2
25	19	25	20	25	30	25	27
26	31	26	15	26	20	26	20
27	8	27	18	27	21	27	16
28	3	28	7	28	32	28	24
29	23	29	11	29	36	29	21
30	5	30	12	30	25	30	28
31	4	31	23	31	8	31	22
32	24	32	8	32	10	32	32
33	9	33	9	33	6	33	29
34	34	34	19	34	31	34	13
35	10	35	28	35	7	35	31
36	35	36	29	36	17	36	36
NI	339		320		222		213
p	0.538		0.508		0.352		0.338

Source: own work

Table 5. Distribution of inversions. Chosen values.

NI (p = 0.05)	213	214	215	216	217
Distr function	**0.0026**	0.0028	0.0031	0.0033	0.0036
NI (p = 0.05)	218	219	220	221	222
Distr function	0.0040	0.0043	0.0047	0.0051	**0.0055**
NI (p = 0.05)	251	252	253	254	255
Distr function	0.0418	0.0444	0.0470	**0.0498**	**0.0527**
NI (p = 0.05)	337	338	339	340	341
Distr function	0.7287	0.7376	**0.7464**	0.7550	0.7634
NI (p = 0.05)	372	373	374	375	376
Distr function	0.9411	0.9443	**0.9473**	**0.9502**	0.9530

Source: own work

We wish to test hypotheses for years 2012 and 2013 firstly. We begin by identifying the null (*PI* means probability of inversion, *NI*- number of inversions) and alternative hypotheses.

$$H_0 : PI = 0.5$$

versus

$$H_1 : PI > 0.5$$

Our Test is Right-Tailed

Assuming significance level 0.05 and using tables of distribution for $PI = 0.5$ (under null hypothesis) we find the critical *NI* value of 374 from Table 5. $P(NI \geq 375) \leq 0.05$ but $P(NI \geq 374) \geq 0.05$. So we fail to reject H_0. Using p-value approach we obtain for $NI = 339$, p-value of 0.2536.

At the usual levels of significance hypothesis H_0 should not be rejected.

For years 2013 and 2014 we consider right tailed hypothesis too. Because 320 < 339 we fail to reject H_0. Therefore for these years the ranking by Sharpe measure seems to irrelevant.

To have significance of a ranking we expect $PI < 0.5$. In this case, the probability of inversion is lower than in a random situation. In addition, in such a situation, the ranking has a predictive value.

We will consider such case in following example related years 2014 and 2015 firstly. Let us consider the following hypotheses:

$$H_0 : PI = 0.5$$

versus

$$H_1 : PI < 0.5$$

Our Test is Left-Tailed

Let us assume the significance level as usual 0.05. In considered case $NI = 222$, (see Table 5) but the critical value (according Table 5) equals (left-tailed test) 254 because $P(NI \leq 255) \geq 0.05$ but $P(NI \leq 254) \leq 0.05$. Therefore H_0 should be rejected.

Using p-value approach we obtain for $NI = 222$, p-value of 0.005506. (see Table 5). At the usual levels of significance hypothesis H_0 should be rejected. It seems that in this case, the 2014 ranking is predictive for 2015.

The last case concerns the years 2015 and 2016. We will consider the following hypotheses:

$$H_0 : PI = 0.5$$

versus

$$H_1 : PI < 0.5$$

As before for significance level 0.05 the critical value is 254. The test statistic NI calculated from the sample is 213. Therefore H_0 should be rejected. Using p-value approach we obtain for $NI = 213$, p-value of 0.0026. At the usual levels of significance hypothesis H_0 should be rejected.

For the second time the classification based on the Sharpe measure seems to be non-random.

An analogous classification can be made using the Treynor measure, Table 6. In this case, the results of the sample suggest that the probability of inversion is less than 0.5 in the given years. Samples values range from about 0.29 to about 0.42. In all cases considered, both hypotheses will have the same form

$$H_0 : PI = 0.5$$

versus

$$H_1 : PI < 0.5$$

This time we will use the p-value approach firstly.

In the penultimate line of 6 table, the number of inversions was calculated, and in the last line the probability of inversion was estimated by frequency. The distribution of inversion is shown in Table 7.

The calculation results are in Table 8 for chosen number of inversions. The decisions are presented in Table 8 (assuming significance level 0.05).

None of the suggested methods did not bind into the power test problem. This will be the last part of the work.

Power of the Test

Using the cited theorem, the distribution of the number of inversions can be found. On Fig. 1. distribution functions for chosen values of p.

Table 6. Comparisons of ranking by Treynor's measure.

Rank 2012	2013	Rank 2013	2014	Rank 2014	2015	Rank 2015	2016
1	8	1	5	1	2	1	2
2	4	2	4	2	8	2	29
3	3	3	3	3	5	3	34
4	1	4	2	4	6	4	4
5	2	5	33	5	4	5	10
6	18	6	35	6	7	6	1
7	31	7	25	7	1	7	5
8	33	8	1	8	3	8	9
9	9	9	6	9	16	9	15
10	21	10	26	10	9	10	33
11	19	11	27	11	22	11	12
12	14	12	36	12	25	12	19
13	24	13	21	13	26	13	7
14	25	14	9	14	15	14	6
15	17	15	14	15	28	15	8
16	20	16	17	16	23	16	18
17	15	17	32	17	14	17	14
18	36	18	10	18	34	18	16
19	10	19	12	19	35	19	11
20	29	20	13	20	27	20	17
21	30	21	11	21	20	21	13
22	5	22	30	22	29	22	22
23	22	23	22	23	33	23	27
24	12	24	16	24	30	24	3
25	16	25	34	25	17	25	23
26	28	26	31	26	21	26	26
27	7	27	24	27	18	27	21
28	6	28	20	28	31	28	25
29	23	29	15	29	36	29	28
30	32	30	18	30	24	30	32
31	26	31	7	31	32	31	24
32	27	32	23	32	11	32	30
33	11	33	8	33	10	33	20
34	13	34	19	34	13	34	31
35	34	35	28	35	12	35	35
36	35	36	29	36	19	36	19
NI	234		266		211		183
p	0.371		0.422		0.334		0.290
	0.429		0.222		0.921		0.476

Source: own work

Table 7. Distribution of inversions. Selected values.

NI (p = 0.05)	181	182	**183**	184	185
Distr function	0.00009	0.00010	**0.00012**	0.00013	0.00015
NI (p = 0.05)	209	210	**211**	212	213
Distr function	0.0018	0.0020	**0.0021**	0.0023	0.0026
NI (p = 0.05)	232	233	**234**	235	236
Distr function	0.0119	0.0128	**0.0138**	0.0148	0.0159
NI (p = 0.05)	264	265	**266**	267	268
Distr function	0.0768	0.0809	**0.0850**	0.0894	0.0939

Table 8. Results for chosen number of inversions.

Years	p-value	Decision
2012/13	0.01378	REJECT
2013/14	0.08505	FAIL TO REJECT
2014/15	0.00214	REJECT
2015/16	0.00012	REJECT

Source: own work

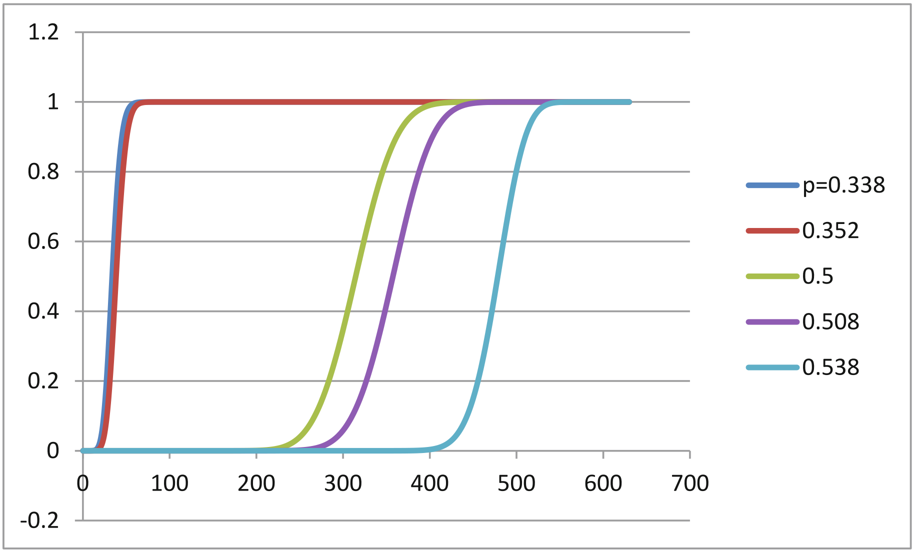

Fig. 1. Distribution function of the number of inversions (chosen values of p) Source: own work

In the case of Sharpe measure, simple hypotheses were considered:

$$H_0 : PI = 0.5$$

(a) $H_1 : PI = 0.508$
(b) $H_1 : PI = 0.538$

(c) $H_1 : PI = 0.352$
(d) $H_1 : PI = 0.338$

Four pairs of simple hypotheses will be considered, $\alpha = 0.05$. Let β be type II error.

$$\beta = P(acceptH_0|p = 0.508) = P(PI \leq 374/p = 0.508) = 0.677$$
$$\beta = P(acceptH_0|p = 0.538) = P(PI \leq 374/p = 0.538) = 0.0002$$
$$\beta = P(acceptH_0|p = 0.352) = P(PI \geq 255/p = 0.352) \approx 0$$
$$\beta = P(acceptH_0|p = 0.338) = P(PI \geq 255/p = 0.338) \approx 0$$

Probability of type II error is very small except the case of p = 0.508. This result is not surprising since the value of 0.508 is very close to the value 0.5. In other cases, the β value is close to zero which indicates a high power of the test.

In the case of Treynor's measure, simple hypotheses were considered.

In all the cases we have left-tailed tests.

For $\alpha = 0.05$ critical value is 255.

$$\beta = P(PI \geq 255|p = 0.29) \approx 0$$
$$\beta = P(PI \geq 255|p = 0.33) \approx 0$$
$$\beta = P(PI \geq 255|p = 0.37) \approx 0$$
$$\beta = P(PI \geq 255|p = 0.42) \approx 0$$

4 Conclusions

The Treynor measure seems to be more useful. In the examples presented above, it was more often distinguishable from randomness, although the studies concerned the same sample using different indicators. In the case of the Sharpe measure, it even occurred that the reverse predicted ranking seemed more likely (estimate probability of inversion greater than 0.5). The problem requires further investigation, but the analysis attempted to favor the measure of Treynor. In both cases the test showed great power. For the inversion probability values analyzed, the test showed practically zero probability of type II error.

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Modelling of Currency Exchange Rates Using a Binary-Wave Representation

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Abstract. Exchange rate of a currency pair can be visualized in a binary representation. Binarization algorithm transforms the course trajectory represented by tick data into an appropriate binary string. This kind of representation allows for a far more precise analysis and can be applied in HFT systems. In the following article a state model for exchange rate in binary representation with use of wave relations is proposed. In the model, states corresponding to particular price change patterns and wave types were defined. The wave detection process uses respective algorithms of wave detection in binary representation. In the article, research was performed for EUR/SEK currency pair with main focus on the possible application of abovementioned model in creating a HFT system with a positive rate of return.

Keywords: Foreign exchange market · High frequency econometric · Technical analysis · Currency market investment decision support · Exchange rate modeling

1 Introduction

The exchange rates usually show a high variability in time (the trajectory changes every few seconds) and therefore are traditionally presented by broker platforms in form of candlestick charts. This kind of data representation is also used in appointing respective indicators and in visual methods of technical analysis of given currency pair exchange rate trajectory [1–5]. The candlestick representation (in which the parameters are dependent on the assumed time interval) leads to a loss of vital information about the dynamic and range of each change happening "inside" the candle. This information could have been used in more precise course prediction. In the following article the concept of tick data representation based on relative absolute price value is introduced. This approach allows for easier analysis of trajectory changes and is characterized by higher accuracy as compared to the candlestick representation, which is highly encouraged while creating High Frequency Trading (HFT) systems.

In order to model the course trajectory an assumption about the wave structure of the market is introduced. As suggested in the existing wave theory (e.g. Eliott's Theory), the direction of a future change of a price trajectory is dependent on the direction and parameters of a current wave [1, 2, 6, 7]. In this paper, two wave detection algorithms are described, which register waves based on binary representation along with the means of

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constructing the latter. Proposed state model of binary-wave representation (SMBWR) allows for precise approximation of probabilities calculated for future trajectory change direction. In the article an analysis of possible application in HFT systems is also performed.

The paper consists of following parts. In Sect. 2 a binary representation of an exchange rate is proposed. Section 3 introduces wave detection algorithms and means of constructing a wave-binary representation. Section 4 contains main assumptions about the state model of binary-wave representation (SMBWR) and results of EUR/SEK (Euro/Swedish krona) course modeling. In Sect. 5 performed research and highlight main conclusions are summarized.

All research performed in the following article was carried out using 6 year-period tick data for EUR/SEK currency pair form Ducascopy broker from 01.01.2011 to 01.01.2017.

2 Binary Representation of Exchange Rate Trajectory

In order to eliminate possible loss of information about the exchange rate trajectory in candlestick representation, a binary representation was proposed in [8]. The concept of exchange rate binarization was known since 30' of XX century and used to create and analyze charts in so called point and figure method [9]. Yet, this kind of representation was soon replaced by the candlestick chart representation.

The basis of a binary representation is the discretization of exchange rate with a given discretization unit. Figure 1 presents an example of a discretization algorithm applied to an exchange rate. The algorithm appoints a value of '0' is the course decreases and '1' if the course increases one discretization unit and this way creates a binary string. As an effect of the algorithm performance, the course trajectory can be represented by such a binary string. The use of binary representation eliminates periods of no course variability (e.g. nights) and registers all changes of given range in periods of a high investor activity.

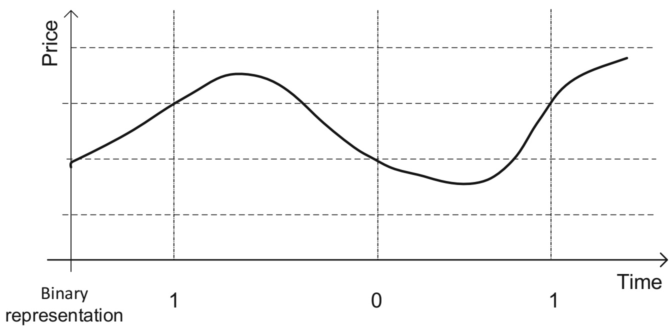

Fig. 1. Binary representation of an exchange rate trajectory

The binary representation can be used in constructing HFT systems. If in the considered HFT system the Take Profit (TP) and Stop Loss (SL) parameters are equally distanced from the opening price by 100 pips, used algorithm will assign the following binarization values for purchase transaction. With binarization unit 100, value '1' will be connected with achieving a positive revenue and value '0' with a registering a loss (opposite for sell transaction).

The quality of course trajectory modeling is dependent on the chosen discretization unit. Appointing too low discretization unit would result in algorithm registering random fluctuations (noise [10–12]). On the other hand, too high discretization unit can lead to a loss of information about smaller changes and causes a smaller number of changes being registered. A decision about the value of a discretization unit should consider its possible applications in HFT systems. In this article and for the researched currency pair the discretization unit of 130 pips have been chosen. This unit is 10 times higher than the spreads offered by brokers (e.g. ICMarket). Appointing a lower discretization unit would mean a high influence of spreads on achieved profit/loss from a given transaction.

3 Wave Structure of an Exchange Rate

A lot of technical analysis methods highly popular among analysts and investors assume a wave structure of quotations. In example, in the visual analysis of a chart, ensuing waves of given parameters create a formation, etc. [1–4] Thus, wave existence does not rise any doubts and can be explained by investors' behavior [13]. The major movements on a market are usually caused by publication of important macroeconomic data, e.g. percentage rates, or unexpected political changes, e.g. dismisses in the government. In such situations, investors who make transaction decisions use obtained information even a long time after the actual announcement, in effect creating a wave of a particular range and duration. Ralph Elliot in 1930' formulated a theory regarding a wave structure of the market and dependences between parameters of ensuing waves. Technical analysis methods (as well as Eliott's theory [6]) assume a visual wave detection on a candlestick chart (Fig. 2). Even despite the loss of information quality of the candlestick chart, the effectiveness of this method relies highly on the subjective and individual analysis performed by a specialist. Without any precisely determined, clear rules of wave detection, a reliable statistical analysis and objective verification of any possible wave dependencies is impossible. Therefore, in this paper, a new method for wave detection in binary representation is proposed.

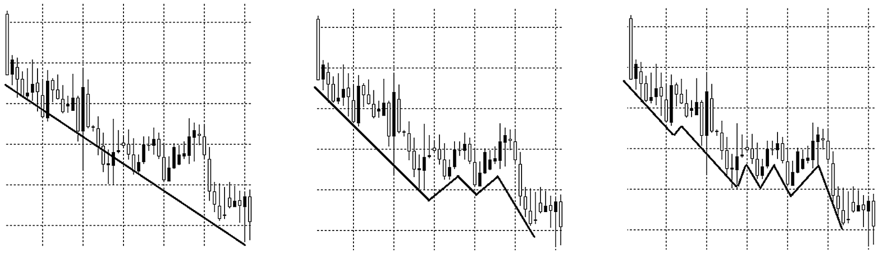

Fig. 2. Three different possibilities of appointing a wave for the same exchange rate trajectory

3.1 Wave Detection Algorithm in Binary Representation (WDABR)

The basis of wave detection algorithms in a binary representation is exceeding of respective thresholds for average values of increases and decreases. Wave Detection Algorithm in Binary Representation (WDABR) is the simplest model in this group. It assigns each i-th course trajectory change (z_i) a value representing the type of current market wave W_i (0 for falls and 1 for increases). It is generally assumed, that a wave continues until a new one is detected. This way – analogously as in Elliot's theory – each course change in binary representation we assign the type of the wave

The algorithm uses two input parameters which determinate its precision: the number of analyzed historical changes (l) and average number of increases/decreases in l previous course trajectory changes starting a new wave (p).

In the Fig. 3 a block diagram for WDABR is presented. The algorithm takes the following steps: after detecting a new i-th course trajectory change it calculates the

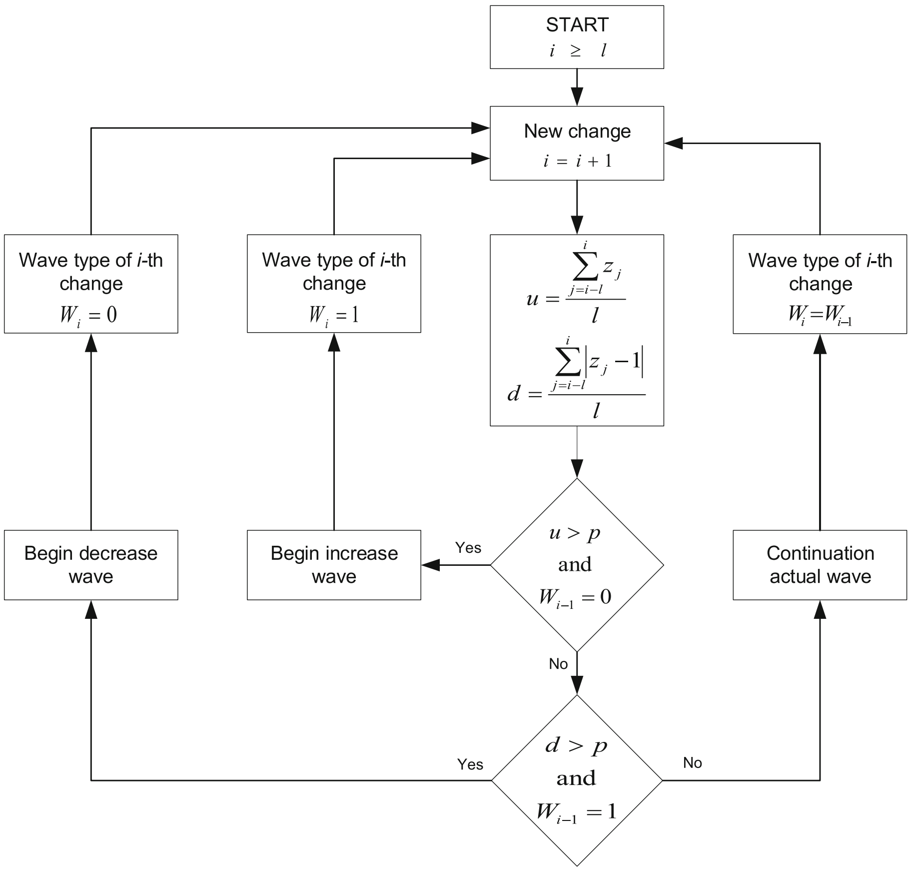

Fig. 3. Block diagram for WDABR

average number of increases (*u*) and decreases (*d*) in previous changes determined by (*i*-*l*). Next, the algorithm checks if a detection threshold (*p*) was reached for an increase wave when under a decreasing one or the other way round. If yes, then WDABR assigns a new wave type to the *i*-th change. If not, the current wave is continued.

3.2 Wave Detection Algorithm in Binary Representation with Consolidation (WDABRC)

In the WDABR it is assumed, that the course trajectory can be placed on an increasing or a decreasing wave. This method of detection causes the consolidation periods to be automatically classified as a continuation of the previous wave. This approach leads to deterioration of the precision and quality of course modeling with the use of waves. In order to increase the modeling accuracy a new wave detection algorithm in binary representation, WDABRC, is introduced. This algorithm includes the consolidation periods. The algorithm uses three input parameters:

l–the number of analysed previous trajectory changes,
n–average number of increased/decreases in *l* previous trajectory changes, starting a neutral wave,
p–average number of increases/decreases in *l* previous trajectory changes, starting an increasing or decreasing wave.

In the Fig. 4 a block diagram for WDABRC is presented. The algorithm uses the following procedure: after detecting a new, *i*-th course change it calculates the average number of increases (*u*) and decreases (*d*) in (*i*-*l*) previous changes. Next, the algorithm checks, if the detection threshold (*p*) of an increasing wave was reached during a decreasing wave (or the other way round). If it was, then WDABRC assigns the *i*-th change a new type of wave. If not, the algorithm checks whether the average number of increase/decrease occurrences in the increase/decrease wave has fallen below *n*. If yes, then it assigns the current trajectory change to the neutral wave

3.3 Wave-Binary Representation

A wave-binary representation can be created with use of wave-detection algorithms (both WDABR and WDABRC). In the wave-binary representation, each *i*-th course trajectory change is assigned a value representing the type of current market wave (0 for falls, 1 for increases, 2 for neutral wave). The form of wave-binary representations is therefore dependent on the type and parameters of applied wave detection algorithm. Based on the wave-binary representation it is possible to analyze and model the exchange rate trajectory while taking into account wave relations.

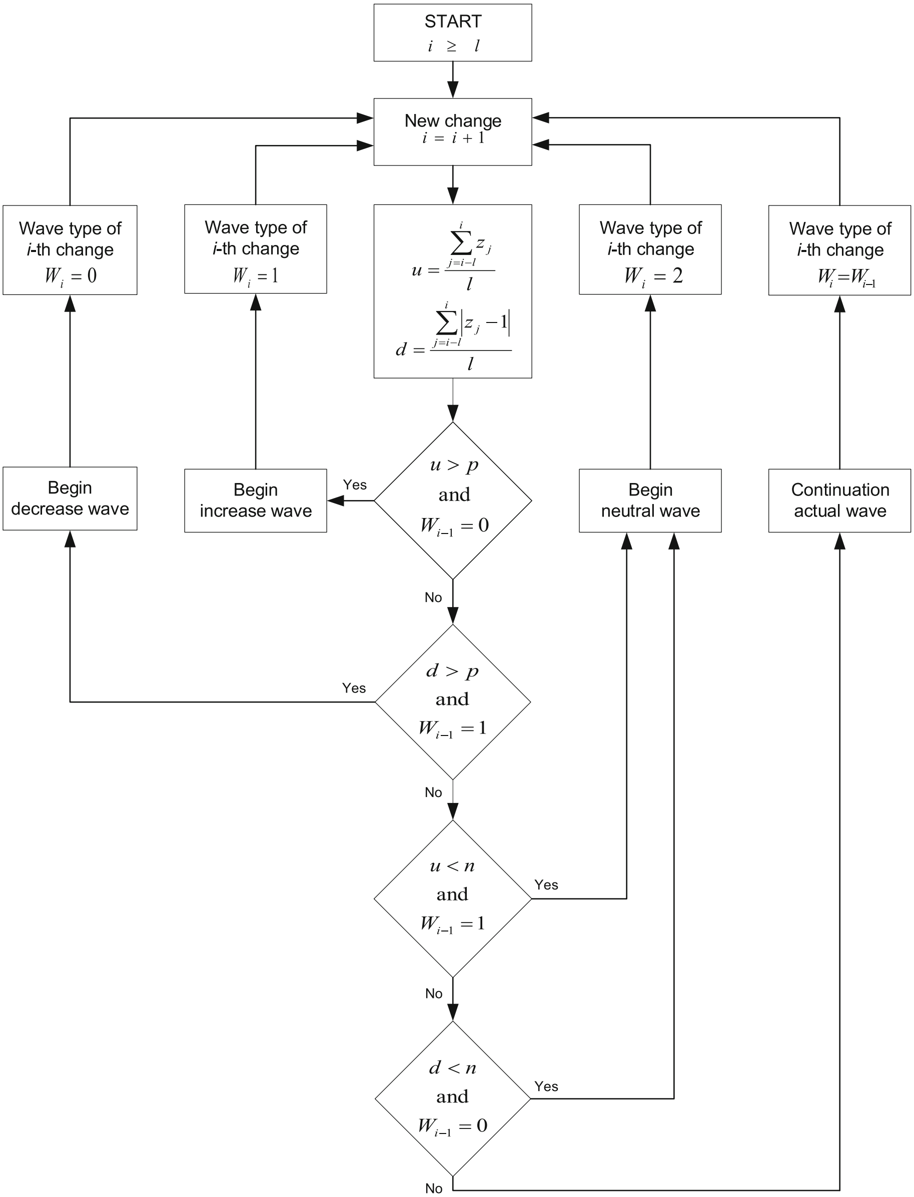

Fig. 4. Block diagram for WDABRC

4 State Modelling for an Exchange Rate

The main idea of state modeling is appointing states which depicts the investors' behavior and calculating probabilities of transitions between those states. The simplest state model, described in detail in [8], is State Model of Binary Representation

(SMBR). In this model a state is defined as m previous exchange rate trajectory changes. In [14] a State Model of Binary-Temporal Representation was presented (SMBTR), which is extended by including the duration of a change. In the article a State Model of Wave-Binary Representation is proposed. This model stands as a generalization of SMBR and corresponds to the most popular technical analysis method that is wave analysis.

4.1 State Model of Wave-Binary Representation (SMBWR)

SMBWR allows for calculating the probabilities of future trajectory change direction in the binary representation, based on the relations occurring in wave-binary representation. The concept of the model is to define such market states that would correspond to respective decrease/increase patterns of given order (analogously as in SMBR) and to assign membership to a respective wave type. The model is characterized by following parameters:

m –number of analyzed previous trajectory changes,
m_f –number of changes in which the membership to the particular wave type is analyzed.

A state in SMBWR is defined as an ordered pair: first parameter is defined as a pattern described by m previous course trajectory changes. The second one is the wave type of registered m_f previous changes (value 0,1 for WDABR or 0,1,2 for WDABRC). Figure 5 depicts an example of state (01,1) in SMBWR{$m = 2$, $m_f = 1$, WDABR ($l = 5$, $p = 0.6$)} in a wave-binary representation.

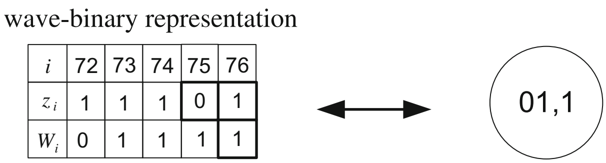

Fig. 5. State (01, 1) in wave representation

State space in SMBWR can be calculated with following formulas:

$$S = 2^{m+m_f} \quad \text{for WDABR algorithm,} \tag{1}$$

$$S = 2^m * 3^{m_f} \quad \text{for WDABRC algorithm.} \tag{2}$$

Consider now a model SMBWR{$m = 2$, $m_f = 1$, WDABR ($l = 5$, $p = 0.6$)}. A state diagram for this model was presented in Fig. 6. The diagram depicts all possible states and transitions between them. In order to present the idea of state model in the clearest possible way, the values of respective transition possibilities are not included in the figure. Let us now analyze the algorithm performance. First, let's assume that the exchange rate dropped in the change before the previous one, and then it increases by one discretization unit. The wave detection algorithm has registered a decrease wave for the last change (the model being in state (01,0)). Next, the course increased and the algorithm detected a Direction change and assigned it an increase wave. Therefore, the model registered a transition from state (01,0) to (11,1).

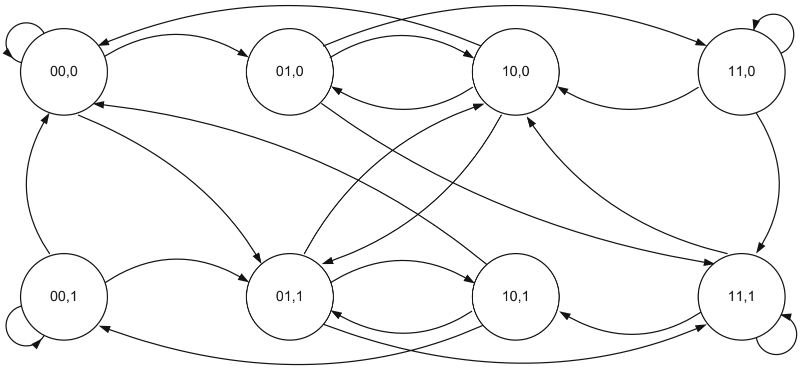

Fig. 6. State model diagram in wave-binary representation with parameters m = 1, n = 1, WDABR(l = 5, p = 0.3).

The most important parameters characterizing a model for a given currency pair are the respective probabilities of transitions between given states. They can be appointed heuristically based on historical data. For the investor or HFT system it is most important to assess the probabilities of future trajectory change direction. The exchange rate can both increase or decrease in either an increasing or decreasing wave (the waves stand only as a kind of indicator). Thus, the probability of an increase/decrease of a price is actually a sum of transition probabilities for respective states. Therefore the probability of an increase in this state $\mathrm{P_{increase}}(01,0)$ can be calculated as follows:

$$\mathrm{P_{increase}}(01,0) = \mathrm{P}[(01,0) \rightarrow (11,0)] + \mathrm{P}[(01,0) \rightarrow (11,1)], \quad (3)$$

where P((state I)→(state II)) symbolizes transition from state I to state II. Analogously, the probability of a fall in state (00,0) is equal to:

$$\mathrm{P_{decrease}}(01,0) = \mathrm{P}[(01,0) \rightarrow (10,0)] + \mathrm{P}[(01,0) \rightarrow (10,1)]. \quad (4)$$

The sum of all output probabilities from a given state equals 1, so:

$$\mathrm{P_{increase}}(01,0) + \mathrm{P_{decrease}}(01,0) = 1. \quad (5)$$

4.2 Currency Pair Exchange Rate Modeling with Use of SMBWR

The quality of Exchange rate trajectory modeling depends mostly on the appropriate appointment of wave detection algorithms. In order to optimize the parameter choice a dedicated software, written in C++ language, was created. This software allows simulating the model performance for different parameter sets. For verifying obtained results an approach native for testing algorithms connected with neural systems is used. The data used for verification comes from a 6-year time period if EUR/SEK quotations and was divided into a two-year teaching period and a four-year test period. Wave detection algorithm parameters were appointed based on data from the teaching period. Figure 7 presents modeling results in the test period for optimal parameter set for WDABR and WDABRC, obtained for SMBWR(m = 2, m_f = 1,…) in state (01,1). Each chart also depicts results achieved for SMBR(m = 2). It can be concluded, based on described analysis, that SMBWR, which includes the wave dependencies in exchange rate trajectory analysis, is more precise.

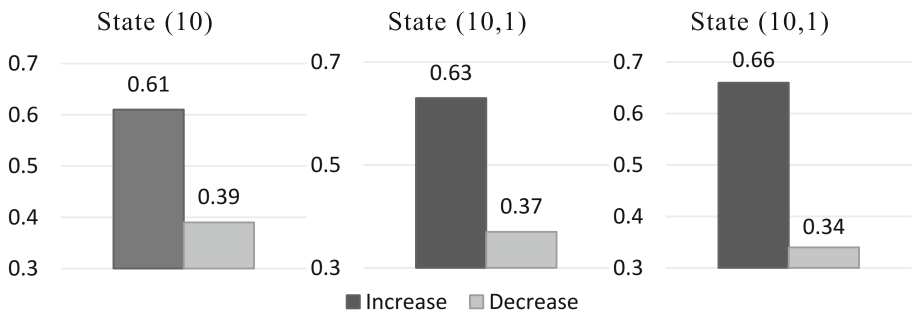

Fig. 7. Probability of next change in (a) SMBR(m = 2), (b) SMBWR{m = 2, m_f = 1,WDABR (l = 5, p = 0.6)}, (c) SMBWR {m = 2, m_f = 1, WDABRC(l = 8, p = 0.9, n = 0,4)}.

Many technical analysis methods are characterized by a high prediction efficiency in periods of strong trends and by fairly low efficiency in consolidation periods (or the other way round). In order to describe the influence of trends, a five-year period of research was divided into 10 equal parts. In each of them respective transition probabilities and a 95% confidence interval, calculated based on t-Student distribution, are appointed. For each states the confidence intervals do not exceed 0.06. Presented results confirm an existence of relations between the wave type and the probabilities of future change direction.

4.3 Application of SMBWR in HFT Systems

Let us now consider a HFT [15] system ma king transactions for which the TP and SL parameters are equally distanced from the current price. The direction of single transaction is appointed based on the SMBWR. Potential profit or loss form a single transaction can be calculated with:

$$Profit = (J - spread) * Lot, \tag{6}$$

$$Loss = (J + spread) * Lot, \tag{7}$$

where J in the discretization unit and Lot is an unit describing the transaction size (equal to 100000 units of base currency). Assuming an equal value of each position the parameter only scales the position value and has no influence in the context of performed considerations. Based on formulas (6) and (7) and after some elementary operations we can MapPoint the limit value of a future change probability assessmentP_g which guarantees a positive return rate in the system:

$$P_g = \frac{(J + spread)}{2J}, \tag{8}$$

The value P_g for applied discretization unit and spread offered by ICMarket broker equals 0.55. The probability assessment fir future trajectory change direction in SMBWR exceeds 0.66. This means that constructed HFT system will be characterized by a positive rate of return. The exact return for an investor is dependent on applied Money Management and preferred risk. The high stability of the assessment in time (small confidence interval) for used discretization unit stands as additional argument for using abovementioned model in HFT systems.

5 Summary

In this paper, a wave-binary representation state model was proposed for modeling an exchange rate trajectory of EUR/SEK currency pair. The model uses wave relations in binary representation in order to approximate the probability of future course change direction. Regarding wave detection, the Author has suggested two algorithms: WDABR which registers increasing and decreasing waves, and WDABRC which allows for detecting additional, so called "neutral" wave, corresponding to the consolidation period on the market.

Analysis of 6-year period quotations of EUR/SEK currency pair confirmed the existence of wave dependences. Based on SMBWR it is possible to predict the future trajectory change direction with 66% success level. This allows for constructing HFT systems with positive rate of return.

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Infrastructure Investments as a Tool for Implementing the Strategy of Sustainable Development of Regional Economic Systems

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Abstract. The purpose of this article is to study the potential of the reference sectors, creating the fundamental basis for the implementation of the strategy of sustainable development of regional economic systems and attracting investment. The authors' position is based on the capacity assessment of the regional transport infrastructure, ensuring the implementation of its strategy for sustainable development. The study presents a model of transport infrastructure capacity assessment in the region – Republic of Tatarstan (Russia) for the formation on its territory of the transport cluster (Eurasian hub), planned within the framework of the Strategy for socio - economic development of the Republic until 2030.

1 Introduction

The search for new ways and methods of attracting investments in transport infrastructure, which is the basis of dynamic development of economy of any country today, becomes one of the fundamental issues of management science and economic practice.

Active consolidation of the countries and their individual regions on the basis of the innovation process necessitates a comprehensive in-depth theoretical and practical study of the instruments of investment support for transport infrastructure. In modern conditions it becomes obvious that the only fundamentally new approaches to the creation of mechanisms of investment support for transport infrastructure is able to provide a level of development sufficient to meet the needs of a dynamically developing society and prospects for sustainable development [1, p. 171].

Investment support for the transport infrastructure today is influenced by such processes as the flow of the credit resources outside the banking system; strengthening the role of regional economies as platforms for the interaction of investment institutes

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and real sectors of the economy; transformation of the assets of the economic entities in the market tools, promoting expanded reproduction of economic systems of regions; restoring the role of technological mode as a basis for the development of the economy [2, p. 711].

The analysis of investment provision efficiency of the transport industry have shown that existing resources are used inefficiently: there is a shortage of long-term investment, there are no effective mechanisms of interaction of institutions in the investment industry and transport companies, attractive conditions for the private investment involvement in transport infrastructure are not developed. In addition, special attention should be paid to the specific features of transport infrastructure, adversely affecting its investment attractiveness: the inability to establish adequate tariffs for use of infrastructure objects, leading to the complexity of assessing the effects of infrastructure on other sectors of the economy; the involvement of natural monopolies in many infrastructure projects; the absence of the generation of financial flows at the stage of initiation of infrastructure projects; low liquidity of investments in transport infrastructure because of the uniqueness of its services.

Besides, there are difficulties connected with the formation of mutually beneficial long-term cooperation of subjects of transport infrastructure and institutions investment sphere [3, p. 129]. This leads to a growing importance of measures on transformation of the organizational systems of the countries and regions, whose main purpose is the creation of a space for inter-institutional interaction of the participants of this cooperation [4, p. 115].

One of the institutional formations that serve as the basis for the formation of a space for interaction between transport infrastructure operators and institutions in the investment industry at the meso-level, can be regional or inter-regional (transboundary) transport cluster, in which will be organized by the successful interaction of actors from government, business and society. Cluster activation in the area of transport infrastructure on regional level will contribute to the growth of the scale of the spatial effects and competitiveness of the economy as a whole, innovation in the field of transport and logistics services, attracting additional investment resources for development of regional transport infrastructure and accelerate economic turnover, creation of resources to ensure sustainable development.

Thus, the problem of improving and implementation of the tools of investment provision of transport infrastructure with the aim of providing innovative variant of development is complex and multidimensional and must be considered in the system of complex interaction of the supporting sectors of the economy (transport and investment infrastructure).

2 Literature Review

The problem of attracting the necessary volume of investments into development of regional transport infrastructure is of particular importance in the context of globalization and integration of economic processes. Russian and foreign experts considered its various aspects.

The etymological basis of the study of investment provision of infrastructure development of the region were laid in the works of A.V. Bazhenov, John Baldwin, V. Bour, V.G. Varnavskiy, A. Vining, L. Goryainova, E. Gramlich, P. Groot, M.A. Deryabina, J. Jacobs, J. Dixon, R. Jochemsen, A.V. Klimenko, R. Prudom, John Richards, J. Sterm, N. Hansen, etc.

The questions of influence of infrastructure on economic growth, the level and quality of life of the population were mentioned by: D. Aschauer, D. Canning, and G. Karras, P. Pedroni, P. Evans.

Research of the infrastructure projects risks and their investment support are represented in the research interests of scientists: N. Bruzelius, R. Bain, E. Molina, D. Pickrell, V. Rothengatter, D. Strambach, B. Flyvbjerg, K. Purnell, K. Shantal.

Research of effective tools for investment development of the real sector of the economy is contained in the works of scientists: E.F. Avdokushin, E.A. Baklanov, G. N. Beloglazova, I.Y. Belyaeva, E.A. Isaeva, I.G. Levina, P. Polukhina, A.A. Porokhovsky, E.V. Rybina, V.V. Ryazanov, O.S. Sukharev, M.A. Eskindarov, etc.

Methodical fundamentals of implementation of public-private partnerships to attract private investment in infrastructure are set out in the papers of: M. Bult-Spiring, John Hamilton, L.K. Gilroy, D. Grimes, G. Dewolf, John Delmon, M.B. Gerrard, G.E. Klein, V. Katari, S.K. Lee, S. Linder, M.K. Lewis, R.W. Pool, G. Segal, P. Nelson, G. B. Tismana, S. Harris, J. Holies.

The problem of applying the cluster approach to investment to ensure economic development of the region is carried out in the works of: E.M. Bergman, K. Morgan, A. A. Migranyan, S.I. Parinova, M.E. Porter, G.R. Hasayev, M. Enright.

Issues associated with the advantages of cluster-type development of the economy are engaged in the works of: K. Burzynski, D. Dickinson, L. Wives, D. Liu, S. Min, J. Sigurdson, T. Xiaoyan, G. Turner, N. Teng, L. Wendon, John Angang, etc.

The formation of inter-firm linkages in sectoral and intersectoral aspects, and the development of clusters at the regional and interregional levels are in the works of: E. M. Isaeva, T.V. Kolesnikova, V.V. Kuznetsova, A.G. Kulikov, E.G. Kulikova, T.S. the Speranskaya, E.A. Yagafarova, M.V. Puchkov, S.P. Savinsky, D.A. Smaktin, O.K. Tsapieva, E.B. Lenchuk, O.A. Romanova, Y.M. Berger, Y.I. Treschevsky.

Methodical bases of use of infrastructure bonds for investment in infrastructure projects is reflected in the following works: D. Platz, John Legland, V. Glushkov, S. Pakhomov.

Despite the considerable amount of research on efficient investment on transportation systems and infrastructure projects, there are no systematic approaches to the development and implementation of tools involving the investment of infrastructure in the implementation of promising infrastructure projects. This study presents a study of the prospects of the transport cluster as a mechanism to attract private investment in transport infrastructure.

3 Assessment of Sustainable Development Potential of the Transport Infrastructure of the Republic of Tatarstan

One of the regions on whose territory in the framework of the Transport strategy of the Russian Federation it is planned to create transport clusters (Eurasian Hub) till 2030, is the Republic of Tatarstan [5, p. 200]. Herewith in the strategy of socio-economic development of the Republic of Tatarstan till 2030 it is necessary to consider the prospect of forming cross-border clusters formation, focused on the effective interaction of investment institutes and actors in the real sector of the economy. Their formation must take into account the problems that have developed in the investment of infrastructure projects, particularly transport [4, p. 115].

We have performed an integrated assessment of the development potential of transport infrastructure of the Republic of Tatarstan as a tool for sustainable development. According to the study, it has a positive trend (Table 1).

Table 1. Integrated assessment of the potential for accelerated development of transport infrastructure of the Republic of Tatarstan

2009	2010	2011	2012	2013	2014	2015
The contribution of transport infrastructure entities in the GRP						
6129.60	6275.63	7062.73	6037.37	24467.64	23572.87	26334.34
The demand for transport services						
8333.29	8920.68	10091.75	10533.00	11251.46	11909.21	12704.55
The logistics of regional transport infrastructure						
6632.38	7010.56	6983.43	7953.49	8028.48	8131.62	8590.40
The financial sustainability of regional transport infrastructure						
1460.87	2512.17	3286.83	2657.02	3803.44	1744.78	3043.87
Socio - demographic conditions of the development of regional transport infrastructure						
6068.81	6971.04	7721.54	8794.14	9801.01 10804.76		11684.44
Investments in regional transport infrastructure						
14966.56	23924.38	39612.43	36632.18	40059.37	39317.21	43648.18
The potential for the development of transport infrastructure of the region						
6539.07	7627.91	9102.17	9286.03	11896.51	11742.33	26334.34

Sectoral diagram (Fig. 1) showed that, despite the fluctuations in values of the ratio of investment in transport infrastructure, it has a relatively high impact on the development of transport infrastructure of the Republic of Tatarstan. This suggests the need to improve the efficiency of the investment support of the development of infrastructure projects instruments, used in the region, which will contribute to the implementation of the sustainable development strategy of the Republic of Tatarstan. One of the effective ways to achieve this goal is to build system of transport clusters with the participation of investment institutions on the territory of the Republic.

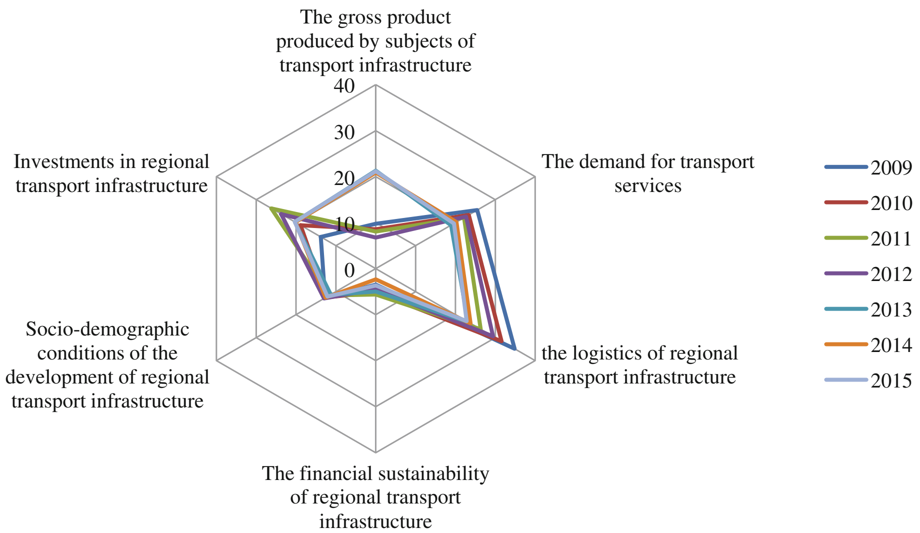

Fig. 1. The coefficients of integral evaluation of the potential accelerated development of transport infrastructure of the Republic of Tatarstan

4 Research Methodology

With the use of cross-border cluster technologies, the approach to the assessment of potential transport of the clusters formation in regional economic systems, which allows to obtain a quantitative estimate of any region of the Russian Federation, and on the basis of gradation data estimates to obtain an idea about the necessity and possibility of formation of transport cluster in its territory is proposed. It is based on a systematic classification of important indicators in the following groups: main characteristics of transport infrastructure in the region; the provision of regions with transport infrastructure; the intensity of use of transport infrastructure; the adequacy of investment in transport infrastructure in the region; addressing the needs of interregional and foreign trade turnover (Table 2).

Each indicator, based on the analysis of the degree of its connection with the indicator “Gross regional product”, has a weight within the group of indicators in which it is included.

The degree of connection is evaluated by constructing a series of models analyzing correlations between the indicator “Gross regional product of the Republic of Tatarstan” and groups of indicators to assess the potential of transport infrastructure of the region for the formation of the transport cluster on its territory, and in each model has no more than three factors included.

According to the results of computer simulation the correlation coefficients (K), the value of which varies from (−1) to 1 were defined. Based on these factors, the weight of the indicators is calculated by the formula:

Table 2. The assessment of potential transport infrastructure of the region for the formation on its territory of the transport cluster

Figure	Bec
The main characteristics of the transport infrastructure of the region (OH)	**0.1483**
Products transport in the gross regional product (OX_1)	0.2905
The ratio of the volume of transport services (OX_2)	0.7095
The provision of regions with transport infrastructure (OO)	**0.5054**
The Engel coefficient (the security of the region's transport network) (OO_1)	0.2014
The ratio of population roads (OO_2)	0.2082
The ratio of the population of the train tracks (OO_3)	0.1854
The provision of vehicles (OO_4)	0.2060
Fixed assets of transport infrastructure in the total amount of fixed assets in the economy (OO_5)	0.1985
The intensity of use of transport infrastructure (IU)	**0.1496**
The density ratio of cargo mass (IU_1)	0.4722
The ratio of the density of passenger traffic (IU_2)	0.3369
The coefficient of depreciation of fixed assets of transport infrastructure (CDF)	0.1909
The adequacy of investment in transport infrastructure in the region (AI)	**0.0186**
The volume of investments in transport infrastructure in the total investment volume in the region (AI_1)	1.0000
The needs of interregional and foreign-trade turnover (NIFT)	**0.1781**
The ratio of development of inter-regional turnover ($NIFT_1$)	0.4179
The factor of development of foreign trade turnover ($NIFT_2$)	0.5821

$$\text{weight}_i = \frac{K_i}{\sum_{i=1}^{m} K_i} \tag{1}$$

where weight_i is the weight rating of the "i" indicator;

K_i is the "i" indicator, with the indicator "Gross regional product of the Republic of Tatarstan";

$\sum_{i=1}^{m} K_i$ - the sum of the linkages of indicators of the j-th group with index "Gross regional product of the Republic of Tatarstan" on the module.

Weight groups of indicators are calculated according to the formula:

$$\text{weight}_j = \frac{\sum_{i=1}^{m} K_i}{\sum_{j=1}^{n} K_j} \tag{2}$$

where weight_j - the weight rating of the j-th group of indicators;

$\sum_{i=1}^{m} K_i$ - the sum of the linkages of indicators of the j-th group with index "a Gross regional product of the Republic of Tatarstan" on the module;

$\sum_{j=1}^{n} K_j$ - the sum of the relationships of all groups of indicators with the index of "Gross regional product of the Republic of Tatarstan".

The final value of the transport infrastructure potential of the region for the formation on its territory of the transport cluster is calculated by the formula:

$$FV = \sum_{j=1}^{n} \text{value}_j * \text{weight}_j \tag{3}$$

where value_j - the total value of the estimations of the j-th group;

weight_j - the weight rating of the j-th group of indicators.

In order to assess the adequacy of transport infrastructure capacity of a region for formation of the transport cluster on its territory it is proposed to use the scale developed on the basis of the scale of Chaddok (Table 3).

Table 3. Assessing the potential of transport infrastructure of the region for the formation of the transport cluster on its territory

Gradation values of the outcome indicator of the potential of transport infrastructure of the region	The potential of transport infrastructure of the region for the formation of the transport cluster on its territory
0–0.1	Missing
0.1–0.3	Low
0.3–0.5	Moderate
0.5–0.7	Noticeable
0.7–0.9	High
0.9–0.99	Very high

5 Results

The potential of transport infrastructure of the Republic of Tatarstan for the formation of the transport cluster on its territory for the period 2000–2015 has positive dynamics (Table 4).

Table 4. Potential of transport infrastructure of the Republic of Tatarstan for the sustainable development of the region

Weight	Year							
	2000	2005	2010	2011	2012	2013	2014	2015
	The main characteristics of the transport infrastructure of the region (MC)							
0.1483	0.09	0.10	0.15	0.16	0.16	0.18	0.18	0.18
	The provision of regions with transport infrastructure (PT)							
0.5054	0.34	0.38	0.60	0.62	0.71	0.73	0.72	0.73
	The intensity of use of transport infrastructure (IU)							
0.1496	0.57	0.48	0.59	0.61	0.61	0.60	0.56	0.57

(*continued*)

Table 4. (*continued*)

Weight	Year							
	2000	2005	2010	2011	2012	2013	2014	2015
	The adequacy of investment in transport infrastructure in the region (AI)							
0.0186	0.12	0.14	0.09	0.13	0.10	0.10	0.10	0.10
	The needs of interregional and foreign-trade turnover (NIFT)							
0.1781	0.11	0.15	0.19	0.19	0.20	0.20	0.21	0.22
	The capacity of the transportation infrastructure in the region							
	0.2923	0.3080	0.3480	0.4646	0.5113	0.5229	0.5136	0.5220

Thus, the capacity of the transport infrastructure of the Republic of Tatarstan for the formation of the transport cluster on its territory for the period 2000–2015 increased from low to visible, which proves the accuracy of the feasibility of formations transport and logistics cluster "Eurasian hub" on the territory of the Republic of Tatarstan.

6 Conclusion

Transport cluster with the participation of investment institutions is by far the best mechanism of attracting private investment in transport infrastructure projects. For optimal results, its implementation required the implementation of effective tools for improving cluster policy of the Republic of Tatarstan, under which the following should be carried out [6, p. 455]:

- improvement of the tax system (tax incentives to companies that invest on a long term basis in the development of transport infrastructure) and the complex use of tools of tax, financial and customs policy [7, p. 250];
- increasing the transparency of the financial market of the region on the basis of uniform information base on regional issuers and professional market participants;
- the introduction of a preferential order of formation of reserve for possible losses on loans provided for investment purposes for the real sector of the economy;
- accommodation on a competitive basis of means of the Federal budget and means of budgets of subjects of the Russian Federation for financing of investment projects;
- development of institution of state guarantees;
- development of specialized banks, the purpose of which will be the development priority and lagging sectors of the economy;
- monitoring of investment activity in the region which facilitates the identification of areas attractive for investment and creating attractive conditions for investment in promising infrastructure projects;
- stimulating domestic demand to revive the production and strengthening of creditworthiness of the enterprises;
- creation on the basis of the existing productive capacity of the capacities, capable to satisfy the need of transport infrastructure in the equipment;

- enhancing private financing of the transport cluster through: ensuring the legal security of private investors, the provision of tax benefits on regional and local taxes;
- promotion of foreign investments in transport infrastructure by creating different incentives for investors and a new policy of openness of the economy;
- ensuring political stability, continuity and predictability of economic policy.

The performance of the proposed tools and activities aimed at creating an effective transport cluster with the participation of investment institutions will determine the future of institutional support for sustainable development of the region.

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Application of Probability and Possibility Theory in Investment Appraisal

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Abstract. There are two kinds of uncertainty the one which arises from the lack of knowledge (ignorance) and the other, which is due to randomness (variability). The majority of researchers agree that different types of uncertainty should be treated separately in risk analysis. This means that each type of uncertainty should be propagated through computation using an appropriate calculation method. If both types of uncertainty are present in a problem, then the appropriate methods must be combined into a single framework in order to obtain a single risk measure. Usually, as a result of such approach, a probability box (p-box) is obtained, which may be difficult to interpret for economic practitioners. In order to make a p-box useful from the practical point of view, in this article we propose methods to aggregate a p-box into a single cumulative distribution function. We demonstrate our approach on the example of the appraisal of an investment, where the distinction between different types of uncertainty is of great importance.

Keywords: Risk of investment projects · Fuzzy random variable · Stochastic simulation · Interval regression

1 Introduction

The choice between tangible investment opportunities is one of most challenging tasks that business executives must made. This kind of decisions is so demanding, because it requires to make assumptions which strongly impact the results of an analysis. Each assumption involves its own degree of uncertainty, which combined together are transformed into calculable risk. It means that elicitation of uncertainty is an important aspect of risk analysis. Distinction between various sources of uncertainty plays very important role in an adequate description of uncertain parameters. In general, we can distinguish two kinds of uncertainty: epistemic uncertainty, which comes from the lack of or incomplete information and aleatory (stochastic), which has its sources in irreducible variability of historical data. In modern approach to risk analysis various uncertainties are modelled using different mathematical theories. In many problems only one type of uncertainty is present. In such case, we can use pure probability or possibility theory in parameter estimation. However, in some cases, such as tangible investment appraisal, uncertainty of parameters comes from both variability and ignorance. Then we must use a hybrid approach, which combines probability and possibility theory.

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In this article, we discuss the choice of tangible investment opportunities. We use the Net Present Value Ratio (NPVR) to compare efficiency of different investments. We assume that some model parameters are described by probability distributions, whereas the remaining one are described by possibility distributions. We use a hybrid simulation to evaluate the risk of an investment. – Within this framework, a nonlinear programming and a stochastic simulation are utilized to propagate uncertainty through a risk model. As a result of the risk analysis, we obtain a set of cumulative distribution functions (CDF) called a p-box or a probability box.

The described above approach is still new and far from mature. There are still many problems, which must be solved in order to use the proposed approach in practice. One of them is how to present the results of the hybrid simulation, so that they can be utilized to compare investment alternatives. In the literature, there are only few propositions to solve this problem [4, 10, 12]. In this article, we propose a method which aggregates the bounds of a p-box into a cumulative distribution function, which allows us to compare various alternatives using stochastic dominance.

The article is organized as follows. First, we present the advantages of hybrid approach to risk analysis. Next, we show how to conduct risk analysis using a p-box structure and we present several strategies of aggregation of a p-box into a cumulative distribution function. Then, using a practical example of the appraisal of an in-vestment we show how to utilize this approach and how to combine it with stochastic dominance. The article ends with concluding remarks.

2 Benefits of Using Hybrid Simulation in Investment Appraisal

In numerous decision-making situations, the nature of the uncertainty of economic parameters does not satisfy the assumptions of the probability theory. Most real-world problems of investment project analysis involve a mixture of quantitative and qualitative data and the conventional probabilistic approach appears to be insufficient to analyze the efficiency of investment project. Therefore, many researchers have come up with alternative ways of describing uncertainty, among which the possibilistic (fuzzy) approach deserves particular attention [2, 3, 8, 9]. The usefulness of possibilistic and probabilistic approaches in decision-making analysis is viewed in different ways. Many researchers voice the opinion that in every single case one needs to decide whether the possibilistic or probabilistic approach will be more appropriate. The selection of the approach should be conditioned mostly by the degree of subjectivity of the available information. On the other hand, Gupta [7] and Smets [13] claim that in decision-making, a probabilistic description of uncertainty is more effective than a possibilistic one. According to [9], selection of the method of representing uncertainty depends mainly on the experience and habits of the decision-maker. Choobineh and Behrens [2] claim that maintaining a probabilistic approach stems more from tradition than from conscious selection. Ferson and Ginzburg [6] suggest that distinct methods are needed to adequately represent variability and im-precision. Baudrit et al. [1] state that randomness and imprecise or missing information are two sources of uncertainty. Therefore, in the process of assessment of the efficiency of investment projects it is necessary to take into account both types of uncertainty. Making no distinction between them, may seriously bias the outcome of economic analysis in a non-conservative manner [2]. For example, in the case of partial ignorance, the use of a single probability measure introduces information that is in fact not available. Therefore, we claim that the use of hybrid data, i.e. data partially described by probability distributions, and partially by possibility distributions [1, 5, 6], allows us to reflect more properly our knowledge on economic parameters.

3 Risk Analysis with Hybrid Simulation

Risk analysis entails the representation of uncertainty of model parameters as distributions taking into consideration associations and interdependency between them. In the case of tangible investment project efficiency assessment, Monte Carlo simulation is performed, where all uncertainty parameters are described by probability distribution. Due to the hybrid uncertainty elicitation in this article, risk analysis is conducted here using the hybrid simulation (for detailed description with reference to efficiency of investments see [11]). Below, we present the short description of the hybrid simulation:

- **Formulating an investment decision problem**, which involves selection of input parameters and identification of the dependency between them. In the case of hybrid simulation, a decision problem usually takes the form of a linear programming model. In the examples, which are discussed in this article, an investment decision problem is solved to obtain efficiency measure *(NPVR* in case of example of this article).
- **Selection of appropriate uncertainty representation for all parameters** based on the origin of uncertainty. In hybrid simulation, stochastic parameters are described by probability distribution and epistemic parameters are described by possibility distribution.
- **Propagation of aleatory and epistemic uncertainty through model.** The propagation of uncertainty is performed by combining the Monte Carlo technique with the extension principle of fuzzy set theory [1]. Each run of simulation consists of the following steps. First, all possibility distributions are divided into α-cuts [1, 19] (each α-cut represents an interval of all possible values of possibilistic variables). Then, the upper and lower bounds of the α-cuts are converted into constraints in a decision problem. This means that each fuzzy parameter becomes an additional variable, in our decision problem, and each α-cut imposes a new constraint. This step usually causes that decision problem becomes a nonlinear programming problem. All probability distributions are sampled in order to obtain the values of stochastic parameter. Finally, two nonlinear programming problems are solved to obtain the worst and the best value of *NPVR* for a given set of parameters. We denote those values as $[\underline{npvr_\alpha^i}, \overline{npvr_\alpha^i}]$. The indices mean α-cut and *i*-th simulation run.

As a result of the hybrid simulation, we obtain m realizations of the intervals $[\underline{npvr_\alpha^i}, \overline{npvr_\alpha^i}]$. Those intervals can be then transformed into a probability box (p-box) or possibility distribution (detailed description may be found in [1]).

When we conduct risk analysis with Monte Carlo simulation we know exact values of cumulative distribution function $F(npvr)$. In case of hybrid simulation we only have a partial information about probability distribution, so for every npvr we have interval $[\underline{F(npvr)}, \overline{F(npvr)}]$ of possible values of $F(npvr)$. Bounds of such intervals are lower and upper cumulative distribution functions - also called probability box or p-box. A p-box $[\underline{F(npvr)}, \overline{F(npvr)}]$ is a set of cumulative distribution functions F(npvr) bounded between two functions, i.e.: $\underline{F(npvr)} \leq F(npvr) \leq \overline{F(npvr)}, npvr \subseteq R$.

Figure 1 compares two approaches: the classical Monte Carlo simulation (dotted line), where variability and ignorance are described by probability distributions and the hybrid simulation, and (solid line) the. As we can see, in addition to the information given by the Monte Carlo simulation, the p-box expresses different kinds of uncertainty. Epistemic uncertainty is represented by the spread between lower and upper bound of the p-box and aleatory uncertainty is represented by the overall curve of the p-box. This is a very important information for a decision maker, because it shows whether the risk comes from expert opinions, which can be biased, or from the irreducible variability of historical data.

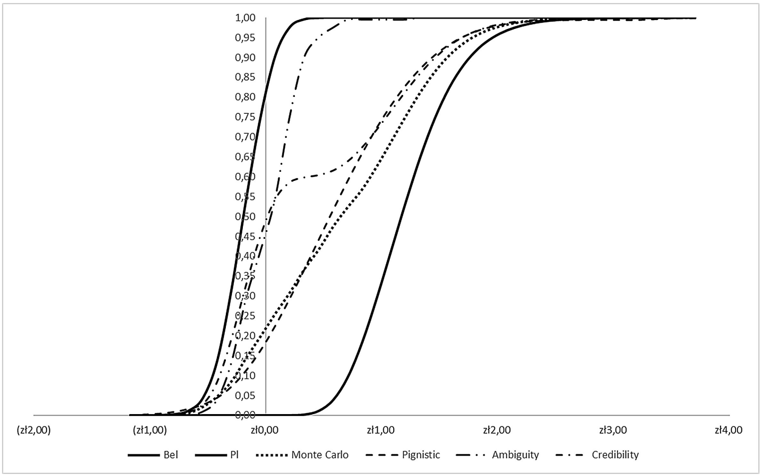

Fig. 1. The comparison of the output of risk analysis conducted by using different methods: Monte-Carlo simulation (dotted line) and hybrid simulation (solid line)

The main barrier to the practical use p-box in risk assessment are difficulties in its interpretation by a decision maker. When risk analysis is made using a Monte Carlo simulation, then as a result we obtain a precise cumulative distribution function. In this case, conclusions about possible values of NPVR can be drawn from the shape and position of a distribution function. The position of is used to determine, e.g., the value at risk (loss probability). In our example $P(F_{MC}(nprv) < 0) = 0.22$. In the case of a p-box, we obtain an interval [0, 0.75], which may baffle a decision maker.

When comparing investment alternatives, besides the described above likelihood that investment will be unprofitable, also relative profitability of investment is taken into consideration. This criterion is based on the comparison of the slant of F's using stochastic dominance. The concept of stochastic dominance allows us to rank the results of risk analysis represented by F's. Stochastic dominance gives only partial ordering. In terms of F's of the risk of two investment alternatives, the first alternative dominates the second one if at least equals at every cumulative probability and exceeds it at least once. It is called first order stochastic dominance. The first alternative exhibits a second-degree stochastic dominance over the second alternative if the area that is constituted by cumulating the differences between F's is either always positive, or never negative and positive at least once. In the case of a p-box, there are two pairs of F's, so it is difficult to build the stochastic dominance.

It's important to stress that described above difficulties in analyzing p-boxes result from more adequate description of risk with hybrid approach. P-boxes play a very important role in communication impact of different kinds of uncertainty to a decision maker. But it is only beginning to understand the risk. As it described below, the p-box allows a decision maker to make more informed decisions.

In classical risk analysis, decisions are made in three situations—certainty, risk and uncertainty. Ellsberg experiments show [14] that in real decision problems decision maker is faced with mix of risk and uncertainty environment, which is called ambiguity. In contrast to risk analysis, where a probability can be assigned to each possible outcome of a situation, the ambiguity applies to a situation where the probabilities of outcomes are not known exactly and are described by intervals. So, the p-box is one of the mathematical representation of ambiguity. Decision maker tries to reduce ambiguity, which corresponds to choosing one arbitrary F from a p-box. There are three strategies that will help a decision maker to choose the best F.

First strategy is called pignistic transformation. It was proposed by Smets [13] and is based on Laplace principle of insufficient reason, where the hybrid simulation results in S, which is a set of possible and indistinguishable from the utility point of view values of npvr. So, each interval $s_{\alpha}^{i} = [\underline{npvr_{\alpha}^{i}}, \overline{npvr_{\alpha}^{i}}], s_{\alpha}^{i} \subseteq S$ may be converted into the uniform probability distribution $f_{uniform}(\underline{npvr_{\alpha}^{i}}, \overline{npvr_{\alpha}^{i}})$. The value of F_{pig} is calculated as:

$$F_{pig}(npvr) = \sum_{npvr \in s_{\alpha}^{i} \subseteq S} \frac{n(s_{\alpha}^{i})}{|s_{\alpha}^{i}|}, n(s_{\alpha}^{i}) = \frac{1}{mk} \tag{1}$$

where k is the number of α-cuts, and m is a number of simulation runs in the hybrid simulation. The main deficiency of this approach is that it does not take into consideration the risk aversion.

The second strategy is based on Hurwicz criterion. In this approach, we use the aforementioned definition of ambiguity. Upper and lower bounds of a p-box defines extreme scenarios. For each $npvr$ we can define probability interval $[\underline{F(npvr)}, \overline{F(npvr)}]$.

Using a Hurwicz criterion and treating the upper and lower bounds of a p-box as extreme scenarios, ambiguity distribution may be defined as follows [15]:

$$F_{amb}(k) = \lambda \cdot \underline{F^{-1}(k)} + (1-\lambda) \cdot \overline{F^{-1}(k)}, k \in [0,1], \tag{2}$$

where λ takes values from 0 to 1, and is called *the indicator of the pessimism (optimism) of a decision maker*. Optimism index may be treated as a simple measure of belief in expert's opinion.

The third approach is a generalization of the credibility theory proposed by Liu [16]. Dubois and Guyonnet [17] extends the measure proposed by Liu with the coefficient of risk aversion β:

$$F_{cred}(npvr) = \beta \cdot \underline{F(npvr)} + (1-\beta) \cdot \overline{F(npvr)} \tag{3}$$

For $\beta = 0.5$ F_{cred} is equal to the credibility distribution.

Generally speaking, ambiguity may be treated as a security interval $[\underline{npvr}, \overline{npvr}]$ for a given probability θ. Credibility is a probability interval $[\underline{\theta}, \overline{\theta}]$ for a given npvr. This distinction is very important in the process of investment appraisal as we will show below. Figure 1 presents pignistic, ambiguity and credibility distributions for a given investment. Optimism index and risk aversion are set to *0.5*.

Table 1 presents comparison of strategies for two decisions:

- **Decision I** Value at risk (probability loss) $P(npvr < 0) = \theta$
- **Decision II** $npvr_0$ such as $P(npvr < npvr_0) = 0.9$.

Table 1. The comparison of VaR and npvr0 for different approaches in risk analysis

	Value at risk (loss probability)	$npvr_0$ (.000 USD)
Monte Carlo simulation	0.2	1.58
F_{pig}	0.16	1.45
F_{amb}	0.42	0.33
F_{cred}	0.45	1.45
Hybrid simulation (p-box)	[0,0.75]	[0.08, 1.7]

As we may see, there are significant differences in the results of the strategies, so it is very important to define situation where each of approaches should be applied.

4 Numerical Example

In order to illustrate the effectiveness of the proposed approach, we present the results of calculations performed for three investment projects. We consider the following investment projects:

– **[Option I] Construction of new department of OC sheet**, production capacity 200 thousand tonnes
– **[Option II] Construction of new department of OC sheet**, production capacity 300 thousand tonnes
– **[Option III] Construction of new department of HDG sheet**, production capacity 400 thousand tonnes.

The effectiveness of the project was measured by net present value ratio (NPVR):

$$NPVR = \frac{\frac{\sum_{t=0}^{T} NCF_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{I_t}{(1+r)^t}} = \frac{NPV}{PVI} \tag{4}$$

where:

NCF_t – net cash flow in year t
r – discount rate,
T – economic life of investment project,
I_t – investment outlays in year t,
NPV – net present value,
PVI – discounted investment outlays.

In the computational experiment, we have taken into consideration the uncertainty of selected parameters. The sales of products (Hot-dip galvanizing sheet – HDG sheet, Organic coated Sheet – OC sheet) were defined by normal probability density functions. The prices of these products, prices of cold rolled sheet – CR sheet (being a batch material for production HDG sheet and OC sheet), consumption per unit indicators for all products and investment outlays for project were defined by possibility distributions. The remaining parameters of the effectiveness calculations were assumed to be deterministic. So, in the efficiency evaluation process, data are partially expressed by possibility distribution and partially defined by probability distribution.

Figure 2 presents the results of the hybrid simulation for each alternative. Let's assume that decision maker follows the strategy. First, he wants to reject all investment options with the value at risk greater than zero, and then to choose the most profitable one. From the figure, we can see that all investment options have non-zero probability of failure, but the probability interval of third option is the widest and ranges from 0 to 1. So, one of the possible options for an investor is to decide that the distance between the upper and lower probability bounds is too big, and thus the epistemic uncertainty should be reduced by performing additional measures. Sometimes, time and budget constraints cause that this option is not possible. So, in second step decision maker should choose one of the strategies described above to aggregate a p-box into the CDF. His choice should be determined by the following rules:

– If risk aversion of a decision maker is not known and we don't know anything about assumption about parameters, the safest way will be to choose pignistic transformation.

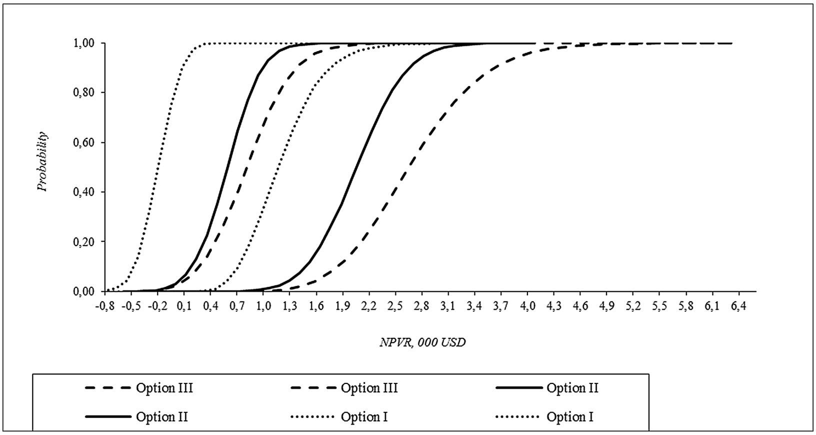

Fig. 2. Output of simulation for each investment alternative

- If only risk aversion or "*expert aversion*" (belief in expert assumption) is known, ambiguity or credibility should be chosen accordingly.
- If we know the risk aversion and expert aversion, the decision depends on what we want to measure – probability or efficiency parameter. In case of probability, the ambiguity distribution should be chosen.

In this example, we stress on the last rule. The decision maker wants to compute probability loss or $P(npvr < 0) = \phi$. Let's assume that the decision maker is neutral to risk $(\beta = 0.5)$ and has more conservative approach to model assumption than experts $(\lambda = 0.25)$. To compute the probability of loss, we have built the credibility distribution for each investment option and have obtained the following results: **option I** – 0,38, **option II** – 0, **option III** – 0.

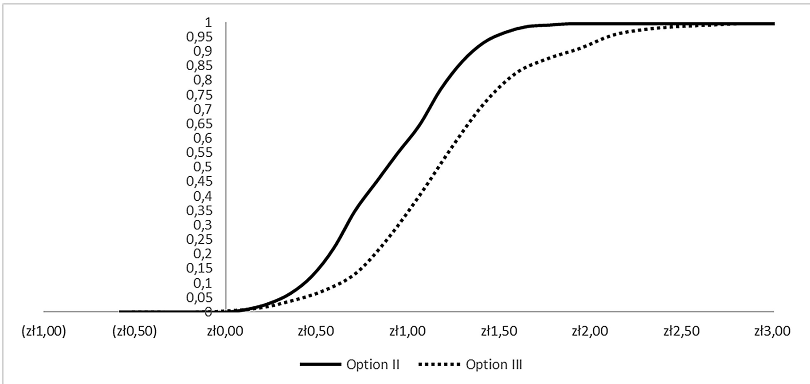

Fig. 3. Comparison between Option II and Option III

This means that the decision maker should reject Option I and compare profitability of Options II and III. To find a more profitable investment, stochastic dominance is used, but in this case we compare two ambiguity distributions which is presented in Fig. 3. We choose ambiguity distribution because now we focus on the value of efficiency parameter not probability. As a result, the DM should choose Option II, because it stochastically dominates Option III.

This simple analysis of three tangible investment options is based on the assumption that arbitrary selection of the CDF by decision maker makes more sense at the end of risk analysis. In our opinion this is true, because we divide risk analysis into two parts. Hybrid analysis faithfully propagates available information and uncertainty up to a p-box. Then, the decision maker analyzes the results and makes a decision. If information about parameter value is considered to be insufficient, he may decide to collect more information. If the information is incomplete, but no data collection is possible, then a judgment must take place with strategies described above.

5 Conclusions

In this article, we stress on the importance of the consistency between different types of uncertainty and adequacy of the description of uncertainty of parameters. We present the hybrid simulation as well, which allows to perform computation on hybrid data. We show how to make a decision when the risk is described by a p-box, which is obtained as a result of the hybrid simulation. We describe three strategies of converting a set of cumulative distribution function into one CDF. Using the presented approach, we are trying to eliminate one of the shortcomings of the existing methods for joint hybrid propagation of uncertainty in context of investment appraisal, i.e. the problem of interpretation of the results. Using a practical example, we present how decision maker can benefit from to use the presented approach.

The main weaknesses of presented approach is the problem with computing the optimism index. In practice, is very hard to assess the quality of experts. Very good explanation, called "megaproject paradox", of this problem was presented by Flyvbieg in [18] in the case of megaprojects. Flyvbieg states that the number of tangible investments made in company does not translate into accuracy of risk analysis of a new one. This is because risk analysis is built on a collective belief in a firm which is usually biased. So, the next step should incorporate stochastic dominance defined on p-box instead of ambiguity theory as it is presented in work [10].

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Quality of Investment Recommendation – Evidence Form Polish Capital Market, Income Approach

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Abstract. In the paper, results of quality assessment of investment recommendations issued by Polish brokerage houses are presented. A hundred investment recommendations were examined, coming from seven different brokerage houses, issued in years 2015–2016. Only income approach and DCF model valuation were analyzed. The research indicates low quality of valuations presented in the Polish investment recommendations. The level of disclosures and assumptions used in the financial models underlying financial forecasting and valuations is not sufficient. Significant objections raises the methodology of discount rate calculation. The risk premium does not cover the local bonus, the assumptions are not revealed, beta is not individually chosen, and beta at level 1 is abused. Problems concerning lack of information about cash flows used for residual value calculation were identified. The study reveals numerous examples of gross methodological errors in investment recommendations, however, common mistakes identified in other studies, like for example the excessive optimism for cash flow forecasting or overvaluation of the long-term cash flow growth rate, were not observed.

Keywords: Business valuation · Investment recommendation · Income approach

1 Introduction

Investment recommendations are reports, analyses or other information sources that suggest investment behavior regarding investment instruments or their issuers. They include opinions concerning the current or future value/price of financial instruments. Investment recommendations are an important part of the capital market and, as the research suggests, can actually shape it by affecting company valuations and behavior of investors, clients and the management. Therefore, investment recommendations are widely pursued by researchers worldwide.

One of the first studies on investment recommendations showed that their implementation can in the short term bring abnormal returns for investors (Groth et al. [11]). Subsequent research confirmed that investment recommendations had caused changes in market valuation, especially buying recommendations that have a positive impact on stock prices and allow higher average market returns both in the short term and up to 90

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days after their publication (Bjerring et al. [1]). The conclusions drawn from these studies suggest that investment recommendations provide important information to investors.

On the other hand, Jegadeesh and Kim [14], as well as many others, showed that significant number of investment recommendations was preceded by companies' good performance. Jegadeesh et al. [13] also indicated that stock recommendations are mainly prepared for companies with superior return, the so called "glamour stocks". Analysts make favorable reports for some firms and they select superior stocks for which recommendations will be positive.

Research on investment optimism has a long history. In some papers optimism was measured by comparing the analyst' forecast for a particular stock to the average forecast for the company made by other analysts in comparable forecast horizon [2]. Several studies showed that most of published recommendations are "buy" rather than "sell" recommendations (Ertimur et al. [7]). Morgan and Stocken [17] introduced analyst's objective function, which is able to assess if the stock price was overvalued due to analyst's lack of objectivity. Kowalski and Praźników [15] suggested that analysts are more likely to announce higher valuation than the historical value drivers and fixed growth model suggests. In all of the analyzed databases the average recommendation optimism indicator was positive.

The potential impact of analysts on the results of valuations can be traced back to numerous studies of their professional careers. Hong and Kubik [12] analyzed optimism forecast from analyst's carrier perspective, and they tried to explain differences between experienced and beginner analysts [6, 16, 18]. The authors showed that the accuracy of the analyses for a particular analyst had a significant impact on their carrier. According to Hong and Kubik [12], analysts were rewarded for optimistic forecasts that support profitable trading strategy of purchasing stocks with the most favorable recommendations. Similar research was performed by Ertimur et al. [7] on the sample of 97 000 recommendations.

Research on the Polish capital market does not confirm the above-mentioned conclusions about the positive correlation between the recommendations and market reactions. Dąbrowski [5] analyzed the results of investing in stocks, based on portfolio composite from stocks, which had the highest analysts' recommendations. In most cases, the price of securities did not achieve the target price indicated in analysts' reports – the effective price calculation was only in 44.63%. More than 70% announcements recommend purchasing direct stocks though recommendations were issued during bear trend in stock market, i.e. when the prices of securities were falling. Zaremba and Konieczko [19] documented overoptimism among analysts, measure efficiency of stock recommendations in the Polish capital market, by examining returns, after investing in securities, based on suggestions from stock recommendations. They studied 128 companies for which stocks were evaluated as negative but achieved the highest returns. Trading strategy of purchasing (buying long) stocks with the most favorable recommendations by analysts achieved abnormal negative returns.

Such reports indicate low utility of investment recommendations for Polish investors. The investment recommendations issued by Polish brokerage houses do not have fixed structure. Typically, they include description of the company's activities, historical performance, description of key value drivers, market position, risks affecting future performance, company evaluation, disclaimers and legal notes. The most common valuation methods are income approach and multiples approach. The recommendation report typically contains detailed results and valuation calculations. In Poland, the scope of disclosure of the content of the recommendation is not regulated at all. There are no formal standards or procedures indicating which methods or models of valuation should be used. The analysts have a free hand in taking decisions about choosing methods, making assumptions, sources of information, disclosures and presenting results.

The literature on valuation methods indicates a number of errors and omissions that often arise in valuation procedures. Fernandez and Bilan [10] indicated collection and classification of 119 errors encountered in business valuations, classified into six main categories. In particular, the income methods are subjected to errors or manipulations. Principles of applying valuation procedures are regulated by business valuations standards, but in Poland there is not one common binding regulation in this respect.

The purpose of the article is to assess the quality of practices used in the analysts' estimates of investment recommendations based on income approach. The article is organized as follows: Introduction, Materials and methods, Results and Conclusions. In Materials and methods, a database of investment recommendations issued by Polish brokerage houses is presented and the research sample is characterized. The Results section shows the results of the research on the methods and practices used in investment recommendations. Results are presented according to the analyzed valuation areas: cash flow forecasting, discount rate, terminal value and other parameters. At the end of the article, summarized conclusions are presented.

2 Methods and Materials

2.1 Research Design

A database dedicated to the project was established with information including (1) general data, (2) information about cash flows forecast, (3) data about terminal value, (4) data about discount rate, (5) information about debt and bonus/discounts, and (6) results of valuations. In all, 81 information pieces were collected for each recommendation.

Each valuation was analyzed in terms of (1) forecasting the expected cash flows, (2) terminal value, (3) discount rate, and (4) others parameters. Financial forecasts were investigated from the point of view of the forecast period, and I assessed compound annual growth rate (CAGR) for crucial value drivers, e.g. sales, EBIT, EBITDA. Additionally, I analyzed if the forecast covers the whole period of growth and the dynamics of value drivers in last forecasted year. Additionally I analyzed the level of capital expenses and the sum of delta working capital in the whole predicted period. To check obtained results I compared them with analogical parameters calculated for Polish market in years 2004–2014. For this purpose the data form StockGround Database by Notoria was used.

The key element of income approach is the residual value (terminal value), which calculates the value of cash flows to perpetuity. Errors in this area can have a major impact on the results and the quality of the valuation. Therefore, I also assessed expected free cash flows used in terminal value and the level of expected growth of cash flows.

Errors in the discount rate calculation and the ones concerning the risk of the company were indicated by Fernandez [9] as the most common. I exanimated parameters of calculated cost of capital taking into account: risk-free rate, beta, market risk premium used for the valuation, and value of tax shields.

The field 4 (other parameters) concerns additional factors of valuation as the value of debt, usage of the specific premium (odd small-cap, odd illiquidity premium) as well as comparing the results of valuation of income approach with current market value and multiples methods.

2.2 Sample Selection

The research was performed on the stock recommendations sample issued by the Polish brokerage houses. Summary 100 investment recommendations were examined, coming from seven different brokerage houses, issued in years 2015 and 2016. The final sample contained 84 companies divided into 22 sectors. 98 recommendations used Discounted Cash Flow Model and they were included in further analyses. In two cases Dividend Discount Model was applied, and they were excluded from the analyses. The description statistics of crucial parameters for the sample are presented in Table 1.

Table 1. Characteristics of the sample

	AVG	Q1	MED	Q2	Max	Min	StDev
Revenue [mPLN]	2 460	276	781	1 583	24 685	10	5 300
EBIT [mPLN]	248	24	66	242	3 484	−1 010	645
EBITDA [mPLN]	437	32	93	431	5 198	−1	979
Market value [mPLN]	3 786	397	1 152	4 014	42 260	16	7 050
Issue price [PLN]	137.8	3.9	29.1	56.8	7 580.2	0.0	824.9
ROS [%]	10.75	5.58	9.28	12.05	53.16	53.16	10.28

Table presents the value of parameters of the first year before forecast. AVG is average, MED-median, Q1 and Q3 the first and third quartile, StDev – standards deviation, in bracket the units are presented.

3 Results

3.1 Cash Flow Forecasting

Errors in forecasting the expected cash flows are often mentioned in literature, especially exaggerated optimism causing low quality of valuation in income approach. The most frequently indicated errors in cash flow forecasting are too short a period of the detailed forecast, not sufficient increase in working capital requirements, and undervalued capital expenses [8]. The analysts of brokerage houses in Poland set the length of the detailed forecast period for 10 years. Of the 98 recommendations, up to 74 analyzed DCF models covered the 10-year forecast period. The observed results show that only some brokerage houses differentiate the length of the forecast period depending on the company under valuation.

To evaluate financial forecasts, I looked into the average change of major forecast drivers, the level of investment in working capital, the net capital expenditures (Capex less amortization), and the last forecast period. The results are presented in Table 2.

Table 2. Evaluation of cash flow forecasting

	AVG	Q1	MED	Q2	StDev	Market t-stat
Panel A: CAGR in the whole forecast [%]						
Revenue	3.0	1.4	2.7	4.5	2.4	0.17
EBIT	3.5	1.9	3.4	5.0	4.1	−0.02
EBITDA	6.1	1.7	2.8	5.2	12.1	0.12
Panel B: Appropriate investment assumption [nd]						
NetCapex/Sales	−1.0	−6.0	−1.1	1.0	11.1	0.08
dWCR/Sales	−2.6	−7.1	−2.4	0.5	13.9	−0.29
Panel C: Last year dynamics of value drivers [%]						
Revenue	1.9	1.0	2.0	2.8	1.5	−8.85*
EBIT	0.7	0.0	1.5	3.5	10.0	−4.79*
EBITDA	0.3	0.0	1.3	2.9	8.5	−4.43*

Abbreviations as in Table 1, last column presents results of t-statistic by comparison results for investment recommendations and the market, sign * indicates results statistically significant at $p = 0.05$. Panel A presents compound annual growth rate in the whole forecast. Panel B presents sum of net capital expenses (Net Capex) and change in working capital (dWCR) in all years of forecast. The sums are scaled by dividing sales of companies in the first year of forecast. Negative number means decrease of free cash flow, positive increase of free cash flow. Panel C presents change in value drivers in the last year of forecast. Two last years are compared.

Compound annual growth of sales as well earnings are comparable with the average for the whole Polish market recommended by Damodaran [4]. The results of t-statistic show that the average growth of value drivers in investment recommendations does not differ from the average for the whole market in years 2004–2014. Similarly, the level of investment included in cash flow forecasting is without reservations. On average, the difference in capital expenses and amortization over the whole forecast period amounted to one-year sale, while the total amount of working capital over the whole forecast period was more than 2.5 times the annual sale. There were not any significant differences found for these parameters compared to the market average.

3.2 Discount Rate

In 63.27% of DCF valuations, there was information in assumptions that the risk-free rate equaled the yield on 10-year government bonds. Such information was not mentioned in 36.73% cases. The market risk premium used in the investment recommendations assumed only three different values. In 73.47% recommendations, market risk premium was used at 5% while in 24.49% at 5.50%. Only two recommendations had a 4.5% risk premium. All the indicated values were significantly lower than the recommended risk premiums in the Damodaran databases [4], which suggested market risk premium at 6.08% and 6.43%. Neither of the investment recommendations indicated the sources of information from which the risk premium was taken.

The investment recommendations do not use formal procedures concerning beta factor calculation. More than half of the recommendations used beta amounting to 1 without any justification. Another 32% did not indicate the source of information for the made assumptions. In 80.61% of the models, when calculating the cost of equity, beta was set at a constant level throughout the forecast period. In 19.39% cases, beta took different values in different years. In 28% cases, the calculation concerning information about process of unlevering beta was mentioned. In the rest cases lever and unlever beta process were not conducted. Some brokerage houses used lever and unlever beta process in all their recommendations, some occasionally and others never.

In 52% investment recommendation, effective tax rate is used, the rest used nominal tax rate. In 26.53% cases assumed tax rate was variable in time.

For 10 recommendations, for calculation of cost of equity, classical capital assets pricing model (CAPM) was not used but additional corrects were applied, however there is lack of any information about the assumptions taken.

3.3 Terminal Value

Residual value has a major impact on valuation. The most common errors in this area are: the use of unstable cash flow and the wrong choice of expected growth [3, 9]. Table 3 shows the results of the analyses in the residual value area.

Table 3. Parameters of terminal value

	AVG	Q1	MED.	Q2	Min	Max	StDev
Panel A: Share of terminal value in results of valuation [%]							
PV(TV)/Eq	72.5	33.4	56.6	67.0	35.3	81.3	27.8
PV(TV)/EV	59.4	35.4	50.8	55.8	9.6	64.7	14.0
Panel B: Expected growth [%]							
g-rate	1.35	1.00	1.00	2.00	−0.04	3.00	0.88

The results obtained confirmed significant influence of residual value on business valuation in investment recommendations. I analyzed the share of present value of TV in equity value and enterprise value. As presented in Table 3, Panel A the former is equal on average to almost 60% and the latter to 72.5%. This results may suggest that period of detailed forecast is too short.

High volatility of long-term cash flow growth rate used in investment recommendations is observed. The most commonly used rate of free cash flow in the residual period (43.88% of all observations) is the rate of 2%. In 32.65% recommendations, the rate is equal to 1%. The highest rate used in the analyzed valuations is the rate of 3%, which occurred only twice in the investigated sample. Growth rate of 0% occurred in 3.06% of observations. One recommendation used a negative growth rate of −0.04%. The used growth rates do not raise any objections and they are in line with standards and good valuation practices (Damodaran [4]).

PV(TV) – present value of terminal value, EV – enterprise value; Eq – value of equity calculated in valuation (Eq = EV – net debt), g-rate – long-term cash flow growth rate, consistent with Gordon Growth Model, others abbreviations as in Table 1.

There are reservations from the point of view of quality, raised by the scope of residual value information. For only 3 recommendations, the residual value is calculated based on the last year of the detailed forecast. In 15 DCF models, there is a separate column with financial data for the residual period. In contrast, 81.63% of the analyzed valuations did not provide any data on the basis of which the residual value was determined. The method of calculating cash flow for terminal value raises reservations. In 16 recommendations for which residual value data were disclosed, there are 3 that assumed in the residual period the depreciation greater than the investment in fixed assets, which should be considered as a significant methodological error.

3.4 Others Parameters

The DCF valuation results do not differ from those presented using the multiples approach and are on average above average market valuation by 20%. In 73 cases, the valuation was higher than the current price and the buy recommendation was given, in other cases the value was lower than the current price and the recommendation was to sell or hold. Table 4 provides detailed results comparing valuations.

Table 4. Comparison of valuation results

	AVG	Q1	MED.	Q2	Min	Max	StDev
DCF/multi	72.5	33.4	56.6	67.0	35.3	81.3	27.8
DCF/MV	59.4	35.4	50.8	55.8	9.6	64.7	14.0

Adjustments in valuations include: short-term financial assets, factoring, associates, non-controlling interests, liabilities to employees, non-operating assets, cash position adjustments, foreign exchange differences, minority interests, dividends and other assets. The most common corrects are minority capitals (22 cases) and dividends (17 cases). Adjustments for liabilities to employees appeared in 4 valuations.

The Table presents surplus of valuation by DCF model with multiples approach (row DCF/multi) and current market value (row DCF/MV). Numbers are presented in percentages. The abbreviations as in Table 1.

4 Conclusions

The conducted research indicates that the quality of valuations presented in the Polish investment recommendations is low.

Restrictions are primarily a result of the low level of disclosures and assumptions used in the financial models underlying financial forecasts and valuations.

The excessive optimism was not identified for cash flow forecasting in investment recommendations. The average value drivers used in the forecasts do not differ from historical market data. The forecast period is not individually adjusted to the situation of the valuated entity. Significant objections raises the methodology of discount rate calculation. The risk premium does not cover the local bonus, the assumptions are not disclosed, beta is not individually chosen, and beta at level 1 is abused. Long-term cash flow growth rate used in the recommendations does not leave any doubts. However, a significant problem is the lack of information about cash flows used for residual value calculation.

Additional performed studies reveal numerous examples of gross methodological errors. Table 5 summarizes statistics of lack of disclosures and methodological errors (Table 6).

Table 5. Lack of disclosures and methodological errors

Panel A: Lack of disclosures of information [number of cases]	
Lack of revenue forecasts	17
Lack of source of information about free risk rate	37
Assumption of beta amounting to 1 without explanation	52
Lack of information about lever and unlever beta process	71
Lack of information about cash flow used for terminal value	81
Lack of information about calculation of the cost of equity, cases when CAPM model is not used	10

Table 6. Lack of disclosures and methodological errors (cont.)

Panel B: Methodological errors [number of cases]	
Inconsistent forecast, wrong period of detailed forecast[a]	7
Assuming that a perpetuity starts a year before it really starts	1
Not considering the country risk	92
Using discount rates lower than the risk free rate	1
Sum of debt share and equity share when WACC calculated is not equal 100%	3
Using the statutory tax rate, instead of the effective tax rate	41
Depreciation > Capex in cash flow forecast used in terminal value	3

[a]As inconsistent were pointed cases where the change in revenue in the last forcastet year differs from previous year more than 10%

The research has several contributions to knowledge. First of all it has a practical application, it can be treated as guidelines for brokerage houses, issuers, exhibitors and investors. The findings from this empirical evidence can be useful for practitioners and researchers involved in work on valuation standards. They can also have impact on research concerning investment recommendations, their publication and how they influence the market and market valuation. It should be emphasized that the presented results come from the Polish capital market, which it is classified as a young and emerging market. The survey concerns a market where the experiences of brokerage houses as well as investors are small, and the usage of valuation methods, issuance of investment recommendations have short history. Form this point of view the results can be important for explanation of differences in findings concerning investment recommendation obtained for Polish and other more developed markets.

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Some Aspects of Management of Innovation

On Application of Recursive Preferences in Optimal Growth Model

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Abstract. This paper deals with the optimal growth model in the finite time horizon and the Epstein-Zin-Weil aggregator function. We formulate the dynamic recursive optimality equation, find the value function and the optimal policy of a consumer. Our results are illustrated by examples.

Keywords: Risk · Recursive utility · Optimal consumption policy

1 Introduction

This paper is devoted to an application of recursive utility to optimal growth model. Most of literature on optimal growth proceeds on the assumption that preferences are represented by a functional which is time additive, see [7, 8]. The class of recursive utility functions has been proposed as a generalisation of time additive utilities. It permits dynamic programming techniques for optimal growth model and enjoys time consistency property. One of the reasons which makes the recursive preferences popular is that it resolves the timing problem of resolution of uncertainty. For instance, let us consider two-stage model with the standard time additive utility function given by $E[u(c_o) + \beta u(c_1)$, where ct is the consumption in period t, u is felicity function in period t; and $\beta \epsilon [0, 1)$ denotes the subjective discount coefficient. If we flip a fair coin at time zero. If it comes up heads, the consumption levels at time 0 and 1 are c_0 and c_1^1, respectively. If it comes up tails, they are c_0 and c_1^2 ($\neq c_1^1$): Now suppose that the consumption level at time point zero is still c_0; but we flip a coin at date 1 with the same outcome c_1^1, c_1^2. Then the expected utility of two experiments is identical $u(c0) + 1 = 2\left[u\left(c_1^1\right) + u\left(c_1^2\right)\right]$. However, as it is emphasised in [1–3, 6], the timing of resolution of uncertainty is relevant in economics, especially in asset pricing. Yet, the time additive expected utility implies that the marginal rate of substitution between consumption today and tomorrow for a constant consumption sequence c is the inverse of the subjective discount factor. More precisely, $MRS_{t,t+1}(c) = \frac{u'(c_t)}{\beta u'(c_{t+1})} = \beta^{-1}$. Hence, MRS is unaffected by the level of consumption. This constant marginal rate of substitution leads to an extreme behaviour of a consumer. A consumer facing a fixed interest rate will try either to save without limit or borrow without limit, except the case when the subjective interest rate equals to the interest rate.

In this paper, we focus on studying the optimal growth model in a finite time horizon. The recursive utility is defined with the aid of conditional certainty equivalent

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proposed by Kreps and Porteus [5] and the aggregator function suggested by Epstein and Zin [3] and Weil [9]. It turns out that such defined recursive utility is a remedy for the aforementioned drawbacks, but still mathematically attractive, because we are able to use dynamic programming methods that lead to the so-called optimality equation. We find the value function and the optimal policy. We illustrate our results by various examples concerning both deterministic and stochastic models.

2 The Model and Recursive Equation

2.1 Certainty Equivalent

First we introduce the notion of *certainty equivalent*. Note that any number α can be viewed as a random variable taking only one value α. Consider a preference order $\succcurlyeq$ in the set of random variables. Assume that for a random variable X we can find a number $\alpha = \alpha(X)$ such that $c \simeq X$ with respect to the order $\succcurlyeq$. In other words, an agent is indifferent between choosing X and α. The number $\alpha(X)$ so defined is called *certainty equivalent*.

For the expected utility maximiser with the utility u the relation $c \simeq X$ is equivalent to $Eu(X) = u(\alpha)$. If u is one-to-one function, then there exists the inverse function u^{-1} and

$$\alpha(X) = u^{-1}(Eu(X))$$

Further, we shall consider the power utility function

$$u(x) = x^{\gamma}; \gamma \epsilon (0; 1]; x \geq 0.$$

The coefficient reflects in some sense averse towards to risk. To see this, let us assume that X has a uniform distribution on [0; 1]: Then,

$$\alpha = (E(X^{\gamma}))^{\frac{1}{\gamma}}.$$

Since it follows

$$E(X^{\gamma}) = \int_0^1 x^{\gamma} dx = \left[\frac{x^{1+\gamma}}{1+\gamma}\right]_0^1 = \frac{1}{1+\gamma}$$

we obtain

$$\alpha = \left(\frac{1}{1+\gamma}\right)^{\frac{1}{\gamma}} = \frac{1}{(1+\gamma)^{\frac{1}{\gamma}}}$$

Note that if $\gamma \to 1^-$, then

$$\alpha \to \frac{1}{2} = EX.$$

This indicates that averse to risk disappears. From the other side, if $\gamma \to 0^+$; then $\theta := \frac{1}{\gamma} \to \infty$ and consequently

$$\alpha = \frac{1}{(1+\gamma)^{\frac{1}{\gamma}}} = \frac{1}{(1+\theta)^{\frac{1}{\theta}}} \to \frac{1}{e}$$

Hence, if γ decreases to 0; then the certainty equivalent decreases to $\frac{1}{e}$. This means that for a lack of uncertainty, we agree to be less paid. Hence the smaller γ is, the risk aversion becomes greater. Observe that for $\gamma = {}^1\!/_2$; we obtain

$$\alpha = \left(EX^{1/2}\right)^2 = \left(E\sqrt{X}\right)^2 = \left(\int_0^1 \sqrt{x}dx\right)^2 = \left(\frac{2}{3}\right)^2 = \frac{4}{9}.$$

2.2 Optimal Growth Model

We shall consider a model in discrete time, i.e., $t \in T := \mathbb{N}$. In period $t \in T$ a consumer faces a single good $xt \geq 0$. The agent decides how much to consume, i.e., he/she chooses $ct \in A(xt) := [0; xt]$. The remaining part $yt = xt - ct$ is invested for the next period. The satisfaction of consumption ct is measured by one-period utility $u(ct) = c_t^\rho$ with $\rho \in (0; 1]$. Moreover, a production function that relates output to input is of the following form

$$xt + 1 = \xi t + 1yt = \xi t + 1(xt - ct), \tag{1}$$

where (ξ_t) is a sequence of independent random variables. Usually, it is assumed that $\xi t + 1 = 1 + rt + 1$; and $rt + 1$ denotes the interest rate from time point t to time point t + 1. Clearly, $rt + 1$ can be either deterministic or stochastic.

Let $Jt(xt)$ be the value function, i.e., the optimal utility in a model with $N - t + 1$ steps, if the level of a good at time point t is $xt \geq 0$. Making use of a dynamic programming principle [6] and assuming that the consumer applies the Epstein and Zin [3] and Weil [9] aggregator,[1] we can write the following recursive optimality equation

$$Jt(xt) = \max_{c_t \in A(x_t)} \left[(1-\beta)c_t^\rho + \beta(E_t(J_{t+1}(x_{t+1})^\gamma))^{\rho/\gamma}\right]^{1/\rho} \tag{2}$$

[1] This aggregator is of the form $W(x; y) = ((1-\beta)x^\rho + \beta y^\rho)^{1/\rho}$ where $\beta \in [0; 1)$ is a subjective discount factor.

The term $(Et(Jt+1(xt+1)^{\gamma})^{1/\gamma}$ is known as a conditional certainty equivalent of Kreps and Porteus [5]. Here, Et denotes the conditional expected value of a random utility given x_t. It is not difficult to guess that both the value function and the optimal consumption policy are linear in x_t. Therefore, we set $J_t(x_t) = A_t x_t$ and $c_t = x_t a_t$, where A_t and $at \in [0;1]$ are some numbers, which we find. Plugging these formulas in (2) and using (1), we get

$$\begin{aligned} A_t x_t &= \max_{a_{t\in[0,1]}} \left[(1-\beta) a_t^{\rho} x_t^{\rho} + \beta (E_t (A_{t+1} x_{t+1})^{\gamma})^{\rho/\gamma} \right]^{1/\rho} \\ &= \max_{a_{t\in[0,1]}} \left[(1-\beta) a_t^{\rho} x_t^{\rho} + \beta A_{t+1}^{\rho} (E_t (\xi_{t+1} (x_t - a_t x_t))^{\gamma})^{\rho/\gamma} \right]^{1/\rho} \\ &= \max_{a_{t\in[0,1]}} \left[(1-\beta) a_t^{\rho} x_t^{\rho} + \beta A_{t+1}^{\rho} (1-a_t)^{\rho} x_t^{\rho} \left(E_t \left(\xi_{t+1}^{\gamma} \right) \right)^{\rho/\gamma} \right]^{1/\rho} \end{aligned}$$

Thus, we obtain

$$A_t = \max_{a_{t\in[0,1]}} \left[(1-\beta) a_t^{\rho} + \beta A_{t+1}^{\rho} (1-a_t)^{\rho} \left(E_t \left(\xi_{t+1}^{\gamma} \right) \right)^{\rho/\gamma} \right]^{1/\rho} \tag{3}$$

Since the functions $a_t \mapsto a_t^{\rho}$ and $a_t \mapsto (1-a_t)^{\rho}$ are concave, then the first order condition yields

$$(1-\beta) a_t^{\rho-1} = (1-a_t)^{\rho-1} \kappa, \text{where } \kappa := \beta A_{t+1}^{\rho} (1-a_t)^{\rho} \left(E_t \left(\xi_{t+1}^{\gamma} \right) \right)^{\rho/\gamma} \tag{4}$$

Consequently, the quantity

$$a_t = \frac{1}{1 + \left[\frac{\beta}{1-\beta} A_{t+1}^{\rho} \left(E_t \left(\xi_{t+1}^{\gamma} \right) \right)^{\rho/\gamma} \right]^{1/(1-\rho)}} \tag{5}$$

attains the maximum on the right-hand side in (3). Now we provide formula for At.

Observe that $AN+1 = 0$ and $aN = 1$: Note that from (3) and (4) it follows that

$$\begin{aligned} A_t &= \left((1-\beta) a_t^{\rho} + (1-a_t)^{\rho} \kappa \right)^{1/\rho} \\ &= \left((1-\beta) a_t^{\rho} + (1-a_t)^{\rho} (1-\beta) \left(\frac{a_t}{1-a_t} \right)^{\rho-1} \right)^{1/\rho} \\ &= (1-\beta)^{1/\rho} \left(a_t^{\rho} + (1-a_t)^{\rho-1} \right)^{1/\rho} \\ &= (1-\beta)^{1/\rho} \left(a_t^{\rho} + a_t^{\rho-1} - a_t^{\rho} \right)^{1/\rho} \\ &= (1-\beta)^{1/\rho} a_t^{(\rho-1)/\rho} \end{aligned} \tag{6}$$

Thus, we conclude that $A_t = (1-\beta)^{1/\rho} a_t^{(\rho-1)/\rho}$.

3 Examples

3.1 Deterministic Case

Put $\beta = \frac{1}{1+r_\beta} = 0{,}95$ and $\xi_{t+1} = 1 + r$ for $t = 1, \ldots, N-1$, where r > 0.

The number r_β is called a subjective discount rate. Moreover, set $N = 50$ and $\rho_1 = 0{,}3$ (the blue colour) and $\rho_2 = 0{,}8$ (the red colour). We will draw the optimal consumption policies.

The quantity $EIS = \frac{1}{1-\rho}$ is known as the *elasticity of intertemporal substitution* and it reflects how strong is the reaction of a consumer with respect to changing prices from period to period. If ρ increases, then EIS increases as well. If $\beta(1+r) < 1$, then $r < r_\beta$. This implies that the consumer is willing to increase his consumption level in the current period at cost of decreasing his consumption in the next period. This is because the price of consumption in the consecutive period will increase, since the resources decrease. Figure 1 reflects this situation for $r = 0{,}03$. Since $\rho_1 < \rho_2$, the blue curve is below the red one.

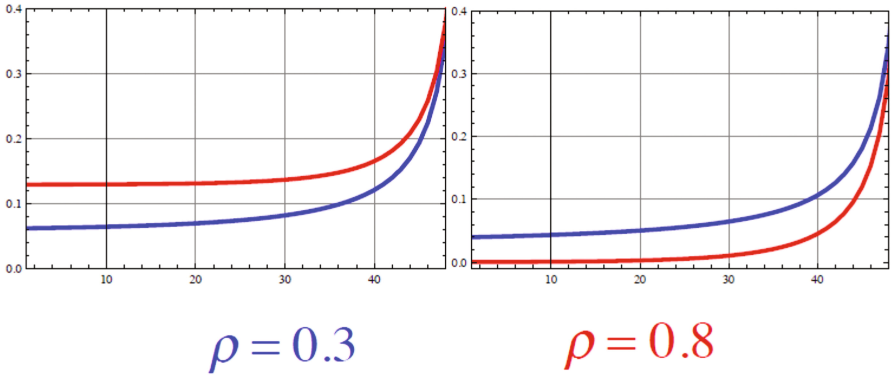

Fig. 1. The optimal consumption policy: the left-hand side for $r = 0{,}03$ and the right-hand side for $r = 0{,}1$.

If, on the other hand, we assume that r = 0,1, then $\beta(1+r) > 1$, and we deal with opposite case, i.e., it pays off to invest more and to postpone consumption for next periods. This implies that the blue curve is now above the red one as in Fig. 1.

3.2 Stochastic Case

Suppose that ξ_{t+1} follows log-normal distribution $LN\left(\mu_t, \sigma^2 s_t^2 + \sigma^2\right)$ where $\delta \in (0,1)$ and $\sigma > 0$ are some given numbers. Moreover, assume that the sequences (μ_t) and (s_t) are defined as follows:

$$\mu_t = (1 - \eta^t)\mu, \quad s_{t+1} = \sqrt{\sigma^2 s_t^2 + \sigma^2}, \quad with \quad \eta \in (0,1), \quad \mu > 0.$$

From Appendix we have

$$E(\xi_{t+1}) = e^{\mu_t + \frac{\sigma^2 s_t^2 + \sigma^2}{2}}, Var(\xi_{t+1}) = e^{2\mu_t + \sigma^2 s_t^2 + \sigma^2}\left(e^{\sigma^2 s_t^2 + \sigma^2} - 1\right).$$

Note that the expected value and the volatility of ξ_{t+1} increase in t. Moreover, formula (8) yields that

$$E\left(\xi_{t+1}^{\gamma}\right) = e^{\frac{1}{2}\gamma^2\left(\sigma^2 s_t^2 + \sigma^2\right) + \gamma\mu_t}.$$

Plugging the above expression and (6) into (5), we obtain

$$a_t = \frac{1}{1 + \beta^{\frac{1}{1-\rho}} A_{t+1}^{1-\rho} exp\left(\frac{\rho\gamma}{2(1-\rho)}\left(\delta^2 s_t^2 + \sigma^2\right) + \frac{\mu_t \rho}{1-\rho}\right)} \tag{7}$$

We calculate and plot the optimal policy *at* for the following cases.

(i) Figure 2 (the left-hand side): $\mu = 0{,}02, s_1^2 = 0{,}06, \gamma = 0{,}5, \eta = 0{,}5, \delta^2 = 0{,}9$, $\sigma^2 = 0{,}006, \beta = 0{,}95$ and the time horizon $N = 50$. As in the deterministic case, we consider two values $\rho_1 = 0{,}3$ (the blue curve) and $\rho_2 = 0{,}8$ (the red curve). It is worth noticing that $E\xi_{t+1} \le e^{0{,}02 + \frac{0{,}06}{2}} = e^{0{,}05} \approx 1,05$.

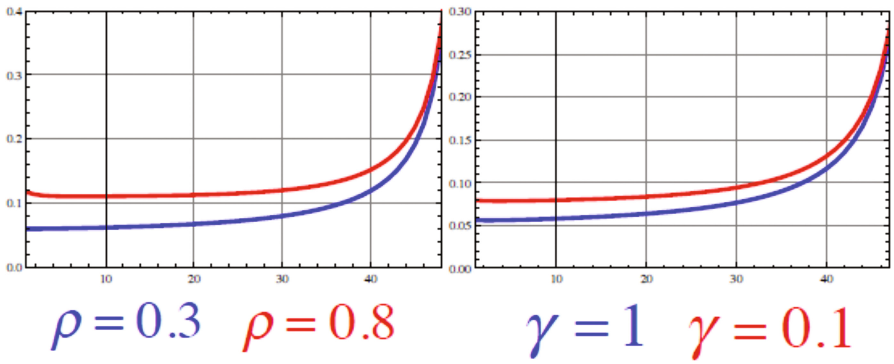

Fig. 2. The optimal consumption policy: the left-hand side for case (i) and the right- hand side for case (ii).

(ii) Figure 2 (the right-hand side): $\mu = 0{,}02, s_1^2 = 0{,}06, \rho = 0{,}5, \eta = 0{,}5, \delta^2 = 0{,}9$, $\sigma^2 = 0{,}006, \beta = 0{,}95$ and the time horizon $N = 50$. In this example, we wish to observe the influence of the risk parameter γ on the optimal policy *at*. Therefore, we draw two curves for $\gamma_1 = 1$ (the blue colour) and $\gamma_2 = 0{,}1$ (the red colour). As we can see in this case there is no significant difference, because the variance of ξ_{t+1} is relatively small, i.e.,

$$Var(\xi_{t+1}) \leq e^{0,04+0,06}\left(e^{0,06} - 1\right) \approx 0{,}07$$

From the picture, we can see that the risk neutral consumer is willing to consume less and invest more for future. On the other hand, the consumer who is risk averse towards uncertain future prefers to consume more and invest less. The outcome is consistent with real-life attitude of decision-makers.

The subsequent examples illustrate the importance of the risk coefficient γ.

(ii) The left-hand side in Fig. 3 presents the optimal consumption policy for the following data: $\mu_t = 0{,}1$ and $s_t^2 = 1{,}5 - {}^1\!/_t$ for all $t \in T$, $\sigma^2 = 1, \delta = 1, \rho = 0{,}5, \beta = 0{,}95$ and the time horizon $N = 5$. As in the previous case the blue curve presents the strategy for $\gamma_1 = 1$ and the red curve for $\gamma_2 = 0{,}1$. The right-hand side in Fig. 3 shows the aforementioned case, but for $\beta = 0{,}5$.

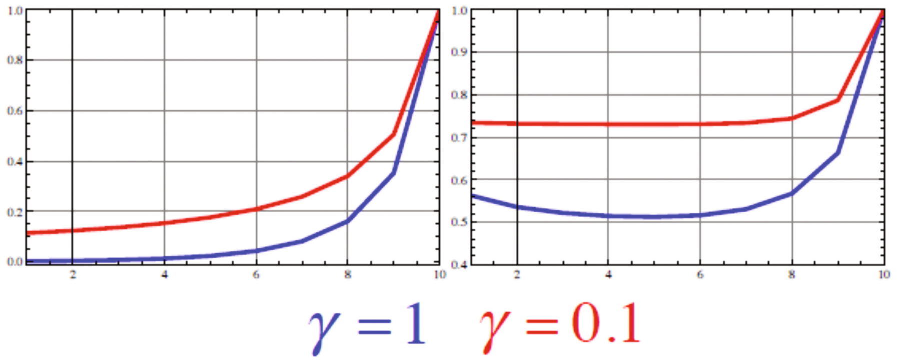

Fig. 3. The optimal consumption policy: the left-hand side for case $\beta = 0{,}95$ and the right-hand side for $\beta = 0{,}5$.

The main difference in Fig. 3 is concerned with the values of *at*. Indeed, the values of *at* for initial t's at the first picture are smaller than in second case. This is because of different values of β. If $\beta = 0{,}5$ then it pays off to consume more. If $\beta = 0{,}95$ or is close to 1, then there is no such a big difference between today and next periods, since the consumptions in the consecutive periods are not too much discounted.

Appendix

Assume that the random variable X follows the log-normal distribution $LN(\mu, s^2)$. Then, the density function of X (see [4]) is as follows

$$f(x) = \begin{cases} \frac{1}{xs\sqrt{2\pi}} exp\left(\frac{-(lnx-\mu)^2}{2s^2}\right), & for\, x > 0 \\ 0, & otherwise. \end{cases}$$

We find EX^b for b > 0. We have that

$$EX^b = \int_0^\infty \frac{x^b}{xs\sqrt{2\pi}} e^{\frac{-(lnx-\mu)^2}{2s^2}} dx.$$

By changing variable $t = ln\,x$ in the above integral, we obtain $dt = \frac{dx}{x}$ and $x^b = e^{bt}$ Hence,

$$EX^b = \int_{-\infty}^\infty \frac{1}{s\sqrt{2\pi}} e^{bt - \frac{-(t-\mu)^2}{2s^2}} dx.$$

Observing that

$$bt - \frac{(t-\mu)^2}{2s^2} = \frac{-(t-(\mu+bs^2))^2 + 2b\mu s^2 + b^2 s^4}{2s^2}$$

we get

$$EX^b = e^{b\mu + \frac{b^2 s^2}{2}} \int_{-\infty}^\infty \frac{1}{s\sqrt{2\pi}} e^{-\frac{(t-(\mu+bs^2))^2}{2s^2}} dx = e^{b\mu + \frac{b^2 s^2}{2}}$$

The above formula allows us to conclude that

$$EX^2 = e^{(2\mu + 2s^2)},$$
$$Var(X) = EX^2 - (EX)^2 = e^{(2\mu+2s^2)} - e^{(2\mu+s^2)} = e^{(2\mu+s^2)}\left(e^{s^2} - 1\right).$$

Moreover, if X has the log-normal distribution $LN\left(\mu_t, \delta^2 s_t^2 + \sigma^2\right)$ and $b = \gamma$ then

$$EX^\gamma = exp\left(\mu_t\gamma + \frac{1}{2}\gamma^2\left(\delta^2 s_t^2 + \sigma^2\right)\right). \tag{8}$$

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The Influence of the Methods of Determining Cost Drivers Values on the Accuracy of Costs Estimation of the Designed Machine Elements

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Abstract. Application of the proposed methods of defining cost drivers values, depending on the possessed information about the product at the stage of its design, enables to estimate total costs with good precision before starting its production. Cost drivers are variables of the function defining costs components of the designed element and its manufacturing process. The proposed methods base on the assumed features of the designed product, current values of cost parameters and are adjusted to unit and small lot production systems.

Keywords: Cost estimation · Activity based costing · Production process design

1 Introduction

Situations like a need for an earlier launch of a new product and looking for methods decreasing total costs force unit and small series production enterprises to integrate the design processes and the processes necessary for products manufacturing with identification of the related costs [7, 16]. The process should take into consideration the information about previous and current production, procurement, production organization processes, at the same time maintaining a proper level of products quality [1, 6]. Consequently, the processes of design and processing new products should, if possible, be supported by a relatively quick and accurate estimation of total production costs in order to avoid excessive expenses during production start-up [8, 9]. A significant influence on the cost consumption of the production process is exaggerated by designers on the stage of product development, in which the concept and functional structure of a product is made, materials, technology and production process parameters are chosen [3, 13].

The aim of the research is to develop methods of cost estimation of designed products on the stage of constructional production preparation, which would be based on proper selection of cost drivers related to activity based costing in order to optimally estimate the cost of a designed element, depending on constructional information. Thanks to simulating the influence of alternative decisions on the stage of production processes design, it is possible to estimate the level of own costs before the decisions

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are taken, and the necessary resources are purchased [2, 11]. Solving the above problem in enterprises with unit and small series production requires:

– assuming a proper description of the features related to the designed element basing on the elementary object method, including constructional, manufacturing and organizational features,
– determining activity costs for an exemplary production system with accuracy corresponding to the description of features of the designed elements,
– developing a set of cost drivers, depending on the assumed cost estimation method,
– determining the volume of cost drivers on the basis of the obtained values from the assumed description of the designed elements' features,
– designing a calculation model for cost estimation which takes into account the available sets of cost drivers and actual activity rates.

2 The Proposed Methods of Estimating Machine Elements Costs

In order to estimate total production costs on the stage of designing and processing new products in unit and small-series production depending on the available information about the designed product, a model (Fig. 1) of conduct has been proposed.

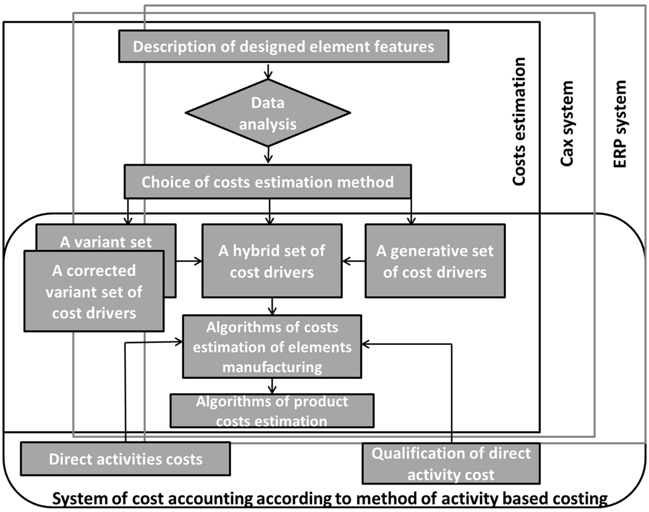

Fig. 1. A general model of procedure in the proposed method.

The starting point is to appropriately apply activity costing which considers as many accounting bases as there are separated kinds of activities [15]. However, activity costs should be properly settled on each level of product structure (sets, sub-sets, elements, or elementary objects), and the account should show the differences in costs for different design concepts, with detail up to particular technological operations. On the basis of the information available in financial-accounting systems about the costs encumbered, and the information on the presence of separate activities in the sample production system, costs of direct activities have been determined, as shown in Table 1. After calculating the cost of direct activities and determining the measures of throughput for these activities, it is possible to calculate the cost rate for particular activities (RateAct).

Table 1. Costs of direct activities – a fragment.

No	Activity	Activity costs by type in PLN	Costs of indirect activity in PLN	Total activity cost in PLN
1	Adopting orders	14 600.93	35 743.59	50 344.53
2	Preparing documentation – typical product	3 416.04	960.76	4 376.80
3	Preparing documentation – modified product	5 607.96	1 587.39	7 195.34
4	Preparing documentation – new product	10 318.59	2 828.41	13 147.01
…	…	…	…	…
20	Activity performed on universal milling machines	2 269.07	2 366.56	4 635.63
21	Activity performed on gear hobbers	5 699.12	4 740.10	10 439.22
22	Activity performed on multiradial drilling machines	3 898.12	3 493.83	7 391.95
…	…	…	…	…
31	Co-operation	1 346.65	365.63	1 712.27
32	Storing elements	1 451.11	309.62	1 760.73
33	Control of elements	30 041.32	6 216.49	36 257.81
34	Sale …	16 796.87	2 677.45	19 474.32
Total cost of activities				516 146.44

The methods of cost estimation described in literature [5, 12] can be used if all characteristic features of a product are known, and the designed manufacturing process is similar to previously produced elements, which causes limitations to using such methods from the point of view of accuracy of the obtained results [4]. These methods are also based on fixed, often outdated cost data, which, in a situation of constantly changing structure of encumbered expenses by an enterprise, cause that the estimated costs significantly differ from the actually borne production costs. A problem of cost estimation on the stage of product design occurs when elements are not definitely designed, or considerably differ from previously manufactured products, which is characteristic and frequently met in case of unit or small series production. The methods which operate on an incomplete set of information necessary to determine total production cost of a designed product are called cost estimation methods [4, 14]. Depending on the amount of available information about the designed product, it is possible to use the proposed fast, more or less precise cost estimation methods. Estimating particular cost components makes it possible for a designer to select a proper constructional solution from many options on the basis of economic criteria [12].

The basis of cost estimation of machine elements is to assume (Table 2) an appropriate description of the features of the designed elements, which, apart from constructional features, will additionally include the description of materials features and organizational features related to the manufacturing process for more comprehensive cost estimation. The description is based on the assumptions given in literature [17]. Depending on the information generated on different stages of production process design aided by the CAx system (computer aided …), or the information stored in databases [10], the procedure follows the possibility of determining a set of cost drivers. Hence, it is necessary to settle such manufacturing process parameters for particular product structure levels (elementary objects, elements…), which unambiguously determine the values of the variables defining cost components together with the way of their estimation.

Table 2. Division of features describing machine elements [17].

<table>
<tr><td rowspan="4">DESIGNED ELEMENT</td><td>Constructional elementary objects, which directly create constructional shape of the designed-there can be simple surfaces: chamfer, undercut, complex ones: toothed ring, threat</td><td rowspan="2">Constructional features describing the designed elements</td><td>Geometrical features (determine the external structure):
- type of shape (disks, shafts, bushings…)
- external shapes (cylindrical elements, flat conical surfaces,…)
- additional external shapes (keyways, threats, undercuts,…)
- internal shapes (opening, centring holes, multi-grooves,…)
- additional internal shapes (flat surfaces, threats, teeth,…)
- …</td></tr>
<tr><td rowspan="3">Features describing the designed elements</td><td>Input material features for production (determine the material, its internal properties, form of raw material):
- half-product (bars, pipes, casts…)
- raw material (steel, iron, non-metal materials)
- thermal and thermo-chemical treatment (annealing, tempering, hardening…), and others…</td></tr>
<tr><td>Manufacturing features describing the elements</td><td>- variant of the manufacturing process (disc process without thermal treatment, with heat improver, with carburizing and tempering,…), and others…</td></tr>
<tr><td>Organisational features describing the elements</td><td>- production series type (unit, series, large-scale)
- organization of the manufacturing process
- …</td></tr>
</table>

The costs are determined on the basis of cost drivers values which, depending on the available information about the designed element, are settled according to different algorithms related to: determination of a variant set of cost drivers; determination of a corrected variant set of cost drivers; determination of a generative set of cost drivers; determination of a hybrid set of cost drivers. Basing on current rates of activity costs determined in a given accounting period, estimated costs of the designed elements are calculated, which, depending on the method of generating the value of a cost drivers set, are called variant costs, corrected variant costs, generative costs and hybrid costs.

3 Determining a Variant Set of Cost Drivers

The proposed method of cost estimation is based on a formalised description of in-formation about features of construction, manufacturing and organisation related to the designed element, automation method of technological processes design (variant design) using methods of group technology and a model of production costs of machine elements based on Activity Based Costing. The first step is related to separating from the elements base, the elements which are possibly closest to the designed element from the point of view of common features describing the elements. The first level of identification arbitrarily determines the kind of production object that the designed element belongs to. Next, on the basis of a set of features describing the elements from a given kind of production object, and a set of characteristics describing the designed element, an attributive code of features is created in form of a zero-one vector. An example of the gathered information about the designed element's features in form of a FP vector, automatically generated during construction records is presented in part a) of Fig. 2, whereas part b) includes an example of a model element together with a FP vector (in the authorial module functioning in the SolidWorks software).

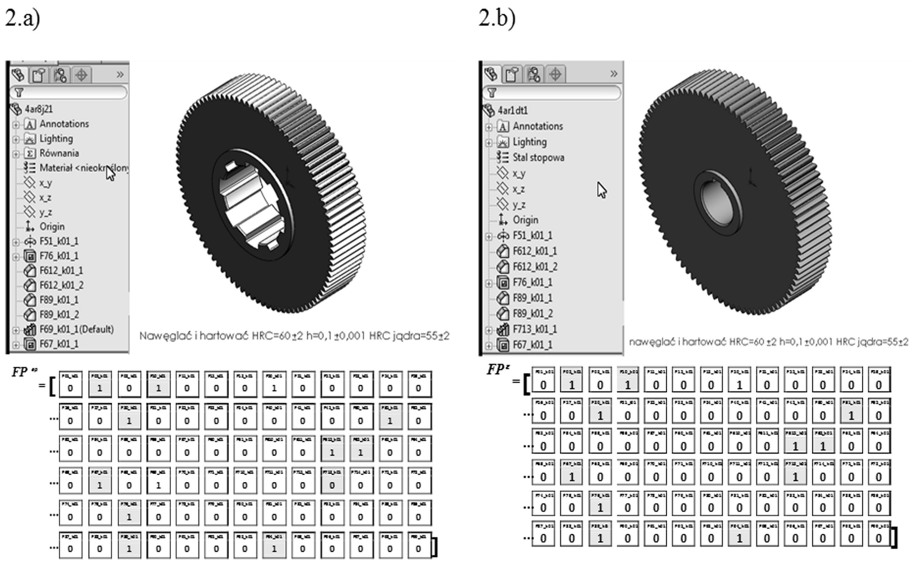

Fig. 2. The feature description of (a) a new and (b) a previously designed machine element

On the basis of the assumed similarity measure, which is the sum of the product of the common feature with binary value 1 and the assumed weight for a given feature determining the influence of the value of the parameters describing a given feature on actual production costs, the elements with the biggest measure are selected, as they are characterized by the highest similarity with the designed element. There can be a few or even about o dozen of such elements (for the above example the sum amounts to 11 and 9 model elements were selected). Next, for the common features of the designed and model elements, it is necessary to compare pairs of common features and the parameters together with their values describing the given features, e.g. for the feature F713_k01 (internal shapes/internal keyway) the related parameters and values are keyway width – 18 mm, length – 38 mm, depth – 4.4 mm, roughness – 2.5. For such pairs the similarity measure is determined on the basis of the Canberra distance. The element with the smallest Canberra distance value is the closest to the designed element.

$$mC = \sum\nolimits_{p=1}^{P} \left| \frac{wc_{n_p}^{ep} - wc_{m_p}^{w}}{wc_{n_p}^{ep} + wc_{m_p}^{w}} \right| \quad (1)$$

where:

$wc_{n_p}^{ep}$- feature value of the designed element ep by the n-th occurrence for parameter p;

$wc_{m_p}^{w}$- feature value of the model element w by the m-th occurrence for parameter p.

The next step is to search the exiting CAPP system's base of the manufacturing processes in terms of feature similarity in order to find a technological process route for a previously designed element, and specifically a set of information about technological processes in different variants, semi-product – its shape, dimensions, kind of materials, machining time standards, tools, production means, production workstations organization, etc. Each element of this set has some ascribed values which characterize the parameters of model element processing. On the basis of these values and a set of cost drivers of the variant model of cost estimation (Table 3), a variant set of cost drivers' values is determined, which, taking into consideration current rates for activity costs, allows to estimate variant cost of the designed element according to cost data from a current period, not historical cost. The method allows to estimate costs for a new product relatively fast and with less workload, which is sometimes connected with accepting limited accuracy of the obtained results.

Values of a Corrected Variant Set of Cost Drivers

The next stage of bringing the estimated costs closer to the actual costs of the designed element is to correct variant values of cost drivers on the basis of parameter values of the features describing the designed element in relation to the parameter values of the features related to the variant element. The most frequently corrected values of variant cost drivers are parameters of the features describing the designed element related to materials, semi-product, dimensions and organizational features. The costs which undergo changes on the basis of correcting the values of cost drivers include:

Table 3. A set of cost drivers for the variant costing model.

Name	Symbol
Unit time; Set-up and break-down time	tu_op_n tsb_op_n
Grade	gr_emp_n
Storage item index	id_stor
Standard materials usage	SM
Standard number of semi-product	no_sprod
Production position	id_posit_n
Type of documentation (typical, modified, new)	t_doc
Type of product (finished product, semi-product)	t_prod
Size of a production batch	s_batch

– costs of direct materials (CDM) may change as a result of other kind of assumed raw material (r_mat), a different half-product (no_sprod) and different dimensions of the designed element (x_brut, z_brut) and the variant element. These changes may influence the choice of storage item (st_it), and the change of material unit price, and, above all, the change of standard materials usage (SM) – an example in Fig. 3,

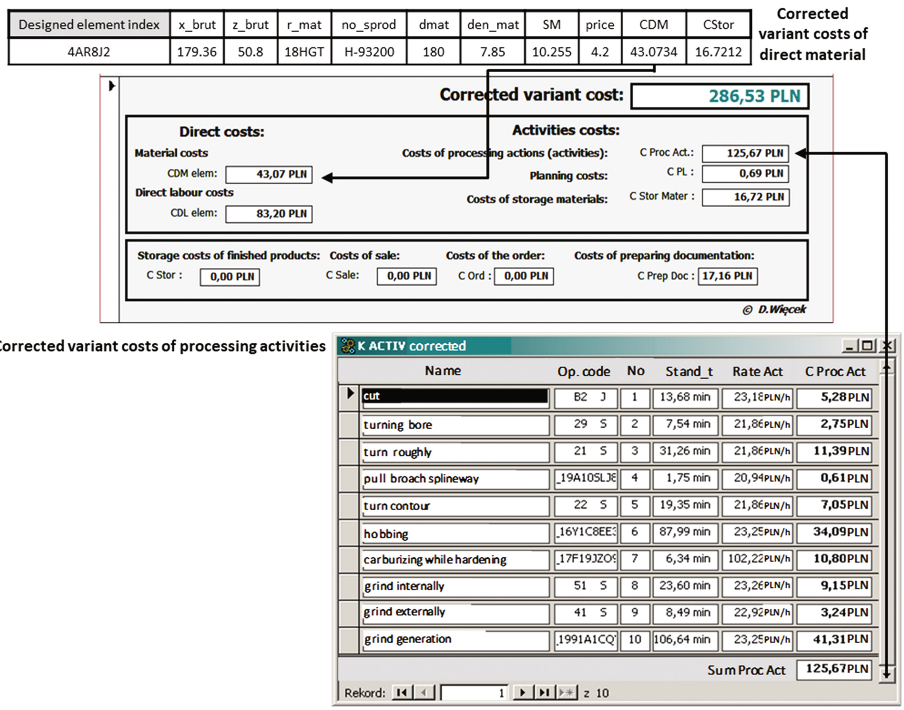

Fig. 3. Estimated corrected variant costs of the designed element.

– costs of direct labour (CDL) resulting from different time consumption standards as a result of changing the machining parameters between the material of variant element and designed element, which is also influenced by unit time (tu_op_n), set-up and break-down time (tsb_op_n), changing worker's grading (gr_emp_n) and changing the size of a production batch (s_batch),
– activity costs of the procurement process resulting from changing the storing position - CStor (id_stor),
– activity costs of processing (CProcAct), which are influenced by changing time consumption standards Stand_t (tu_op_n, tsb_op_n) and changing a production batch (s_batch) – Fig. 3.

The corrected variant costs for the exemplary element are presented in Fig. 3.

4 Determining a Generative Set of Cost Drivers

A generative cost is determined on the basis of values of the cost drivers (Table 4) related only to parameter values of the features describing the designed element. Consequently, it is necessary that all features which describe the given element are clearly determined.

Table 4. A set of cost drivers for generative costing model.

Name	Symbol
Dimension of starting material - x; - y; - z	x_brut; y_brut; z_brut
Raw material type	r_mat
Main dimension of starting material	dmat
Material density	den_mat
Lead time related to technological treatment	tl_treat_t
Auxiliary time related to technological treatment	ta_treat_t
Employees' grading for technological treatment	gr_emp_t
Production workstation related to technological treatment	id_work_t
+ variant set of cost drivers	…

Generating cost drivers was divided into a few levels according to the levels of cost aggregation:

– into factors of the level of features describing an element, in order to get constructional parameters according to constructor's assumption and the settled variant of the manufacturing process. These factors concern a set of the required technological treatments (tl_treat_t, ta_treat_t) related to direct labour costs and processing sub-activities. A basic tool on this level is an assumed dedicated expert system, in which a base of technological knowledge has been separated. This knowledge relates to the information about sets of technological treatments for the given feature, achieving the assumed parameter values in the adopted variant of the manufacturing process, the information about production workstation (id_work_t) and employees' grading (gr_emp_t) for the desired technological treatment,

- into factors related to the dimensions (x_brut, y_brut, z_brut), features of materials (r_mat, den_mat), selection of semi-product (id_stor, dmat) for the designed element, which allows to determine direct material costs,
- into factors determining completion of technological operations on the level of cost aggregation related to the element, influencing the cost of direct labour and processing activities. Adoption of a framework technological process takes place with the use of an advisory system, which, on the basis of the determined features of the designed element, proposes a given variant of the technological process with standard working time for particular operations (tu_op_n, tsb_op_n, s_batch, gr_emp_n, id_posit_n),
- into factors determining activity costs of the procurement processes which are dependent on the type of semi-material (no_sprod, SM), activity costs of planning on the production batch size (s_batch) and other costs on the basis of the kind of the designed documentation (t_doc), information if the element will be re-sold, if it will be a product component (t_prod), etc.

With determined values for the required set of cost drivers and current rates of activity and sub-activity costs, it is possible to estimate generative costs of the designed element by means of proper algorithms.

5 Determining a Hybrid Set of Cost Drivers

The hybrid approach finds application when a set of features describing the designed element has not been fully determined. In such a case it is not possible to use only generative approach to creating cost drivers, as the settled estimated costs on an incomplete set would significantly differ from actual costs. The hybrid approach applies the rules of selecting a variant set of cost drivers and creating a generative set of cost driver values (Table 5). Hybrid cost is an estimated cost whose important components are generative sets of cost drivers' values composed on the basis of the values of parameters clearly determined for the features describing the designed element, and generative parameter values for analogical features describing a variant element. Therefore, hybrid cost value is the value of corrected variant decreased by the value of generative costs determined for a variant element, and increased by the value of generative costs determined by the designed element. The cost decrease and increase concern only clearly determined features: costs of direct labour (CDL) and processing costs (CProcAct).

The remaining costs – direct material costs (CDM), costs of order acceptance (COrder), material storing costs (CStorMater), planning costs (CPl), costs of preparing documentation (CDoc) - are settled according to corrected variant cost. Connecting these two methods allows to avoid getting insufficient amount of information in case of the generative method, and conditions cost estimation accuracy on the similarity level to the closest element in case of the variant method.

Table 5. A sample hybrid cost of a designed element.

Costs	Corrected variant cost (PLN)	Generative cost of exemplary element - for unambiguously described features (PLN)	Generative cost of designed element - for unambiguously described features (PLN)	Hybrid cost of designed element (PLN)
CDL	83.20	72.98	69.34	83.20–72.98 + 69.34 = 79,56
CProcAct	125.67	110.96	104.27	125.67–110.96 + 104.27 = 118,98
CDM	43.07			43.07
COrder	11.12			11.12
CStorMater	16.72			16.72
CPl	0.69			0.69
CDoc	17.16			17.16
Total	297.63	Decrease of 183.94	Increase of 173.61	287.30

6 Conclusions

Particular cost components are dependent on the variables called cost drivers, so we can say that the value of a given cost component is a function of a certain set of cost drivers related to a given cost component. Sets of cost drivers created on the basis of variant, generative and hybrid approaches allow to determine different estimated costs for the designed element. These costs, depending on the stage of creating production documentation for a given element, that is the amount of information about the element's features, are characterized by a higher of lower level of cost calculation accuracy. The proposed method bases on the required sets of cost drivers and on proper value estimation of these factors, which allows to, adequately to a given period, estimate costs possibly similar to actual costs on the basis of appropriate algorithms and by using current rates (activity costs in previous periods are not considered).

Cost drives make it possible to understand what influences the cost of a particular activity or direct cost, and how we can minimize the resources used to perform this activity or to manufacture a given element. Knowledge about these factors allows to get better results in the area of cost-cutting and provide designers with valuable information about costs (both direct and indirect) in the moment when they have the highest possibility to influence them.

The proposed methods require full implementation of activity based costing in an enterprise, operation of the CAPP system with an up-to-date base of technological possibilities of the production system and an analysis of constructional documentation in order to create a base of features describing the designed elements. The proposed solutions were adapted to production systems operating in conditions of unit and small series production.

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An Experimental Investigation of Lead Time and the Effect of Order Crossover

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Abstract. This paper presents results from an experimental investigation of lead time distributions. The focus is on the order crossover phenomenon where slower orders are overtaken by faster orders and the impact of this on the structure of the observed lead time distribution. The natural conclusion is that the likelihood of order crossover occurring strongly depends on the skewness and variance of the lead time distribution. Furthermore, the conclusion is that while lead times may be i.i.d. random variables, when crossover occurs lead times observed in the sequence orders are received are in fact mutually dependent. This has a significant impact on how supply chain members should estimate lead times and lead time distributions. That lead times are in fact mutually dependent is a major finding and has implications for both practice and academia.

Keywords: Stochastic lead times · Supply chain management · Bullwhip effect · Order crossover

1 Introduction and Background

Order crossover is a phenomenon that has been studied for many years [1, 2], but has received increased attention in recent years especially in the context of supply chain management. Order crossover occurs (as illustrated in Fig. 1) when orders due to stochastic lead times are received in another sequence than that in which they are placed. In practice Riezebos [3] argues that there are three real causes for order crossover to occur and that there is a real risk of systems exhibiting this kind of behavior. Bagchi et al. [4] show that lead time variation is a major source of uncertainty in inventory management and argue that a compounded lead time demand distribution is used. Robinson et al. [5] argue that order crossover is increasingly important and suggest using shortfall distributions rather than lead time demand to calculate inventory positions. Bradley and Robinson [6] argue that when faced with order crossover the normal methods for estimating lead time demand are insufficient and especially the assumption of normality of the lead time demand distribution are violated. In the contexts of supply chains Disney

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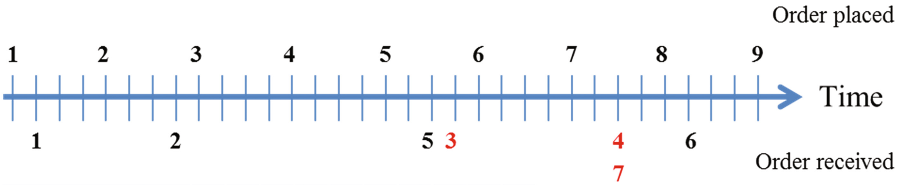
et al. [7] recently investigated order crossover. However, what seems to be lacking in current state is an analysis of how lead time distributions behave when crossover occurs. Bischak et al. [8] state that the majority of supply chain literature ignores order crossover and as a consequence overestimates the lead time variance. Hayya et al. [9] similar argue that order crossover can lead to reduced lead time variance. This is highly relevant as we from Michna et al. [10] and Chatfield et al. [11] know that lead time variation is in fact a major cause of bullwhip effect. Chopra et al. [12] argue that reducing lead time variability has a larger influence on performance than reducing lead times, but also argue that there is a complex relationship between lead times and lead time variability. Michna et al. [10] underline that the need to estimate the lead time distribution (more particularly the mean and variance of the lead time distribution), are in fact highly significant in determining the bullwhip effect. When lead times are in fact treated as stochastic rather than deterministic the need to predict their behavior as one would e.g. predict demand becomes relevant. In current supply chain literature lead times are (when not considered deterministic) assumed to be i.i.d. random variables. In practice a member of a supply chain must estimate the lead time distribution using the lead time observations that are available [10]. The need for estimating the lead time distribution is under-researched and the impact of order crossover has not been studied. For future reference we denote the original lead time distribution LT and the distribution as the orders are received LT^*. In this research we aim to demonstrate that this lead time estimation is significantly influenced by whether one observes LT or LT^*. Especially if one has a limited number of observations available for the estimation. This is supported by Nielsen et al. [13], who argue that this may be the case, due to the potential unstable nature of lead times.

Let us assume that LT in fact consists of i.i.d. random variables, then it becomes interesting to consider whether LT^* retain this attribute. For order crossover to occur a few prerequisites must be in place: the order frequency must be high enough compared to the variation of the lead time distribution to allow orders to crossover. It follows that "slow" orders will be overtaken by "fast" orders. Let us consider the following example: we place orders at a fixed interval once every four time units, we sample lead times from a discrete exponential distribution (with rate $\frac{1}{4}$) and get the lead times as seen in Fig. 1 and then orders are received.

One can notice from Fig. 1 that only three orders (1, 2 and 10) are actually received in the same sequence as placed. Twice orders are received at the same time (orders 4 &



Order placed at time	0	4	8	12	16	20	24	28	32	36
LT	1	3	11	14	2	9	2	11	1	3
Received at time	1	7	19	26	18	29	26	39	33	39
LT*	1	3	2	11	14	2	9	1	11	3
Sequence LT*	1	2	5	3	4	7	6	9	8	10

Fig. 1. overview of orders, lead times and order receipt.

7 and 8 & 10). Of special interest is the fact that while LT are random i.i.d. variables the observations from LT^* appear to have some structure, i.e. fast orders (e.g. order 5) have overtaken slow orders (e.g. orders 3 and 4). So it appears that LT^* is mutually dependent in its structure. This phenomenon has not previously been addressed experimentally in literature. It is of particular relevance for the situations (as argued in Michna et al. [10]) where the lead time distributions must be estimated based on a limited number of observations. Estimating the mean and variance of the lead time distribution will under limited information availability be influenced by whether or not the observations can be considered to be i.i.d..

The remainder of the paper is structured as follows. First, we conduct an experimental study of lead time distributions and investigate the behavior of LT^*. Second, implications from the results are discussed. Finally conclusions and avenues of further research are presented.

2 Experimental Investigation

Having determined that there is a likelihood that lead times will in fact exhibit non-randomness when order crossover occur and lead times are observed in the sequence orders are received, we set about investigating two critical questions experimentally:

1. What is the likelihood of order crossover occurring?
2. What kind of structure does LT^* exhibit?

First, we must determine which lead time distributions are relevant to investigate. Bagchi et al. [4] use Gamma, Exponential, Gaussian and Geometric distributions in their study of the impact of stochastic lead times on the lead time demand distribution and consider them representative lead time distribution. Nielsen et al. [13] demonstrates at least one case where lead times (for 50 different products) are in fact distributed close to the exponential distribution. Hayya et al. [14] investigate the unbounded Gaussian and Gamma distributions, while Chatfield et al. [11] and Bischak et al. [8] use the Gamma distribution, Hayya et al. [14] use the exponential distribution and Wensing and Kuhn [1] use a discrete uniform distribution (but only allow for pair-wise crossover to occur). For this reason we limit our investigation to the discrete versions of the: Exponential, Gaussian, Uniform and Gamma distributions. The characteristics of the tested distributions are shown in Table 1. These values are chosen as they ensure a limited need for truncation (for the normal distribution) and still allow for significant variance to be present in the data. All distributions are truncated at 0 and we allow zero lead times to occur (i.e. instantaneous delivery).

The experiments are run with varying time between orders for all distributions shown in Table 1, starting with an order frequency of one order per time unit incrementally increasing by one time unit between orders until 30 time units between orders. We denote the time between orders as n. The shape of the distributions (as seen in Table 1) will ensure that they will have a likelihood of crossover occurring for low values of n. For each of these order frequencies 50.000 lead times are generated and placed at intervals of n time units. The experiments are run in R [15] an open source

Table 1. Lead time distribution characteristics.

	Mean (μ_{LT})	Median	Variance (σ^2_{LT})	Skewness	Kurtosis
LT_{exp}	10.0	7	100	2.0	8.9
LT_{norm}	10.0	10	6.3	0.0	3.0
LT_{gamma}	10.0	10	5.1	−0.43	3.3
LT_{uni}	10.0	10	27.1	0.0	1.8

statistical software. Initial experiments on the structure of the LT^* indicate that it is only the first 3 lags in observations that are in fact significant and that the first lag is always strongest correlated. To limit the investigation only these will be investigated in the following as they will aptly underline if observations from LT^* are in fact mutually dependent or independent.

Figure 2 shows the likelihood of crossover occurring. As expected the likelihood depends on both the time between orders (n) and the shape of the distributions. Of course for some of the distributions this likelihood decreases sharply as the time between orders increases above a given threshold. For LT_{exp} the likelihood of crossover occurring is still above 7% when n is three times the mean of the distribution (n = 30). It is also worth noting that LT_{gamma} and LT_{norm} behave very similar with respect to the likelihood of order crossover. With the Gaussian distributed lead times exhibiting slightly higher likelihood of crossover.

Figure 3 shows the 1st, 2nd and 3rd lag autocorrelations for the LT^* distributions for $n \in \{1; 30\}$. The mutual dependent structure of LT^* naturally depends very much on the initial LT distribution and on n (time between orders).

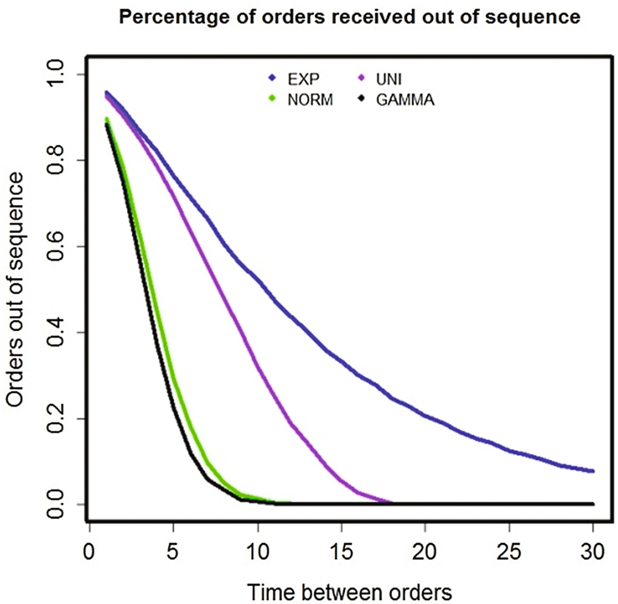


Fig. 2. Likelihood of order crossover occurring for the four distributions as a function of the time between orders.

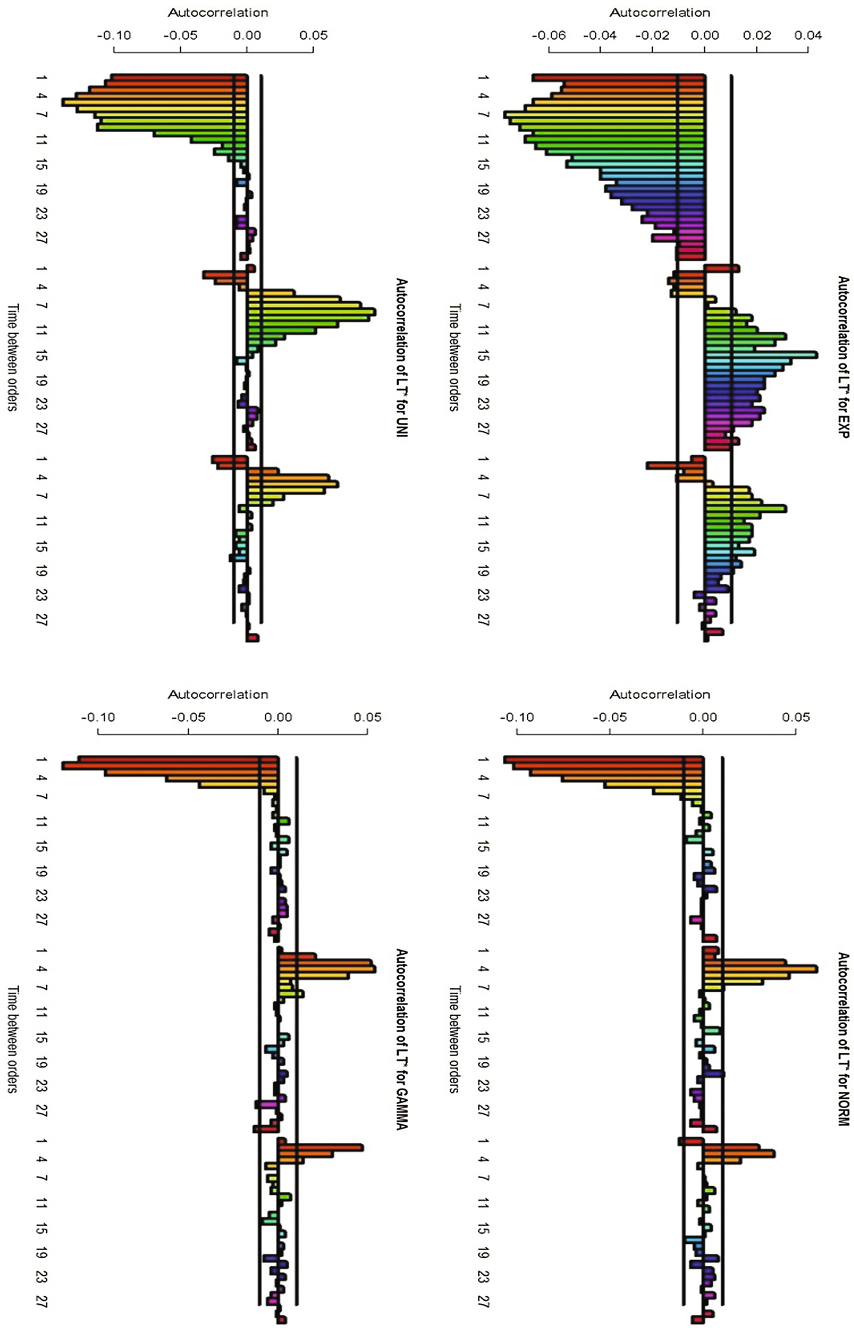


Fig. 3. Lag 1–3 autocorrelation for the four investigated distributions with 1 to 30 time units between orders.

In Fig. 3 the horizontal lines indicate a 0.01 significance level for 50.000 observations. From Fig. 3(a) it is clear that the structure of LT^*_{exp} is in fact mutual dependence for most values of n. It is interesting to note that although the likelihood of crossover occurring is non-zero for all the order intervals, LT^*_{exp} is in fact only behaving mutually independent for time between orders above 29 and the strength of the correlation is rather weak for values of n larger than 15. For the shorter order frequencies, where time between orders is low compared to the mean there is a high degree of dependency in LT^*_{exp} and the structure is more complex than just a first order model. LT^*_{gamma} and LT^*_{norm} exhibit similar behavior with rather strong dependencies between observations for n up to 5, to the extent that both lag 2 and 3 are in fact also significant. The strength of the dependency is much stronger than the ones observed for LT^*_{exp}. It would be logical to conclude that while order crossover in general is a problem for supply chains with exponentially distributed lead times, it is more so a problem in supply chains with Gaussian and Gamma distributed lead times and high order frequency (low values of n compared to mean lead time). LT^*_{uni} exhibit characteristics of all the other three distributions. First, for n less than 10 there is a strong dependence between observations. Second, the maximum strength of the dependence is on level of that observed for both the Gaussian and Gamma distributions. It seems that LT^*_{uni} have the worst characteristics of all the three distributions.

In general it appears as the following holds true. The larger the variance of LT, the higher likelihood of order crossover occurring for even high values of n. The lower the variance, the stronger the mutual dependency in the observations from LT^* for high order frequencies compared to the mean of LT.

3 Discussion

Some important findings can be inferred from the above experimental study. First, the likelihood of crossover occurring as expected depends on the shape of the original lead time distribution and the time between orders. It is interesting to note that regardless of the original lead time distribution's shape, given a sufficiently high order frequency (i.e. low $^{n}/_{\mu_{LT}}$ ratio) there is a large likelihood of order crossover occurring. Second, this high likelihood of order crossover occurring directly results in LT^* being mutually dependent, despite LT being i.i.d random variables. This dependence is the same across all four investigated distributions and the conclusion is that the first lag is always (when significantly correlated) negative. Third, the strength of dependency seems to be a bit counter-intuitive in the sense that the distributions with the lowest variance exhibit the strongest dependency between observations for low values of n. Reversely the distributions with largest variance have dependencies between observations for much larger values of n. This strongly suggests that in practice one must consider both the shape of the lead time distribution and the time between orders when evaluating whether or not order crossover is going to pose real challenge in managing the supply chain. Fourth, there seems to be a critical level of likelihood of crossover above which LT^* are mutually dependent. Further studies seem to be warranted to determine specifically how large the order crossover likelihood should be before the observations from LT^*

are in fact mutually dependent. This would be a good indicator for when the estimate of the mean and variance of the lead time distribution will be influenced by whether one observers LT or LT^*. For illustrative purposes the likelihood of crossover is plotted against the first order autocorrelation in Fig. 4 for all four distributions. The vertical line in Fig. 4 indicates the 0.01 significance level for 50.000 observations.

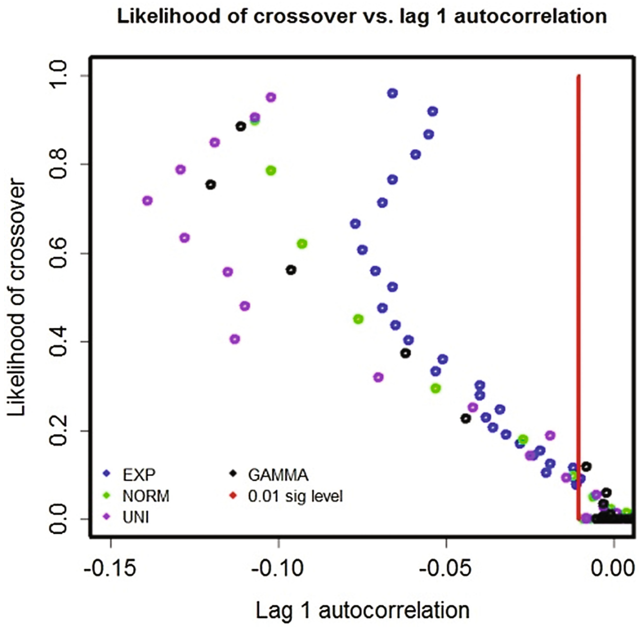


Fig. 4. Lag 1 autocorrelation plotted as a function of the likelihood for crossover occurring.

Although the graphs in Fig. 4 indicates that LT^* are mutually dependent for even low likelihoods of crossover, the strength of the correlations are relative low and it may be that in practice the crossover likelihood can be higher than indicated by the significance level. It is also interesting to note that the strength of the dependence between observations remains rather constant for likelihoods of order crossover below 0.3. Correspondingly the strength of the dependency quickly decreases for likelihoods of crossover below c. 0.3.

For the Gamma, Gaussian and Uniform distributions it is obvious that there is a $^n/_{\mu_{LT}}$ value above which crossover cannot occur. For the uniform distribution this is clear as the distribution is bounded. For the Gaussian and Gamma distributions it is equally clear, even if they are not bounded the likelihood of observing lead time values above/below a certain value is in practice zero and there for they can in practice be considered bounded. For the exponential distribution this is not the case and the structure of LT^*_{exp} is as a consequence mutual dependence even for large values of n. This is interesting as empirical investigations of lead times by both Disney et al. [7]

and Nielsen et al. [13] seem to indicate that lead times may in practice follow distributions with characteristics such as the exponential distribution. In practice this means that not only is it likely that crossovers will occur, but it is also likely that observations from LT^* are in fact mutually dependent. However, what is of equal interest is perhaps that the bounded distributions exhibit very non-random behavior for low $^{n}/_{\mu_{LT}}$ values.

4 Conclusions and Further Research

Order crossover is potentially critical in determining the performance of supply chains with stochastic lead times. Michna et al. [10] demonstrate that lead time estimation is critical in determining the bullwhip effect in a supply chain. However, as demonstrated in this research while lead time may be mutually independently distributed random variables they must under certain circumstances be considered mutually dependent if order crossover occurs. The conclusion is therefore that given limited information to estimate the lead time distribution, this mutual dependence/ordering of lead time observations is in fact significant for the estimation process. This means that academia must critically review the current state. It also implies that order crossover will result in nervous supply chains at least if managers are not aware of how order crossover impacts their chain. Here we must emphasis that crossover can influence the dependence structure between lead times (independent to dependent) and the estimation of their distribution.

Future work will focus on two streams of research. One will elaborate on the impact of the dependency on estimates of the lead time distribution. One will focus on the impact on the bullwhip effect in supply chains given crossover occurs.

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The Stability of the Financial Indicators over Time

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Abstract. The article attempts to assess the stability of the financial indicators in the period of ten years (2006–2015). Nearly 1600 companies have been examined within the manufacturing sector – including 800 bankrupt companies. For each enterprise the five selected ratios were calculated for each year. The stability of calculated variables during the research period was measured by (1) the standard deviation and normal distribution, (2) the correlation matrix, and (3) the discriminant ability (by using the t-Student test). The results indicated a substantial degree of instability of analyzed indicators over the last decade.

Keywords: Stacjonarity of ratios · Standard deviation · Correlation matrix · Discriminant ability

1 Introduction

The number of ratios in the literature is enormous. So far, there have been done many research studies on the usefulness of indicators (mostly financial indicators) of evaluating the business financial standing [4, 5, 13]. The studies very often are performed by the authors who create models for assessment financial condition of a company [1, 3, 26] in order to select those ratios, which are characterized by the predictive and discriminant abilities [16–19, 21–23] as well as have a normal distribution [7, 24]. Sometimes, the ratios are coped in various models [16], which may mean that they are useful in evaluating financial condition of enterprises.

One of the disadvantages of the models of assessing financial condition of a company is the decrease in their correct classification of a company with the passage of time since the construction of the model [8, 11, 16, 20]. It is worth adding that one of the assumptions of the models is the stability of ratios over time. However, not every ratio can be stable over time. Therefore, there were attempts to study the stability of ratios [2, 6, 9, 15]. The results showed that some of ratios are instable over time.

The article also presents the study of variability of selected ratios over the last decade. The variability of the indicators was examined based on the analysis of standard deviation, normal distribution, correlation coefficients as well as discriminant ability.

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2 Research Methodology

2.1 Sample

One has analyzed nearly 1,600 companies, including 800 companies that had gone bankrupt in the period of ten years (2007–2016). Firstly, the financial statements of failed businesses were selected, that were available within a year before bankruptcy. The source of financial reports is the Serwis EMIS (A Euromoney Institutional Investor company)[1]. The access to reports in a year prior to bankruptcy of enterprises was as follows:

- there was access to 42 reports of companies that went bankrupt in 2016
- there was access to 72 reports companies that went bankrupt in 2015
- there was access to 58 reports companies that went bankrupt in 2014
- there was access to 28 reports companies that went bankrupt in 2013
- there was access to 129 reports companies that went bankrupt in 2012
- there was access to 106 reports companies that went bankrupt in 2011
- there was access to 57 reports companies that went bankrupt in 2010
- there was access to 38 reports companies that went bankrupt in 2009
- there was access to 50 reports companies that went bankrupt in 2008
- there was access to 7 reports companies that went bankrupt in 2007

A total of 597 failed businesses have been covered by the analysis. The equivalents of failed businesses were chosen that are still running a business and have not undergone any bankruptcy process. In the selection of these enterprises, the following criteria were used: industry, the period of time, the good financial standing and size of the company.

2.2 Financial Ratios

The financial indicators that were chosen for the research study are indicators that have been used and classified as useful in several past studies [16, 25]. The ratios are presented below:

$$X1 = \frac{currentassets}{shorttermliabilities} \tag{1}$$

$$X2 = \frac{equity}{totalassets} \tag{2}$$

$$X3 = \frac{netsales\,revenue(n)}{netsales\,revenue(n-1)} \tag{3}$$

$$X4 = \frac{(shorttermliabilities * 365\,days)}{netsales\,revenue} \tag{4}$$

[1] www.emis.com.

$$X5 = \frac{(net\,sales\,revenue - costs\,of\,goods\,sold)}{netsales\,revenue} \tag{5}$$

These ratios represents different type of groups. The first one current liquidity ratio stands for liquidity ratios. The second one equity to assets ratio represents the debt ratios. The third one income dynamics ratio is used in the initial analysis. The four one payables turnover stands for turnover ratios. The last one ratio gross margin represents profitability ratios.

2.3 Statistical Analysis

The author assesses the stability of financial indicators over time. First, the standard deviation and normal distribution were estimated for bankrupt and non-bankrupt companies and the results were compared in ten-year time. Second, the correlation coefficients among the variables for each year in the period were calculated and analyzed. Third, in order to analyze the discriminant ability of financial ratios t-Student test for independent samples has been used. The t-Student test was performed with Statistica.

3 Results

3.1 Standard Deviation and Normal Distribution Chosen Ratios

The standard deviation is a method that is used to measure the volume of variation or diffusion of a data set. A low value of standard deviation points out that the values in data set are similar to the average, while a high value of standard deviation means that the values in data set are broaden. This method appears to be the strongest measure of index stability [6]. The Figs. 1, 2, 3, 4 and 5 present the results of the standard deviation of chosen indexes for bankrupt and non-bankrupt businesses as well as for whole sample.

The research results presented in figure from 1 to 5 indicate that there were significant differences in the values of bankrupt companies for all analyzed indicators. The greatest variation in the period was characterized by current liquidity ratio. Whereas the lowest fluctuation of data during the period was marked by income dynamics ratio. It is worth pointing out that the values of non-bankrupt businesses for all analyzed indicators were more stable than the values for bankrupt businesses. In the last decade, the values of equity to assets ratio, income dynamics ratio as well as gross margin ratio were most stable.

Next, the test for normal distribution of the five chosen ratios was carried out for each year separately, keeping division on the bankrupt and the non-bankrupt businesses[2]. A total distribution of 100 ratios has been tested (2 groups of companies, 5 indicators for 10 years). The summary results of the Kolmogorov - Smirnov test are presented in Table 1.

[2] See [10].

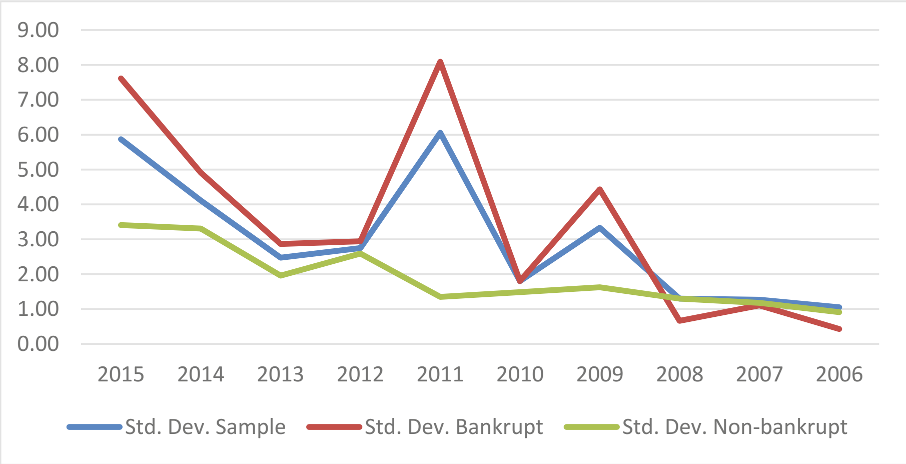

Fig. 1. The standard deviation of current liquidity ratio

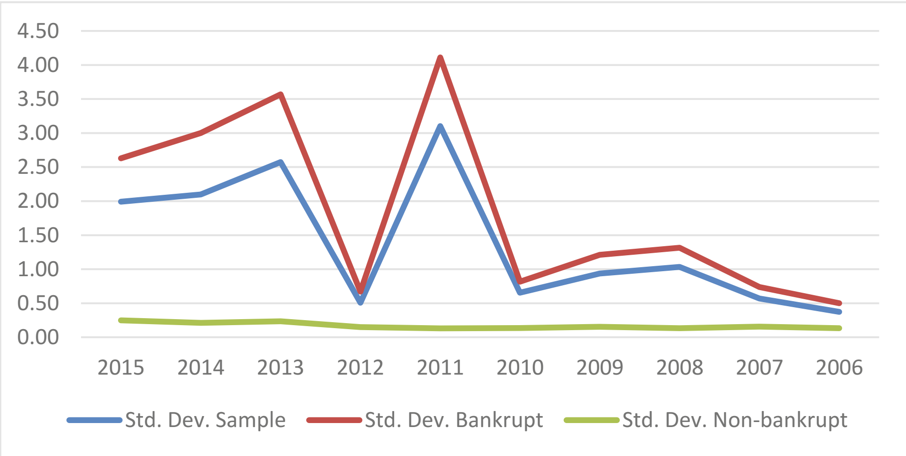

Fig. 2. The standard deviation of equity to assets ratio

Analyzing the results of the Kolmogorov - Smirnov test for chosen ratios, it can be observed that the values of income dynamics had a normal distribution for both companies with bad and good standing with some exceptions. The values of equity to assets ratio and payables turnover were also similar to a normal distribution but only for non-bankrupt companies with some exceptions. The rest of analyzed values of indicators were not characterized by a normal distribution. The results are consistent with the results presented by [16].

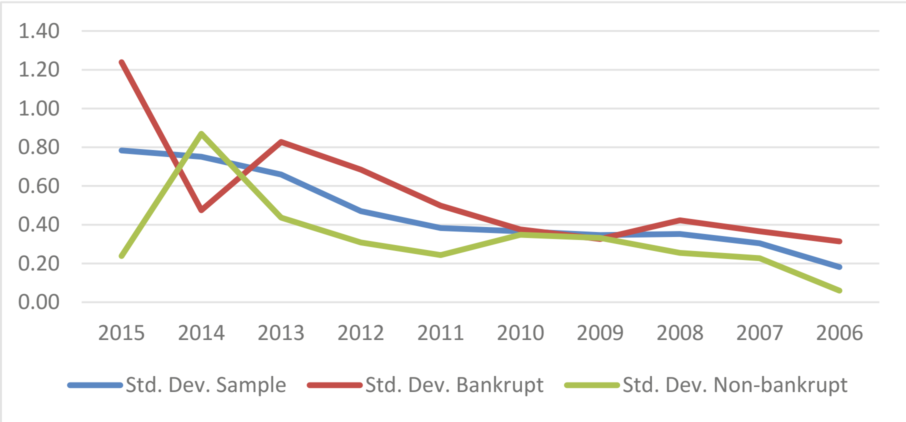

Fig. 3. The standard deviation of income dynamics ratio

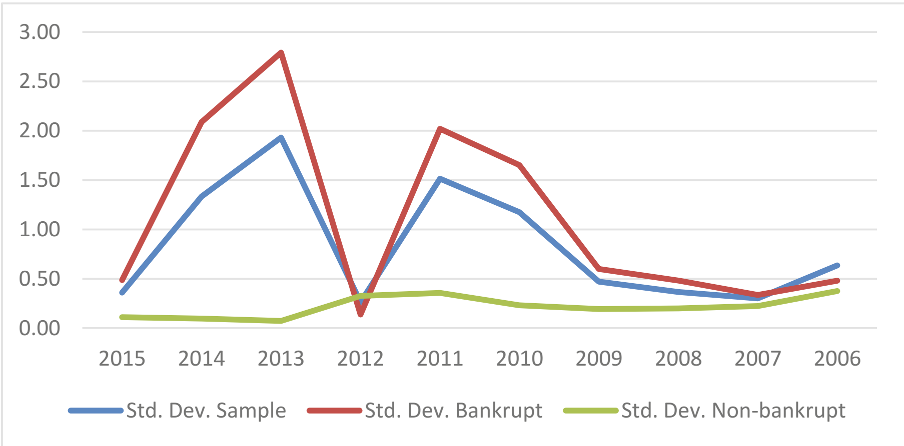

Fig. 4. The standard deviation of gross margin ratio

3.2 The Correlation Among Chosen Indicators

In turn, the correlation between variables determines which variables possess similar information capacity[3]. The higher correlation among variables the more similar information they possess. Table 2 presents only correlation higher than 0.5 [12] among the analyzed indicators in each year as well as mean in the period of 2015–2006.

By analyzing the above Table 2, it can be concluded that the relationship among variables was varied, for example, income dynamics ratio was not correlated with other indicators. Although in 2013, 2012 and 2006 there was strong correlation between

[3] See [14].

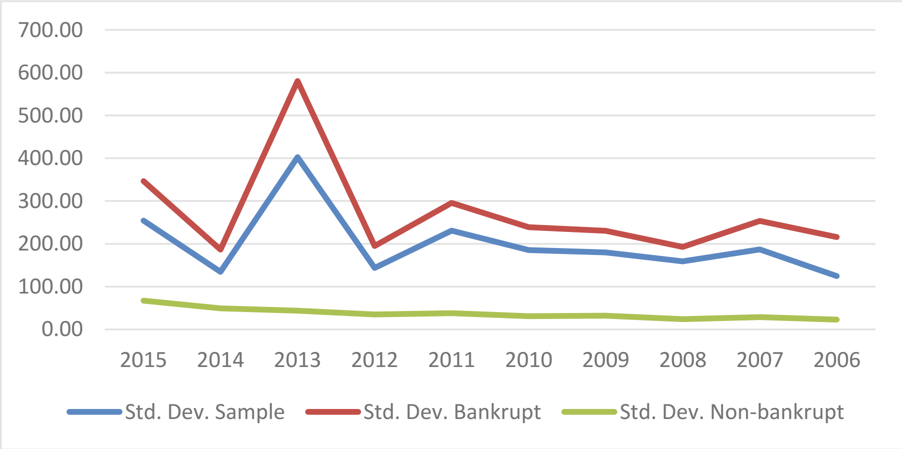

Fig. 5. The standard deviation of payables turnover ratio

Table 1. Kolmogorov - Smirnov for bankrupt companies and non-bankrupt companies.

Ratio	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006
Current liquidity	No	No	No	Yes	No	No	No	Yes	No	Yes*
	No	No	No	No	No	No	No	No	Yes	Yes**
Equity to assets	No	No	No	No	No	No	No	No	No	No*
	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes**
Income dynamics	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes*
	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No**
Gross margin	No	No	No	No	No	No	No	No	No	No*
	No	Yes	No	No	No	No	No	Yes	No	No**
Payables turnover	No	No	No	Yes	No	No	No	No	No	Yes*
	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes**

Legend: *bankrupt companies, **non-bankrupt companies

income dynamics ratio and gross margin ratio. Generally, there was only one moderate linear relationship between variables namely payables turnover and equity to total assets by analyzing the mean in the research period. Perhaps if one used liabilities turnover ratio instead of payables turnover the correlation between the indicators would be reduced. The difference between the rates is in the denominator. The denominator in the first rate is the cost of product sold and net sales in the second. The liabilities turnover ratio can be considered as useful indicator [26].

Table 2. The correlation between the chosen indicators within 10 years.

Ratios	Current liquidity	Equity to assets	Income dynamics	Gross margin	Payables turnover
Current liquidity	1	*0.51 (2007)* *0.67 (2006)* 0.38 (Mean)	−0.01 (Mean)	0.04 (Mean)	*−0.51 (2008)* *−0.57(2006)* −0.34 (Mean)
Equity to assets	*0.51 (2007)* *0.67 (2006)* 0.38 (Mean)	1	0.06 (Mean)	0.06 (Mean)	*−0.60(2014)* *−0.64 (2011)* *−0.52 (2010)* *−0.54 (2009)* *−0.65 (2008)* *−0.58* (Mean)
Income dynamics	−0.01 (Mean)	0.06 (Mean)	1	*−0.65 (2015)* *−0.73 (2013)* *0.72 (2006)* −0.03 (Mean)	*−0.57 (2006)* −0.14 (Mean)
Gross margin	0.04 (Mean)	0.06 (Mean)	*−0.65 (2015)* *−0.73 (2013)* *0.72 (2006)* −0.03 (Mean)	1	*−0.56 (13)* −0.19 (Mean)
Payables turnover	*−0.51 (2008)* *−0.57(2006)* −0.34 (Mean)	*−0.60 (2014)* *−0.64 (2011)* *−0.52 (2010)* *−0.54 (2009)* *−0.65 (2008)* *−0.92 (2006)* *−0.58* (Mean)	*−0.57 (2006)* −0.14 (Mean)	*−0.56 (2013)* −0.19 (Mean)	1

Source: Own work.

3.3 The Discriminant Ability of Chosen Ratios

In order to verify the discriminant ability of selected indicators the t-Student test was applied. The test is a commonly used method for evaluating dissimilarities between the means in the two groups (failed and non-failed companies). This test one can assess

Table 3. The results of the t-Student test for failed businesses and non-failed businesses.

Ratio	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006
Current liquidity	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Equity to assets	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Income dynamics	No	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes
Gross margin	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes
Payables turnover	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes

Legend: No – differences between the average of failed and non-failed companies are statistically insignificant; Yes – differences between the average of failed and non-failed companies are statistically significant.

whether the existing difference in means of examined groups is statically significant[4]. The summary results of the test are presented in Tables 3.

Carrying out analysis of the results presented in Table 3, it can be observed that none of analyzed indicators had the stable discriminant ability over last decade. However, the differences between the values of failed and non-failed companies for equity to assets ratio only in 2012 were statistically irrelevant. Based on the research, this indicator is the most stable one in the analyzed period. The result considering the current ratio may be surprising. The discriminant power of this ratio is only in the period of 2010–2006. In the rest of analyzed period this ratio did not have such a power. It is worth noting that the indicator occurs in many predicting corporate bankruptcy models [16].

4 Conclusions

The article deals with an important topic that is the stability of variables over time. The stability of indicators was verified based on the standard deviation, the normal distribution, the correlation coefficients as well as the discriminant ability. The analysis of standard deviation and the normal distribution showed that there is serious variation in the values in data set. Most of ratios were not characterized by normal distribution with one exception of equity to assets ratio but only for non-bankrupt companies. In last decade also the correlation coefficients among variables were diverse. However, only two indicators were highly correlated payables turnover and equity to total assets. The results on discriminant ability was shocking because the ability was not stable over time for all analyzed indicators. Concluding the results obtained, it should be said that the indicators were characterized by high variation during the period considered. The next step in the research will be to analyze much more indicators than only the five as well as to assess their predictive and discriminant powers over time.

[4] See [10].

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Crowdsourcing-Based Open Innovation Processes on the Internet

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Abstract. Using Internet in open and networked innovation processes has transformed people from consumers of products, services to active prosumers (producers and consumers). They take part in creating value, knowledge, innovations in open (web-based) innovation platforms (OPIs) on the Internet, also as participants of crowdsourcing platforms. The purpose of this paper is to propose the model of developing open, networked innovation process thanks to creation of knowledge based relationships (cooperation) among its participants, and to describe application of this model on crowdsourcing platforms on the Internet, also in the economic practice. Using collaborative networks of open communities on crowdsourcing platforms enable companies to learn new values, innovative solutions from the crowd on the Internet. Organizing effective knowledge based cooperation with and among active members of the crowd, and motivating them make easier development of open innovations on crowdsourcing platforms. Companies can successfully innovate by using complementary resources of knowledge, innovative competencies and creative abilities of the crowd during execution of open innovation process activities on crowdsourcing platforms.

Keywords: Open innovation process · Crowdsourcing · Prosumer

1 Introduction

Contemporary companies are under pressure to reinvent their business models as company borders are dissolving and the value and innovation creation processes are changing from linear to networked, from closed to open, from centralized to decentralized [4]. In the closed innovation model, internal R&D activities enable the company to produce own new products are bring them to innovation markets by the company itself. Open innovators employ a systematic strategy for motivating the creation and utilization of external sources of knowledge or innovations, such as universities, R&D entities, laboratories, competitors, and engaged consumers, also open innovation platforms (OIPs) on the Internet [6].

OIPs are designed for contribution and collaboration of one or two typologies of members: individuals and companies in open innovations. OIPs can be a means for companies to accelerate the open innovation process [1]. The following types of OIPs are developed on the Internet: crowdsourcing, peer production and open source software platforms.

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The emergence of crowdsourcing platforms is driven by new technology, active users, and the move towards open innovation. The goal for any crowdsourcing platform is to engage a crowd that has both the willingness and capacity to create value, knowledge, innovation solutions [14].

The purpose of the paper is to present the model developing of open and networked innovation process thank to creation of knowledge based relationships (cooperation) among its participants, and to describe application of this model on crowdsourcing platforms on the Internet, also in the economic practice.

This paper presents an idea of developing open and networked innovation process, and characterizes types of OIPs (crowdsourcing, peer production and open source software platforms). It determines assumptions of using crowdsourcing by innovative companies and the role of active members of the crowd (prosumers) and their motivation in creation of innovative solutions on the Internet. The paper presents development of knowledge based relationships between the crowd and partner-companies during execution of activities in open and networked innovation process on crowdsourcing platforms, also on the example of the platforms that are managed efficiently on the Internet.

2 Development of Open, Networked Innovation Processes also on the Internet

Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation of a company [4]. Open innovation is an emerging innovation management model comprised of two dimensions: (1) unbound open innovation, which is the practice of establishing relationships with external organizations or individuals with the purpose of accessing their knowledge and technical, scientific competences for improving internal innovation performance and (2) outbound open innovation, which is the practice of establishing relationships with external organizations with the purpose of commercially exploiting technological knowledge [15]. Contemporary companies evaluate from close (firm-centric) innovations and using internal resources of knowledge towards open innovations that are centered on external resources of knowledge, innovations and development of them in outside networks, also by communities on the Internet.

Innovations are results and knowledge products of innovation processes accomplishment by innovative companies and their external collaborators within the framework of innovation networks, also on the Internet [5]. Implementing open innovation process by a company in practice requires establishing knowledge based relationships (cooperation) with a variety of partners (suppliers, consumers, co-creators of knowledge) and managing complementary, internal and external innovation networks to enable efficient creation, development and application of innovations.

Innovation networks are defined as business network structure within which actors are intensively interacting to develop and implement innovations through adaptation, cooperation and coordination [20]. Such networks aim at improving the effectiveness of innovation performance and at linking firms with different assets and competences together in response to new market opportunities [11]. Firms no longer innovate in isolation but through a complex set of interactions and knowledge based relationships with external collaborators, also users of OIPs during execution of open innovation processes on the Internet.

In OIPs, stakeholders contribute to and collaborate on ideas, propose new concepts and trends, present innovative solutions, take part in their commercialization to win contests and to answer companies' needs [1]. Innovation networks on the Internet establish users of OIPs (companies or their employees, consumers). They are engaged in execution of one, a few or all the following activities of open innovation process: foresight, generation of new ideas, screening of new concepts, innovation elaboration, testing, application, development, innovation commercialization (promotion, sale), diffusion [1, 18].

External knowledge of the innovative company derives from its partners and/or competitors within the innovation network, and is generated in its environment i.e. the area of their microenvironment (innovation markets) and macroenvironment [7]. Assimilation, diffusion and development of external knowledge, innovative solutions depends on the company's capacities of co-creating effective knowledge based relationships with participants of open innovation processes within the framework of outside innovation networks, also on the Internet. The model of creating knowledge based relationships by the innovative companies with outside collaborators, also participants of OIPs in open and networked innovation process activities is proposed in this paper (see Fig. 1).

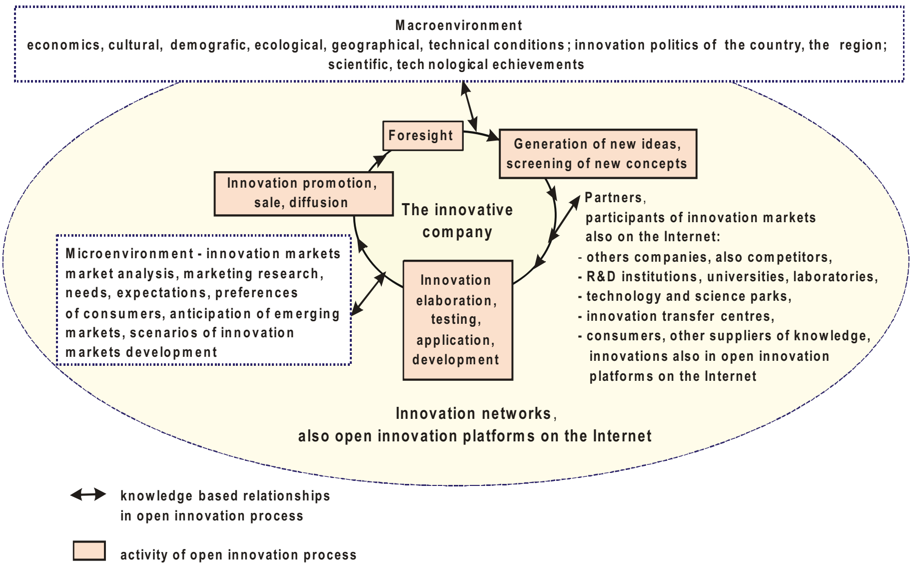

Fig. 1. Open and networked innovation process Source: own elaboration

The innovative companies may create knowledge based relationships with following partners within external innovation networks:

- companies and their customers and/or suppliers/distributors of knowledge, value, information, innovative solutions, also in OIPs on the Internet,
- R&D institutions, universities, laboratories, clusters, technology and science parks, innovation transfer institutions, consulting firms, innovation sale and/or promotion service firms, associations of innovators.

The following three forms of participation and cooperation in OIPs are developed: crowdsourcing, peer production, and open source software. Crowdsourcing is defined as the act of a company taking a function once performed by employees and outsourcing to an undefined (large) network of people in the form of open call. The process of crowdsourcing is sponsored by an organization that directly manages the crowd. Peer production refers to a new model of socio-economic production where a large number of people is coordinated into large projects without traditional hierarchical organization. Peer production is an organizational innovation along three dimensions: (1) decentralized conception and execution, (2) diverse motivations, including a range of non-monetary motivations, are central, (3) organization (governance and management) is separated from property and contract. Open source software is software that is developed collaboratively by different and independent geographically distant program developers. All three share the notion of openness and the use of the Internet as a collaboration platform [2, 13].

The active role of customers in OIPs is accompanied by evolving global trend of social communities representing innovative abilities and economic possibilities of engaged prosumers (producers and consumers) as executors of open and networked innovation process activities on the Internet.

3 Creation of Open Innovations on Crowdsourcing Platforms

Crowdsourcing platform is the initiative of a single company and is used by the company's employees and/or stakeholders. Crowdsourcing is defined as "the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call. This can take the form of peer-production (when the job is performed collaboratively), but is also often undertaken by sole individuals" [12]. Crowdsourcing is a form of IT-enabled open innovation and as the connection of open and networked innovation processes enable companies to learn and/or to receive innovative solutions from the crowd.

Crowdsourcing-based open innovation model consists of three elements. First, companies building their business upon the crowd need to adopt an open business model. Second, opening up certain processes and resources to external creators can make a significantly greater set of resources available to the company and allows it to share social networks, user-generated content, and mobile connectivity to invite users to participate in value creation activities. Third, these business models transfer value creating activities to crowd members. The co-create value with the platform provider or by interacting with other groups of users, partners [21].

Today, users of crowdsourcing platforms not only contribute ideas and input to product development, but they also share goods, services, space, and money to deliver solutions that traditionally have been performed strictly by the companies themselves [14]. Users of OIPs can be involved in all activities of the innovation process, beginning with the acquisition of weak signals and future needs, continuing up to sharing user experiences and further developing ideas, innovative solutions, and presenting concepts how, when, where use the final products and services [1]. Moderators and/or community managers on crowdsourcing platforms manage and monitor interactions, disputes, knowledge based relationships of their users during accomplishment of open innovation process activities.

Different levels of concreteness during open innovation process activities execution may be analyzed. Open innovation process on crowdsourcing platforms may consists of different activities and each platform may serve one or more, or all of these activities. The platforms offer participants of the crowd the opportunity to resolve the presented challenges, problems and issues, and/or to propose, design and create products, services, and/or innovative technological solutions. Members of the crowd may participate and/or collaborate in execution of the following activities of open innovation process in accordance with the proposed model in this paper: (1) foresight, (2) generation of new ideas, screening of new concepts, (3) innovation elaboration, testing, application, development, (4) innovation commercialization (promotion, sale), diffusion. Description of open innovation process activities, which may be executed on the crowdsourcing platforms is presented in Table 1.

The crowd can intervene at different activities of the innovation process, contributing to idea generation, technical problem solving, product or service design, sale. The contribution of individual consumers to the development of innovative solutions varies strongly. Therefore, the identification and selection of the right customers play a critical role [3, 8].

Only when consumers are qualified and motivated to contribute promising ideas and relevant know-how they are able to add value to a producer's open innovation process [8]. Being motivated means being encouraged to act. The motivations attributable to different people can differ significantly and can be differentiated not only by the degree of motivation required (i.e. how much motivation) but the reasons (i.e. type of motivation) [1].

The literature on crowd motivation suggests that users of crowdsourcing platform can be motivated by [1, 18]:

- extrinsic motivation factors, which are subdivided into - economic motivations (include monetary rewards, free final products, services, cash bonuses, price reductions), - individual (growth of professional status, career benefits, personal learning, higher reputation) and - social motivations (establishing relationships with other professionals of the community, for the purpose of knowledge exchange, sharing with others, building social capital),
- intrinsic motivation factors (not monetary rewards), that is - individual (opportunity to express individual creativity, sense of membership, enjoyment, fun, entertainment, altruism) and - social (social identity, sense of cooperation, sensible and creative work during collaborative innovation) motivations,

Table 1. Activities of open, networked innovation process on crowdsourcing platforms

Activity	Of the crowd	Of the company
Foresight	- Learning how to be prepared to face an uncertain markets, create new knowledge - Presenting new values, determining new needs, expectations of customers	- Engaging the crowd in identifying weak signals from macro- and/or microenvironments, anticipating emerging markets, evolution of markets
Generation of new ideas, screening of new concepts	- Generating new ideas, concepts of new products and/or services, submitting them online - Users evaluate the design ideas, they comment, discuss, and vote on design ideas, describe opinions, comments on proposed designs, - members of the crowd decide which of the design ideas, concepts seem most suitable for the market	- Organizing contests for ideas, design concepts testing in collaboration with the crowd - Harvesting new ideas, designs, which helps the company to improve or innovate activity, create new products and/or services - The wisdom, experiences of the crowd, analysis of financial and marketing aspects of innovations enable the company to choose accurate, profitable solutions quickly
Innovation elaboration, testing, application and development	- Active (co-)creating, developing designs for new products and/or services, collaborating during problem solving, innovation application, development, testing and evaluating innovative solutions (also products and/or services) using proper software	- Developing design ideas of users into new products and/or services and/or technological solutions - The company pays only for profitable solutions hence designs are cost effective, having large number of testers make possible to test innovative solutions by members of the crowd
Innovation promotion, sale, diffusion	- Innovation promotion by the crowd usually took place via own community and users' social media channels, participating with the company in sale of innovations via online and/or physical channels, diffusion of innovative solutions	- Connection of innovation (also product, service) design with its viral marketing - Cooperation with the crowd acting as a company's promotion, sale, diffusion advisor and force - Activating and motivating users in profitable selling of innovations

Source: own elaboration

The crowdsourcing platform managers must understand how to motivate the crowd and stimulate users and companies' mutual collaboration, knowledge effective development and using in open innovation process activities.

4 Examples of Using Crowdsourcing Platforms

Execution of open innovation process activities and creating knowledge based relations among users on crowdsourcing platforms are presented for the following platforms: LEGO Cuusoo, Dell IdeaStorm and CrowdSpirit.

LEGO is an example of a large and established manufacturing company that successfully implemented crowdsourcing with foreign partner-firm Cuusoo (technology company based in Tokyo). Cuusoo provides IT-enabled crowdsourcing services for such firms as LEGO, Muji, and Nissan.

The LEGO Cuusoo crowdsourcing platform allowed users to submit LEGO-related ideas for crowd evaluation and LEGO's consideration for implementation of product design. Users used actual bricks, software, or any combination to prepare their design ideas before submitting them to LEGO Cuusoo platform. They had various options to interact and to comment, discuss, and vote on design ideas. Receiving support via votes was most crucial on the platform because design ideas were considered by LEGO only when reaching a 10,000-vote threshold. Cuusoo passed all designs that met the vote threshold on to LEGO on a quarterly base [16, 19]. This crowdsourcing solution automatically provided an effective market test of new product design for LEGO.

A LEGO expert panel reviewed the winning ideas and determined which ideas were the best candidates for implementation and sale. The engaged users of Cuusoo crowdsourcing platform would be a product designers, that would be an artwork designer, looking at what the packaging would be and that would be people on the different markets looking at the positioning of the product idea in the US, Europe, and in Asia. And there would be financial control of the LEGO company in looking into the financial aspects of a product implementation and commercialization. Design ideas that survived both the crowd voting and the LEGO review then became part of LEGO's product offerings. LEGO listed the new models in catalogues and sold the models via its online and physical channels [19].

LEGO activates users in actually selling the product. The platform promises to offer both fame and financial gain to an originator of a successful idea approved by the LEGO Review Board. The owner of the idea will receive 1% of the net revenue from that particular model sold but also opportunities to work with professional LEGO designers, who create the final set based on the originator's idea, to be featured in set materials, and to be recognized as the product creator. LEGO aimed to involve users in commercialization the product after launch, moving directly from crowdsourced product design to viral marketing. This form of promotion by the users usually took place via users' social media channels [16]. LEGO crowdsourcing in en example of effective knowledge based cooperation the LEGO company and Cuusoo as its crowdsourcing platform manager with the crowd in accomplishment of open innovation process.

Dell introduced IdeaStorm crowdsourcing platform to its customers in 2007. Within the first five months, IdeaStorm users worldwide submitted over 6,200 ideas to help Dell become a better, more innovative organization. Several hundred of these gained immediate popularity, and Dell initially implemented them. These user ideas covered a wide variety of areas, such as preinstalling the Linux operating system to introducing a new tablet. As of August 2010, over 14,500 ideas with roughly 730,000 votes and almost 90,000 user comments were posted to IdeaStorm, and 417 ideas, approximately 3% of all ideas, were marked as implemented by Dell [9]. Through IdeaStorm, users can submit, vote, and comment on ideas. Users must create a username and account to post their ideas about new innovations. They provide an idea title and description and have the option to classify the idea from over 30 categories (e.g., Linux, Desktops, Sales Strategies). Once posted, other users in the IdeaStorm community are able to promote or demote the idea (vote), signaling whether it should or should not be adopted by Dell. Users are not given a financial incentive for participating, but they can benefit in other ways. Top users are honored on the Top Idea Makers list [10]. Dell and IdeaStorm have received many public acknowledgements from IT news magazines, professional bloggers for effective introducing crowdsourcing platform and adopting a user-driven open innovation process.

CrowdSpirit is a crowdsourcing platform launched in France (Grenoble). Its aim is to apply crowdsourcing to new electronic products development. In the initial CrowdSpirit business model, users submitted ideas for innovative electronic products that they would like to own, the community voted on the ideas, and the best ideas were worked on by a community of designers who developed and drafted the specifications. Following this, investors provided financing, development partners made the prototypes and the manufacturing was done by ad-hoc subcontractors in China. The business model was based on the idea that CrowdSpirit would sell the products designed by the community on the CrowdSpirit website. It became clear, however, that the original model was not viable and CrowdSpirit abandoned it. CrowdSpirit then turned to a more classical innovation intermediary model, whilst continuing with the concept of collective work done by the crowd. The following concept was adopted: the solutions of collective created goods could be negotiated directly by the community leader with a corporate firm (without any transaction fees) and CrowdSpirit would earn revenue on additional services for firms such as the use of the platform for open innovation [3]. CrowdSpirit platform manages R&D activity and its crowd participates in activities from idea generation to the design of new high-tech products development in open innovation process.

The success or failure of crowdsourcing platform is connected with its manager's ability to motivate the crowd to active, engaged participation and knowledge, designs development in open innovation process activities. It is also connected with building relationships with external partners of the platform.

Crowdsourcing relationships with external partners of the platform can take three forms [14]:

- Partnerships to grow and support creative members of the crowd - tapping into the user base of partners is a quick way to grow a platform community. Zooppa is building relationships with creative media programs at universities to bring in talented designers and filmmakers. Local Motors partners with established car companies such as BMW to bring in additional revenue and creates opportunities for the crowd to engage in creative problem solving.
- Extend the value of platform - particularly in the product platform, collaboration with partners becomes a central source of value creation. Companies pursuing this model actively search for novel ways of working together with customers or

complementors to extend their business. By creating partnerships with device manufacturers, Leap Motion extends the value of their platform.

- Partnerships to grow consumers - integrators partner with distribution channel companies to get the crowd's creation in front of consumers. Arcbazar reported that the first year of their partnership with AngelList (the startup-listing site) accounted for half of their clients.

Companies have much to learn from crowds. They empower members of crowd to leverage their innovative creativity (Zooppa's community creates advertisements for leading brands), share creativity (Threadless's community submits designs), or use their product domain (Innocentives's community tackles these challenges), also differentiate themselves in the marketplace and sustain their competitive edge [14, 17].

5 Conclusions

The paper describes using crowdsourcing by innovative companies, creation knowledge and innovations by the crowd, also during cooperation between engaged members of the crowd and partner-companies in open innovation process activities on crowdsourcing platforms. It presents the accomplishment of open and networked innovation process activities on the economic practice on the example of the chosen crowdsourcing platforms.

The creation of collaborative networks of open communities on the Internet plays an important role in effective innovation development on crowdsourcing platforms. By means of collaborations, companies can successfully innovate by sharing complementary resources of knowledge, innovative competencies and creative abilities of the crowd, and learning innovative solutions on crowdsourcing platforms.

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Optimization of Mesh-Type Logistic Networks for Achieving Max Service Rate Under Order-Up-To Inventory Policy

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Abstract. The paper addresses optimization issues in inventory management networks organized in an arbitrary – mesh – topology. The stock at a network node, depleted according to uncertain, external demand and internal transshipments, is replenished with positive lead-time delay from other nodes and exogenous sources. The replenishment process is governed by the order-up-to policy, implemented in a distributed way. The objective is to ensure maximum customer service rate while minimizing the overall holding costs. In order to answer the computational challenges arising from the complexity of system structure a simple heuristic to tune the policy parameters is proposed and evaluated in numerical experiments.

Keywords: Logistic networks · Order-up-to policy · Optimization

1 Introduction

In the current literature, the articles concerning the problems of efficient goods distribution in inventory management systems, although already challenging from the analytical and numerical viewpoint, cover relatively simple structures [1–3]. The most common topologies cover:

- single-echelon systems [4, 5], in which external sources are connected directly to the distribution node via a single link;
- serial [6, 7], where all the nodes are linked to each other in sequence;
- tree-like ones [8, 9], wherein the node connections merge to form groups with parallel linkage.

The growth of goods distribution industry demands development of more complex and sophisticated inventory management systems. By using the processing power of modern computers, the design, implementation, and performance optimization of logistic networks is possible. The subject of this work is examination of mesh-type, multi-echelon networks using order-up-to inventory policy to control the stock replenishment process at the nodes. In this policy, the key factor behind the optimal network performance is proper selection of the reference stock level (reorder point) at the nodes.

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For a specific sequence of demands imposed on the nodes, a numerical study may be conducted to determine the reference levels. However, this operation requires use of sophisticated numerical tools (due to intricate interdependencies in the networked construct), which may not be immediately available to the industry practitioners. It is therefore advisable to formulate rules for the reference level selection that would not require advanced computing mechanisms. For that purpose, in this work, an easily implementable heuristic is proposed. The presented tuning rule allows one to obtain maximum service rate, as verified in extensive simulation study for different network sizes and topologies and using various numerical algorithms, yet with much relieved computational effort as compared to the simulation-based optimization.

2 System Setting

2.1 Entities in Logistic Processes

The goods distribution in the considered class of systems takes place in a network of logistic nodes (stores, retailers, etc.). Each node has finite warehouse space allocated for goods storage. The node interconnections form a mesh topology. Each connection is characterized by two attributes: delivery delay time (DTT) which represents the time since an order for goods acquisition is placed until the goods appear at the issuer and supplier fraction (SF) that reflects the percentage of goods quantity to be retrieved from a particular supply source chosen by the ordering node. By assumption, the network is connected – there are no isolated nodes without linkage to any other node or to an external supplier. Apart from the initial reservoir at the nodes, the goods in the network are provided by the external suppliers. They feed the network with a certain DTT. The fact that the network is connected ensures that there exists a finite path between each network node in and at least one external source. The system driving factor is the external (customer) demand imposed on the nodes. The demand can be placed at any node and its future value is not known at the moment of issuing an order. The business objective is to satisfy the entire external demand, which excludes the customer disappointment due to unfulfilled requests and ensures a 100% service level, at the same time avoid unnecessary increase of operational costs. Thus, the optimization purpose is to obtain the full service level at the lowest possible cost of goods storage at the nodes, i.e., minimizing the total network holding cost (HC).

The logistic network under consideration consist of N nodes n_i, where index $i \in \Theta_N = \{1, \ldots, N\}$, and M external sources m_j, $j \in \Theta_M = \{1, \ldots, M\}$. All the entity indices are included in the set $\Theta = \{1, \ldots, N + M\}$. Let $l_i(t)$ and $d_i(t)$ denote, respectively, the on-hand stock level (the amount of goods already stored) and the external demand imposed on node i in period t, $t = 0, 1, 2, \ldots$ An example of such mesh-topology network is shown in Fig. 3. The network does not contain any separated nodes, neither nodes that would supply the stock for themselves. There also exists a finite path between each internal node in the network and at least one external source. Each connection between nodes i and j is directed (not bilateral) and characterized by two attributes $(\alpha_{ij}, \gamma_{ij})$, where:

- α_{ij} – SF between entities i and j, $\alpha_{ij} \in [0, 1]$;
- γ_{ij} – delivery delay time at the connection between entities i and j, $\gamma_{ij} \in [1, \Gamma]$, with Γ – the maximum delay between any two linked entities.

2.2 Entity Interaction

The operation sequence at a given network node in each period is illustrated in Fig. 1.

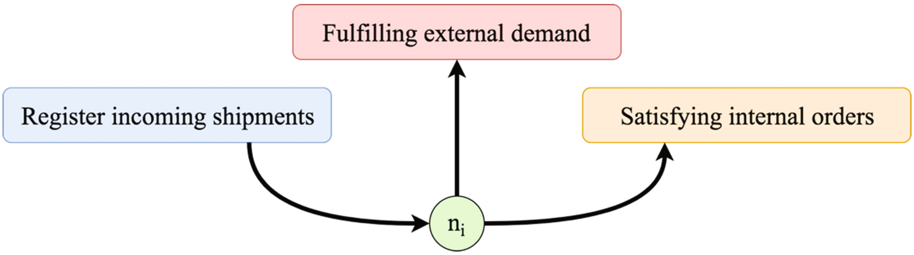

Fig. 1. Node operational sequence.

For the sake of compactness only major aspects are treated here. The derivation details for a similar model are given in [10]. Let us introduce the following notation:

- $\Omega_i^S(t)$ – amount of goods sent by node i in period t,
- $\Omega_i^R(t)$ – amount of goods received by node i in period t.

The stock level dynamics at node i can then be expressed by

$$l_i(t+1) = \left(l_i(t) + \Omega_i^R(t) - d_i(t)\right)^+ - \Omega_i^S(t), \quad (1)$$

where $(f)^+$ is the saturation function $(f)^+ = \max\{f, 0\}$. Representing $s_i(t)$ – the satisfied external demand at node i in period t – by

$$s_i(t) = \min\left\{l_i(t) + \Omega_i^R(t), d_i(t)\right\}, \quad (2)$$

formula (1) may be transformed into

$$l_i(t+1) = l_i(t) + \Omega_i^R(t) - s_i(t) - \Omega_i^S(t). \quad (3)$$

Denoting by $o_i(t)$ the total quantity of goods to be ordered by node i in period t, both from the external sources as well as other cooperating nodes in the network, the goods quantity sent by node i,

$$\Omega_i^S(t) = \sum_{j \in \Theta_N} \alpha_{ij}(t) o_j(t). \quad (4)$$

In turn, the amount of goods acquired by node i in period t may be calculated as

$$\Omega_i^R(t) = \sum_{j \in \Theta} \alpha_{ji}(t - \gamma_{ji}) o_i(t - \gamma_{ji}). \tag{5}$$

The nodes attempt to answer both the external and internal demand. In case of insufficient stock level to fulfill the requests, the fraction of total quantity is reduced accordingly, yet

$$\forall_i \, 0 \le \sum_{j \in \Theta} \alpha_{ji}(t) \le 1. \tag{6}$$

When a node receives a request from another node in the network and is able to fulfill it, then $\alpha_{ij}(t) = \alpha_{ij}$. Otherwise, $\alpha_{ij}(t) < \alpha_{ij}$. The external sources are assumed to have an infinite reservoir of goods, and thus they are able to satisfy every order originating from the network.

2.3 State-Space Model

For the purpose of convenience of further study, a state-space model of the considered logistic network will be introduced. The dynamic dependencies are grouped into

$$\vec{\boldsymbol{l}}(t+1) = \vec{\boldsymbol{l}}(t) + \sum_{\gamma=1}^{\Gamma} \boldsymbol{M}_\gamma(t-\gamma)\vec{\boldsymbol{o}}(t-\gamma) + \boldsymbol{M_0}(t)\vec{\boldsymbol{o}}(t) - \vec{\boldsymbol{s}}(t), \tag{7}$$

where the applied symbols denote:

- $\vec{\boldsymbol{l}}(t)$ – vector of stock levels (system state)

$$\vec{\boldsymbol{l}}(t) = [l_1(t), l_2(t), \ldots, l_N(t)]^T, \tag{8}$$

- $\vec{\boldsymbol{o}}(t)$ – vector of stock replenishment orders

$$\vec{\boldsymbol{o}}(t) = [o_1(t), o_2(t), \ldots, o_N(t)]^T, \tag{9}$$

- $\vec{\boldsymbol{s}}(t)$ – vector of satisfied (external) demands

$$\vec{\boldsymbol{s}}(t) = [s_1(t), s_2(t), \ldots, s_N(t)]^T, \tag{10}$$

- $\boldsymbol{M}_\gamma\,(t)$ – matrices specifying the node interconnections; for each $\gamma \in [1, \Gamma]$,

$$
\boldsymbol{M}_{\gamma}(t) = \begin{bmatrix} \sum\limits_{i:\Gamma_{i1}=\gamma} \alpha_{i1}(t) & 0 & 0 & \cdots & 0 \\ 0 & \sum\limits_{i:\Gamma_{i2}=\gamma} \alpha_{i2}(t) & 0 & \cdots & 0 \\ 0 & 0 & \sum\limits_{i:\Gamma_{i3}=\gamma} \alpha_{i3}(t) & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & \sum\limits_{i:\Gamma_{iN}=\gamma} \alpha_{iN}(t) \end{bmatrix}, \quad (11)
$$

- $\boldsymbol{M_0}(t)$ – matrix describing stock depletion due to the internal shipments

$$
\boldsymbol{M_0}(t) = -\begin{bmatrix} 0 & \alpha_{12}(t) & \alpha_{13}(t) & \cdots & \alpha_{1N}(t) \\ \alpha_{21}(t) & 0 & \alpha_{23}(t) & \cdots & \alpha_{2N}(t) \\ \alpha_{31}(t) & \alpha_{32}(t) & 0 & \cdots & \alpha_{3N}(t) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \alpha_{N1}(t) & \alpha_{N2}(t) & \alpha_{N3}(t) & \cdots & 0 \end{bmatrix}. \quad (12)
$$

2.4 Order-Up-To Inventory Policy

One of the popular stock replenishment policies applied in logistic systems is the order-up-to (OUT) inventory policy. It attempts to keep the current stock at a predefined – reference – level. A new order is issued by the node if the sum of the on-hand stock and goods quantity in the pending replenishment orders is below the reference level. The reference level should be chosen so as to maintain constant readiness to satisfy the external demand, yet avoid excessive goods accumulation. Figure 2 illustrates the operational sequence of the OUT policy.

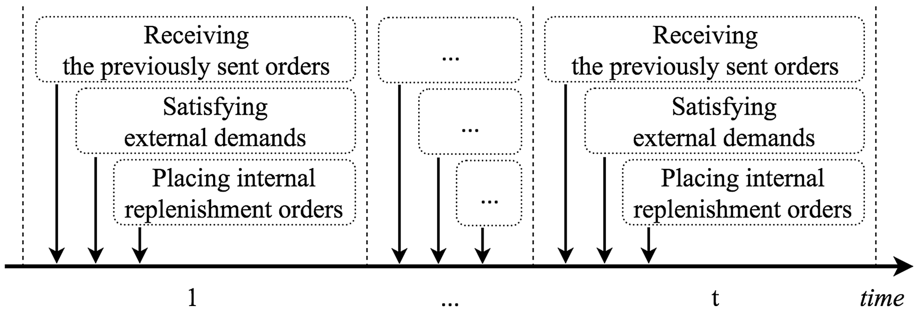

Fig. 2. Order-up-to policy operational sequence.

From the technical perspective, the network optimization procedures discussed in a latter part of this work provide guidelines for the reference stock level selection under uncertain demand, i.e., the demand that is not known exactly while issuing the replenishment orders. According to [10] and [11], for the OUT policy implemented classically in a fully distributed way, the quantity of the replenishment order placed by node i in period t may be calculated as

$$o_i(t) = l_i^r - l_i(t) - \Phi_i(t), \tag{13}$$

where:

- l_i^r – the reference stock level set at node i, $i \in [1, N]$,
- $\Phi_i(t)$ – the quantity of goods in the pending orders issued by node i.

For convenience of further discussion in the context of distributed implementation of policy (13) the order quantity computation is summarized into a vector form

$$\vec{\boldsymbol{o}}(t) = \vec{\boldsymbol{l}^r} - \vec{\boldsymbol{l}}(t) - \sum_{k=1}^{\Gamma} \sum_{\gamma=t-k}^{t-1} \boldsymbol{M_i}(\gamma)\vec{\boldsymbol{o}}(\gamma), \tag{14}$$

where $\boldsymbol{l}^r$ denotes the vector of reference stock levels.

According to the assumed objectives, the logistic network should retain a high service level. It will be quantified through the fill rate, i.e., the percentage of satisfaction of the external customer demand imposed on the nodes. The optimization objective is to indicate such reference level for each node so as to preserve the lowest holding cost while keeping a 100% fill rate. As initial approximation, using only the knowledge about the highest expected demand in the system $\boldsymbol{d}_{max}$, the 100% fill rate (for arbitrary demand pattern) can be obtained if the reference stock level is selected according to the following inequality [10]

$$\vec{\boldsymbol{l}^r} > \left(\boldsymbol{I_N} + \sum_{\gamma=1}^{\Gamma} \gamma \boldsymbol{M_\gamma}\right) \boldsymbol{M}^{-1} \vec{\boldsymbol{d}}_{\max}, \tag{15}$$

where $\boldsymbol{I}_N$ is an identity matrix of size $N \times N$.

However, if the average demand differs significantly from the maximum value, inequality (15) overestimates the safety stock thus leading to increased holding costs. In such circumstances, it is reasonable to apply another formula, incorporating the fundamental statistical parameters of demand – mean and standard deviation. Inspired by the classical inventory theory applied previously to simpler, single-echelon constructs [11], in this work, it is proposed to assign the reference stock level for the networked, multi-echelon system according to

$$\vec{\boldsymbol{l}^r} = \left(\boldsymbol{I_N} + \sum_{\gamma=1}^{\Gamma} \gamma \boldsymbol{M_\gamma}\right) \boldsymbol{M}^{-1} \vec{\boldsymbol{d}}, \tag{16}$$

where

$$\vec{\boldsymbol{d}} = \vec{\boldsymbol{d}}_{mean} + \boldsymbol{D_C} \vec{\boldsymbol{d}}_{sd} \tag{17}$$

with

- $\vec{\boldsymbol{d}}_{mean}$ – vector of demand mean values,
- $\vec{\boldsymbol{d}}_{sd}$ – vector of demand standard deviations,
- $\boldsymbol{D_C}$ – safety factor,

$$\boldsymbol{D_C} = diag\{D_{C_1}, D_{C_2}, \ldots, D_{C_N}\}. \tag{18}$$

The safety factor allows for determining the safety stock, i.e., the stock level needed to cover all the customer demands [11]. It grows rapidly with increasing the service level to be attained. Based on the numerous simulations performed for various network topologies and system parameters, a dependence between the safety factor and demand standard deviation has been established to follow

$$\boldsymbol{D_C} = \mu \vec{\boldsymbol{d}}_{sd}. \tag{19}$$

Table 1 shows the number of topologies with maximum fill rate and associated cost increase with respect to the optimal solution for different μ.

Table 1. Effect of μ on holding cost.

μ	% of topologies with max fill rate	Holding cost increase
0.04	1%	1.37–1.53
0.05	13%	1.51–1.87
0.06	43%	1.55–2.30
0.07	68%	1.92–2.67
0.08	84%	1.99–3.10
0.09	92%	2.65–3.44
0.10	96%	2.73–3.75
0.11	97%	2.96–4.24
0.12	99%	3.30–4.74
0.13	100%	3.55–5.03

In the examined scenarios, the value of μ falls in the range [0.04, 0.13] with μ = 0.09 covering more than 92% of the cases when the 100% fill rate was achieved with minimum holding costs.

3 Numerical Study

For the purpose of conducting a thorough numerical investigation of heuristic (16), a specialized, MATLAB®-based application was created. The simulations for different topologies and systems settings involved exhaustive search (fundamental topologies) and an evolutionary method – random mutation hill climbing algorithm [12] (more complex configurations).

One of the considered topologies is depicted in Fig. 3. It encompasses three external sources ($M = 3$) and six internal nodes ($N = 6$). The external demand, imposed on each node, has been generated using Gamma distribution with *shape parameter* = 5 and *scale parameter* = 10.

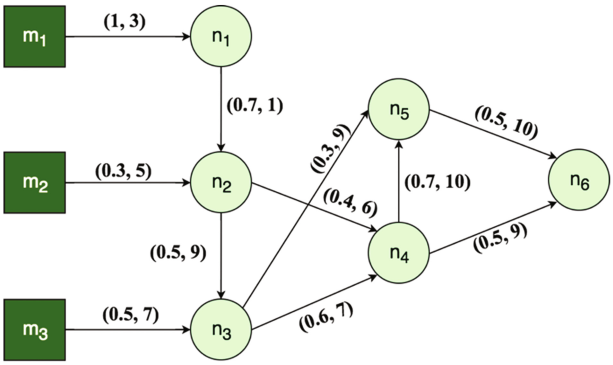

Fig. 3. Logistic network scheme.

The summary of heuristically determined reference stock levels vs. those obtained from the optimization process for the safety factor $\mu = 0.06$ is given in Table 2. It indicates that the RSLs of controlled nodes connected directly to external sources have been overstated. The proposed value of safety factor is better suited for the nodes that process smaller distribution of goods. It follows that the longer the path from the node to external sources, the bigger μ should be applied. Figures 4 and 5 display the corresponding stock evolution at the nodes. Both the heuristic and simulation-based approaches result in the maximum service rate. Although the stock level is close to the horizontal axis, the heuristic tends to overestimate the safety stock. Figure 4 illustrates that the stock level at the nodes which are closer to external sources may be too high. The readiness to fully satisfy customer demand and internal replenishment requests from other nodes is ensured, yet with some redundancy. Taking a single value of the safety factor for the entire network may be justified in the situations of balanced node localization and should serve as first approximation. In case of large structural differences in various network fragments μ should be adjusted separately for each node.

Table 2. Results of reference stock level (RSL) calculations.

Node	Heuristic RSL [units]	Optimal RSL [units]	Ratio
n_1	1100	885	1.24
n_2	913	753	1.21
n_3	2187	1653	1.32
n_4	1583	1398	1.13
n_5	1350	1182	1.11
n_6	839	779	1.08

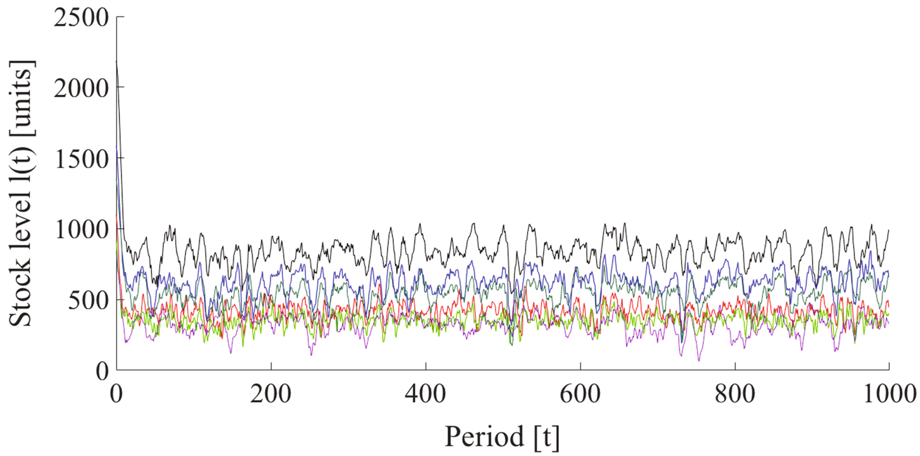

Fig. 4. Stock level at the nodes in heuristic approach.

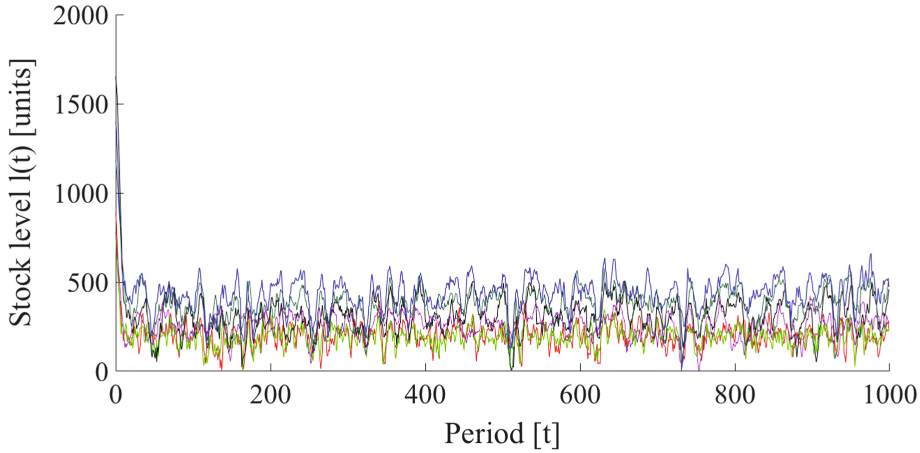

Fig. 5. Stock level at the nodes for optimal reference level selection.

4 Conclusions

The paper explores the use of order-up-to inventory policy for goods distribution in mesh-type logistic networks. The optimization objective is to reduce the overall system holding cost while ensuring full customer satisfaction. For that purpose, the key point is adjusting the reference stock level. In the paper, a heuristic selection rule which depends solely on basic demand statistical parameters – mean and standard deviation – is proposed. The tests executed for different network topologies, sizes, and structural parameters show that the presented approach allows one to achieve reasonable network performance without recurring to sophisticated numerical tools. Although straightforward to apply, the heuristic would need further adjustment in case of networks with disparate architecture to mitigate the holding cost increase.

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Dimensions of Business Ecosystem Efficiency

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Abstract. The research paper refers to the complexity of the business ecosystem's efficiency by attempting to describe the dimensions of organizational efficiency of the business ecosystem. The paper presents a business ecosystem as a set of organizations that interact with one another by creating various correlations and relationships of a symbiotic character - from competing to cooperative. Eight models of measurement of organizational efficiency were identified and systematized following the subject literature. Their analysis and own research allowed the authors to point out another model of measuring the efficiency of business ecosystems, which was named relational.

Keywords: Determinant · Efficiency · Business ecosystem

1 Introduction

Ecosystem is a concept from ecology that has been borrowed to describe the dynamic relations between a given organization and other organizations functioning in its business environment. Traditionally, the organization has been perceived as an element of a sector or industry that attempts to adopt trends and phenomena in its environment by analyzing and studying them. Failure to adapt to these changes signifies the organization's crisis, which in extreme cases may lead to its collapse. However, the understanding of an organization as an active entity in the ecosystem shows other possibilities for the organization's functioning. The organization not only adapts to changes in the environment, but actively shapes them. Depending on its role and position in the ecosystem, the organization shapes it independently or together with other ecosystem's participants.

"Ecosystem" conveys the idea that all the pieces of an economy come together in particular places, and that their strength and interactions determine prosperity and economic growth.[1] That you prosper only because you're surrounded by lots of

[1] e Business Ecosystem, Rosabeth Moss Kanter, "Can America Compete?" September–October 2012, Harward Magazine, http://harvardmagazine.com/2012/09/the-business-ecosystem, 2.02.2017.

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resources that make it possible to succeed, beyond what your own entity controls. I developed the idea associated with this transition from the industrial to the digital in World Class: competitive communities had to reach the highest standards in the world because your customers and employers now knew what the highest standards were, and didn't necessarily need you to access them—they could go even outside their country. Those developments pointed to networks and larger systems—what cities and regions and small businesses needed to do to remain prosperous (See footnote 1). The concept of ecosystem is derived from a Greek words oíkos and sýstēma, i.e. "the environment of connections" and is a complex ecological system that creates conditions for living organisms, inhabited by a group of species related to one another (PWN Encyclopaedia, 2015). This concept, essentially related to the biological environment, in a different configuration, is transferred to the business environment. In the business environment, one may discuss relations, connections and interactions between various entities that create an environment of economic activity where the organization plays a leading role.

Economic organizations are evaluated from the perspective of their efficiency. The organisation's efficiency refers to all positive results coming from a given organization's activities and do not necessarily have to be intentional (Baker and Stabryla 1989, pp. 178–179). The concept of organizational efficiency may and should be also referred to a collection of many organizations occurring in various forms including the business ecosystem. It can be stated that the efficiency of the business ecosystem is a condition for its survival. It combines a targeted approach (creativity, productivity, loyalty, employee satisfaction, as well as willingness and ability to adapt to changes) and systemic (the ability of the business unit to use resources coming from the environment while minimizing risk; on the other hand, the ability to maximize the use of available resources in the context of the long-term ability to maximize the company's income), which is referred to as a multicriterial approach.[2]

The purpose of this paper is to analyze factors influencing the efficiency of business ecosystem. Starting from the review of literature on organizational effectiveness models and the factors of its measurement, and ending with the authors' classification of dimensions of ecosystem efficiency including a proposal for one of them.

2 The Concept of Business Ecosystem

The concept of the business ecosystem was introduced by Moore in 1993 with the description: "An economic community supported by a foundation of interacting organizations and individuals - the organisms of the business world. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organizations also include suppliers, lead producers, competitors, and other stakeholders. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more

[2] Skrzypek E. *Jakość i efektywność,* Wydawnictwo Uniwersytetu Marii Curie-Skłodowskiej, Lublin, 2000, Str. 192–193.

central companies. Those companies holding leadership roles may change over time, but the function of ecosystem leader is valued by the community because it enables members to move toward shared visions to align their investments and to find mutually supportive roles." Business ecosystems are analogous with biological ecosystems. Moore (1996)[3] uses biological metaphors. Moore's model is actually an attempt to replace the static environment with a dynamic business ecosystem. In the presented model a central role is held by an organization expanding its perception and impact on the environment across new areas (layers), starting from the key business, through the extended business, to the business ecosystem. The business ecosystem is another layer of business (competitors, stakeholders, government agencies, regulators) to be discovered and explored, as well as build new relationships based on cooperation.

Similarly, Iansiti and Levien (2004a)[4] use congruencies between biological and business ecosystems, but emphasise that analogies between these ecosystems can be dangerous and one should be careful when using them. In fact, they point out critical differences between the ecosystems, for example, innovation, competition for members and intelligent actors (e.g. planning, forethought), to differ from its descendant biological ancestor. However, despite of the susceptibility to risk in the term "business ecosystem" it fits well in the scope of this thesis and accentuates the varieties and possibilities of different interactions of business activities. In addition, the ecosystem analogy borrows viewpoints for understanding the challenges and opportunities in business ecosystems and inspires the seeking of them.

Thus, this thesis uses Iansiti and Levien's (2004b)[5] definition of business ecosystem. They define business ecosystems through interconnected business networks: "these loose networks - of suppliers, distributors, outsourcing firms, makers of related products or services, technology providers, and a host of other organizations - affect, and are affected by, the creation and delivery of a company's own offerings"[6].

Where a business ecosystem is described as "like an individual species in a biological ecosystem, each member of a business ecosystem ultimately shares the fate of the network as a whole, regardless of that member's apparent strength.". An interesting perspective on the evolution of the ecosystems is co-evolution; where ecosystem member organisations or parts of the ecosystem evolve in alignment. An example of

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[6] Marko Karhiniemi, Creating and Sustaining Successful Business Ecosystems, Information Systems Science Master's thesis, Department of Business Technology HELSINGIN KAUPPAKORKEA-KOULU HELSINKI SCHOOL OF ECONOMICS, 2009.

co-evolution is a Digital Ecosystem and a Business Ecosystem evolution, which Moore (2003)[7] introduces as the Digital Business Ecosystem (DBE).[8]

Digital business ecosystem is a European Union funded environment, which provides a structure, where software coded by European SMEs can act like organisms in an ecosystem. The main goal is to enhance possibilities of SMEs to compete with larger software houses.[9] Nachira proclaims that it produces an extraordinary competitive advantage for a region if small organisations within it adopt digital business ecosystem early (Nachira 2002, 21)[10] There is evidence that if you make the connections between knowledge creators and businesses tighter, you can increase success.[11]

The current perception of the business ecosystem is much broader because the ecosystem is perceived not in terms of layers, but in terms of networks, where an organization, key business and extended business are the components of this ecosystem. Contemporary business ecosystems are multidisciplinary, multifunctional multirelational networks that interact with one another. Such a perception of the business ecosystem is closest to the traditional concept of the natural ecosystem. The structure of the business ecosystem is arranged as a network of organizations whose activity is concentrated on coordinating jointly undertaken actions for the relationship of goals. This structure consists of:

(Boulding 1956)

- points (junctions, vertices) - meaning organizations;
- connections (ties, relationships, interrelations) between points, i.e. organizations, characterized by varying intensity (weak and strong ties) and different degrees of formalisation (formal and informal ties).

The structure of the business ecosystem understood in this way can be the subject of determining levels, dimensions and efficiency evaluation. In the case of business ecosystem, at least two levels of efficiency can be discussed:

- the junctions' efficiency (single organizations),
- the efficiency of the whole structure of the business ecosystem, which consists of the sum of the individual organizations' efficiency and their mutual relations.

7 Moore, J.F. (2003). Digital Business Ecosystems in Developing Countries: An Introduction Berkman Center for Internet and Society, Harvard Law School.

8 Marko Karhiniemi, Creating and Sustaining Successful Business Ecosystems, Information Systems Science Master's thesis, Department of Business Technology HELSINGIN KAUPPAKORKEAKOULU HELSINKI SCHOOL OF ECONOMICS, 2009. pp. 5–7.

9 M Peltoniemi, E Vuori, Business ecosystem as the new approach to complex adaptive business environments Proceedings of eBusiness research forum 18, pp. 267–281.

10 Nachira, F. 2002. Towards a Network of Digital Business Ecosystems Fostering the Local Development. European Commission Discussion Paper. Bruxelles. 23 p. http://www.digitalecosystem.org/html/repository/dbe_discussionpaper.pdf

11 The Business Ecosystem, Rosabeth Moss Kanter, "Can America Compete?" September–October 2012, Harward Magazine, http://harvardmagazine.com/2012/09/the-business-ecosystem, 2.02.2017.

Considering the fact that business ecosystems do not have a homogeneous structure other intermediate levels of efficiency, understood as the sum of the results and attributes of all participating ecosystems, can be distinguished.

3 Determinants of the Business Ecosystem Efficiency

The constantly changing environment, the pursuit of development and the competitiveness prompt us to consider the determinants of the ecosystem's efficiency. The leading factors affecting both the business unit and the business ecosystem are the mechanisms and conditions occurring in the environment as well as internal factors:[12]

- external factors:
  (1) international environment, e.g. globalization of the economy, situation on the world markets, economic situation, market liberalization, free movement of capital, goods and services, etc.
  (2) national environment, e.g. the state policy, level of economic growth, innovativeness of the economy, legal regulations resulting from the state decisions,
  (3) sectoral environment, determinants of activity in the sector or industry,
  (4) local environment, determinants of activity one the local market,

- internal factors - competitive potential that depends on the company, organization, ecosystem as well as their internal:
  (1) material resources,
  (2) intangible assets,
  (3) the efficiency of management,
  (4) business relationships and arrangements,
  (5) product competitiveness,
  (6) the ongoing activities and processes,

Apart from the determinants of development there are also many barriers that prevent it:[13]

- legal barriers, i.e. complex procedures, lack of proper protection of personal interests such as trademark, ambiguity and ignorance of regulations;
- economic barriers, including: government policy, the scarce availability of financial services, high costs of bank loans;

[12] Mitek Anna, Miciuła Ireneusz, Współczesne determinanty rozwoju przedsiębiorstwa prywatnych, WNEiZ nr 28, pobrane 20.03.2016. *Mitek A., Miciuła I., Współczesne determinanty rozwoju przedsiębiorstwa prywatnych, WNEiZ nr 28, pobrane 20.03.2016.*

[13] Krajewski K., Determinanty rozwoju małych i średnich przedsiębiorstw, Warszawa, 1999, [w:] Miłek Anna, Miciuła Ireneusz, Współczesne determinanty rozwoju przedsiębiorstw prywatnych, pobrane 07.01.2016.

- management barriers, ignorance of innovative management techniques, lack of learning abilities, incompetent use of information from the environment;
- personnel barriers, such as high employee rotation and low level of the employee's skills;
- educational barriers, i.e. lack of competencies in internet use and limited access to business information;
- social barriers, low culture of the business unit and lack of acceptance of the social stratum.

In the process of pursuing efficiency one need to involve factors that have a significant impact on the success of the entire business ecosystem. Certainly, the efficiency of the enterprises in the business ecosystem is an issue that is a prerequisite for the efficient and proper functioning of the economy, because it is a single economic entity that creates a real national income. The key to success is shaping appropriate relationships, cooperation that secure the development of the ecosystem in the long run. The assessment of the ecosystem is concentrated on several key elements, including species (ecosystem components), relations between species (ecosystem network), results - achievements (ecosystem condition), dynamics (ecosystem evolution) as well as enterprises' strategies and behaviours (the role of each component in the ecosystem). What is most important in the assessment is the condition of the ecosystem understood in the following categories:[14]

- Values - creating niche,
- Efficiency - critical mass,
- Effectiveness - continuous improvement of the performance system,
- Economical co-evolution or otherwise co-learning and optimization effects.

An ecosystem is a form of cooperation in which companies merge their individual offers into homogeneous solutions of significant value to the client. The benefits are obtained both from the competition and cooperation with other organizations - the phenomenon of coevolution. A well-functioning ecosystem is characterized by good condition, enabling organizations to create values they would not otherwise be able to generate alone. Furthermore, the ecosystem is not stable, being a subject to continuous evolution processes. This evolution consists in matching between the organization and its specific ecosystem, which eventually is a selection system that determines whether the organization will survive. Ecosystems are objects that emerge, which in turn explains the theory of emerging. Emerging of the business ecosystem involves continuous reshaping, i.e. transformation of the population in the ecosystem or transformation of the ecosystem form. Reshaping is characterized by acceleration, qualitative-economic, technological and social novelties.[15]

[14] Stańczyk-Hugiert E.I., Dynamika srategiczna w ujęciu ewolucyjnym, Wydawnictwo UE we Wrocławiu, 2013, s. 39.

[15] Stańczyk-Hugiert E.I., Dynamika srategiczna w ujęciu ewolucyjnym, Wydawnictwo UE we Wrocławiu, 2013, s. 42–43.

4 The Models of Business Ecosystem's Efficiency

The analysis of literature allowed the authors to identify and systematize eight leading models of organization's efficiency, which can be used to describe the efficiency of business ecosystems (according to Boulding's systems hierarchy). The following efficiency models were identified and described along with the evaluation criteria: target-oriented, system, of internal processes, of interpersonal relations, of competing values, of interest groups, of ability to acquire resources, of social justice.[16]

In a target-oriented model, the efficiency of an organization is related to outlining the vision and setting up the targets, as well as creating the conditions for their effective implementation. The determinants of evaluation are the following: rationalization of the targets, target orientation, maximization of production, minimization of costs, technology improvement, the optimal use of resources, specialization, division of labour, competitiveness, productivity, survival, return on investment.

The system model implies the balance of organizations participating in the ecosystem and the balance of the whole ecosystem with its environment. This balance is supposed to guarantee the survival (viability) of the organization in the ecosystem and the ecosystem in the market environment. During the evaluation the attention is drawn to changes in the environment, flexibility, adaptability, alignment of the organization to the environment, errors in differentiation and integration, responsiveness to changes in the environment, adaptation to external conditions, as well as management style.

The model of internal processes refers to the efficiency of the processes implementation. It underlines unity and unified management of the entire ecosystem, the order, social and technical match for internal processes within the ecosystem, efficient information processing, the internal cohesion and open communication. In this case, emphasis is placed on the proper management of information, work processes, projects and coordination of undertaken actions.

In the model of interpersonal relations efficiency is perceived as providing the appropriate interpersonal relationships in the organization, taking into account the individual needs of employees. It assumes that there is a group of factors that are more important to employees than technology and working conditions. These include: relationships between employees, their interactions, team spirit, teamwork, loyalty, open-mindness, employee satisfaction and a good atmosphere conducive to effective work. The determinants of evaluation should also include low rotation of employees, productivity resulting from job satisfaction, loyalty, openness, as well as productivity being a result of employee engagement.

[16] Źródło: opracowanie własne na podstawie: M. Bratnicki, M. Kulikowska-Pawlak, Uwarunkowania pomiaru efektywności organizacji, Zarządzanie i Finanse, 2013, vol. 4, s. 53–66; H.R. Greve, Positional rigidity: Low performance and resource acquisition in large and small firms, "Strategic Management Journal", 2011, nr 32; Keeley M. (1978), A social justice approach to organisational effectiveness,"Administrative Science Quarterly", nr 22, K.S. Cameron, R.E. Quinn, Kultura organizacyjna – diagnoza i zmiana. Model wartości konkurujących, Oficyna Ekonomiczna, Kraków 2003, s. 36–41; K. Kostro, Koncepcja sprawiedliwości F. A. von Hayeka, [w:] Efektywność a sprawiedliwość, pod red. J. Wilkina, Wyd. Key Text, Warszawa 1997, s. 78.

The model of competing values assumes the need to combine all the four earlier models of efficiency (target-oriented, system, internal processes and interpersonal relations). These models are seemingly mutually contradictory. Hence, this model is called of competing values. According to Cameron high efficiency in, for example, a target-oriented sense does not necessarily mean inefficiency from the perspective of interpersonal relations. A defined perspective becomes dominant in given circumstances, but providing results, on at least an average level, in terms of remaining perspectives is sufficient to ensure high overall organizational efficiency (Cameron et al. 2003). The authors of this model, Cameron and Quinn, based on their research, identified four basic cultures that can refer to the business ecosystem: clan, adherence, hierarchy and market (Cameron et al. 2003, p. 40). The first two cultures are based on values such as flexibility and freedom of action, while the other two are based on stability and control. The efficiency of such an ecosystem is strongly influenced by culture, it is the result of the efficiency of many cultures, where non-dominant organizations are imposed with culture or values of dominant participants in the relationship. The assessment takes into consideration the orientation to internal affairs and integration, the orientation to the environment and diversity, as well as stability and unity.

In the model interest groups the organizational efficiency is perceived through the level of fulfilling expectations of the key stakeholders. The ecosystem includes not only organizations highly oriented on highly economic targets, but also those whose interests are linked to other goals, such as ecological and social. In this case, the ecosystem is a medium of various interest groups, such as owners, customers, suppliers, government and social organizations, etc. The condition for the efficient functioning of the business ecosystem is not only competition but also competence and cooperation between organizations, the level of fulfilling the expectations of internal stakeholders, the relative stakeholders' strength.

On the other hand, the model of ability to acquire resources encompasses a broad definition of resources, including both material resources - traditional (money, raw materials, facilities, equipment and labour) and intangible resources - intellectual (knowledge, ideas, reputation). This model is based on inputs, and the efficiency of this approach is measured by the ability of the organization to acquire rare and valuable resources, primarily intellectual ones, from the environment, the ability of decision-makers to recognize environmental constraints, and the responsiveness to environmental changes (Greve 2011). What is important for the assessment is the organization's ability to acquire rare and valuable resources from the environment.

The model of social justice implies equality of following social and market rules, emphasizing the needs and expectations of the least favoured and even excluded groups of stakeholder (Keeley 1978). In the efficiency evaluation the following are taken into account: distributive justice (material equality, the need for reallocation of income), commutative justice (the impersonal market process), exclusion of all political control, needs and expectations of least-favoured stakeholders, material equality, hierarchization of stakeholders' needs.

The multidimensional nature of the concept of efficiency influenced the development of various organizational efficiency models in practice. It is necessary to agree with the views of Bratnicki and Kulikowska-Pawlak, who recommend the use of criteria derived from many models when evaluating the organizational efficiency

(Bratnicki and Kulikowska-Pawlak 2013, p. 54). Following such thinking, the authors suggest to put eight organizational models described in this paper together to describe the efficiency of the business ecosystem.

5 Factors of Business Ecosystem Efficiency in Business Incubator as an Exemplary Ecosystem

Considering the assumed purpose of identifying the factors of business ecosystem efficiency and taking into account the developed classification of efficiency models along with their determinants, empirical research was conducted within the business incubator functioning in Wrocław, and being an example of a real ecosystem. The study was conducted in January–May 2017 on a sample of 48 Polish companies from the SME sector concentrated in the studied business incubator. After rejecting incomplete research questionnaires, the results were further analyzed for 40 entrepreneurs. The selection of the sample was deliberate and therefore the results should be treated with caution and as hypotheses, since the data collected do not allow for a clear verification of the meaning of the factors and are fragmentary. Nevertheless, the research can be considered a survey that may contribute to further discussion.

For the purpose of the study, 8 specified efficiency models were synthesized and factors were listed that could be considered to influence the efficiency of the business incubator, i.e. de facto the ecosystem studied. The selection of factors was made by elimination, based on a survey and interview verification and the simplicity of understanding the individual concepts by the respondents. The specified factors were grouped within three levels of the assessment of the ecosystem efficiency corresponding to three areas of efficiency: i.e. effectiveness, economy and operational performance. The aim of the study was to isolate the efficiency factors of the examined ecosystem without linking them with the developed efficiency classifications so that, based on the results obtained, the results are not burdened with the features of the individual models.

Organized and grouped efficiency factors were included in the research questionnaire, and respondents were asked to identify the most important efficiency factors of the ecosystem in which they functioned. The respondents were tasked to grade the importance of the factors being assessed. The five-grade scale was used, whose extreme responses were defined as lack of impact and very high impact. The figures in Table 1 show the percentage of indications for responses that have a high impact and a very high impact.

According to the data analysis, the surveyed representatives of the incubator companies highly evaluated two factors: effectiveness of the operation through the perspective of business intermediation and the office-organizational support (54% of all respondents). From the economic point of view, as a factor of success of the business ecosystem, which was the examined business incubator, there has been distinguished legal and administrative assistance, as well as offering favourable rents (67% in total). From the perspective of operational performance, the respondents pointed out professional support for development on the market and modelling business behaviours (47% in total).

Table 1. The factors of the efficiency of the examined business ecosystem with their importance described in percentage according to surveyed respondents [own research]

Efficiency levels	Factors of ecosystem efficiency	The frequency of the factor's importance
Effectiveness of the ecosystem	Business intermediation	29%
	Training support	13%
	Legal support	17%
	Entrusting	1%
	Office-organizational support	25%
	Location	15%
Economy - assessed based on supporting new enterprises in achieving their goals (growth, development, income)	Legal and administrative assistance	33%
	Offering favourable support loans	12%
	Offering favourable rents for new organizations	34%
	Help in business intermediation	13%
	Matching the training offer to the organization's and market needs	8%
Operational performance of the ecosystem	Activities integrating companies within the incubator and market	14%
	Professional support for the development on the market	26%
	Modelling business behaviours	21%
	Informative-educational activities	14%
	Personnel qualifications	10%
	Trust = Honesty	15%

The obtained results confirmed the authors' assumptions that the classified organizational efficiency models would not be adequate to assess the ecosystem of the business incubator. For these reasons, it was justified to propose a new model for assessing the efficiency of the ecosystem and the bases for the concept of the relational model were formulated.

6 Conclusions - the Proposal of the Assessment of the Business Ecosystem Relational Efficiency

Taking into account the conducted research, interviews and literature analysis, it is recommended to introduce alongside the classified eight models of business ecosystem efficiency also the relational model, which is the authors' proposal. It has been noted that the binder of the arrangement that is business ecosystem is the relationship between the organizations involved. The basis of these relationships is sympathy, then co-exchange of values, co-creation of new values, and sharing of new values. Relational efficiency requires establishing particularly stable relation between organizations in the business ecosystem. This stability is based on the acceptance, satisfaction and uniqueness of each organization that contributes to the structure of the business ecosystem. The concept of relational efficiency was defined as the sum of sympathy efficiency (EWo), efficiency of co-creation (EWs), efficiency of co-exchange of values and experiences (EWs), and sharing (EWd) new values and experiences.

"Sympathy" understood as a moral feeling and referring to the ability of a human being to understand the needs of other people in the process of exchanging goods and services. By operating on the market and making moral judgments, both the individual and the organization must take into account the behaviour of the others in their environment. For organizations that form a business ecosystem, the trust or similar evaluations and moral judgments of the stakeholders in this organization are important to build a partner relationship in business for the purpose of exchanging resources and creating new values (Smith 1989, pp. 230–223).

Sympathy could be measured by the following: the amount of mutual transactions within one ecosystem and the amount of business co-operation measured by the number of recommendations, planned and conducted projects, organised business events and co-operation meetings, the number of co-operating advertisements, the number of acquired investors, etc.

Another key element of relationship in the business ecosystem is co-creation of values. This value does not originate from a physical product or a communication network and information technology supporting the ecosystem, or even from the social network or skill network, but derives from the experience of co-creation, in which a particular organization takes part at a specific time, place and in the context of a particular event (Prahalad and Ramaswamy 2005, p. 21). The co-creation experience arises from the interaction of organizations that shape the ecosystem of the business community. Each participating organization is equally interested in defining the relationship and the context of events occurring as its result. The key elements of the discussed co-creation process are: dialogue, access, risk assessment, transparency - DART (Prahalad and Ramaswamy 2005, p. 31).

What can be the measurement on co-creation is the share of profits generated by individual companies, the number of companies that make up the ecosystem, the number of patents that are the product of the co-operation of companies in the ecosystem, the number of submitted and conducted projects, the number of signed cooperation agreements, the amount of advice on supporting the development of the ecosystem entities, and advice on the strategic development of the market, the number of companies registered with help of the incubator's employees etc.

The co-exchange of values refers to both material and non-material resources between participants in the business ecosystem. The values conveyed are, among others: money, things, raw materials, materials, as well as intangible resources to which we include information, knowledge and values related to organizational culture - emotions, trust, empathy, prestige and credibility. Sharing values in the business ecosystem, i.e. sharing the organization's newly created values, is a part of the so-called sharing economy. By using the available IT resources (e.g. online platforms) organisations jointly and agreeably use new assets, resources, time, skills or capital without transferring ownership. In such an arrangement, all organisations in the business ecosystem are co-creators and consumers of the values they have established, and the relationships between them build a new space of market opportunities and organizational skills for the future (Greve 2011).

The measure of co-exchange could be the number of interactions between the participants in the ecosystem, the amount of training provided, the amount and value of loans from dedicated support funds incurred by the ecosystem entities, the amount of consultations on the possibilities of cooperation, the number of publications and studies, the recommendations and the study reports, the size of the proposed investment sites, the number of proposed offices for rent etc.

Sharing values in the business ecosystem, i.e. sharing the organization's newly created values, is a part of the so-called sharing economy. By using the available IT resources (e.g. online platforms) organisations jointly and agreeably use new assets, resources, time, skills or capital without transferring ownership. In such an arrangement, all organisations in the business ecosystem are co-creators and consumers of the values they have established, and the relationships between them build a new space of market opportunities and organizational skills for the future, and management accounting in its most basic tool assesses the efficiency as well as the model concentrated on possibilities to acquire resources and on the level of their use (Greve 2011).

Adopting a systemic perspective means focusing on such elements of the system as: inputs, transformations, outputs, and relationships between these elements. The three elements listed above are highlighted by different authors (Hall 1999, p. 252), nevertheless there is a need to study the efficiency of organizations from the perspective of acquiring resources from the environment, of transforming the system's merits into its products and of system's outputs into the environment. Observing the management accounting tools, it should be noted that the cost of operations (especially operational) complies with this interpretation.

It requires the use of a system of measures, both absolute (in monetary terms these are e.g. resource costs) and nominal (such as the profitability of a given customer), the number of documents prepared by employees for registration and support of business entities, the number of consultations related to selecting the organisational-legal form of planned business activity, the number of consultations and support during the process of preparing business plans, the amount of SWOT analyses conducted, the number of simulations of selection sources of financing, the number of consultations concerning the profile of conducted business activity etc.

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An Analysis of Selected Correlations Between Microenterprises' Financing and Its Characteristics. A Case Study

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Abstract. The article is devoted to analysis of several aspects of financing methods of microenterprises created under the Human Capital Operational Programme in the Fundacja Inkubator – a non-profit foundation form Lodz, one of beneficiates of the Human Capital Operational Programme in Lodz region. The issues concerning micro entrepreneurs' preferences of financing methods, importance of particular factors associated with external financing selection, problems with getting financial support and their statistical correlation with firms' characteristics and survivability were analyzed. The analysis was based on the data from a Computer Aided Web Interview (CAWI) survey, which was conducted among the participants of several projects, realized by the Fundacja Inkubator. The survey covered 146 microenterprises out of more than 400 firms created in 13 projects completed between years 2008 and 2015 under Measure 6.2 Support and promotion of entrepreneurship and self-employment and Sub-measure 8.1.2. Support for adaptation and modernization processes in regions under the Human Capital Operational Programme.

Keywords: Human Capital Operational Programme · B-N_X_K aggregate · Microenterprises' survivability

1 Introduction

The researches of the ability to remain alive or continue to exist are conducted in various fields, starting from ecology and medicine through actuarial science and economy, management, up to engineering and military science. Especially there are a lot of publications concerning several aspects of micro-, small and medium enterprises survivability (see e.g. [2, 5, 7–9, 12, 13, 16]). The other question concerns microentrepreneurs'

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preferences of financing methods and their correlation with firms' characteristics. There are also a lot of studies devoted to this problem (see e.g. [3, 10, 11]). The research presented below include Computer-Assisted Web Interviewing (CAWI) survey of 146 microenterprises created in a few projects under the Measure 6.2 (Support and promotion of entrepreneurship and self-employment) and under the Sub-measure 8.1.2 (Support to adaptation and modernization processes in regions) in the years 2007–2013 under the Human Capital Operational Programme carried out by the Fundacja Inkubator, which is one of beneficiaries of the program. Within these projects more than 400 persons from Lodz region received grants to start their own businesses. The survival rate of these newly created microenterprises is relatively high (higher than average startups' survival rate in Poland and higher than average survival rate of startups created under the Human Capital Operational Programme in Lodz region – see Fig. 1.

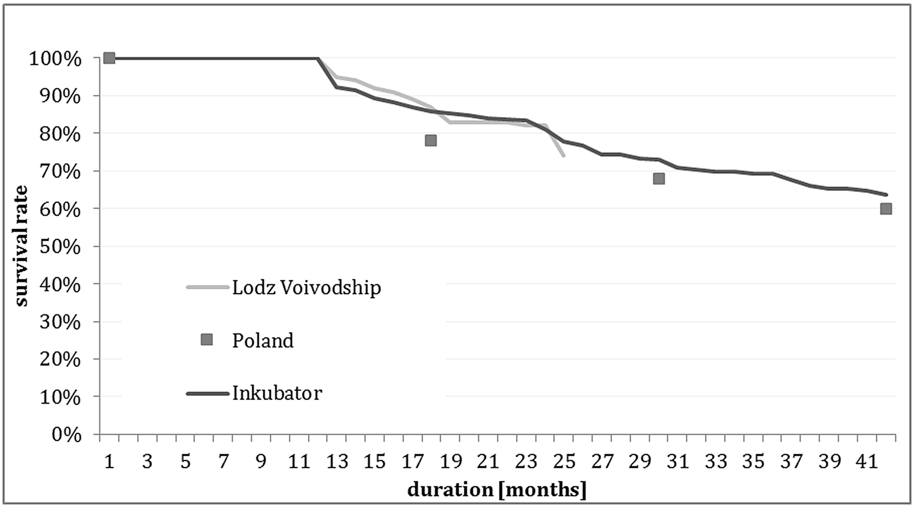

Fig. 1. Comparison of survivability of small enterprises between Poland, Lodz voivodeship, and microenterprises created under the Human Capital Operational Programme in the Fundacja Inkubator. Source: own research.

To allow the comparison, only microenterprises that have existed for at least 42 months have been shown in the Fig. 1. Table 1 shows detailed information about all companies created in 13 projects. For all of them since the moment of creation, a period of at least 2 years has elapsed (for the longest working over 6 years).

Fundacja Inkubator's microenterprises survival rate is shown in the Fig. 2.

The graph also shows some special moments when there is an increased tendency to liquidate companies. The first one occurs after 12 months, which is related to the obligation imposed by the project conditions to maintain the company for at least 12 months (for the WB2 project for 24 months). The second moment of the increased dynamics of companies liquidation was the 24 months since their establishment - in

Table 1. Fundacja Inkubator Companies' survival rate in subsequent years since the creation shown by particular projects. Source: own research.

	Survival rate after X years				
Project	X = 2	X = 3	X = 4	X = 5	X = 6
CNB	87%	85%			
DDB	80%	66%	54%	52%	
KB	64%	52%			
MB	84%				
MFMP	85%	77%	65%	65%	
MNS	79%				
NS	78%	70%			
PMBTT	93%	87%	67%	50%	50%
PNS	68%	54%	46%		
WB	74%	63%	52%	37%	33%
WB2	92%	72%	72%	56%	56%
WB50	92%				
ZSS	85%	81%	58%	58%	
Overall	82%	67%	59%	53%	49%
Number of companies	533	434	245	217	108

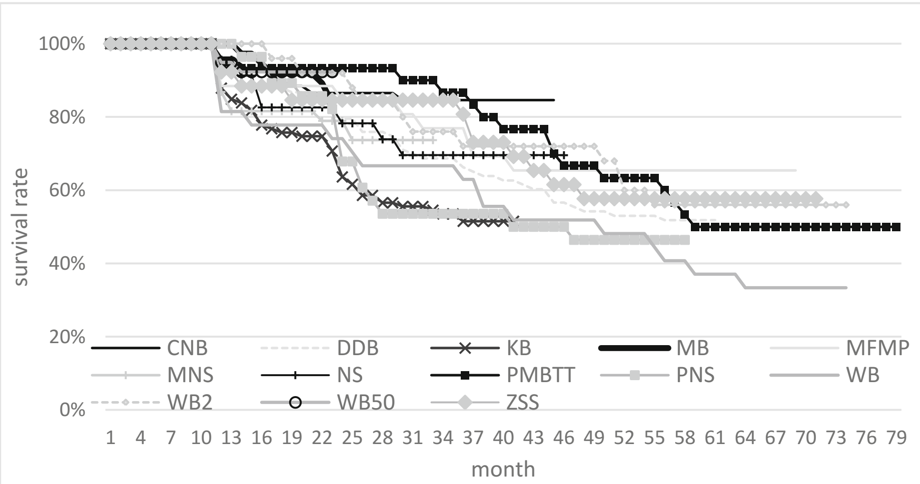

Fig. 2. Fundacja Inkubator's microenterprises survival rate. Source: own research.

one of the projects, this was due to the above-mentioned condition of maintaining the activity, while the rest was likely to incur increased insurance expenses.

2 The Survey

The survey invitation was sent by email to more about 400 Fundacja Inkubator's microenterprises. The questionnaire was available on the web for a few weeks and 146 microenterprise owners decided to participate in the survey. The most of them represent still living enterprises (see Fig. 3).

The sample structure (place of residence, age, sex etc.) was similar to the whole population structure except education (the better-educated people better responded to the questionnaire – see Fig. 4).

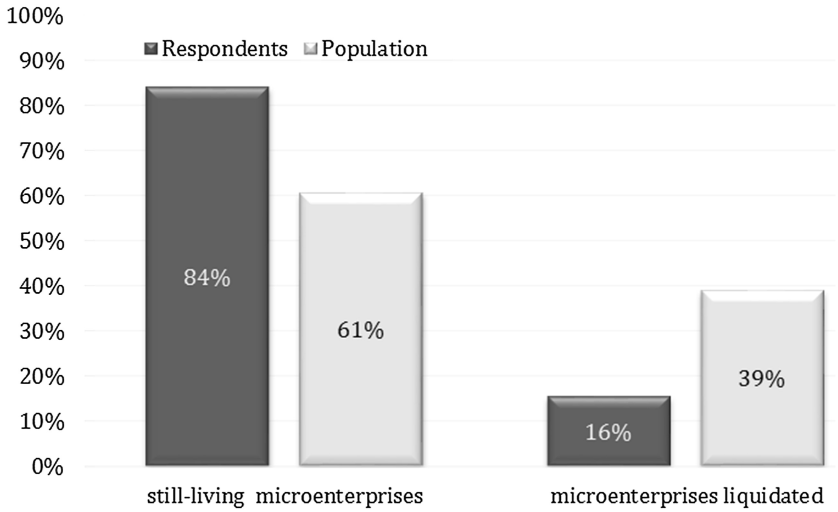

Fig. 3. Comparison of the population and CAWI responders structure. Source: own research.

Detailed information about the whole population and the survey sample may be found in [14, 15]. Although the main goal of the research concerns the microenterprises' survivability the financial aspects are also analyzed. In the CAWI survey, which was consisted of 22 questions, a set of questions (numbered 13–14d) concerned financial aspects of the microenterprise was included:

13. Was the financial support to start a business sufficient?
    - yes – the financial support was sufficient to start a business
    - there was the need for raise new founds
    - there was the need for investment reduction
14. Have you used other financial sources to start a business?

14a. Please indicate which additional sources of funding you have used

- Own resources
- Loan from family

- Loan form friends
- Bank credit
- Leasing
- Local government subsidies
- Other

14b. What is the most important for you when selecting an external source of financing?

- Cost of funds
- Recommendation by friends
- Amount of the one-time installment to be repaid
- The amount of funds available
- Necessity and amount of own contribution
- Speed of receiving funding
- Credibility of the financing institution
- Availability of information about the source of funding
- Number of required documents

14c. Have you encountered any problems with applying for external funding?
14d. What problems have you encountered with applying for external funding?

- Very large number of documents to fill
- Incomprehensible language of documents
- Lack of a person to explain and help in completing the application
- Too high requirements for the applicant
- Lack of communication
- Other

3 Results

For 146 answers in question (13) 68 microenterprise's owners declared the need to raise new funds, 24 - stated that it was necessary to reduce the planned investments and 54 persons declared that financial support to start a business was sufficient, however in question (14) only 54 persons declared the use of additional sources of funding (92 persons did not use additional funds) so only these 54 persons answered questions (14a)–(14d). Interestingly microenterprises that owners declared the need to raise new funds have higher survivability (91%) then the other (80% in the group of owners declared that financial support to start a business was sufficient and only 75% in the group with the investment reduction – see Fig. 5).

Concerning question (14a) - 50 microenterprise's owners used their own resources, 23 declared use loan from their families, only 14 used bank credit and 7 persons declared use of other financial sources.

The most important factor determining the choice of financing method in question (14b) was cost of funds (41 persons marked it as "very important"), more than half of responders considered as "very important" also: the credibility of the financial

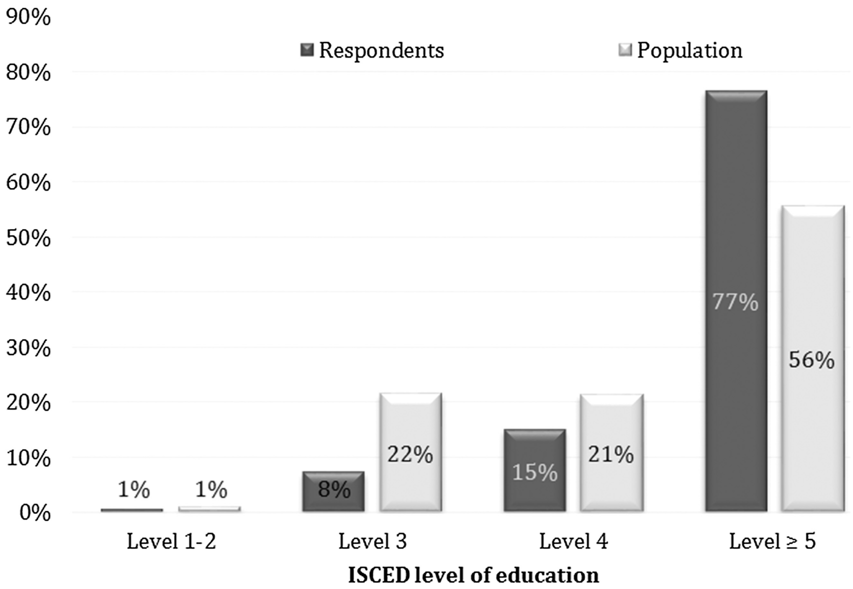

Fig. 4. Comparison of the population and CAWI responders' level of education ISCED characteristics (see: [6]), where level 1 – Primary education; level 2 – Lower secondary education; level 3 – Upper secondary education; level 4 – Post-secondary non-tertiary education; level ≥ 5 – Tertiary education. Source: own research.

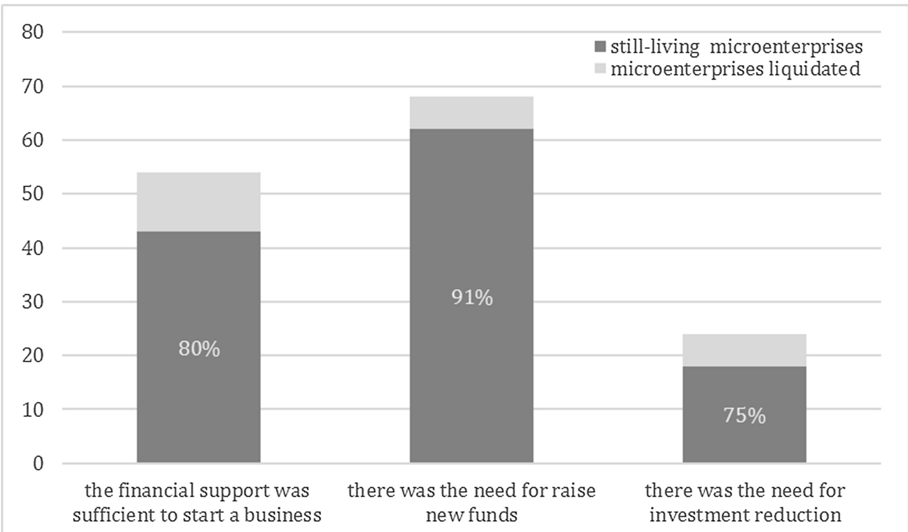

Fig. 5. Figure answers for the question about sufficiency of the financial support to start a business in living and liquidated microenterprises.

institution, the amount of funds available, the speed of receiving funding. As a non-important were recognized: the recommendation by friends and number of required documents.

In question (14c) only 11 of 54 microenterprise's owners encountered problems with applying for external funding (14c). The most important problems declared in question (14d) were: too high requirements for the applicant and a very large number of documents to fill.

In the next step the existence of a stochastic relationship between the answers to the individual funding questions and the other features of the surveyed companies was investigated. For this purpose, appropriate conditional distributions were compared and the Cramér's phi intercorrelation coefficient was calculated, given by the formula (1):

$$\mathrm{V} = \sqrt{\frac{\varphi^2}{\min(k-1, r-1)}} = \sqrt{\frac{\chi^2}{\mathrm{n} \cdot \min(k-1, r-1)}} \tag{1}$$

where:

φ^2 is the phi coefficient.
χ^2 is derived from Pearson's chi-squared test.
n is the grand total of observations.
k is the number of columns.
r is the number of rows.

The most interesting relationships are shown below:

- Between education and the availability of information - the less well-educated persons considered information as important (phi = 0.41);
- Between the responder's subjective importance of a single loan installment and belonging to a group Total Business Economy except Financial and Insurance Activities aggregate (based on Eurostat classification NACE rev. 2 i.e. B-N_X_K - see. [4]) – (phi = 0.38); Responders included in the aggregate consider the amount of the installment to be less important, the persons outside the aggregate consider the amount of the installment to be more important;
- Between assessing the necessity of making a personal contribution and answering one of other questions: "did your previous professional experience relate to the current activity"; Persons whose previous work experience was not related to their current business assessed the need to contribute their own contribution as less important (phi = 0.35)
- Between assessing the speed of receiving funding and belonging to the B-N_X_K aggregate (phi = 0.35). Responders included in the aggregate consider the speed as less important, the persons outside the aggregate consider it to be more important;
- Between the assessment of the need to contribute own contribution and belonging to a to the B-N_X_K aggregate (phi = 0.28). Responders included in the aggregate consider it as less important than the others
- Between the need to contribute own contribution and business owner's gender (phi = 0,32). Women recognized the need as less important;

- Also, the fact of living in the countryside or in the city differentiated the questioned microenterprises' owners in the context of assessment of elements: cost of funds raised and the availability of information on the source of funding (phi = 0,31 in both cases).

4 Summary. Directions for Further Research

The most interesting conclusion seems to be the correlation between appreciation of financial support as insufficient and high survivability and a few correlations distinguishing responders belonging to Total Business Economy except Financial and Insurance Activities aggregate. Concerning the first conclusion: one might wonder what kind of relationship this is? Whether it was easier to get additional funding for companies that were (correctly) considered as promising by organizations that provide such funding or additional funding has allowed businesses to stay on the market? This phenomenon needs confirmation in wider research.

Concerning the second one: belonging to the B N_X_K aggregate seems to be one of the determinants that differentiate financial needs of particular microenterprise. The explanation might be related to fact that a big part of enterprises outside the aggregate (such as e.g. consulting services, advocates, private medical practices etc.) have a relatively smaller costs, so factors like the speed of receiving funding are less important to them comparing to firms inside the aggregate, especially that using "low price quantity" strategy (see e.g. [1]) with big costs, big turnover and small profit per unit, but the correlation also should be confirmed in wider research.

The detailed discussion of survey results and research concerning modeling of the microenterprises survivability and its key success factors will be published in the near future.

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Management of Organization

Context Specification in Support of Business Processes and Knowledge Management Integration

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Abstract. Applying a process approach in organisation managing and supporting it through knowledge management systems requires finding a way to combine both approaches. Especially in the case of creating information systems that would support them. In order to be successful in an organisation, it is necessary to consider the organisational, technical and social aspects in the construction of such systems. One of the theories of the development of process oriented knowledge management is the use of context in the process of modelling such a solution. Designing business process oriented knowledge management support systems requires indication of methodological basis for the development of such systems. The aim of this paper is to analyse the definition of the operation context of a business process oriented knowledge management system. The paper presents elements of a proposed methodology that refer to developing the context of knowledge usage as an element of a business process and IT system.

Keywords: Context · Business process · Knowledge management system · Integration

1 Introduction

Integration of knowledge management as part of systems designed to support business processes is one of key aspects of the development of the theory of knowledge management systems [1]. As pointed out by Grambow et al. [2], the main problem of KM systems is "providing the required knowledge to the right person at the right time for dealing with the right situation". IT technologies are one of key factors of successful use of KM in organisations [3, 4].

In this area, KM systems should facilitate making contextual knowledge available within a performed business process [5]. This, however, gives rise to a range of problems such as [2]: the need to automatically obtain the context from the environment and classify it with respect to the current situation, to automatically process contextual data in order to respond to changes in the contextual conditions and to integrate contextual data within the process. One of the concepts that may help to solve these problems is the use of the autopoietic approach in the process of designing and building such systems [6, 7]. In this approach, the knowledge contained in knowledge

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management systems can be directly integrated within a performed business process or processed by the autopoietic system in the first place. Only after it has been processed, it is used within a business process. As pointed out by Zacarias et al. [8] adaptive and agent-based workflows are enhancing workflow's flexibility. The research undertaken in the paper deals with modelling of relations between a business process and a knowledge management autopoietic system and is continuation of the author's research [5, 6].

The article presents the initial stage of constructing the support system's context integrating business processes and knowledge management systems. Author's previous research pointed out that building the process oriented autopoietic knowledge management support system requires reference to the three stages of its construction:

1. Analysis and development of a business process – this is a stage connected with designing a business process. The approach uses BPMN diagrams as a basis for defining a business process.
2. Identification of organisational knowledge resources – this stage refers to diagnosing knowledge that will be used to support the performance of a business process and used by an autopoietic system.
3. Design of process oriented autopoietic knowledge management system - this stage involves definition of the design of an autopoietic system.

In this article the first two stages and their impact on the third stage will be shown. The aim of this paper is to analyse the process of defining the context of the operation of a business process oriented knowledge management system using an example of the author-applied methodology for designing such systems. The first and second chapter will present the theory of the development of the context of IT systems' operation. The third chapter will present selected stages of designing the operation context of the author-developed methodology for building a business process oriented knowledge management support system. The fourth and fifth chapter will provide an example and evaluation of its use.

2 Aspects of Modelling the Context of a System's Operation

The development of autopoietic systems requires addressing a range of characteristics possessed by such systems. Based on [9–14], it can be stated that such systems should be subject to division into a range of autonomous sub-systems that operate independently and have clearly defined boundaries. The systems should be characterised by self-production, self-organisation, auto-adaptability and self-referentiality. Additionally, they should use organisational knowledge and generate necessary knowledge in subsequent cycles of their use to be integrated with the organisation's knowledge. Such features of autopoietic systems require that the context of knowledge usage during the design is addressed in two ways. On the one hand (as is the case with process oriented knowledge management), there is the context of knowledge use within a business process, while on the other hand - the context of knowledge use as part of autopoietic systems. The problem of defining the context (apart from knowledge management, quality management, information coordination and processes automation) is one of key aspects of building process oriented knowledge management systems [2].

Referring to the basic concepts of data, information and knowledge, knowledge can be defined as information used in a certain context. Such contextual knowledge can be viewed as knowledge that is relevant and can be used to understand a decision-making problem in certain circumstances [15]. The aspect of information usage in terms of IT solutions refers to the use of information to perform certain tasks which have been assigned to them or which they should support. In the literature of the subject, we can find proposals to divide knowledge about context into contextual knowledge and proceduralized context [16]. The first type of knowledge refers to general knowledge that enables the identification of the context and definition of actions that an IT system or a decision maker can take. It constitutes a kind of a background for decision-making processes which specifies the scope of possible actions. The second type of knowledge is knowledge about activities and related procedures that can be performed based on identified actions. Both these types of knowledge can be used in the process of modelling knowledge about the user and actions that can be undertaken.

3 Stages of Context Specification

The author's current research is concerned with the use of autopoietic systems considered against the background of the theory of software agent societies in supporting knowledge management processes in organisations. The author's research analysis of methodologies for designing software agent societies pointed out a range of problems related to their use in supporting knowledge-based organisations [17]. Against this background, a methodology for designing such systems has been proposed [5, 18, 19]. This chapter will present only the stages connected with the process of defining the context of using such a system and the context of using knowledge.

3.1 Context of a Business Process Supported by an Knowledge Management System

The methodology proposed by the author deals with the integration within the business processes of the codified knowledge of the organization [19]. To this end the first stage "1. Analysis and development of a business process" is associated with the process of developing a BPMN diagram, which specification is based on the "3.1 Identification of the context of usage" stage and "2. Identification of organisational knowledge resources" is extended by the resources of organisational knowledge.

Figure 1 shows the main stages of this process and relationships between the individual stages. The arrowhead shows the initiating direction of the information flow between the stages. The presented methodology assumes possibility of returning to an earlier stage if it is diagnosed as uncompleted.

The red line (the relationship [1.4]-[3.1.1]) refers to the context of a business process use. In the case of using an knowledge management system, the system is triggered through initiation of a specific task of a business process or an event in this

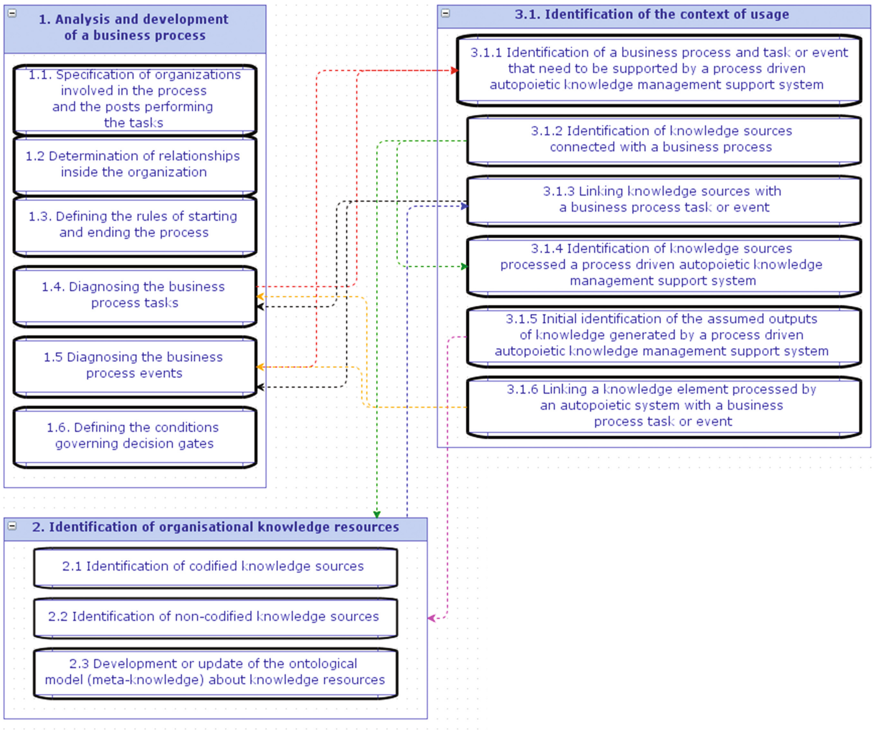

Fig. 1. Context of a business process in the proposed methodology

process. Thus, the designer's task is to initially define which knowledge resources will be associated with the task or the event (the green line - the relationship [2]-[3.1.2]). The stage of an organisation's knowledge identification, related with stage 2, has been intentionally omitted. Additionally, the designer may indicate at this stage which knowledge resources will be initially made available to the knowledge management system (green line). In the next stage, the designer's task is to define which elements of organisational knowledge will be directly made available to the user during the performance of the business process (black line - relationship [1.4,1.5]-[3.1.3]) or will be directly used during defining the conditions of events (black line). While defining the context of using the knowledge management system, the designer's task is to indicate what knowledge will be generated by the autopoietic system further. For that purpose, the organisational knowledge resource should be extended to include the definition of knew knowledge, which will be stored by the knowledge management system (Magenta line - relationship [2]-[3.1.5]). As a result, the newly-defined resource of knowledge generated by the knowledge management system is made available as part of the business process as an element of the task or event (orange line - relationship [1.4,1.5]–[3.1.6]).

3.2 Context of Knowledge Use in an Autopoietic System

When building an autopoietic system, it is necessary to indicate the context of using knowledge as an element of autonomous components of such a solution. Figure 2 presents the relationships between the elements of the developed methodology.

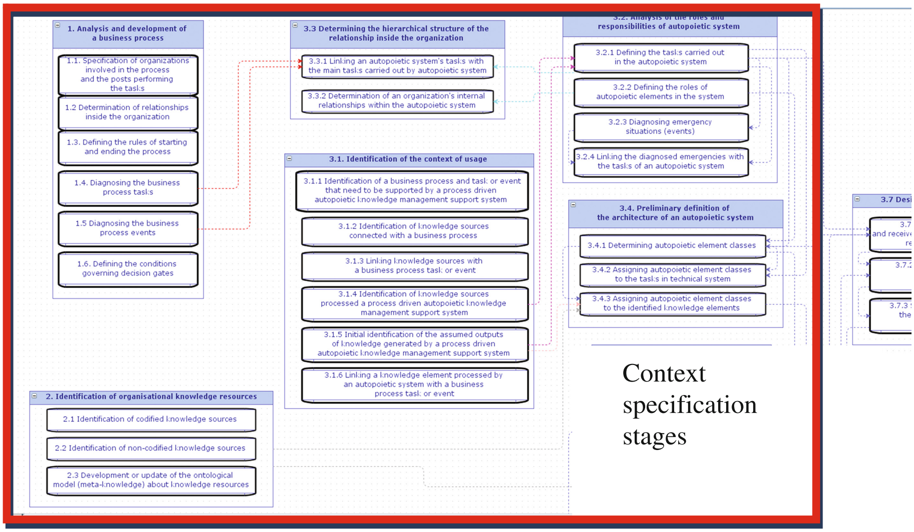

Fig. 2. Definition of the context of building an autopoietic system

The red and blue lines indicate stage 3.3.1 where an autopoietic system's tasks are linked with specific tasks and events of a business process. This example has been presented in paper [5] showing the base architecture of the system. Such linkage allows to define which areas of a business process should be supported by the autopoietic system and indicate the tasks of the autopoietic system that should be performed to meet informational needs. The informational needs have been shown by means of the pink line. The needs diagnosed during building the context of a business process are translated into the scope of tasks of the autopoietic system. Thanks to that, apart from the context of knowledge resources that are used by the system and generated by the autopoietic system, the designer can refer to the elements of a process that will be supported. Based on that, the autopoietic element of the knowledge management system is developed.

The elements presented here do no cover the whole cycle of building an autopoietic system. They only refer to the aspect of the context of its use in the area of knowledge and a business process. To illustrate the element of context modelling, an example of using a developed system will be presented.

4 Example System Implementation

The evaluation of proposed stages refers to the use of the proposed methodology in the process of modelling business processes connected with the actions needed to be taken by a person responsible for personal data protection in a company. This process requires knowledge about the company's organisational structure, its employees, technical resources, sets of processed data and other data specified in the personal data protection law. The process cannot be directly supported by an ERP system, as typical systems of this class do not have a module designed to support such tasks, despite the statutory requirement concerning data protection imposed on organisations. In the current version the software supporting the application of this method is based on BPMN Context modeller, Knowledge Resource modeller, User interface modeller and Autopoietic elements platform.

Figure 3 presents an example of a process instance for which an autopoietic system is modelled. This diagram was developed basing on the stages presented in Fig. 1 (stages 1, 2 and 3.1). The diagram proposed the extension of BPMN notation elements and artifacts used in this approach with the elements of the knowledge base, as described hereinafter.

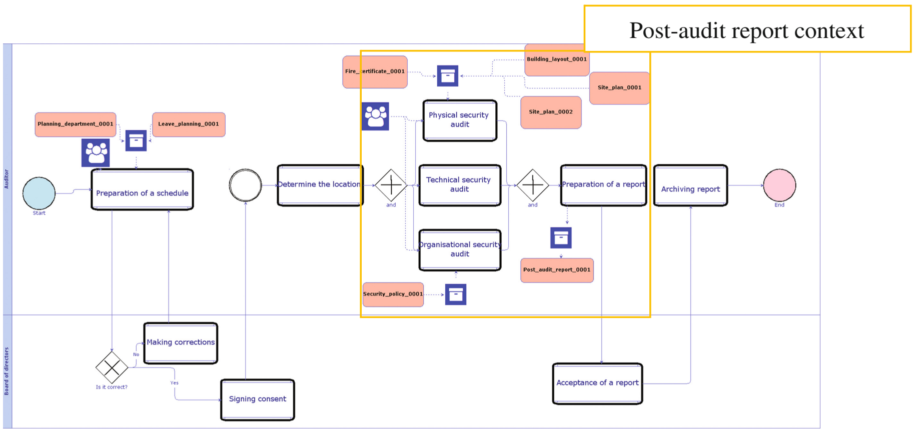

Fig. 3. The process of information security audit – extended BPMN notation

As was indicated in Fig. 3, the task of formal assessment of data processing compliance is extended by an autopoietic system. In this case, the task of the system is to provide the auditor with knowledge about employees, sets of data processed in the organisation, how these resources are linked with the place where they are processed and how these sets are linked with specific employees. Additionally, the task of the system is to indicate the legal base for such activity. The diagnosed data sets that are necessary to achieve that have been presented in Fig. 4. In the implemented solution the knowledge metamodel was divided into three parts. The first is the domain ontology, for which The Organisation Ontology was adapted (W3C Recommendation

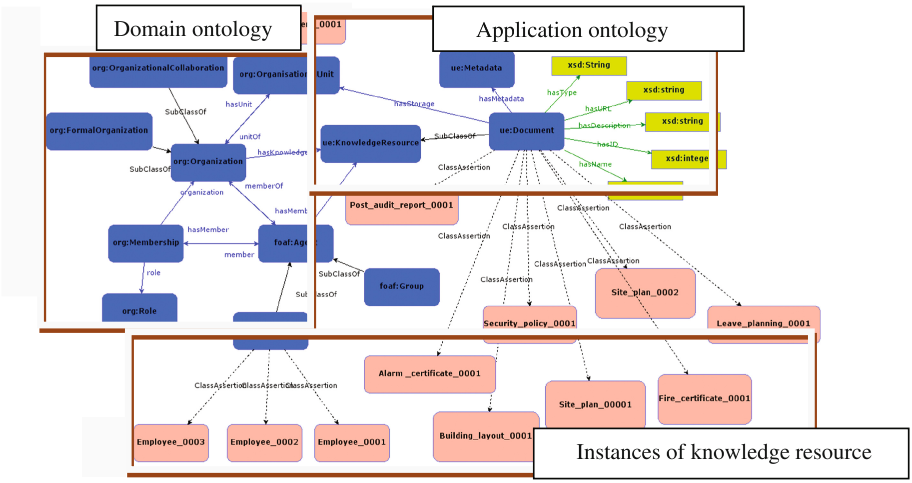

Fig. 4. Definition of ontology (in OWL2 standard) based on stage 2

from 2014) [20]. It provides interoperability of the developed model and its portability. It was expanded with application ontology elements defining the knowledge resources description. Red artifacts reveal example instances of knowledge resources i.e. building layout, site plan, certificate of the validity of inspections and systems. These objects are available from the user interface and autopoietic system level.

In order to indicate the context of using an autopoietic system connected with stages 3.3 and 3.2 (Fig. 2), it is necessary to indicate the relationship of knowledge resources of the business process stage and the tasks of the autopoietic system. For that purpose, diagrams of the autopoietic system's tasks (Fig. 5) is built. Figure 5 additionally reveals architectural elements of the developed system.

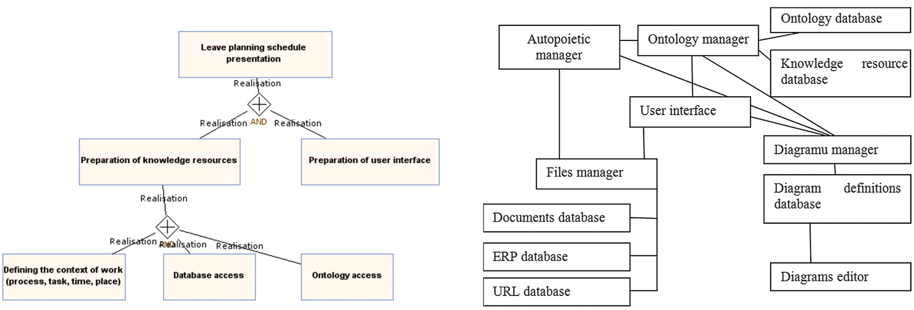

Fig. 5. Diagram of the system tasks built at stage 3.2.1 and system architecture

The lowest element of the architecture is a database which stores business data. This data can be mapped within a semantic server, which allows for semantic mapping of information resources. Apart from that, additional semantic definitions can be developed if a given resource is not represented in the database system. Figure 6 shows a user screen displaying knowledge elements.

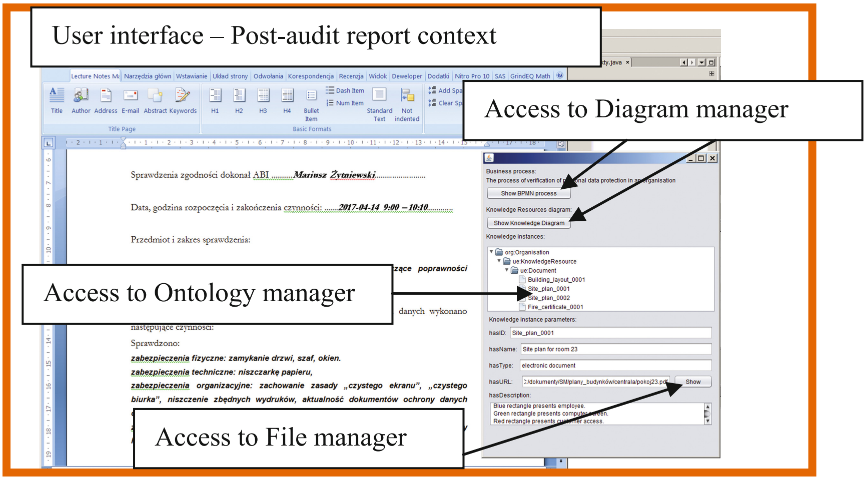

Fig. 6. User screen with appropriate resources of organisational knowledge

As a result, the elements of a business process oriented autopoietic knowledge management support system defined in this way support actions of the user responsible for implementing the indicated stage of a business process.

5 Implementation Results

The proposed process oriented knowledge management system context modelling method was used during the implementation of the presented system. Effects of the proposed approach implementation were:

- identification of 12 business processes related to the context of the audit's report preparation presented in the article.
- defining knowledge ontology, which will be further extended while defining further contexts of system use.
- identification of 27 knowledge resources regarding the context of the system operation proposed in the article.
- the inclusion of such defined knowledge resources and business processes to the knowledge organisation's portal.

As a result, it speeded up the process of audit activities by providing contextual knowledge to the auditor. In the case of "Preparation of the schedule" task, it's realisation time was shortened to a dozen or so seconds (previously, the stage lasted even a dozen minutes and required the involvement of personnel department along with audited department). The report preparation task was shortened to a few minutes, thanks to the auditor's direct access to knowledge resources (in the absence of irregularities). Earlier, the report preparation process lasted between 30 and 40 min. In addition to the results of the system's implementation, the main features of the proposed approach should also be highlighted here:

- extending currently used standards for describing business processes to include sources of knowledge that supports the performance of users' tasks (in the context of the process, place and time),
- enabling direct integration of organisational knowledge within any business processes taking place in an organisation within the scope of the process in which this knowledge should be used and the task that it supports,
- automating processes of assessing the functioning of KMSs in terms of their usefulness in supporting business processes,
- generating new organisational knowledge at the interface of business processes and knowledge management,
- using semantic mechanisms for knowledge description for easier integration of possessed knowledge with internal organisational knowledge,
- independent operation from used IT solutions and enabling integration of any KMSs and a process-oriented solution.

The presented pilot implementation of the proposed solution will be extended in author's further studies with evaluation elements of the system's impact on the user.

6 Conclusions and Future Work

Integration of knowledge management systems within an organisation's business processes is an important element of an organisation's operation. The approach to building a business process oriented knowledge management support system which has been presented in this paper can be used both in processes supported by an ERP system, extending knowledge obtained from such systems by additional knowledge.

The proposed approach for modelling business processes and their support by knowledge management systems can be extended with the use of codified knowledge by the autopoietic system. This research indicated the need to address a wider context of research, i.e. the methodological aspect of modelling such solutions, whose earlier aspects in the author's research referred to the application of the theory of software agent societies and their use in knowledge-based organisations [18, 21].

The theories, elements of the developed methodology and the example of the operation of the developed system, which have been presented in the paper, constitute continuation of the author's research in the area of the use of artificial intelligence in the process of supporting knowledge management in an organisation. The methodology presented in the paper can be used to support the process of integration of business processes and knowledge management systems in the context of integration of such solutions, which were addressed earlier by the author in works [5].

The next aspect of the research will be relation of the presented methodology (whose element of context development has been presented in this paper) to a life cycle of knowledge management systems and business process management systems.

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The Actual Nature of Lead Times in Supply Chains Following a Strict Reorder Point Based Approach

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Abstract. The aim of this research is to demonstrate that supply chains by their very nature will experience stochastic rather than deterministic lead times. The presented study focuses on simulating delivery lead times in supply chains, where each echelon is servicing the next downstream member from inventory. The aim is to highlight the need for increased research focus on supply chains with stochastic lead times. Through a simple numerical example we conclusively show that lead times in any real supply chain following a re-order point method must be stochastic even in the case where lead times between individual echelons are in fact deterministic.

Keywords: Lead times · Supply chain · Bull whip effect · Stochastic lead times

1 Introduction and Background

Supply chain management and the variation in inventory throughout supply chains have long been of interest for both academia and industry [1]. For several decades focus has been on the so called bull whip effect also known as the Forrester effect or somewhat misleading as demand amplification. Until the last ten years focus was more or less exclusively on how demand signals influenced the performance of supply chains and how this signal is distorted as it moves downstream in the chain. In recent years focus has shifted to supply chain optimization [2, 3] and on the analytical side to the impact of lead times first as deterministic [4] and later as stochastic [5, 6]. Bagchi et al. [7] show that lead time variation is a major source of uncertainty in inventory management and argue that a compounded lead time demand distribution is used. Chatfield et al. [8] note that there is a cascade effect in the supply chain when multiple neighboring supply chain members experience stock outs simultaneously. This cascade effect is the primary focus of the research presented in this paper. This research aims to investigate the nature of supply chains' lead times and how these will impact supply chains' performance.

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From literature [5, 6, 8–10] we know that only the mean (μ_{LT}) and variance (σ_{LT}^2) of the lead time distribution between echelons impacts the long run performance of the supply chain in the form of the bullwhip effect. In that sense it becomes interesting to investigate what the coefficient of variation is for the lead time distribution $\left(\frac{\sigma_{LT}}{\mu_{LT}}\right)$ and how it depends on the service level of the chain. Likewise from e.g. Do et al. [11] we also know that the shape of the lead time distribution impacts the time it takes for a supply chain to reach a steady state. Skewed lead time distributions result in longer time/more order cycles being needed to achieve steady state. For that reason it would be interesting to investigate what shape the lead time distribution will assume.

The remainder of the paper is structured as follows. First, a simple supply chain model is introduced. This model is used to estimate the lead time distribution observed by any given member of the supply chain. Second, we introduce a numerical example that is used to investigate how lead times are in fact behaving in such supply chains. Finally we provide a discussion of the results and the implications of these for research and practice before providing conclusions and avenues of further research.

2 A Simple Supply Chain Model

Let us assume a simple supply chain consisting of n members or echelons as illustrated in Fig. 1.

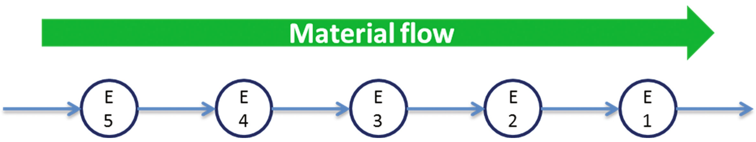

Fig. 1. Simple linear supply chain.

Each member E_j of the supply chain observes demand from the subsequent upstream echelon E_{j-1} and places orders at its subsequent downstream echelon E_{j+1} for which each member observes lead times. Each member of the supply chain follows a simple re-order point (ROP) method (as assumed in the vast majority of supply chain literature see e.g. Chen et al. [4]) and has a certain service level (SL_j). SL_j is also often referred to as Fill Rate and describes the fraction of demand (in volume) met without lost sales and back orders [12]. In practice this means that e.g. a service level of 0.98 would indicate 98% of all demand volume is satisfied from inventory. This corresponds to a 2% likelihood of not being able to satisfy demand from inventory. In the context of this research we for simplicity's sake assume that the lead time between each neighboring pair of echelons is deterministic and that each supply chain echelon has a constant known service level. We also assume that sales are not lost in case of insufficient inventory, but rather back ordered. This assumption means that any order not directly satisfied from inventory at echelon j must be fulfilled – i.e. it is back ordered and satisfied when possible. In this case it means that this particular demand will experience a lead time consisting of the lead time between several echelons instead of just between one pair of echelons. This behavior is illustrated in Fig. 2 and is normal behavior for supply chains where there multi-sourcing does not occur.

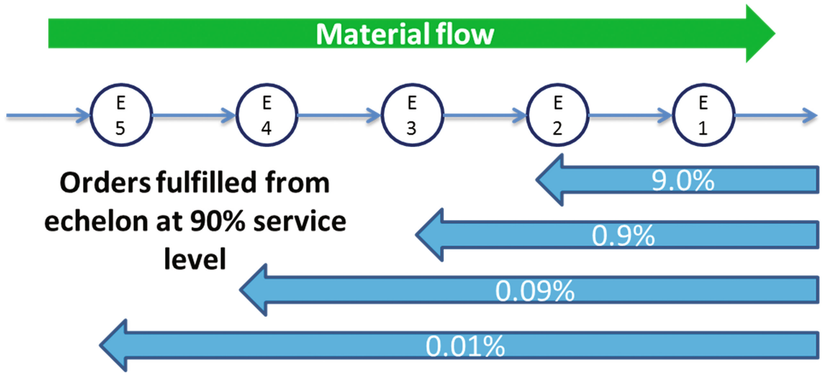

Fig. 2. Illustration of how far an order penetrates the supply chain before being satisfied from inventory.

As illustrated in Fig. 2 if there is a service level of 90% in all echelons, 90% of demand is fulfilled from echelon 1 directly, 9% is satisfied from echelon 2. This means that the lead time for satisfying demand is the combined lead time from echelon 2 to the customer for 9% of the demand. A step further one can see that 0.9% of the demand is satisfied from echelon 3 (making the lead time for the customer a combination of lead times between echelon E_3 and E_2, E_2 and E_1 and lead time from E_1 to the customer) and so on. With this in mind let μ_{LT}^{j} denote the lead time for delivery between echelons j and $j + 1$ and n denote the total number of echelons in the supply chain following the ROP method for supply replenishment. If the behavior of the supply chain is as listed above we get that $\tilde{\mu}_{LT}^{j}$ (estimated mean lead time at E_j) is as follows:

$$\tilde{\mu}_{LT}^{j} = \mu_{LT}^{j} \cdot SL_j + \left(\mu_{LT}^{j} + \mu_{LT}^{j+1}\right) \cdot \left(1 - SL_j\right) \cdot SL_{j+1} + \left(\mu_{LT}^{j} + \mu_{LT}^{j+1} + \mu_{LT}^{j+2}\right) \cdot \left(1 - SL_j\right) \cdot \left(1 - SL_{j+1}\right) \cdot SL_{j+2} \cdots$$

where SL_j is the service level at E_j and $1 - SL_j$ is the corresponding stock-out likelihood. This corresponds to that the mean expected observed lead time for the *j'th* echelon is depending on the stock-out likelihood in all previous echelons and the lead time between previous echelons. This makes practical sense, since it implies that orders not directly satisfied from inventory at E_j, are backordered and satisfied when possible by the previous echelons in the supply chain. It follows that large values of SL_k $(k > j)$ result in $\tilde{\mu}_{LT}^{j}$ depending primarily on the service level and lead time from echelons of lower order than k and any echelon further upstream can be dropped from the practical implications. Specifically it also follows that for any $SL_k = 1$ any echelon $k + 1$ or lower will not influence the lead time at E_j. In practice this indicates that the supply chain is always able to guarantee a maximum lead time to E_j. We can likewise determine that $\tilde{\sigma}^{j^2}_{LT}$ (variance of lead times at E_j) is:

$$\tilde{\sigma}^{j^2}_{LT} = \left(\mu^j_{LT} - \tilde{\mu}^j_{LT}\right)^2 \cdot SL_j + \left(\mu^j_{LT} + \mu^{j+1}_{LT} - \tilde{\mu}^j_{LT}\right)^2 \cdot \left(1 - SL_j\right) \cdot SL_{j+1} + \left(\mu^j_{LT} + \mu^{j+1}_{LT} + \mu^{j+2}_{LT} - \tilde{\mu}^j_{LT}\right)^2 \cdot \left(1 - SL_j\right) \cdot \left(1 - SL_{j+1}\right) \cdot SL_{j+2} \cdots$$

As can be seen $\tilde{\mu}^j_{LT}$ and $\tilde{\sigma}^{j^2}_{LT}$ depend on two parameters; the delivery lead time between echelons and the service level (or the stock-out probability) at each echelon.

Some interesting observations can be made on the boundary behavior of $\tilde{\mu}^j_{LT}$ and $\tilde{\sigma}^{j^2}_{LT}$. If $SL_1 = 1$ then $\tilde{\mu}^j_{LT} = \mu^1_{LT}$ and $\tilde{\sigma}^{j^2}_{LT} = 0$. If $SL_j = SL_{j+1} = SL_{j+2} = \ldots SL_k = 0$ for a chain of k members, then $\tilde{\mu}^j_{LT} = \sum_{i=1}^{k} \mu^i_{LT}$ and $\tilde{\sigma}^{j^2}_{LT} = 0$. These are the extreme situations corresponding to the first echelon having a 100% service level and all echelons have 0% service levels. Given that there are other echelons of higher order than j it follows that for $SL_j < 1$:

$\tilde{\mu}^j_{LT} > \mu^j_{LT}$ so the mean lead time experienced in E_j is always larger than the lead time between E_j and E_{j+1}.

$\tilde{\sigma}^{j^2}_{LT} > 0$ so that the lead times at E_j have non-zero variance, i.e. are not deterministic, but rather a stochastic variable.

From the behavior of $\tilde{\mu}^j_{LT}$ and $\tilde{\sigma}^{j^2}_{LT}$ we can also estimate the coefficient of variation (CV) of lead times $\frac{\tilde{\sigma}^j_{LT}}{\tilde{\mu}^j_{LT}}$ through numerical investigations. This is relevant as a normal threshold for considering a variable as stochastic rather than as deterministic would be a coefficient of variation of 0.05.

3 Numerical Illustration

In the following we present a simple numerical illustration of the principles outlined in the previous section. We allow for the following assumptions to simplify the problem and the analysis:

1. Delivery time between each echelon is 1 time unit i.e. we set $\mu^j_{LT} = \mu^{j+1}_{LT} = \mu^{j+2}_{LT} = \ldots = 1$
2. All echelons have the same service level at a given time i.e. we set $SL_j = SL_{j+1} = SL_{j+2} = \ldots$
3. The supply chain consists of up to 10 echelons.

Assumption (1) is used to remove the effect of longer lead times in either the beginning or end of the supply chain on the variation of the lead time in the final echelon and to ease comparison. Assumption (2) is used to limit the scope of the study. Further work will focus on investigating the behavior of $\tilde{\mu}^j_{LT}$ and $\tilde{\sigma}^{j^1}_{LT}$ when $\mu^j_{LT} \neq$

$\mu_{LT}^{j+1} \neq \mu_{LT}^{j+2} \neq \ldots$ and $SL_j \neq SL_{j+1} \neq SL_{j+2} \neq \ldots$. Assumption (3) is simply used to limit the size of the supply chain. In practice it is very unlikely to find a consistent supply chain of such a length where each echelon is pursuing a ROP based replenishment strategy. However, as the illustrations in Fig. 2 show this assumption is rather trivial as no orders will in practice penetrate that far through the chain unless very low service levels are encountered.

We let the service levels vary from 0.65 to 1 and calculate $\tilde{\mu}_{LT}^1$, $\tilde{\sigma}_{LT}^1$ and the skewness and kurtosis of the lead time distribution at echelon 1 at each service level.

As can be seen from Fig. 3 even at service levels at 0.99 through the whole chain the lead times are in fact acting as a stochastic variable with a *CV* of 0.1 and that for supply chains with service levels below 0.99 it misleading to assume that echelon 1 will in fact observe deterministic lead times. From the right hand side of Fig. 3 one can note that the lower the service level, the larger $\tilde{\mu}_{LT}^1$ is compared to μ_{LT}^1. An interesting phenomenon is that the relative effect on the mean observed lead time is relatively small for high service levels, whereas it is relatively large on the variance of the observed lead times. This is interesting as it indicates that there potentially is larger mistake in assuming deterministic lead times than in the underestimation of the actual observed lead times.

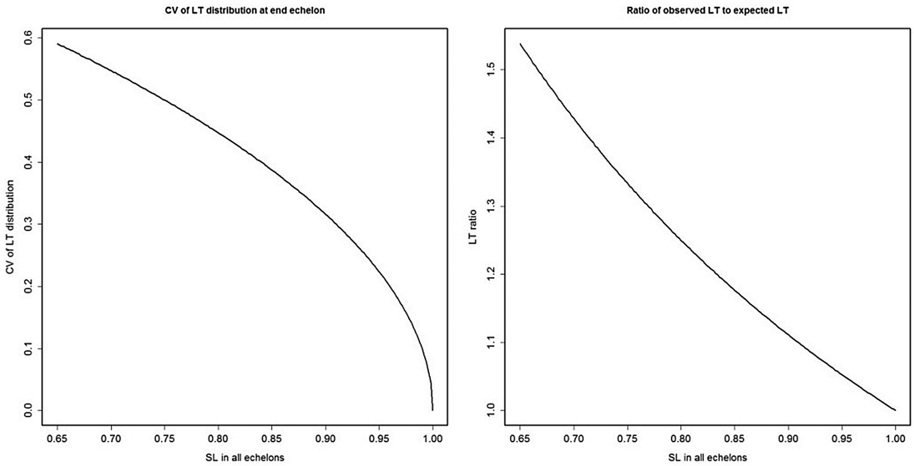

Fig. 3. left hand: $\frac{\tilde{\sigma}_{LT}^1}{\tilde{\mu}_{LT}^1}$ as a function of service level. Right hand: $\frac{\tilde{\mu}_{LT}^1}{\mu_{LT}^1}$ as a function of service level.

From Fig. 4 it can be seen that the lead times at the final echelon is always positively skewed (when the service level is the same through the whole chain) and has a positive kurtosis indicating peakness of the lead time distribution. That the lead time distribution is by definition positively skewed has the interesting implication that at any given time it is more likely to experience a lower lead time than the mean expected lead time and that for high service levels the lead time distribution is in fact exhibiting very

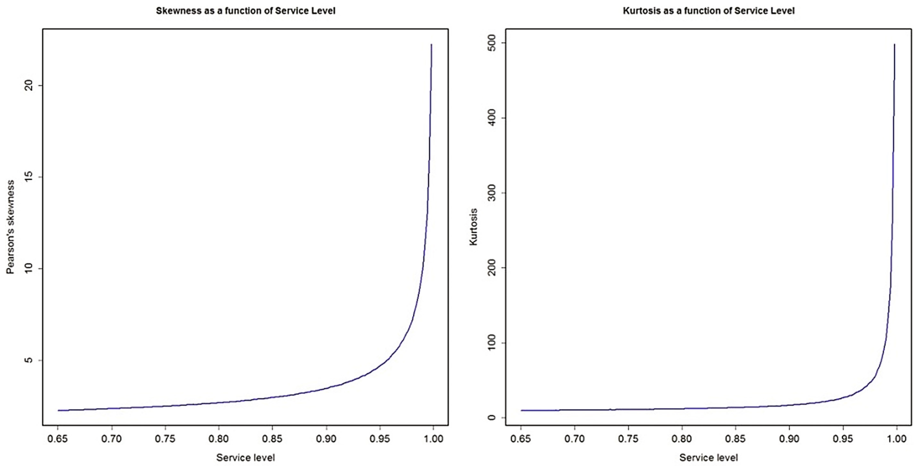

Fig. 4. Skewness and kurtosis for $\tilde{\mu}_{LT}^{1}$ as a function of service level.

peaked behavior. This phenomenon must hold true for $SL_j > 0.5$ as this would indicate that the majority of lead times observed stem from only the *j'th* echelon and not a combination of subsequent echelons. That the distributions are rather peaked for large values of SL_j is rather trivial as it simply indicates that supply is satisfied from the previous supply chain member ($j + 1$), rather than a subsequent combination of upstream members ($j + n$).

4 Discussion

From Duc et al. [9], Kim et al. [10] and Michna et al. [5] we know that lead time variation and the need to estimate lead time distributions are in fact a major source of bullwhip effect in supply chains. It is also interesting to note that the research into stochastic lead times in supply chains is rather limited. Especially since the research presented in this paper proves that lead times in supply chains using ROP-methods must in practice be stochastic rather than deterministic. From the study and the conceptual model we can reach a number of central conclusions. First, let us assume that a supply chain member must rely on a combination of shared information from other members and its own observations to make inventory decisions. If lead time information is not shared in the chain a supply chain member can only rely on what it observes. In this case the above conclusively proves that the observed lead times will in fact (for service levels below 0.99 under conditions of the same lead time between all echelons) act as a random variable. This conclusion is significant in the sense that it underlines that assuming that lead times are deterministic is incorrect and that supply chains by their very nature have to deal with stochastic lead times. What is also interesting to note is that in the numerical example even relatively high service levels (e.g. SL = 0.96 gives a CV $\left(\frac{\tilde{\sigma}^1_{LT}}{\tilde{\mu}^1_{LT}}\right)$ of 0.20 if all echelons have the same service level) result in a significant amount of variation in the lead time distribution at the last supply chain member. From Michna et al. [5] we know that lead time variance and the subsequent need to estimate lead times are in fact a (if not the) major source of bullwhip effect. So even at relative high service levels we can now conclude that supply chains (that are not sharing lead time/service level information) will experience a significant bullwhip effect alone due to lead time variation even if lead times between individual echelons are in fact deterministic. The second main conclusion is that it follows from the above that, regardless of the lead times between echelons, the observed lead time distribution will in fact be positively (right) skewed in chains with the same service level at each echelon. This conclusion matches research on practical lead time distributions [13, 14] which indicates that real lead time distributions are in fact positively skewed. Seen in connection with the research in Do et al. [11] this indicates that supply chains of this type will find it more difficult to stabilize performance and there will be a larger need to buffer on safety stock to compensate for the lead time uncertainty. It also tends to indicate that assuming lead time demand is normally distributed will be difficult for short lead times. A third conclusion that requires a bit of extrapolation is that the mean actual lead time experienced by a supply chain member is roughly increasing linearly to the stock out (*1-SL*) likelihood throughout the chain. That the mean lead time must increase as a function of stock out likelihood is rather trivial. However, the finding that this increase is roughly proportional to the stock out likelihood has some interesting implications as we know from literature (e.g. Chen et al. [4]) that increasing lead times result in increasing bullwhip effect. A final interesting conclusion is that while demand signals are amplified upstream lead time variation can be considered to be amplified downstream. So demand uncertainty propagates upstream, while lead times propagate downstream as illustrated on Fig. 5.

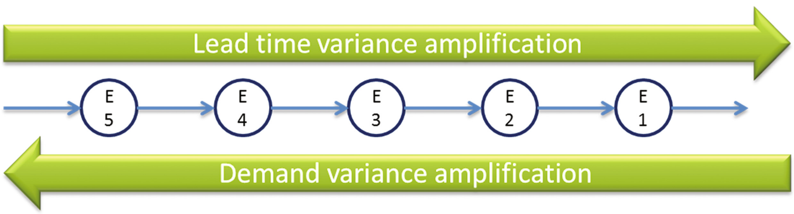

Fig. 5. The nature of variance propagation in supply chains.

This finding is interesting as it runs contrary to the majority of supply chain literature, where focus is very much on upstream demand and downstream capacity signaling. We consider this to be a significant point that requires further attention in the future. It also seems to support the findings of e.g. Michna et al. [5] that the bull whip effect is strongly linked to the variance of lead times.

5 Conclusion and Further Research

The conclusions from the study are quite simple. If a supply chain consists of members that supply subsequent downstream members from inventory using Re-order point based methods and the SL in the chain is less than 0.99, lead times will in fact behave as stochastic with coefficients of variance above 0.1. In this case it would be patently wrong to assume that lead times are in fact deterministic in nature. Even short supply chains will in fact have stochastic rather than deterministic lead times. Consider the simple example with service levels 0.90; 0.90; 1.00 and lead times 1;1;1 in echelons 1, 2 and 3. In this case $\frac{\tilde{\sigma}_{LT}^{1}}{\tilde{\mu}_{LT}^{1}}$ is 0.31 and $\tilde{\mu}_{LT}^{1}$ is 1.11.

Further work will including extending the conclusions to cover the situations where delivery lead times between echelons are in fact stochastic rather than deterministic. Furthermore it would be beneficial to extend the conclusions to supply chains where there is a non-constant service level and varying delivery lead times across all echelons.

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Into Organizational Structure Simplicity

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Abstract. The article attempts to define the principle of the simplicity of the organizational structure and its determinants. It has been established that abiding by the principle of simplicity means minimizing the level of structural characteristics (such as hierarchy, centralization, specialization and formalization), as well as increasing the transparency of organizational rules. The factors shaping the simplicity of the organizational structure were also indicated.

Keywords: Organization · Organizational structure · Simplicity of activities

1 Introduction

It is assumed that the organizational structure is a set of rules regulating the behavior of the organization members. As Steinmann and Schreyögg emphasize, it has to "… not only facilitate the smooth implementation of activities, but also lead the conflicts to the right paths, create pathways for the emergence of new ideas, or unify the outward appearance" [28]. They define the way in which the members of the organization work, making them more predictable, with the principle that the more organizational rules, the more work is deprived of the individuality.

The organizational structure, which is an element of every organization, serves the needs of management primarily. Especially:

- defines the division of labor,
- introduces the link between carried out activities,
- shapes the division of power,
- regulates relations with the environment [9, 19, 29]

Shaping the organizational structure is one of the fundamental issues of management science. It is no wonder then that management classics have formulated its principles [5], which can be divided into two groups:

- concerning the solution of the fragmentary problems connected with shaping the structure [19],
- concerning the desirable characteristics of the structure as a whole.

One of the basic principles of the second group is the simplicity of a structural solution, usually associated with its configuration [3, 4, 32]. However, the organizational structure is characterized not only by configuration but also by, e.g. centralization, specialization or formalization. Moreover, the model of the simple structure, closely related to

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the principle of simplicity, is not indisputable, especially regarding the degree of centralization.

In the literature, the W.R. Ashby's law, which states that each variety should be balanced by another, is increasingly questioned. Following the growing complexity of the environment usually ends with the bureaucracy's ineffectiveness, which prevents an effective response to changes in the environment [3]. It is increasingly widely believed that structural solutions need to be simplified, although it is not easy and requires detailed analysis [15]. Despite this, simplifying actions are being implemented in some organizations to build the competitive advantage [13]. They are undoubtedly justified because organizations, including their structural solutions, are often highly complex. It was confirmed by a survey made by Camelot Management Consultants [26] among 150 organizations from various industries. It turned out that almost 83% of them described the level of organizational complexity as too high.

It also draws attention to the fact that the organizational structure is not considered from a holistic point of view. Of course, in such modern management instruments as lean management or reengineering, structure simplification is a part of multidimensional ventures, but they are not a core of those instruments. Therefore, it is not surprising that it is difficult to find in the literature concerning these instruments any statements, which would point to some recommendations to simplify organizational rules adequately linked to other elements of the organization and the environment.

The arguments mentioned above result in the need for a new approach to the simplicity of the organizational structure, which is a relative notion, also because it is gradual and there is a need for identification of its most important determinants. This article attempts to address this need, i.e., designations of the activities related to the observance of the organizational structure simplicity principle regarding shaping it and the more important conditions of simplicity. The realization of these intentions was based on:

– critical analysis of literature in the field of organizing activities;
– analysis of the simplicity (complexity) of structural solutions using the fractal calculus;
– empirical research on the factors shaping the simplicity of the structure.

2 Simple Organizational Structure Principle

In the literature concerning organizational structures, a simple structural solution is described in a very similar way (Table 1).

It can be said that it relies more or less on the model of a simple structure proposed by H. Mintzberg, in which the main part is the so-called strategic vertex and basic coordination mechanism - direct supervision. The mid-level staff does not appear because the management team is a small group of top management or even one person. Techno-structure and auxiliary services are reduced to a minimum and usually do not occur at all. A good example of an organization with a simple structural solution is a small workshop in which the owner deals with all matters, e.g., determines the order of individual operations execution, seeks new orders, controls, etc.

Table 1. Simple organizational structure according to some authors (own work)

Author(s)	Characteristic
Pawlak, Smoleń [20]	A small number of organizational units' positions and organizational links
Robbins, DeCenzo [22]	A small degree of specialization, formalization, flattened hierarchy, significant centralization
Sobczak [27]	A small degree of internal variation, high degree of centralization
Zakrzewska-Bielawska [34]	A small number of management levels, low level of specialization, significant centralization
Ashkenas [1]	A small complexity of the hierarchy, a small degree of specialization
Malik [17]	A small degree of specialization and standardization of activities, a flattened hierarchy
Global Simplicity Index [7]	A small number of management levels, a small spread, significant centralization

However, such a structure can be seen as a restrictive solution, as the rules of action are set by one person, and the rest must be subordinated to them. The maneuvering area is, therefore, small [6]. It would certainly be greater if the basic coordination mechanism was not direct supervision, but mutual alignment, consisting of the direct coordination of the members of the organization, equipped with high decision-making powers.

Hence, the following question arises: is such a structure, which gives people greater freedom of decision-making action, simpler? Its legitimacy is also supported by e.g.:

– the accepted definition of organizational structure, which is the simpler, the less organizational rules, the number of which depends in turn on the scope of human decision-making freedom;
– the fact that the simplification of the structural solution requires the limitation of imposed rules so that people can creatively react in a complex and dynamic way [12].

The answer to this question was formulated based on the idea of a fractal tree, which resembles a simple structure configuration. The calculations revealed that when the intensity of direct supervision increases, the complexity of the structure also increases, although this is not a linear dependence [12]. This means that a simple structure is not a centralized but a decentralized solution in which the top management allows all subordinates to manage their activities independently. It is also characterized by the small degree of specialization and formalization of activities, just like in the case of the H. Mintzberg's simple structure.

The opposite of such a structural solution is a complex structure, characterized by an extensive hierarchy, a high degree of centralization, specialization, and formalization. Therefore, it can be said that the continuum of organizational structures may by drawn by their simplicity, which is illustrated in Fig. 1. Moving along in it towards the Z point means an increase in the complexity of the structure (lowering the simplicity) while moving toward the P point means an increase in the simplicity (reduction of complexity).

Fig. 1. Organizational structure continuum (own work)

On this basis, the following research question can be formulated: what the organizational structure should be regarding its simplicity? It can be said, paraphrasing words of A. Einstein (“everything should be done as simple as possible, but not simpler”), that structures should be as simple as possible, but not simpler [21]. This means that:

– the structure should be appropriate to the characteristics of the other elements of the organization and its environment (context);
– from the set of context-sensitive structural solutions, the simplest ones should be chosen, i.e. the one placed on the continuum closest to P point [12].

Therefore, obedience to this principle of structure simplicity leads not only to the formation of a rational structural solution but also to the reduction and promotion of elasticity of organizational management [14].

3 Actions Simplifying the Organizational Structure

With all the attacks directed nowadays in the world of the organization against the hierarchy, it must be remembered that there is no organization without hierarchical order, which is not denied either by virtuality or by the idea of organizational learning [25, 28]. However, the hierarchy should be as compact as possible, so that the chain of commands is as short as possible. As Drucker wrote many years ago, “… an extra hierarchy level hinders the achievement of common direction and mutual understanding. Each such additional level distorts the purpose and distracts attention from what is essential. Each chain link contributes additional tension, creating one more source of inertia, friction, and sluggishness.

And above all, especially in big business, every extra level hampers the formation of tomorrow’s managers, on the one hand, because it raises the time of promotion, on the other, because in such an arrangement, promotion is more likely for specialized workers than managers.” [4]. The demand for flattening organizational structures is formulated by many other management theorists and managers. Among others, previously cited M. Crozier and J. Welch and S. Welch wrote once that “it is precisely because of the irresistible pursuit of ranks that I propose that you flatten your company’s structure by 50% in comparison with what you would normally feel good about. Managers should have at least ten direct subordinates and even 30% to 50% more if they have more experience” [32].

Being guided by the principle of simplicity also requires solving the problem of the number and size of basic organizational units, i.e. units that are separated from the “top” hierarchy level. In particular, the question is whether there should be fewer, but larger ones or more smaller ones.

This question can be answered based on the example of two structural solutions, which ideological schemes are shown in Fig. 2. They differ both in the number of basic organizational units and in their size, but the common feature is that they illustrate solutions that regulate the behavior of the same number of employees (16).

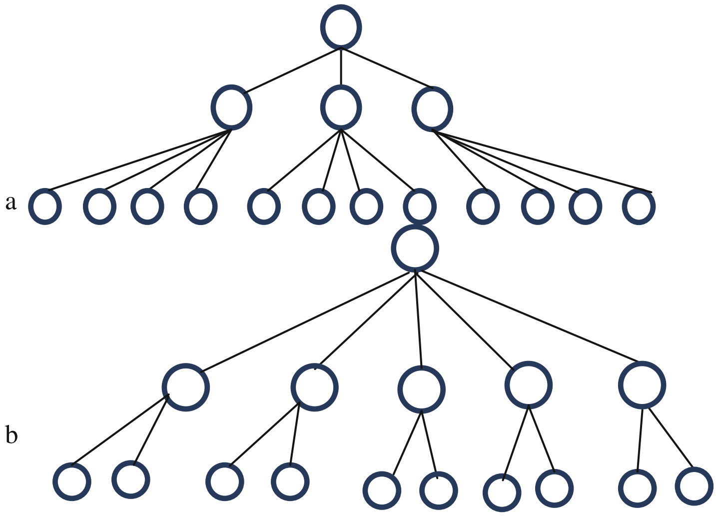

Fig. 2. Ideological schemes of two structural solutions (own work)

If we assume that the measure of the structure complexity can be based on the fractal dimension, then its value for both solutions can be calculated using the following formula:

$$D_s = \sum_{i=1}^{k} \frac{1}{i} \cdot \sum_{j=1}^{n} \frac{\ln x_{ij}}{\ln \frac{1}{\gamma}} \quad (1)$$

where:

x_{ij} – span of control (i-th level, j-th manager) in the organizational unit, which is a typical fractal tree

γ – intensity of direct supervision as a coordinating mechanism[1]

The calculations (Table 2) show that:

– The greater the number of basic organizational units, the greater the complexity of the structure. Within the "a" structure, there are more expanded units than in the "b" structure, but according to the formula for complexity (Ds), the impact of lower levels on total complexity is smaller than that of higher levels. Therefore, the "b" structure is more complex than the "a" structure.

[1] The assumptions for deriving this formula are outlined in the article [10].

Table 2. The complexity of the two structures regarding different intensity of direct supervision[a] (own work)

γ-intensity of direct supervision (in % of power owned by the manager)	50 (0,5)	33 (0,33)	25 (0,25)
Dsa	4,58	2,89	2,29
Dsb	4,82	3,03	2,41

[a]The concept of direct supervision is used in the sense given to it by Mintzberg [18]. The example of gamma values illustrates the decrease in the intensity of supervision as an instrument of coordination.

– The lower the intensity of direct supervision (the greater the decentralization), the simpler the structure.

It can be concluded that the simplicity of the structure is conducive to the creation of the smallest possible number of basic organizational units. This applies both to performance-oriented units and to object-oriented units (e.g., manufacturing specific products), although object-oriented units are typically characterized by a greater degree of decentralization [9].

The biggest possible decentralization means that members of the organization do not act by predetermined rules but are required to develop their own rules of conduct. In other words, there is a need for creating positions with autonomy and responsibility. Moreover, their actions cannot be homogeneous and reproducible, but as diverse as possible, forcing them to think systemically, and therefore remain not specialized.

It should be underlined that the image of positions created by the principle of simplicity should be as transparent as possible. This requires, among others:

– The assurance of the suitability of the scope of tasks performed in positions, powers, and responsibilities. The greater the suitability, the simpler the structure.
– The assurance of the separation of duties and responsibilities. The more this requirement is respected, the simpler the structure.
– The observance of the principle of unity of order, because multi-line structures are more complex than one-line ones.

The limitation to the minimum of the necessary auxiliary, advisory, and control positions. The fewer staff posts, the simpler the structure.

Also, the degree of formalization should be kept to a minimum. Of course, this applies to the rules introduced in an official way, but also to those introduced in other ways. Intelligent formalization exists because the opportunity is created for the organization members to create non-formal rules spontaneously. Those rules have a kind of backstage character and are the source of indicative patterns and expectations [28]. If they comply with formal rules, they will pass the exam in their daily work.

However, there is no such thing as an organizational structure devoid of any problems. All structural solutions are imperfect because they generate conflicts due to both organizational differentiation and organizational integration. There is also no ideal simplification of the structure. It usually requires compromises, primarily due to the rapidly growing uncertainty of the environment. Although transparency of organizational rules is an important aspect of simplicity, it is not possible to exclude instances in which matrix structural solutions (not based on the unity of order) are indispensable because they have no alternatives at present. As Malik [17] rightly points out, they are a threat to good governance. The key to achieving good results is the principle of focusing attention on the most important issues, which compliance is very difficult within the matrix structure.

The principle of unity of order is also not respected in solutions designed to be a sign of a modern management approach. It is the constant "overlay" of various forms of teamwork into traditional solutions, such as functional, which is the DNA of entirety of organizational rules [16, 23]. However, such solutions are by their relatively complex due to the hybridity of them, especially when teamwork is poorly organized, which unfortunately does not occasionally happen [17]. This implies the need for caution in the application of such structural solutions. Hence, they should not be the first choice.

4 Conditions of Structure Simplicity

The simplicity of the organizational structure seems to depend on many different factors. One of them is the uncertainty of the environment. High uncertainty undoubtedly requires a great deal of decision-making freedom for members of the organization. They may then, according to the paradigm of Burns and Stalker [28], quickly and rationally react to the changing environment and responsibly manage their work. On the other hand, the more stable the environment (less uncertain), the more unpredictable the behavior of organizational members might be and, therefore, the smaller their decision-making freedom. This means that the less uncertain is the environment, the more complex the organizational structure becomes. Conversely, increasing uncertainty leads to a simpler structural solution.

Another factor is the organization's dependence on the environment. It is easy to see that the increase in this dependence requires greater adaptability, which is conducive to the flexibility of the structural solution, which is equal to the increase of decision-making freedom of the organization members. Hence, the greater the organization's dependence on the environment, the simpler the structural solution is, while the reduction in dependence seems to result in an increase in the complexity of the structure.

The natural consequence of the increase in the number of organizational members or its revenue is the increase in the number of positions, including management positions, a number of hierarchy levels, procedures and organizational documents [29]. The larger the organization, the more complex the structure and vice versa (the smaller the organization, the simpler the structural solution).

Over 50 years ago Chandler [28] found that increased diversification of production is often accompanied by the introduction of functional, more complex, structural solutions. It can be assumed that between the diversification and the simplicity of the structure there is the following relation: the lower the diversification, the simpler the structure (and vice versa, the increase in the degree of diversification leads to an increase in the complexity of the structure).

Another factor is organizational culture, which can be divided into open and closed, depending on the formation of three dimensions: anthropological, social and cognitive. The first is the freedom that an organization has in deciding its fate, the other defines whether it is dominated by individualism or collectivism, and the third is the question of whether human cognition is considered infallible or unreliable [8]. It is easy to see that both “opening up” of organizational culture and the simplification of structure not only increase decision-making freedom but also facilitate organizational learning and rational response to environmental challenges. It follows that “the opening up” of culture is conducive to the simplification of the structural solution, and its “closing” is conducive to its complication.

It is assumed that the professionalism of the organization members is “a set of skills which allow them to solve complex, non-routine problems independently” [24]. Reaching the benefits of the professionalism of the organization members requires a structural solution that enables them to be highly independent and responsible for decision-making. This means that the more professional the participants are, the simpler the structure, and the less professional, the more complex the structure.

The leadership can be distinguished as classical and organic leadership (scattered). The first is based on a strong individual or group that gives the others an unquestioned (mainly due to fear or respect) command, while the essence of distributed leadership is that it emerges from the relationship between the members of the organization. Classical leadership fits into a mechanistic (complex) structural solution and dispersed into a highly flexible, that allows people, among others, to react quickly to the rapid changes in the environment. The more distracted the character is, the simpler the structure, and the vice versa, the more classical it is, the more complex is the structural solution.

The impact of another factor, i.e. the leadership aspiration to simplify the organization, is undoubtful. The more determined the leadership is in the efforts to simplify the organization, the simpler the structural solution (and the less the determination, the more complex the structure).

Manufacturing technologies and organizational structure are also interdependent, as certain structures exclude specific technologies (e.g. organic structure and assembly line), and certain technologies can only be used with appropriate structures (e.g. pipeline production requires a stable structure). Based on the often-quoted literature and findings of Wodword [33], it can be assumed that the greater the routine of applied technology, the more complex the structure is and vice versa, the more non-routine technology, the simpler the structure.

Many researchers underline that information technology increases the independence of employees by increasing their knowledge of goals and processes, enabling them to access up-to-date and important information, and simplifying and intensifying communication within the organization and with the environment [2]. According to many authors, the use of information technology leads to the flattening of structures [30, 31]. This means that the greater the range of information technology, the simpler the structure and vice versa, the smaller the range, the more complex the structure.

It is impossible to disagree with Ashkenas [1] that gradual accumulation of changes in organizational structure not only leads to an increase in complexity, but also to the difficulty of functioning and development of the organization. Consequently, the following correlation seems to be relevant: the more structural changes and the longer the organization's lifetime, the more complex the structure. Conversely, the shorter the period of the organization and the number of changes in the structure, the simpler it is [11].

The above hypotheses were subject to preliminary verification. A survey among 100 companies operating in Lower Silesia revealed that among structural factors, none were predictors (the use of stepwise regression) of all dimensions of the structure, although each of them had statistically significant models. The results point out that:

– The hierarchy is less developed when the organization is smaller, less diversified, and more driven by the management to simplify it. This dimension of the structure is explained in 47% by the mentioned factors.
– The degree of centralization is smaller when the organization is larger and younger, with more open organizational culture and manufacturing technology with more non-routine character is used (corrected $R^2 = 0.04$).
– The degree of specialization is smaller (simpler structure in this dimension) when manufacturing technology with more non-routine character is used (the degree of specialization is explained in 65% by this factor).
– The structure in the dimension of formalization is simpler (i.e. the formalization of activities is smaller) when the organization is smaller, less dependent on the environment and there is greater involvement of the management in simplifying the organization (adjusted $R^2 = 0.433$).
– The degree of standardization of activities is smaller (and therefore a simpler structure in this dimension) when the organization is smaller and manufacturing technology with more non-routine character is used. This dimension is explained in 20% by both factors [12].

Although these dependencies are neither unavoidable nor certain, it authenticates the influence of organization size, diversification of business activity, manufacturing technology, organizational culture, and management determination in organizational simplification (including structure) on the simplicity of the organizational structure.

5 Summary

The principle of simplicity of the organizational structure seems to be crucial in the management. Its adherence requires twofold action:

– Limiting to the necessary minimum the level of formation of such structural characteristics as hierarchy, centralization, specialization and formalization. This means, among other things, that the number of levels of hierarchy, basic organizational units, workstations, organizational documents, as well as decisions taken by senior management should be reduced as far as possible.
– Increasing the transparency of organizational rules, e.g. by as precisely as possible determining the scope of tasks, increasing the appropriateness of tasks, powers, and responsibilities, limiting the number of staff posts and meetings, and striving for the unity of order.

It can be concluded that simplifying the structure is not easy. Requires, among others, implementation of complex activities related to shaping an open organizational culture. Its efficacy also seems to depend on the efforts of the organization's leadership to simplify it, the importance of which, as a structural factor, will probably grow as the dynamics and complexity of the environment grow.

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Simulation Approach to Forecasting Population Ageing on Regional Level

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Abstract. The paper discusses the simulation model that uses system dynamics method to study the demographic changes forecasted for the population, based on the aging chain approach. The goal of the study was to elaborate the method to overcome the drainage problem that manifests itself in the smaller number of individuals belonging to the simulated cohorts, as compared to the real population data. The solution for the drainage problem is presented. We propose the original modelling methodology that assumes the coexistence of main and elementary population cohorts. The simulation model was verified based on the historical data for Wrocław Region population and the results of the experiments prove the high degree of compatibility of the simulated age and gender related characteristics with the empirical data, which entitles us to formulate the perspectives of using this approach in the next stages of our research.

Keywords: Simulation · System dynamics · Ageing chain · Population

1 Introduction

A wide range of economic studies requires the credible demographic forecasts to be performed before the essential stage of research is started. When the quantitative evaluations of micro or macroeconomic performances depend on the effects of demographic trends then the proper examination of long-term implications of population dynamics can heavily influence the quality of final conclusions formulated for economic and managerial decision problems.

Financial sustainability of social security systems and, more generally, the burden on the state's budget due to the pensions paid to senior citizens, depends on the size of the older population and the percentage of insured employees [18]. The credible forecasting of the future demographic trends enables to indicate the optimal retirement age that would stop the budget deficit to grow.

It is proved [12], that there is a strong correlation between demography and savings, and between the population ageing and the economic growth. The authors investigated the life cycle hypothesis and empirically confirmed that population ageing has the negative influence on the society's savings. The working period favors the savings to grow and the retirement gradually weakens and stops this trend.

Population projections are necessary when studying the healthcare management problems. Lagergren [11] analyzed the relations between the increase of the older population and the growth of the number of seriously ill patients. Based on the

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demographic data it was possible to estimate the total resource requirements for Swedish healthcare system in the future. Senese et al. [17] used the population projections to forecast the growing needs for human (personnel) resources. Ansah et al. [1] stressed the importance of demographic analysis when estimating the requirements for long-term care services. The knowledge about the structure and the number of the population with certain diagnose (i.e. dementia) enables to carefully plan the financial and human resources needed to cover the future demand for treatment. Jagger et al. [7] emphasized the importance of planning not only the number but also the certain types of medical specialties to best suit the population needs.

In this paper, we present the aging chain model that replicates population evolution according to continuous simulation paradigm. In our previous research [13, 14], we discussed the implementation of the cohort modeling approach using the system dynamics (SD) method. The projections of long-term population evolutions were performed on the aggregated data and the analysis was focused on pre-specified age-gender cohorts. The demographic groups were described using demographic parameters such as birth and death rates, life expectancy, and migration descriptors.

The challenge to be solved when using the SD approach to model the chronological aging of the population is the wastage of individuals that belong to particular cohorts. Using a series of stocks to represent population, the level of individuals in every cohort and the total population are smaller than expected if there are intermediate outflows that drain the cohorts located in the middle of the chain [3]. This phenomenon is particularly evident when the aging chain is defined for a long-run horizon. In our model, the cohort drainage is a troubling issue because every cohort is drained by at least two intermediate outflows (i.e. deaths and emigration).

To overcome the drainage problem we propose the method that eliminates the differences between the historical and the simulated values of age-gender cohorts in the aging chain population model. The goal of the paper is to introduce the solution and verify its credibility by comparing the empirical data, taken from [6] and the results of the simulation.

2 Aging Chain Modeling

Aging chains population models are usually built using SD method, the continuous simulation approach developed by Forrester [5]. The SD demographic model consists of the series of stocks to represent the sub-groups of population being at the similar age and the same gender. The stocks accumulate individuals that move through the system. An individual is born and immediately becomes a member of the youngest cohort. After the pre-specified length of time, a person grows up and is moved to the older cohort. The maturation is continued along the aging chain and at the end, after the lifetime, an individual reaches the last age-gender subgroup. In steady state the average age of population is equal the average lifetime which is also the average age of people dying. The flows in demographic SD model are used to represent the movement of individuals over a specified period of time, which is interpreted as the average residence time needed for example for a child to leave the youngest cohort and enter the subsequent one (i.e. from cohort 0–4 to cohort 5–9).

Each person in each moment of simulation belongs to only one age-gender cohort and in the next point of time a person can only be moved forward (the age of an individual can only increase). An individual becomes a member of the particular age-gender cohort when one of the following events takes place: birth (concerns only the youngest cohort, i.e. the cohort starting with the age zero), maturation (a person leaves the previous cohort and enters the next one when the maximum age, as defined for the younger cohort, is reached), immigration (the sources for immigration are irrelevant here). A person ceases to be a member of the cohort when she/he dies, is old enough to become a member of the older cohort, emigrates (the target for the emigration is irrelevant here).

The maturation time is equal to the difference between the oldest age that entitles to stay in the cohort and the age the person entered the cohort plus one. In other words, an individual stays in the cohort for the time that equals the age range of this cohort plus one, unless the person dies or emigrates.

3 Modelling Technology

3.1 Basic Assumptions

The simulation model was built according to SD approach [5], using ExtendSim software, based on the demographic data from Wrocław Region. The model is a part of the master hybrid model, in which the continuous changes of the population dynamics influence the discrete events of the health care model [13].

Ten state variables define the population inside 36 main cohorts (0–4, 5–9, 10–14, 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85–105): 18 female and 18 male cohorts. Each cohort represents a separate state variable described by the *stock level*. A stock represents the number of individuals that belong to one cohort and a *flow* is equivalent to a rate that describes the intensity of the changes observed in the stock. The structure of the simulation model is determined by the available historical input data and the stability of the cause-effect relations that describe the population. We have assumed the availability of following data:

- Cohorts are described by the number of people of the same gender and the similar age. In particular, the initial values for each of the 36 main cohorts and for 14 historical years (from the year 2002 to 2015) were collected.
- Birth rates describe number of children born during each year. These parameters depend on the number of women from particular female cohorts.
- Death rates describe number of people belonging to particular cohort who died during each year. For the last cohort the average life expectancy is used instead.
- The volume of immigrating and emigrating people depend on the size of each cohort.

3.2 Challenges

The previous version of aging chain model, developed for Wrocław Region (WR) and described in [13], was characterized by some serious drawbacks. The natural maturation lengths, interpreted as the differences between the maximum and the minimum age for each cohort, led to the small but noticeable deviations from the historical data. The prediction error suggested the population was aging too fast. Many different attempts have been made to solve the problem, to name the most important:

- the time ranges for each cohort were extended,
- the birth and death rates were modified,
- the corrections within the computation algorithm were suggested,
- the maturation times were extended based on the genetic optimization algorithm.

The results were satisfactory from the quantitative (numerical) point of view, however each of the above mentioned solutions was difficult to accept because of the non-transparent explanations that lie behind them. For example, when applying such a solution for another region, the tedious calculations would have to be made each time the new data were added to the input data base.

Eberlein and Thompson [4] used the continuous cohorting approach and they assumed that every input flow entering the cohort is delayed by the time that has to be spent in the previous cohort. Extendsim delivers the block that acts just as the conveyor type solution applied by Eberlein and Thompson [4], however this block can not be used for discrete simulation and therefore its use is excluded in hybrid modeling as well. For this reason such a solution was rejected from our study. Sato et al. [16] suggested to consider the year of birth instead of the age of the person when defining the consecutive cohorts, however such a solution forces the entirely new approach to be used when defining the input statistical parameters. For example, the migration rates for people who were born in the same year change over time and they would have to be modified accordingly.

In our model we decided to divide the WR population into 105 elementary cohorts for both genders. One cohort simulates one year of aging of males and (separately) females. To properly run the simulation, the specially designed blocks were developed, tested and implemented in the simulation model.

3.3 Hierarchical Blocks - General Background

The population model was developed in Extendsim 9.2 using the blocks from Value library. The set of hierarchical blocks was designed to represent the elementary and the main cohorts. These new blocks are ready to be used in the future implementations of Extendsim environment. The blocks can be compiled, incorporated into the users' libraries and used repeatedly. Their equivalent in object-oriented programming languages is object plus private variables, methods for processing information and the mechanism such as encapsulation/inheritance and instantiation. Every modification made in the structure or the internal code of the hierarchical block is automatically replicated in its instances. This approach enabled us to create and run the model composed of over one hundred hierarchical blocks for both genders. Each block simulates one year aging of the population cohort. The concept of hierarchical modeling and the example of the hierarchical block designed by the user is discussed in [8].

The model works inside the master model and has to cooperate with the discrete submodel and therefore the compatibility with the library Item has to be ensured. One of the requirements was the adoption of named connection approach. When the different model regions work simultaneously, then the correction of the names of the connections is required in order to avoid names' duplication.

3.4 Key Elementary Blocks in Extendsim Environment

Modeling in Extendsim environment is done through selecting the block from the library, inserting the block's instance into the model, parametrization using the dialog boxes and input connectors, and creating the relations between the instances through the connectors. The connectors are divided into input, output, informative and object, (c.f. [8, 9]). The blocks usually used in the continuous simulation modeling are: HOLDING TANK, CONSTANT, SELECT VALUE IN, and EQUATION.

One of the most useful block is HOLDING TANK. This block is equivalent to stock in SD approach. It accumulates the dynamic objects (for example the individuals in aging chain simulation) coming through input connector and it could be withdrawn through the output connector want. The initial value of holding tank can be defined through init connector. Another connector (RS) is used to reset the tank's value and get connector enables to read the tank's level recorded in the previous simulation step.

Another key block, i.e. EQUATION enables the complex computation of the variables and sends the results of simulation to submodel's output or next block input.

4 Modelling Approach

4.1 Main and Elementary Population Cohorts

Every main cohort is divided into a number of elementary cohorts (see Fig. 1) and two variants are eligible: the cohort with constant age range equal to one year and the cohort with the age range calculated based on the formula (1). In this paper the first variant was applied.

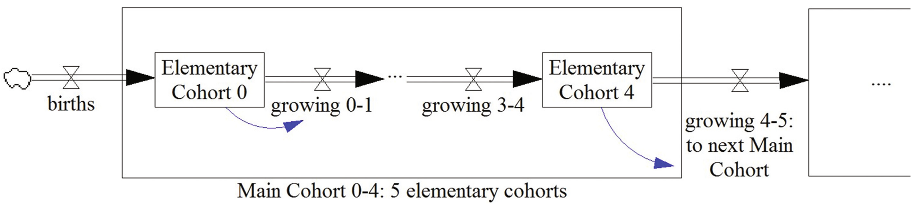

Fig. 1. The illustration of the hierarchical block: main cohort decomposes into the chain of elementary cohorts.

$$\frac{upper\ age\ of\ main\ cohort - lower\ age\ of\ main\ cohort + 1}{number\ of\ elementary\ cohorts} \tag{1}$$

For simplicity it was assumed that demographic factors are constant for each elementary cohort being a part of the main cohort. For example, the death rates are the same for every elementary cohort that forms the 5–9 main cohort, however the initial state of the main cohort is evenly distributed between each of the elementary cohort. For the oldest cohorts, when an individual reaches a maximum age, he leaves the population (he/she dies).

4.2 Feedback Loops

The following feedback loops are defined in the model for the main cohorts.

- Positive feedback loops between the birth input flow of the main youngest cohort (i.e. 0–4 for both genders separately) and the number of women from all main female cohorts. The intensities of these feedback loops are described by the products of birth rates and the number of women in main female cohorts.
- Negative feedback loops between the death output flows and the sizes of the main cohorts. The intensity is described by the product of death rate and the size of the main cohort or by the quotient of the length of the average life expectancy (this applies to the oldest cohort) and the size of the oldest main cohort.
- Optional positive or negative feedback loops between migration flows and the sizes of main cohorts. The type of the feedback depends on the migration direction.

There are 18 main cohorts for each gender (36 in total) and each main cohort decomposes into a chain of elementary cohorts. Elementary cohort is the key construct of the model and it represents individuals being at the same age (described as the integer number) and the same gender. There are 105 elementary cohorts for each gender designed and programmed in the form of the hierarchical blocks.

The feedback loops affecting the elementary cohorts are basically the same as for main cohorts but some additional ones had to be defined:

- Positive feedback loops between the birth input flow of the elementary youngest cohort and the number of women from all main female cohorts. The intensities of these feedback loops are described by the products of birth rates and the number of women in main female cohorts.
- Negative feedback loops between the death output flows and the sizes of the elementary cohorts. The intensity is described by the product of death rate (death rates inside the main cohort are constant) and the size of the elementary cohort or by the by the quotient of the length of the average life expectancy (this applies to the oldest elementary cohort) and the size of the oldest elementary cohort.
- Negative feedback loops between the maturation flows and the sizes of elementary cohorts. This feedback loop is absent on the main cohort level. The intensity of the maturation feedback loop depends on the age range of the elementary cohort and the variant discussed in Subsect. 4.1 (it is equal to one in the discussed model and is constant inside the main cohort).

- Optional positive or negative feedback loops between migration flows and the sizes of the cohort. The type of the feedback depends on the migration direction and it is constant inside the main cohort.

4.3 Input Data

The elementary cohort needs the following input data delivered through the input connectors (see Fig. 2):

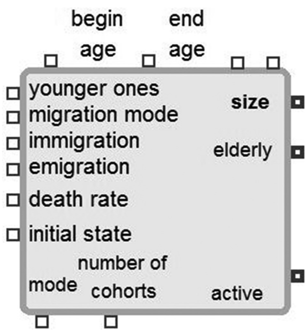

Fig. 2. The external interface of the hierarchical block of elementary cohort.

- the oldest age of the individuals belonging to the main cohort: *end age*,
- the youngest age of the individuals belonging to the main cohort: *begin age*,
- the maturation flow between two consecutive elementary cohorts: *younger ones*,
- the size of immigration/emigration flows: *immigration/emigration*,
- the annual death rates: *death rate*,
- the initial state of the cohort: *initial state*,
- the variant selected to divide the main cohort into elementary cohorts: *mode*.

The output data of the elementary cohort is described by:

- the size of elementary cohort: *size*,
- the maturation flow between two consecutive elementary cohorts: *elderly*,
- the information whether the cohort is active or inactive. The cohort is activated based on the user's decision that defines the size of the main cohort. The wider age range of the main cohort, the higher number of elementary cohorts: *active*.

4.4 Internal Relations

Many linear and nonlinear relations were defined in the model. The most important are described below.

$$population_{gender} = \sum\nolimits_{1}^{x} population\ in\ main\ cohort_{gender} \tag{2}$$

$$Population\ in\ main\ cohort = \sum\nolimits_{1}^{y} population\ in\ elementary\ cohort_{gender} \tag{3}$$

$$birth\ rate = \begin{cases} \sum\nolimits_{gender}^{x} birth\ rate_{i,j} \times popul.\ in\ main\ cohort_{j,female} & when\ i = 1, j = 1 \cdots x \\ 0, & when\ i > 1 \end{cases} \tag{4}$$

$$death\ rate_{elemental} = death\ rate_{i}\ where\ elemental\ \in\ i \tag{5}$$

$$\text{Mode 1:}\ migration\ rate_{elemental} = \frac{migration\ rate_{i}}{5\ or\ 20} when\ i = 1 \cdots x \tag{6}$$

$$\text{Mode 2:}\ migration\ rate_{elemental} = migration\ rate_{i}\ when\ i = 1 \cdots x \tag{7}$$

$$\text{Mode A:}\ start\ population_{elemental} = \frac{start\ population_{i}}{5\ or\ 20} when\ i = 1 \cdots x \tag{8}$$

$$\text{Mode B:} \begin{cases} start\ popul._{elemental} = \frac{start\ population_{i}}{5\ or\ 20}\ when\ i = 1 \ldots x - 1 \\ start\ popul._{elemental,j} = \frac{j}{1 + \ldots + j} \times start\ population_{x}\ when\ j = x \end{cases} \tag{9}$$

Where:

x is total number of main cohorts of one gender,
y is time range that describes the age of individuals in the main cohort + 1,
i is the number of cohort,
j is the number of cohort from which the mother of the new-born child comes from,
elemental is the number of elementary cohort,
5 or *20* is the number of elementary cohorts in the main cohort, however the last main cohort is different because it encompasses 20 elementary cohorts (85–105).

4.5 Input and Output Data Bases

Input data are stored in two-dimensional tables (matrices) [2] either as integer or real numbers. The most important data describe:

- the sizes of female/male cohorts for the years 2002–2014,
- the birth rates for females/males in relation to mothers' age for the years 2002–2014,
- the death rates for female/male main cohorts for the years 2002–2014,
- the migration rates for female/male main cohorts for the years 2002–2014.

The output data are stored in two tables, each presenting the information separately for the main cohorts and for particular time steps:

- the table with the sizes of main cohorts calculated every 0.2 year step,
- the table with the sizes of main cohorts calculated at the beginning of each year (starting from 2006).

In Extendsim the access to source data is available from *Database* menu level or by using the cloned button *Show Extendsim Database* [9]. It is also possible to connect the Excel files [10].

4.6 Hierarchical Blocks

The elementary population cohorts are discussed in Subsect. 4.1. The series of elementary cohorts is a part of the bigger hierarchical cohort (see Fig. 3).

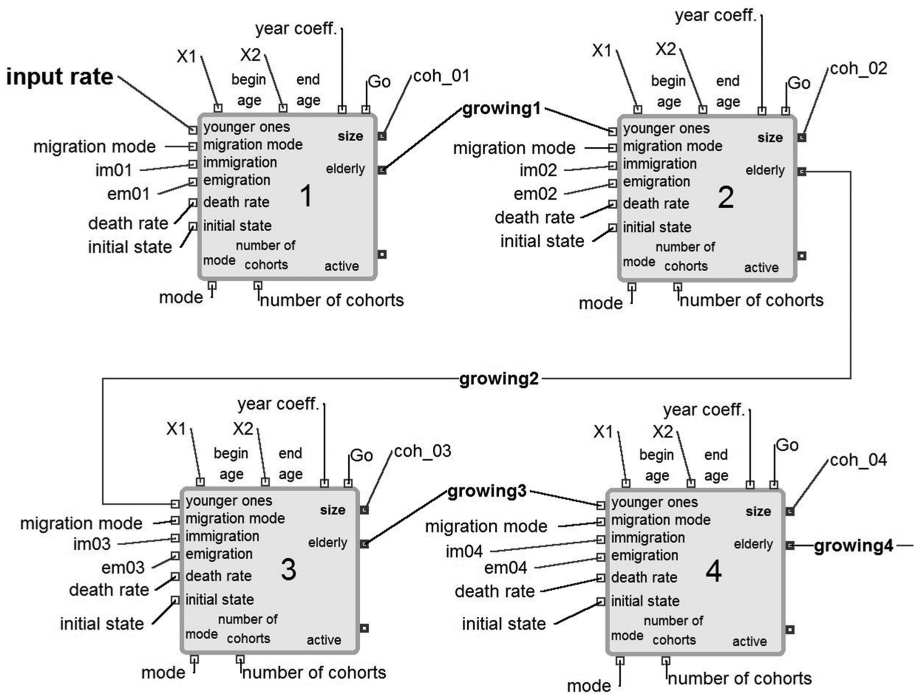

Fig. 3. The part of internal structure of the youngest hierarchical (main) cohort with input and output connectors.

The elementary cohorts can communicate with each other through the connectors growing. In the first elementary cohort the feeding flow comes from the younger main cohort. The main cohorts are connected through input-output connectors (see Fig. 4).

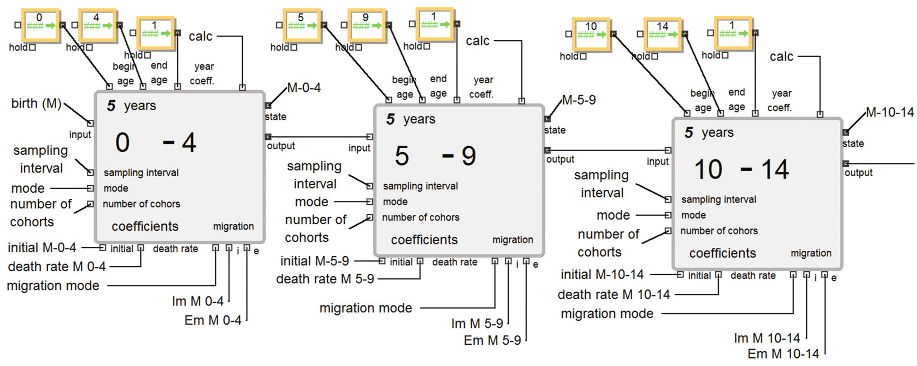

Fig. 4. The fragment of the chain of three hierarchical (main) male cohorts.

The main cohorts operate on the following input data delivered through input connectors:

- the beginning age of the main cohort: *begin age*,
- the ending age of the main cohort: *end age*,
- the intensity of the flow of individuals leaving the younger main cohort and entering the older main cohort, because of the maturation process: *output/input*,
- the intensity of the migrations and the mode of including migration parameters: *migration/migration mode*,
- the death rate for the main cohort: *death rate*,
- the initial size of the main cohort: *initial*,
- the variant of the division of main cohort into elementary cohorts (as mentioned earlier in Subsect 4.1): *mode*.

The output data of the main cohorts are described by:

- the size of main cohort: *state*,
- the intensity of maturation flow between two consecutive min cohorts. In the case of the last main cohort the individuals older than 105 years are not considered: *output/input*.

5 Simulation Results

Our previous version of the ageing chain model [13] was positively validated for the historical data. That model used the genetic algorithm (delivered through the Optimizer block) to select the values of maturation times in such a way that the differences between the simulation and the empirical sizes of the cohorts were acceptable. That solution delivered the satisfactory results however the maturation times were artificially elongated and the model was heavily bound to the data. The application of the model in another empirical context would require the optimization process to be started from the beginning. The solution described in this paper, based on the main and elementary cohorts, produces at least as accurate results as the previous version of our model (see Fig. 5). Mean Average Percentage Errors (MAPE) are comparable and in some cases even smaller than in the previous model, where the optimization algorithm was applied.

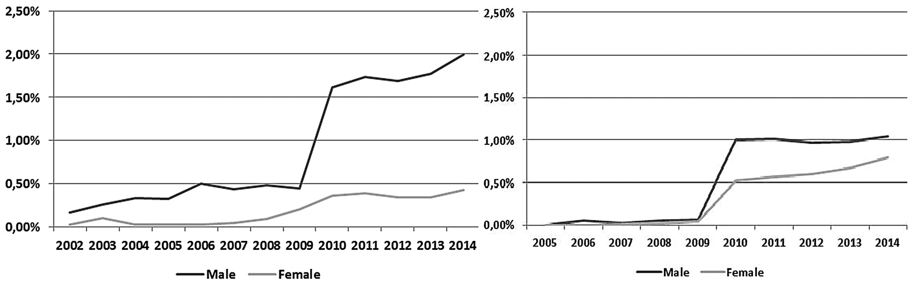

Fig. 5. The comparison of MAPEs for the previous model with optimization algorithm (left) and the current model with the hierarchical structure of the main cohorts (right).

The drawback of the new solution is the longer simulation time caused by the modular structure of the computations, however this cost is not very annoying. SD simulation requires only one replication and the more important issue here is the high accuracy and the credibility of the computations. Moreover, the model became independent from the particular age-gender real population structure, the main cohorts are more precisely described, the birth rates are connected to all female cohorts and the final structure of the model became transparent and intuitively understandable.

6 Future Works

Population models are applied to many fields [15]: biology, epidemiology, health economics, management and many others. This research builds upon previous studies on using simulation approach to properly address the demographic evolution. We managed to significantly improve our previous model by introducing the hierarchical structure of age-gender cohorts. The main age-gender cohorts define the basic aging chain of the population, however each main cohort decomposes into a range of one-year elementary cohorts. This solution enabled us to overcome the drainage problem and at the same time to keep the transparency of the model. The results demonstrate the usefulness of the approach in capturing the population evolution.

The accuracy of the output data and the technology applied offer a well-defined starting point for future research. The several research topics seem to be warranted. First, we would like to concentrate on the more credible integration of SD approach with discrete modeling. We aim at the development of a hybrid simulation model that would allow alignment of continuous demographic forecasts with the discrete model to simulate the demand for healthcare services on the regional level. This would require the better integration of the two modules driven by different simulation paradigms and the definition of the relations between the size of the particular cohort and the intensity of the demand generated by the population of this cohort. We expect the frequency distributions of the demand to be defined individually for each classified disease unit with regard to demographic, temporal, and geographical factors. The verification of such model will be based on the comparison of the historical data describing number of patients arriving to healthcare system during the predefined time unit with the results of the simulation.

Next, we would like to enhance the time range of the simulation horizon and to forecast the expected population evolution for the consecutive years. This would enable us to define the influence of the population factor on the morbidity level of the particular disease unit on the regional level.

The final research direction leads to the economic analysis that would enable to forecast the future material/financial/human resources needed to cover the healthcare demand being the result of the demographic changes observed within the population.

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Factors Determining the Development of Small Enterprises

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Abstract. This material refers to research on the key factors for the success of small enterprises. The results of research conducted among 120 enterprises from the SME sector operating in the Dolny Śląsk region of Poland are presented as compared to the characteristics of enterprises from the SME sector, along with current statistical data related to their operation. The research was supposed to identify the factors for success, including innovations, and its impact on their development. The first part of the article presents the characteristics of a micro, small and medium enterprise. Then, the problems of these enterprises related to the barriers for their development are presented. The third part is a review of literature presenting the key factors for success. The last part is the presentation of research results indicating how enterprises identify and perceive the key factors for success. Examined entrepreneurs.

Keywords: SME · Barriers for development · Development · Factors for success

1 Introduction

The literature related to the management of enterprises provides various ways to gain advantage on the market and development, which are often contradictory but are nonetheless effective. Numerous publications and reports, for instance the Global Innovation Index (GII) or the European Innovation Scoreboard, emphasize the crucial role of innovations in the process of pursuing success on the market. However, it should be noted that such reports quote research conducted on all enterprises without distinguishing the size of the enterprise, namely they do not divide enterprises into micro, small, medium and large ones. Therefore, the question was asked whether innovativeness truly has the same meaning for small enterprises as compared to averaged observations for all enterprises. For this purpose, research on 120 enterprises from the Dolnośląskie province was conducted in 2016 and it was presented in comparison to the discussion about the characteristics of the sector of small enterprises and the key factors for success indicated by the literature on the subject.

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2 Characteristics of Small Enterprises

The SME sector in Poland earns as much as 50.1% of GDP, with total share of enterprises in earning GDP at the level of 73.5%. Micro enterprises are an important group because they have the highest share in earning GDP, at the level of 30.8% [1]. This fact confirms the relevance of conducting research regarding factors determining the development of this group of enterprises.

The characteristics of small and micro enterprises, as defined by Commission Regulation (EC) No. 364 dated February 25, 2004 as well as Art. 104–106 of the Polish Act dated July 2, 2004 on the freedom of business operations, is presented in Table 1.

Table 1. Guidelines determining the size of an enterprise

Type of enterprise	Average annual employment (full jobs) not more than	Value of revenues in the last financial year (not more than) OR	Value of assets in the balance sheet at the end of the last financial year - not more than
Micro	10	EUR 2 million	EUR 2 million
Small	50	EUR 10 million	EUR 10 million
Medium-sized	250	EUR 50 million	EUR 43 million

The most current and reliable data about the number of enterprises is provided, among others, by the Central Statistical Office of Poland (GUS). According to data from GUS, there were 1.91 million active non-financial enterprises in 2015, 99.8% of which were micro, small and medium enterprises. Large enterprises - approx. 3,500 entities [2].

When analyzing the data, it should be indicated that 254,600 enterprises were registered in 2015, of which commercial units constituted the highest percentage (21.4%). 68.9% of enterprises survived the year 2015 - most often these were entities conducting operations in the field of information and communication (82.8%). Newly created enterprises in 2015 employed 285,700 people. The average number of employees in a one-year enterprise was at the level of 1.6 people. 71.2% of entities registered in 2015 earned profit after the first year of operations [3].

3 Problems of Small Enterprises

In the case of small enterprises, it is essential to indicate the barriers for their development. Since there are numerous barriers, they may be divided into external and internal barriers, depending on the place of their occurrence. Internal barriers are mainly financial barriers. Every enterprise at the beginning of its operations needs to contribute a capital ensuring its start-up. Depending on the source of this capital, there are various related risks. However, it very often turns out that the necessary outlays in subsequent months of operations are greater than those previously assumed. Another internal barrier which may be encountered is the problem with management over the enterprise. This barrier is related to the organization strategy and, in practice, it also results from the current conditions of operations, which may also include: incorrect grounds for the strategy of development, poor selection of assortment, incorrect selection of irresponsible business partners, etc. Another internal barrier which should be indicated applies to the size and location of business entities. The size of the company determines its manufacturing capacities, the demand for materials or the sales volume. The following are also very important: the place in which the enterprise is located with respect to transport routes, whether it is part of the owner's property, problems with production factors strictly related to the specific nature of conducted operations. The following factors are significant as well: age of machines, problems with the acquisition of new technologies, small manufacturing capacities, or the problem with acquiring materials. The last group of internal barriers are barriers from the field of human capital, namely related to the weakness of competences, knowledge, skills, etc. [4].

External barriers faced by an enterprise include, among others [4]:

- information and education barriers meaning, in general, the lack of information on the strategy of development of the local market, the system of trainings and consulting, business partners, legal regulations, or market niches.
- infrastructural barriers consisting in the inadequate availability of infrastructure reducing investment costs (availability of roads and motorways, water management, power infrastructure, etc.).
- economic policy barriers - this includes numerous limitations created by the government towards entrepreneurs, such as: deficiencies in financing, unclearly defined assumptions of aid programs, complicated procedures, excessive tax burdens, discrepancies in the interpretation of regulations, excessive frequency of tax settlements and many others.
- market barriers are barriers appearing when the demand for products or services offered by the enterprise decreases, which involves the decrease in the enterprises' sales. These may also be growing competition, saturation of the market with given products, the lack of new sales markets, or the emergence of new needs which the enterprise is unable to satisfy.
- legal barriers, such as the instability of legal regulations, the ambiguity of legal regulations, the introduction of retrospective legal regulations, etc.
- social barriers are related to the number and quality of human resources on the job market (such as poor mobility, high fluctuation of employees or low qualifications).

Small enterprises are based to a greater extent on informal research and development activities, which are difficult to measure, and they use external sources of knowledge (consulting services and licenses) less frequently than their larger equivalents. This phenomenon reflects the lower capacity of SMEs to absorb external knowledge. Therefore, it is necessary to define new notions, terms, processes, or strategies which would more precisely describe the special nature of enterprises from the SME sector. The available literature stresses the impact and the importance of internal and external factors for the success of enterprises from the SME sector in a unidimensional manner. It basically only describes the crucial role of material and financial resources, recognizing them as the main factors determining the success of the innovative process in an enterprise from the SME sector. The very structure of the innovative process is also related to large companies and such a perspective is hardly useful for SMEs, in particular for micro enterprises, which do not have units dealing with the development and implementation of innovations.

The most important barriers for the development of entrepreneurship include [5]:

1. Market barriers related to:
   - the regional diversity of demand - difficulties in finding new sales markets as well as the drop in the number of orders (the SME sector is related to the local and regional market and, as a consequence, it is sensitive to the drop in local demand, which results from the deterioration of the financial income of the local population; searching for sales beyond the region is hindered, which is related to the lack of funds as well as knowledge regarding marketing),
   - strong competition on the market - it is connected both with small companies operating on the local market and large foreign companies (large commercial institutions are perceived as a threat for small domestic companies).
2. Financial barriers related to financing of the start-up of business operations, regarding:
   - the limited access to financial funds from banks or other financial institutions - high interest rates for credits and loans as well as very high formal requirements to obtain them,
   - the financing of development - difficult access to external sources of capital,
   - leasing (as a form of financing of investment projects) - lack of standardized regulations regarding the institution of leasing,
   - the lack of reliable information about business partners - the dispersion of business registers makes it difficult to acquire information about potential business partners,
   - the tax system - high tax rates, frequent changes in regulations, the instability of the tax system, complicated procedures regarding the calculation, collection and return of VAT, excessive requirements resulting from statutory regulations of the employment relationship.
3. Barriers related to the government's policy [5]:
   - the introduction of legal acts - the variability of regulations,
   - the vagueness of regulations in business law - poorly defined and complicated statutory regulations,
   - the licensing of business operations,
   - the regional policy - the lack of clearly defined principles of the state's regional policy, poor use of the possibilities of local governments.
4. Barriers related to production:
   - production factors - low degree of innovative equipment, limited production capacities, inappropriate management of the enterprise, hindered access to new production techniques and technologies, undeveloped access to franchising agreements,

– employment - low qualifications and the lack of a system motivating employees to work legally, the state's use of too extensive social policy regarding the job market,
– poor technical infrastructure and barriers related to real estate.

5. Barriers related to the access to information at the local level - poor availability of information as well as the instability of legal regulations, volume of fees and taxes which are regulated by the law and complicated legal regulations [6].

The literature also contains such groups of factors as: consequences of planning, organizational problems, problems with management, or individual problems [7].

It is quite common that enterprises go bankrupt already in the first year of their operations (or after the first several years). Those enterprises which remain on the market are often characterized by a very fast growth. Since micro, small and medium enterprises are so numerous, it is worth taking a closer look into which factors determine their quick or slow growth [8].

4 Factors for the Success of a Small Company

The factors for the success of a company are variables which should guarantee the effective (profitable) functioning of a company. These factors will be different depending on the time, the moment of their definition, the location, as well as the size of the enterprise. These factors may include the legal system which is favorable for the operations of small enterprises. Not only the country in which the business operations are conducted is important, but also the province, the county or even the commune. This results, among others, from various prices of land, tax rates or the favorable disposition of the authorities, demonstrated in local support programs for the development of entrepreneurship in order to overcome unemployment. Another important factor is employment - two opposing aspects are important in this case. The first, positive one, is employment itself, which is positively assessed by the local authorities, the other, negative aspect, is the micro enterprises' aversion to employ employees - due to significant employment costs. A factor heavily restricting the operations of small enterprises is bureaucratization, which is particularly significant and may determine the survival of a micro enterprise in which one person is involved in the production/provision of services, administration, accounting, contacts with customers, suppliers, etc. Another surprising factor is corruption as well as connections. This factor touches the issue of ethics in conducting business operations, because an enterprise often faces a dilemma of whether to give a bribe and receive a contract, solve a troublesome official case or not [9].

According to research from 2016, the owner/manager himself may determine the success in the context of: remuneration, attractiveness, social responsibility, or emotional intelligence. These features are significant mainly due to how the owner will cooperate with the environment. Another group of factors often present in analyses include: financial resources, technological resources, the entrepreneur's skills, support from the government, the marketing strategy and the quality of business planning, as well as the access to information and positive relations with business partners, the environment and the authorities [10]. When analyzing the international literature on the subject, we may find different classifications of the key factors for success - depending on the author's country or continent. In his thesis, Yassine Sefiani indicates internal and external factors.

He divides internal factors into those that result from [11]:

1. The specific nature of a small and medium enterprise
   - the size of the company, there are numerous factors indicating that the enterprise's success comes along with its growth,
   - the age of the enterprise, where the older the enterprise, the higher the chances for survival,
   - the location which, when appropriately chosen, may be one of the main factors for success.
2. The nature of the entrepreneur
   - socio-demographic features,
   - the age of the entrepreneur - research shows that older entrepreneurs are less willing to implement innovations, and they are more conservative in their beliefs,
   - the sex, it cannot be clearly specified which sex guarantees success,
   - the experience, which has a very large impact on creative invention in business operations,
   - the education - it may be of critical importance depending on the sector,
   - upbringing and family traditions - educated/entrepreneurial parents stimulate the child's development from the early years and thus the child has an easier start into life,
   - the nature - mainly: the need for achievements, the need for control (locus of control), the will to undertake risk, competences and skills, entrepreneurship, leadership, being organized.
3. The company's strategy, the strategy of innovativeness is most often indicated as crucial, although there are scientists who claim that innovativeness is not beneficial for the development of small and medium enterprises, but only for large enterprises.

External factors are divided into [11]:

1. Macro-economic factors - financial resources, taxation, political and legal factors, technological factors (access to technologies, information, infrastructure), socio-cultural factors,
2. Micro-economic factors - such as relations with customers, suppliers, the competitors (Fig. 1).

A different approach is presented by Svensson, a Swedish scientist, who presents more specific factors for success: [12]

- non-standard original products,
- a customer willing to pay any price,
- high quality of production,

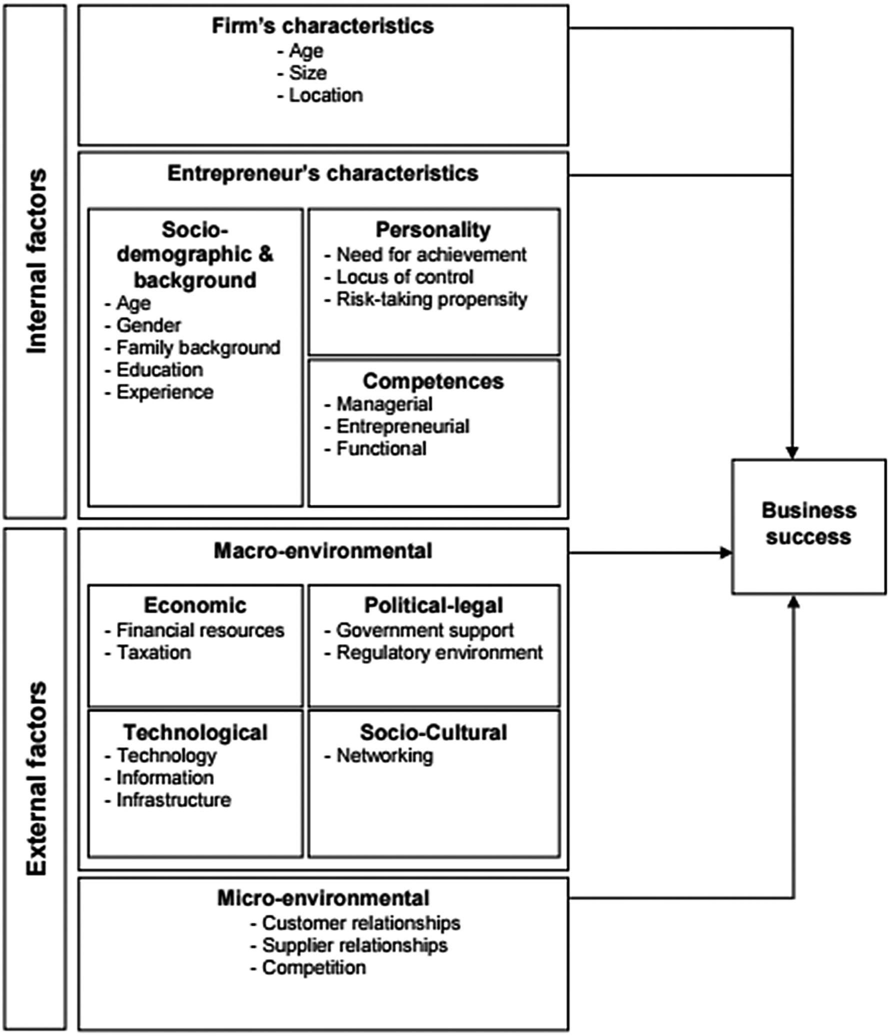

Fig. 1. Factors for success of a company [11]

– the Internet (an online store),
– the press, YouTube and other unconventional channels,
– strong belief in one's own abilities,
– branding.

The research on factors for success should cover not only enterprises operating within a given country but also those operating on the international market. In this case, Bose, among others, emphasizes the importance of factors such as: the network, connections, clusters, building value, the policy, or innovations [13].

The development (also innovativeness) of the SME sector depends to a large extent on the size of development capital, which comes from the entrepreneur's own resources and from foreign (external) capital. The acquisition of capital for innovations is particularly difficult in the case of small and medium enterprises. Acquiring long-term capital by entities from the SME sector is complicated, often ineffective and is referred to as the Macmillan gap (capital gap). It means the lack of capital for financing of innovative operations of the enterprise in the initial stage of the project or the difference between capital which entrepreneurs may acquire from private sources and capital for which they may apply to entities from the capital market. This is one of the main barriers for development in the SME sector. A loan or a credit is not a good solution because they increase the degree of financial risk [14].

The state's current financial and tax policy does not encourage collecting funds for development and promotion of export. Therefore, it is necessary to undertake actions which will result in the reduction in the amount of taxes and other fiscal burdens. Depreciation deductions do not ensure the regeneration of fixed assets. High social insurance contributions increase the costs of labor, which affect the growth in the prices of products/services and limit an organization's competitiveness [15]. Conditions to be met in order to obtain a credit are another barrier. The real interest rate, which is often high, involves the risks of losing the enterprise's liquidity and even going bankrupt [16]. The banks' high requirements make it difficult to access financing from a bank. There is a connection between the amount of debt of SMEs and the investment attractiveness of the region in which the enterprise is operating. Delays in paying obligations adversely impact SMEs [17]. There are also great obstacles of a bureaucratic nature, which make it difficult to start and conduct business operations. They are related, among others, to difficult-to-meet conditions, procedures and criteria for obtaining licenses and permits, as well as the vagueness and the need to obtain additional information regarding the interpretation of legal regulations [18].

The economic condition and the innovativeness of SMEs are also affected by micro-economic conditions such as [19]:

- the size of assets possessed by the entrepreneur,
- the ability to implement research and technical progress,
- the ability to manage the enterprise's resources,
- the knowledge and entrepreneurship of employees,
- the quality of offered products,
- the level of profitability,
- cooperation connections.

A factor which has already been mentioned in this study, and which is very often emphasized as important, is innovativeness (including product innovativeness). Numerous authors stress the fact that innovations are necessary for building a competitive enterprise. It is often emphasized that innovations are necessary for survival, and they should be the main strategy leading to the development of the company. Innovativeness brings only advantages, both for the customers and for the enterprise itself [20]. However, when reference is made to the key factors for the success of enterprises, economic factors are listed very often, with the main emphasis on the innovativeness of a product or a technology. It is demonstrated that innovative enterprises develop more quickly and cities with a larger number of companies conducting innovative operations are at a higher level of growth. Hence the interest in the issue of innovativeness as the key factor for success [21]. However, as has been presented earlier in the article, there are opinions that innovativeness is not beneficial for the development of small companies, but is effective only for larger entities. Since the publications which refer to innovativeness are international publications, the authors of this study decided to verify which factors are crucial for the development of small enterprises and whether innovativeness is one of the most important factors.

5 Factors for Success - Studies in the Lower Silesia Region

Empirical research conducted from April to May 2016 on the sample of 120 small enterprises operating in different sectors in the Lower Silesia region was used in order to pursue the objective of this article, namely the identification of factors determining the success of s small enterprise. The research was conducted by a research team led by Agnieszka Parkitna, PhD as well as the Lower Silesia Agency of Economic Cooperation. The research sample was selected in purposive sampling, and thus the following results should be treated with caution, in the category of hypotheses, because the collected data does not allow a clear verification of the significance of factors and is fragmentary. However, it may be the basis for further discussions and in-depth research.

The conducted survey research consisted in a questionnaire with multiple-choice questions regarding the barriers and factors for development, which were referred to in the previous literature search. When asked about support from the Polish law for the development of enterprises, as many as 78% of the respondents said that there is no such support from the law in Poland.

Another question related to the mental, ethical approach to conducted business operations. As many as 92% of the respondents pointed to the great significance of fairness in conducting business operations.

The respondents answered questions related to key factors for the success of their operations as well as environmental factors affecting them. In the case of the significance of human and intellectual resources, the respondents were asked about the significance of particular factors (Fig. 2).

As may be seen from the analysis of data, the greatest significance, more than 10%, is attributed to the competences of the staff, the personnel's qualifications, knowledge, and skills. The appropriate selection of staff, trust from the staff, production capacities, or the atmosphere at work are slightly less significant. Anticipated needs and post-sales services seem slightly less important – respectively 8.51% and 7.84% of the surveyed pointed out these answers, respectively, while the sex of the owner was indicated as significant only by 2.93% of the respondents. Some of the key factors, in turn, are factors typical of a small company, e.g. atmosphere at work or the staff's skills and trust.

Another group of questions was concerned with factors supporting business operations (Fig. 3).

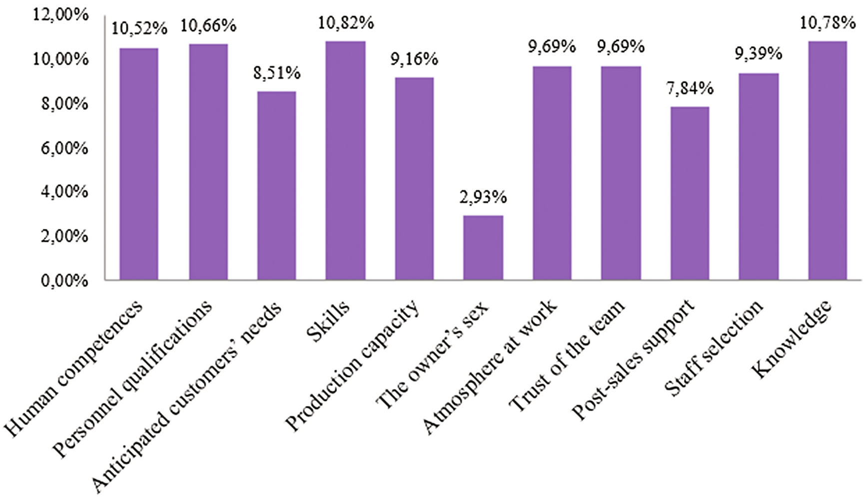

Fig. 2. Key success factors part one

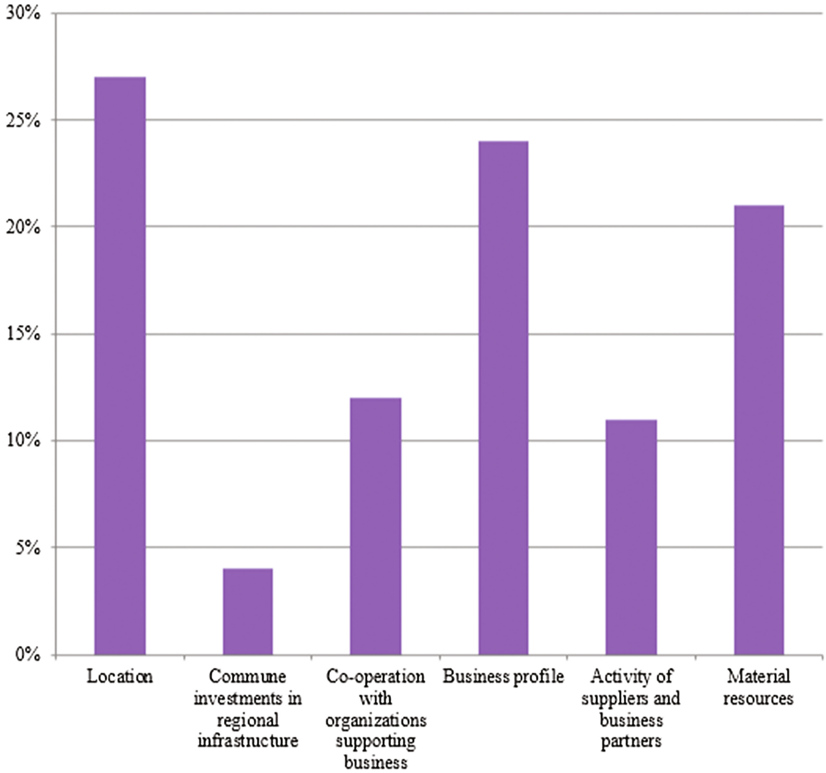

Fig. 3. Key success factors part two

The locations of conducted operations were indicated by the respondents as one of the key factors. The second place was occupied by the company's profile, which may be slightly misleading, because it shows that it is not important what business operations are conducted, but where it is done. The third factor is the availability of material resources. The cooperation with organizations supporting business, the activity of suppliers and other business partners, as well as commune investments in regional infrastructure should be considered "less important".

The last diagram presents factors for the success of companies. Entrepreneurs could indicate 5 out of the 11 suggested factors in the group (Fig. 4).

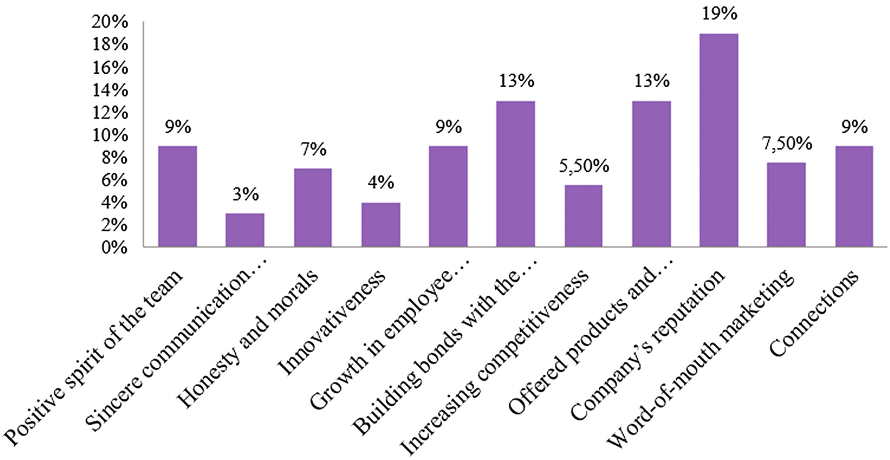

Fig. 4. Key success factors part three

As is shown by the conducted research, the most important factor is the company's reputation, while the offered services and products, as well as building bonds with the customer were ranked second and third, respectively. This, again, includes a contradiction, because reputation is the result of all the other factors yet it was indicated by the respondents as the most important one. Another factor proves the importance of the human factor, since approx. 11% of the respondents pointed out the positive spirit in the team and the growth in employee commitment as significant factors. It is not a surprise that as many as 9% of the respondents in Poland indicated connections as an important factor for success. The result of innovativeness is a surprise - only 4%. Only sincere contact with the employees turned out to be less important.

6 Conclusions

The basic factors for the success of an enterprise were selected at the beginning of the article on the basis of literature on the subject. The analysis of data obtained in the conducted research made it possible to select factors, which slightly differed from those present in the literature and, unfortunately, confirmed the unpopular opinion about the poor role of innovativeness - only 4% of the respondents in the sector of small enterprises. Entrepreneurs considered the company's reputation, the product offer, as well as building bonds with the customer as the three key factors. Then, a positive team spirit, which stimulates the growth in employee commitment so typical of small enterprises or start-ups, as well as connections were ranked equally high. A conclusion may be drawn that significance is attributed not only to money and connections, but also intangible assets, such as honesty, moral principles or the trust of employees.

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Design of EA Development Guideline for Small Enterprises Based on TOGAF 9.1

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Abstract. Information Technology (IT) become more and more important for business. Aligning between IT and business is a key success to get maximum benefit for enterprise as well as small enterprise. Enterprise Architecture (EA) framework allows an enterprise to get best alignment between business and IT, because EA represent business side and IT side together in a single model. However, todays EA framework (including TOGAF) is not dedicated designed for Small Enterprises or Small Business. In other hand, Small Business usually have very specific condition. In this case, they have very limited resources related to IT. It will be better if there is a more dedicated guideline as a reference for Small Enterprises in developing EA. So, by their limitations, Small Business can design good EA to support their business. This research is conducted to develop "EA Development Guideline for Small Enterprise" that modified from TOGAF 9.1. The resulted guideline has been tested and fulfilled all criteria from both content specification and format criteria.

Keywords: Enterprise Architecture · Guideline · Small enterprise

1 Introduction

1.1 Background

Small Enterprises play vital role to help countries to achieve their economy goals. Many governments, including government of Indonesia, aware of this situation which led to establishment of the Strategic Plan of Ministry of Cooperatives and SMEs (Kementrian Koperasi dan Usaha Kecil dan Menengah) [13]. This strategic plan suggests Small Enterprises to consider Information Technology (IT) investment in their business. However, IT investment must be aligned with the business needs of the enterprise or so called Business-IT Alignment.

There is a concept for aligning business and IT within an enterprise, called Enterprise Architecture (EA). Basically, EA is a conceptual blueprint which has an objective to optimize the enterprise by integrating fragmented processes into integrated processes and at the same time provide aligned IT system to support it to achieve business strategy. The benefits of having EA is a creation of an efficient business process execution and IT support. One of the best practice framework to develop an EA

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in an organization is TOGAF (The Open Group Architecture Framework), developed by The Open Group. Today, TOGAF used mostly by Large Enterprises all around the world. TOGAF can also be used by Small Enterprises to develop an EA but it will be feel complicated to be used by Small Enterprises that have very limited resources.

TOGAF can be customized for Small Enterprises, so any Small Enterprise can use the customized version of TOGAF. By applying this approach, small enterprises can develop their EA with a minimum effort and resources.

Many factors must be put into considerations when we want to customize TOGAF. One of the most important factor is specific enterprise's characteristics or in this case, Small Enterprise's characteristics [5]. By finding general characteristic of small enterprises, it is possible to modify TOGAF to be a Small Enterprise version of TOGAF.

This research identifies the common characteristic of small enterprises. These characteristics will lead to step by step process of customizing TOGAF to be more specific version of TOGAF that can be used by small enterprise. The result is "EA Development Guideline based on TOGAF 9.1". The guideline includes related architecture principles, architecture domain, and the phase to be conducted to specify principles and domain according to the Small Enterprise's business context.

1.2 Small Enterprise

Every country has its own definition of Small Enterprise. For example, in Indonesia, Small Enterprise is defined as an independent productive economy activity, conducted individually or as a business entity which is not subsidiary or part of medium or large enterprise. It has 50 million IDR to 500 million IDR worth of asset and 300 million IDR to 2.5 billion IDR annual revenue. Another example, in European Union, type of enterprise is defined according to number of employee and financial ceilings. Small Enterprise is defined as an enterprise which has less than 50 employees, less than 10-million-euro turnover, and less than 10 million euro of balance sheet [5].

According to [8], even though Small Enterprise has different definitions for each country, it has several similar characteristics. Those characteristics are: informal culture, quick communication, responsive, flexible, relying on individuals, nowhere to hide, wide knowledge, limited knowledge, and high unit costs [8]. Other research conducted by The Open Group, enterprise can be categorized by five characteristics: holding pattern, location, organization structure, business units, and IT requirement. Small Enterprise usually owned by individual or family, its location limited to small geography area, it has small and flat organization structure, limited business units, and has little dependency to information technology [14].

1.3 EA (Enterprise Architecture)

The concept of EA firstly introduced by John Zachman in 1980s as a method to integrate three big companies into single company. This first concept was evolved continuously and today there are many reference frameworks for helping us to build an EA [14].

IBM defined EA as an architectural discipline that merges strategic business and IT objectives with opportunities for change and governs the resulting change initiatives [9]. CIO Council defined EA as a strategic information asset base, which defines the mission, the information necessary to perform the mission and the transitional processes for implementing new technologies in response to the changing mission needs. An EA includes a baseline architecture, target architecture, and a sequencing plan [2].

Among many definitions of EA, one of most comprehensive definition of EA is proposed by Bernard. Bernard define EA as a framework which includes business, strategy, and technology in a single paradigm. It is also both management program and documentation method which will give the management an overview of strategic direction, business services, information flows, and resource utilization [11].

1.4 TOGAF

TOGAF is a framework which provides methods and tools to help architect to produce, deploy, and maintain an EA. This framework covers four architecture domains which are as follows [7].

1. Business Architecture. Defines business strategy, governance, organization, and main business process.
2. Data Architecture. Describes the structure of logic and physical data assets owned by the organization and data management resource.
3. Application Architecture. Provides certain application design to be deployed its interaction and relationship to the organization's main business process.
4. Technology Architecture. Describes software logic and hardware capability required to support business, data, and application services. It is also including IT infrastructure, middleware, network, security, communication, processing, standard, etc.

The core of TOGAF is TOGAF ADM (Architecture Development Method) which is the development method of EA. It consists of 10 iterative cyclic phases that guide user to develop EA. Each phase has its own inputs to be considered, processes to be conducted, and outputs to be produced. Outputs of each phase are also known as deliverables, artifacts, and building blocks [7].

2 Methodology

The methodology used in this research is adapted from Design Research Methodology (DRM). DRM is a generic research methodology developed by Professor Blessing in TU Berlin which basically consists of Research Clarification, Understanding Design, Developing Design, and Evaluating Design [3]. The final methodology for this research are as follows.

1. *Problem Identification.* The objective of this phase is to deepen the knowledge of the research context. It includes anything related to Small Enterprise and EA.

2. *Analysis*. Analyzing Small Enterprises capability, Small Enterprises characteristics, TOGAF ADM, and the impact of Small Enterprises capability and characteristics to TOGAF ADM which resulting requirement specifications.
3. *Design*. Tailoring TOGAF ADM and designing architecture principles and architecture domain as the main content of the guideline.
4. *Testing*. Verifying designed content guideline according to its requirement.

3 Analysis and Design the Guideline

3.1 Requirement Specifications

As mentioned before, an analysis towards Small Enterprises capability, Small Enterprises characteristics, TOGAF ADM, and relation between them must be conducted. Small Enterprise capability, especially financial capability, will affect their ability to buy or invest on Information Technology (IT). So, the framework must recommend the best architecture and solution that (1) in one side, it don't need high investment and (2) in other side, it can fulfill the business needs.

Another factor that might affect the guideline and its content that will be developed is **Small Enterprise characteristics**. To simplify the analysis of Small Enterprise characteristics, many characteristics that come from many sources are mapped into three categories: (1) people, (2) process, and (3) technology. People means any characteristics that related to the capability or capacity of the human resource inside the organization. Process means any characteristics that related to activities or process inside the organization. Finally, technology means any characteristics which related to the utilization of technology inside the organization. According to those definition, Small Enterprise characteristics can be mapped and grouped as can be seen below.

1. People: Relying on individuals, General knowledge (not specific and deep), Small and flat organization structure
2. Process: Informal culture, Quick communication, Responsive, Flexible, Limited knowledge, Nowhere to hide, Geographical limited, Limited business unit
3. Technology: Low IT dependency, IT used as an enabler.

Those characteristics must be fulfilled by the proposed guidelines. The more detail requirement specifications can be seen in Table 1.

3.2 Architecture Principles

Architecture principle is a basic rule or guideline which represents the way of how organization works. It also defines rules or guideline of how to utilize IT resource in the organization. There are several things which need to be considered to create architecture principle, such as organization mission, organization characteristic, external constraints, current IT system, and industry trends. Based on the characteristic and requirement stated in previous part, Architecture Principles defined and the result can be seen in Table 2.

Table 1. Requirement specification

No	Requirement description
1	Guideline is built based on TOGAF ADM of TOGAF 9.1 with several adjustments on steps and deliverables. Only focus on adjusting preliminary phase until technology architecture
2	Guideline support EA development based on Small Enterprise's financial capability
3	EA is simple and can be understood easily. It can be used by human resource with limited IT capability. Thus, a glossary is needed
4	Guideline supports the development of Knowledge Management oriented EA. It allows to describe the way to finish a work in the organization
5	Guideline supports the development of EA which provide quick and flexible information flow
6	EA guideline provides relevant technology options
7	Guidelines supports the development of EA which allow the organization to plan strategical issue efficiently

Table 2. Generic architecture principle

1	Name	Minimum investment
	Statement	IT investment must be within a minimum cost
	Rationale	Enterprise has a limited financial capability
	Implication	Technology options with a sufficient has to be affordable
2	Name	Distributed information/knowledge
	Statement	Any kind of information and/or knowledge within the organization are distributed and clearly described
	Rationale	Knowledge regarding the organization only owned by the CEO
	Implication	All organization element has the same knowledge regarding the organization so it might operate optimally
3	Name	Quick information flow
	Statement	Information within the organization spread quickly
	Rationale	Organization has a fast communication method/process
	Implication	Organization can access and process information directly and easily
4	Name	Efficient strategic planning
	Statement	Any kind of planning must be conducted efficiently
	Rationale	Business is highly focus on operational only and has no resource to think about strategic issues
	Implication	System which utilize owned resource to gain insight related to business is needed

3.3 Architecture Domain

Designing Architecture Domain as the main content of guideline is started by using Porter's Value Chain to represent Business Architecture [1]. The Business Architecture will be translated into Data and Application Architecture, and finally translated into IT Architecture as can be seen in Fig. 1.

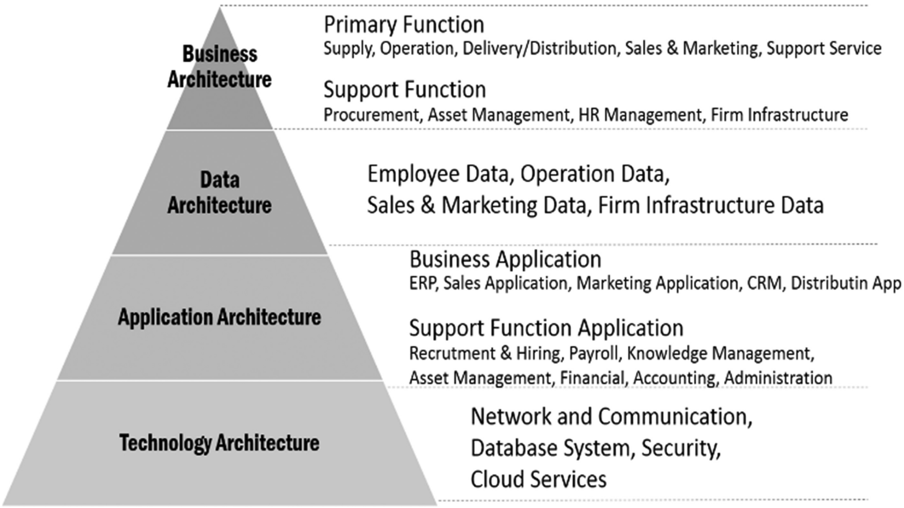

Fig. 1. Conceptual architecture domain

1. Business Architecture

There are two business functions which is defined in this business architecture. Those functions are: (1) primary function, and (2) support function. Primary functions adapted Primary Activities of Porter's Value Chain which include supply, operation, delivery/distribution, sales and marketing, and support service. Support functions represent Support Activities which includes procurement, asset management, human resource management, and firm infrastructure.

2. Data Architecture

There are four information system areas which is included in this data architecture. Those areas are as follows.

a. *Employee:* Employee Data, Payroll Data, Recruitment Data, and Training Data
b. *Operation:* Supplier Data, Resource Data, Asset Data, and Product/Service Data
c. *Sales and Marketing:* Market Data, Customer Data, Sales Data, and Distribution Channel Data
d. *Firm Infrastructure:* Finance Data, Accounting Data, Legal and Administration Data, and Standard Operating Procedure.

3. Application Architecture

In this architecture, there are two application services. Those services are as follows.

a. *Business Application:* Enterprise Resource Planning, Distribution Application and Management System, Customer Relationship, Sales Application and Management System, and Marketing Application and Management System

b. *Infrastructure Application:* Recruitment and Hiring, Payroll, Knowledge Management, Financial, Accounting, Asset Management, and Administrative.

4. Technology Architecture

Four technology services are defined in the designed technology architecture. Those technology services are as follows.

a. *Cloud Service*: A service architecture which allow the user to access any kind of service via internet without physically having those service. Service category used in the cloud service are business service, firm infrastructure service, and storage service. Cloud service is the core technology architecture of EA for small enterprise.
b. *Network and Communication*: Technology which allow data or information transaction automatically or based on user's input.
c. *Security*: Technology to protect existing IT infrastructure, including hardware, software, and network, within the organization from theft and damage. in this technology
d. *Data Management:* Function which includes planning and execution of a policy, practice, and project, to gain, control, protect, give, and add value of data and information assets. Four main functions included are Data Governance, Data Development, Data Operation Management, and Data Analytics [6].

3.4 Guideline Format Consideration

The format of EA Development Guideline adapted many popular existing guidelines/frameworks, such as TOGAF, BABOK, PMBOK, ITIL, and COBIT. By analyzing those frameworks, there are several criteria which will be considered to develop EA development guideline for small enterprises. Those criteria are: (1) it must contain introduction to explain the description and objective of guideline, (2) general overview of each phases using conceptual diagram, (3) detailed explanation of each phase in the same format of documentation, (4) reference map, (5) additional technique explanation and recommendation, and (6) detail of related deliverables.

4 Result

The guideline is made as the result of analysis and design stated in previous section. It consists of following composition.

1. *Introduction.* It explains background and objective of the guideline. It also contains explanation about foundation and structure of the guideline.
2. *Core Concepts.* It contains core definition of EA, including benefits, architecture principles (Sect. 3.2), and architecture domain (Sect. 3.3).
3. *Glossary.* It contains definition of terms which commonly used in EA development environment.
4. *Architecture Development Method.* It is main part of the guideline which explain the development method to build the EA. It contains initiation phase and architecture development phase, as can be seen in Fig. 2.

5. *Additional Techniques.* It is a collection of additional techniques that might be useful to develop EA
6. *Deliverables Format and Description.* It explain format and description of related deliverables from each phase of EA development method.

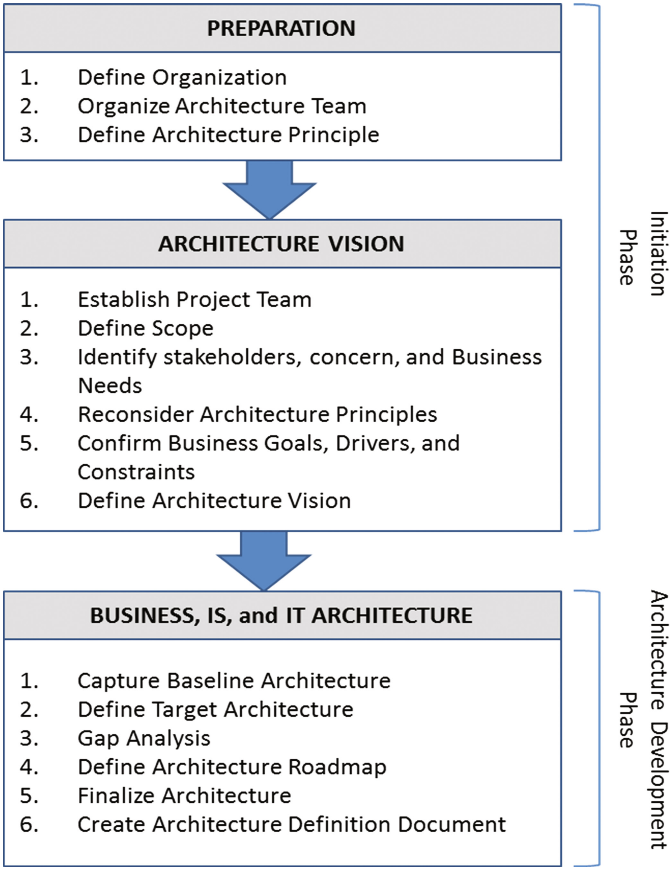

Fig. 2. Architecture development method

5 Evaluation

Principally, testing conducted to verify the fulfillment of requirement that stated in the developed guideline. The testing aspect is requirement/criteria of guideline content and format of guideline. The test result show that all the requirement/criteria from both aspects are fulfilled and can be seen in Tables 3 and 4.

Table 3. Format criteria fulfillment

No	Format criteria	Status
1	Contain introduction to explain the description and objective of guideline	✓
2	Contains general overview of each phases using conceptual diagram	✓
3	Contains detailed explanation of each phase in the same documentation	✓
4	Contains reference map	✓
5	Contains additional technique explanation and recommendation	✓
6	Contains detail of related deliverables	✓

Table 4. Requirement fulfillment

No	Requirement description	Guideline content [10, 12]	Status
1	Guideline is built based on TOGAF ADM of TOGAF 9.1 with several adjustments on steps and deliverables	The method which is used in the guideline is based on TOGAF ADM of TOGAF 9.1 with several adjustments on its steps and deliverables	✓
2	Guideline supports EA development based on Small Enterprise's financial capability	Cloud computing is used as its core technology architecture which is affordable for Small Enterprise	✓
3	Guideline has glossary to ensure that the EA is simple and can be understood easily is required	The guideline contains glossary which has more than 30 EA related terms	✓
4	Guideline supports the development of Knowledge Management oriented EA	In the application architecture, which is aimed in the guideline contain Knowledge Management	✓
5	Guideline supports the development of EA which provide quick and flexible information flow	Technology architecture use cloud computing as its core technology which has easy and fast accessibility	✓
6	Guideline provides relevant technology options	Cloud computing is used as its core technology architecture which is relevant for Small Enterprise	✓
7	Guideline supports efficient strategic planning	Technology architecture contains data analytics which might ease decision making. It is also supported by related architecture principles	✓

6 Conclusion

This research has delivered "EA Development Guideline for Small Enterprise based on TOGAF 9.1". This Guideline consider several important factors. The most prominent factor is characteristic of the organization, especially financial and human resource capability. In this proposed guidelines, those important characteristics are transformed into requirement specifications which must be fulfilled by the guideline as well as guideline format. The designed guideline has fulfilled all requirement, both EA specification and guideline format. By having this guideline, small enterprise can increase the quality of governance by applying IT effectively, especially for strategic alignment and value delivery.

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Analysis of Measurement Convertibility from FP to CFP: Conversion Formula and Monotonicity Condition

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Abstract. The article describes the basics of two software measurement methods: the FPA method, which represents the first generation of Functional Size Measurement (1G FSM), and the COSMIC method, which represents the second generation of such methods (2G FSM). It discusses both the similarities and the observed differences between the two methods. The discussions also include the influence of the increasing variable values on measurement results in both measures.

Drawing upon previous research, an analysis was performed into the relation between the results obtained from both measurement methods. The hypothesis on a linear relation was tested by employing a statistical method of linear regression analysis to investigate a sample of 13 software requirements specification documents. The obtained result was verified on a group of 14 different applications, by using the MMRE and Pred(0.25) measures.

Keywords: Convertibility formula · Functional size unit · Linear regression model · User requirements

1 Introduction

As companies shift from measuring their software or requirements specifications with Function Points (FP) towards COSMIC Function Points (CFP), the need to draw on the many year experience of various programming teams necessitates conversion of the number of function points into CFP or vice versa. Hence, the research into the relation between these two measures is performed for both theoretical and practical purposes. The FPA (Function Points Analysis) method and its later, commonly used versions have been extensively described, especially from the perspective of estimating effort in IT projects[1] [8, 9].

Users of the FPA and CFP methods expect the ratio between the measurement results in both methods to be expressed by a value approximating 1. However, research results published so far indicate that the difference between the FP and CFP is

[1] One of the examples is the Software Productivity Research (SPR) indicator method for effort estimation, which allows calculating the requisite effort N = S/P, where N is requisite effort, S is estimated software size in FP, and P is mean productivity of the project team in FPs per person-month, as calculated for a given programming language.

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greater (Table 1). Therefore, research should be continued to further investigate and describe the relationships between the measurement results obtained from the two methods and to understand the reasons for the observed differences. This project analyzes the extent to which the variability of the arguments in the FP and CFP formulas influence the final measurement result and uses a linear regression analysis method to describe the linear relation between the FP and CFP measures. The resulting new conversion formula was evaluated with the MMRE and Pred(0.25) tools.

Table 1. A set of linear conversion formulas published by various authors.

No.	Formula	R^2
1	y(CFP) = 1.1 * (UFP) − 7.6 [4]	0.97
2	y(CFP) = 1.2 * (UFP) − 87 [12, 13]	0.99
3	y(CFP) = 0.75 * (UFP) − 2.6 [1]	0.85
4	y(CFP) = 1.2 * (UFP) − 108 [1]	0.99
5	y(CFP) = 0.84 * (UFP) + 18 [1]	0.91
6	y(CFP) = 1.0 * (UFP) − 3 [3]	0.93
7	y(CFP) = 1.22 (NESMA FP) − 64 [7]	0.97

2 Description of the FPA and COSMIC Methods

2.1 The FPA Method

In the second half of the 1970s, Allan Albrecht together with other IBM engineers developed a new measure of “functional points”, which was meant to overcome the shortcomings of the “code line” method employed at that time. Function points are a conventional measure, which is independent from the programming language. The method can be used from an early stage of requirements analysis, and through the entire project life cycle, including software maintenance and development. Function points allow the measurement of software size by identifying two types of an application’s components and evaluating their complexity, as well as the so-called technical complexity.

The FPA procedure is divided into three quantitative steps [5, 6]:

1. Unadjusted function points computed from expression

$$UFP = \sum_{i=1}^{5} \sum_{j=1}^{3} z_{ij} \times w_{ij} \tag{1}$$

where:

UFP – Unadjusted Function Points,
z_{ij} – number of components of i^{th} type and j^{th} complexity,
w_{ij} – weighing value of components of i^{th} type and j^{th} complexity.

2. Adjustment factor

$$VAF = 0.65 + (TDI \times 0.01) \quad (2)$$

where:

VAF - Value Adjustment Factor,
TDI - Total Degree of Influence.

3. Adjusted function points

$$FP = UFP \times VAF \quad (3)$$

where:

FP - Adjusted Function Point count,
UFP - Unadjusted Function points,
VAF - Value Adjustment Factor.

In the first step of the method, unadjusted function points (UFPs) are calculated, by first identifying, and then by analyzing the complexity of the identified two types of data and three types of functional processes. The complexity of the data types and of the process types is determined by counting the number of structural elements in Internal Logical Files (ILF) and External Interface Files (EIF), as well as by calculating the number and complexity of references to data in each of the EI, EO and EQ processes (External Input, External Output and External Query, respectively). The complexity of references is characterized not only by the number of referenced files but also by the number of elementary data used. When added, the numbers become a basis for a two-dimensional qualification of each of the components into one of the three complexity levels. The complexity level thus established (L - Low, A - Average or H - High) allows the selection of an appropriate multiplier (weighing value)[2].

In the next step of the method, the value adjustment factor, previously referred to as the technical complexity factor, is established by estimating the degree of influence (on a scale from 0 to 5) of each of the given characteristics. Originally, this degree of influence was a subjective criterion for evaluation. However, after the IFPUG (The International Function Point Users Group) gathered sufficient experience using the method and after some necessary evaluation criteria were introduced, the results have become acceptably objective and their usage in various comparative analyses have become possible. The method developed by Alan Albrecht distinguishes 14 technical

[2] The values of constant weighing numbers were experimentally determined by Allan Albrecht and have been since used in unchanged form (Table 4).

complexity factors, while subsequent FPA-based methods have various numbers of factors – for instance the Symons method distinguishes 20 such factors [11].

In the third step of the method, a final number of function points is counted, adjusted with the adjustment factor determined in the previous step.

2.2 The COSMIC Method

The COSMIC method [2] was developed as a response to the need to measure software in a broader scope than business applications only, as well as to adjust to the terminology related to object methodologies which started to occur in the modeling language. First research in this field was initiated in the late 1990s and works are still continued [10]. In 2002, the COSMIC method was acknowledged as international standard ISO/IEC 19761. It is an open method, and can be used on the basis of the documents available at www.cosmicon.com [14]. The method can be applied to business software, in which significant quantities of data must be managed, to real-time software used for process control and automatic data acquisition, as well in software which is a hybrid of the two types.

COSMIC is an FSM method, in which functionality is measured on the logical level, without a physical design and without a chosen implementation technology. In COSMIC method, user requirements are referred to as Functional User Requirements (FUR) and comprise only functional requirements. Non-functional requirements, such as reliability and security, are not included.

The measurement process consists of three phases [2]:

1. Establishing a measurement strategy, which is outlined before the measurement procedure and includes a definition of the purpose and scope of measurement, as well as identification of functional users and of the granulation level for the artefacts available in the measured software.
2. Mapping, which consists in the identification of functional processes, objects of interest and groups of data.
3. The measurement consists in identifying data movements and classifying them into one of the four types: E – Enter, X – Exit, R – Read or W – Write. In the next step, the measurement function is performed and the measurement results are aggregated for each functional process at the same granulation level. By definition, the COSMIC measurement method is a mathematical function, which assigns a value to its arguments, i.e. to the identified data movements. In the COSMIC method, the measurement unit is referred to as a COSMIC Function Point (CFP) and corresponds to one data movement; thus 1 CFP is equal to one data movement.

Each functional process may comprise multiple data movements, and hence the size of a functional process is determined as an arithmetic sum of all identified data movements expressed as units of CFP. The measurement formula [2]:

$$\mathrm{Size}(\text{functional process}_i) = \sum \mathrm{size}(\mathrm{Enter}_i) + \sum \mathrm{size}(\mathrm{Exit}_i) + \sum \mathrm{size}(\mathrm{Read}_i) + \sum \mathrm{size}(\mathrm{Write}_i) \tag{4}$$

Thus, the functional size of a piece of software is directly proportional to the number of its data movements.

For each functional process, the method defines a minimum size of 2 CFP: one Enter and either one Exit or one Write. The upper limit of the functional size for a single process is not defined and as a consequence no upper limit exists for the functional size of a piece of software.

2.3 Comparison of the Basic Principles Behind the Methods

The FPA method enables the assessment of both functional and non-functional requirements, while the COSMIC method allows the measurement only of functional requirements (Table 2). Both methods allow the measurement of applications supporting organization management systems, in which the amount of stored data is more important than the complexity of data processing procedures. Additionally, the COSMIC method can be applied to real-time systems. Both methods are similar in using a functional point as a conventional measure; the FPA method, however, can be used through the entire project life cycle, while the COSMIC method is intended for use at an early stage of this cycle.

Table 2. Comparison of the FPA and COSMIC methods in relation to features.

No.	Compared feature	FPA	COSMIC
1	Area of application for the software	Management Information Systems	Management Information Systems Real time system
2	Application development methodology	Structure and object oriented approach	Structure and object oriented approach
3	The phase of project life cycle	Early phase of project life cycle Requirements Detailed design Testing Implementation Maintenance	Early phase of project life cycle Requirements
4	The scope of features measured in the application	Functional and non-functional features	Functional features
5	Type of measure	Conventional, functional	Conventional, functional
6	Monotonicity condition	Partially restricted	Unrestricted

Although both methods represent the same Functional Size Measurement group, their detailed definitions indicate some differences. The most significant differences include the scope of features measured in an application and the fact of satisfying the monotonicity condition, which is described and analyzed in detail later in this paper.

2.4 Monotonicity Condition for the UFP and CFP Measures

This analysis focuses on comparing measures in the FPA and COSMIC methods, without regard to non-functional software features, as in other conversion formulas (Table 1). Narrowing the analysis to unadjusted function points UFP (1), which are the result of calculations only for the first stage of the FPA method, is justified, since the investigated measurement values must relate to the same attributes of the compared object.

The Formula for the FPA Method

In the formula for the FPA method, result UFP (1) depends on variable z_{ij}, which corresponds to the number of components, and on an appropriate constant w_{ij}, which in turn depends on the type of the component (ILF, EIF, EI, EO, EQ) and on its complexity level (L, A, H). Hence, the variable is two-dimensional, one dimension being the component type, and the other dimension being its level of complexity. However, a more detailed analysis shows the level of complexity to be dependent on yet two other variables: DET and RET/FTR (Table 3). In the case of the ILF and EIF data files, the variables comprise the number of elementary data DET and the number of hierarchical relations RET, and in the case of functional processes, they comprise the number of elementary data DET and the number of logical reference files FTR. Further analysis indicates that while the increase in the number of DET, RET and FTR may be unlimited, the impact of this growth on the size of UFP is restricted by constant multipliers assigned to particular DET and RET/FTR value ranges (Table 4).

Table 3. Complexity matrix for EIs. (Source: 6, p. 121).

File Types Referenced (FTR)	Data Element Types (DET)		
	1–4	5–15	≥ 16
<2	Low	Low	Average
2	Low	Average	High
>2	Average	High	High

Table 4. Multipliers of FPA components for high complexity (Source: 6, p. 123).

Type of component	RET/FTR	DET	w_{ij} multiplier
ILF	2–5	≥ 51	15
	>5	≥ 20	
EIF	2–5	≥ 51	10
	>5	≥ 20	
EI	2	≥ 16	6
	>2	≥ 5	
EO	2–3	≥ 20	7
	>3	≥ 6	
EQ	2–3	≥ 20	6
	>3	≥ 6	

For instance, for an EI transaction, the FTR number of 3, 5 or even 10 and with the DET number equal to 16, 20 or 45 will always result in High complexity and the same value UFP = 1 × 6 (Table 4). The above fact means that in the case of variables DET and FTR, boundary values for EI's second range are reached at DET between 5 and 15, and RET > 2, while the third range is reached at DET = 16 or more and RET > 2. Any excess of these levels will have no influence on the increase in the complexity of this type of component, and hence on its size measured with UFP. Therefore, the final UFP value for a given application will depend only on variable z_{ij}, i.e. solely on the number of components of a given type.

The above analysis allows a conclusion that since the increase in the values of variables RET/FTR and DET has no influence on the increase of UFP, the required monotonicity condition is in this case partially restricted.

Additionally, boundary values of variables RET/FTR and DET with complexity High for all types of components indicate that this complexity is reached for two different combinations of RET/FTR and DET values for each type of component, but with the same multiplier value (Table 4).

The Formula for the COSMIC Method

The formula for the COSMIC method (4) implies that the final result of the measurement depends on two variables: the number of functional processes and the sum of each type of data movement: E, X, R and W. This means that an increase in the number of movements of each type and an increase in the number of functional processes effects an increase in the final CFP result without any upper limits for maximum size of an application.

Summary

The above analysis of the influence of the values of variables which occur in the formulas for both methods allows the following observations:

1. In the FPA method, increasing DET and RET/FTR variables have a partially limited influence on the UFP result but may have a potential influence on the difference between the UFP and CFP values for the same application,
2. In the COSMIC method formula, no upper limit restricts the increase in the values of four variables.

The observed partial growth restriction for applications, whose size is measured with the FPA method entails a question, if one can expect applications with limit DET and RET/FTR values reached or exceeded to show the same or similar size values when evaluated using the FPA and the COSMIC method. The above question has been investigated and described below.

3 Projects and Research Results

3.1 Measurement Results for the Collected Projects

13 project documentation sets were collected, which comprised requirements specifications for the MIS (Management Information Systems) computer applications, such as

applications for the management of commissioned works at a university, for investment management in an industrial establishment, for book sales management, or for planning timetables in a secondary school. All sets of documents comprised data models, function models and completed CRUD matrices, thus enabling the use of the FPA method. The measurement using the COSMIC method required additional analysis of documentation and performing calculations compatible with the COSMIC formula. The methods were FPA 4.1 [6] and COSMIC 3.0.1 [2]. The results obtained for both methods (Table 5) show values from 73 to 957 UFP and from 72 to 950 CFP. Importantly, the analyzed group consists of one small application 73/72), two big applications (843/845, 957/950) and 13 medium size applications from 107/136 to 275/284 and 268/292.

Table 5. Comparison of measurement results for the FPA and CFP methods

Project no.	FPA method					CFP method				
	ILF and EIF	EI	EO	EQ	UFP	E	X	R	W	CFP
P1	84	100	35	12	231	57	100	42	57	256
P2	119	88	21	40	268	57	92	92	51	292
P3	504	232	116	105	957	144	296	361	149	950
P4	280	421	28	114	843	244	275	144	182	845
P5	105	48	14	8	175	28	58	48	24	158
P6	73	52	28	6	164	30	44	30	69	173
P7	98	49	26	6	179	46	45	52	40	183
P8	105	72	30	14	221	29	59	76	28	192
P9	35	54	14	4	107	31	53	25	27	136
P10	35	18	14	6	73	19	22	16	15	72
P11	91	68	29	33	221	33	92	60	22	207
P12	112	76	14	31	233	38	85	72	37	232
P13	119	90	42	24	275	68	81	84	51	284

3.2 Relationship Between the Measurement Deviation and the Indicator of the Share of H Components

In order to answer the question posed in the summary of the discussion on the influence that the variables in formula (1) have on the final UFP result, firstly an analysis was performed which was focused on the relationship between UFPs obtained from the highest (H) complexity components and the total number of UFPs (Table 6).

Columns from 2 to 5 (Table 6) show the relation between the value of UFP(H) for each type of component (ILF, EIF, EI, EO, EQ) and the total UFP. All cells in column 2 show 0%, which means that these projects had no data types of highest complexity, while for other types of components, these values are within the range of 0% to 100%, which indicates they have a varied share in the UFP of the investigated projects. Values

Table 6. Comparison between the analysis results for the share of the H complexity components and the difference of UFP and CFP.

Project no.	UFP(H)/UFP [%]				Sum of UFP(H)	UFP(H)/ UFP [%]	CFP-UFP
	ILF and EIF	EI	EO	EQ			
1	2	3	4	5	6	7	8
P1	0.00	72.00	100.00	100.00	119.000	51.515	25
P2	0.00	0.00	100.00	0.00	21.000	7.836	24
P3	0.00	56.90	96.55	11.43	256.000	26.750	−7
P4	0.00	9.98	100.00	10.53	82.000	9.727	2
P5	0.00	100.00	100.00	0.00	62.000	35.429	−17
P6	0.00	92.31	100.00	100.00	82.000	50.000	9
P7	0.00	36.73	80.77	100.00	45.000	25.140	4
P8	0.00	100.00	70.00	42.86	99.000	44.796	−29
P9	0.00	100.00	100.00	0.00	68.000	63.551	29
P10	0.00	0.00	100.00	0.00	14.000	19.178	−1
P11	0.00	26.47	72.41	90.91	69.000	31.222	−14
P12	0.00	78.95	100.00	77.42	98.000	42.060	−1
P13	0.00	100.00	100.00	100.00	156.000	56.727	9

in column 6 comprise the UFP(H) sum calculated for all types of components in a given project. Column 7 shows the ration between the UFP(H) sum and the total UFP number.

In the second step of the analysis, a reason for the difference between the FPA and COSMIC methods is proposed. The suggested reason was the restricted influence of increasing variable values in the FPA method. This analysis required finding a proper linear correlation coefficient. To this end an indicator of the UFP(H)/UFP relationship (column 7 in Table 6) was used together with the difference between the CFP project size and the UFP project size (column 8). The correlation coefficient between these values appeared to be 0.1752. a result at this level does not support the proposed conclusion. Additionally, it shows that the UFP result strongly reacts to the increase of variable z_{ij}, i.e. to the growing number of functional processes.

3.3 Confirmation of the Linear Relationship Between UFP and CFP

In order to confirm a linear relationship between the FPA and COSMIC measurement results obtained from the set of 13 collected projects (Table 5) a linear regression analysis method was used (see Fig. 1). The result was the formula with the linear model adjustment (coefficient of determination) R^2 having the value of 0.996:

$$y = 0.991 \times UFP + 5.221 \tag{5}$$

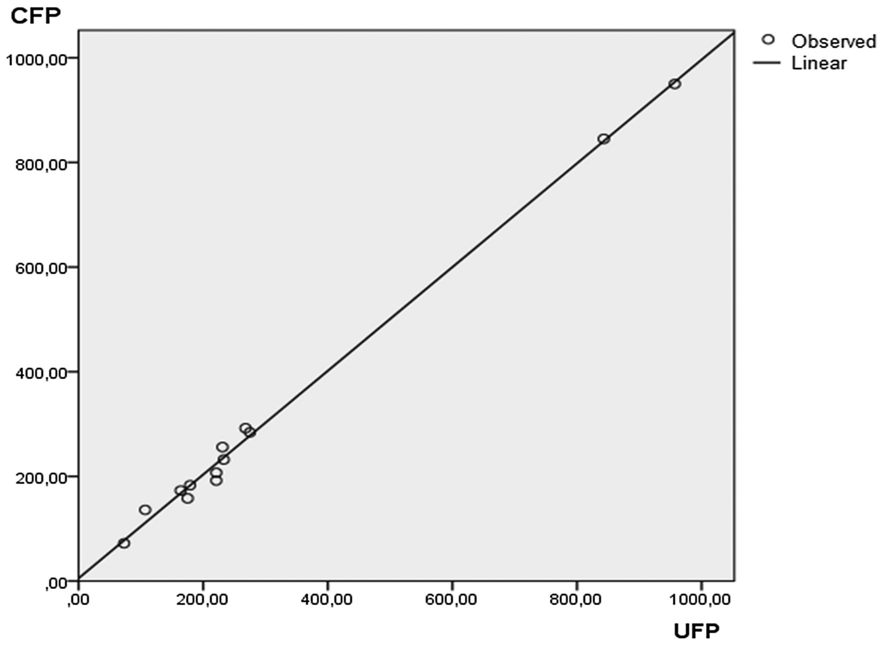

Fig. 1. Graphic representation of the linear relationship between the UFP and CFP measurement results (Computed with PS IMAGO V.4.0).

3.4 Validation of the Obtained Conversion Formula

In order to verify the obtained formula (5), an estimation of CFP values was performed for a group of 14 projects described by Desharnais et al. [3].

Columns 2 and 3 (Table 7) show the results of an actual project measurement performed using the FPA and COSMIC methods, while column 4 contains the results of estimations performed with formula (5). Column 5 shows the differences between the estimated values and the actual values, and column 6 shows the relative error as a percent indicator of the relationship between the difference (5) and the actual value (3).

Of the 14 projects (see Fig. 2):

- 6 projects have the estimated value below 5%,
- 2 projects are above 5% and below 10%,
- 5 projects are above 10% and less than 20%,
- 1 project is above 20%.

Importantly, 2 projects have the indicator below 1%, and only one project has the indicator above 20%, albeit with a high value of approx. 50%.

Evaluation of the accuracy of estimations performed with the obtained formula was based on the MMRE measure and on Pred(V) = n/N, where V is the required estimation accuracy, n is the number of projects with relative estimation error lower than V, and N is the total number of projects. The acceptable estimation reliability measure was MMRE of 25% and $\text{Pred}(0.25) \geq 0.75$. After calculations MMRE = 0.108,

Table 7. Comparison of the results calculated using the obtained formula with the results of measurements as presented in [3].

Project no.	UFP	COSMIC 2.2	Formula CFP (5)	CFP-COSMIC (4–3)	(CFP-COSMIC)/ COSMIC (5/3)
1	2	3	4	5	6
1	383	364	384.774	20.774	5.71%
2	647	565	646.398	81.398	14.41%
3	400	398	401.621	3.621	0.91%
4	205	188	208.376	20.376	10.84%
5	372	448	373.873	−74.127	−16.55%
6	126	88	130.087	42.087	47.83%
7	111	115	115.222	0.222	0.19%
8	287	298	289.638	−8.362	−2.81%
9	500	579	500.721	−78.279	−13.52%
10	344	291	346.125	55.125	18.94%
11	317	294	319.368	25.368	8.63%
12	258	252	260.899	8.899	3.53%
13	113	114	117.204	3.204	2.81%
14	447	467	448.198	−18.802	−4.03%

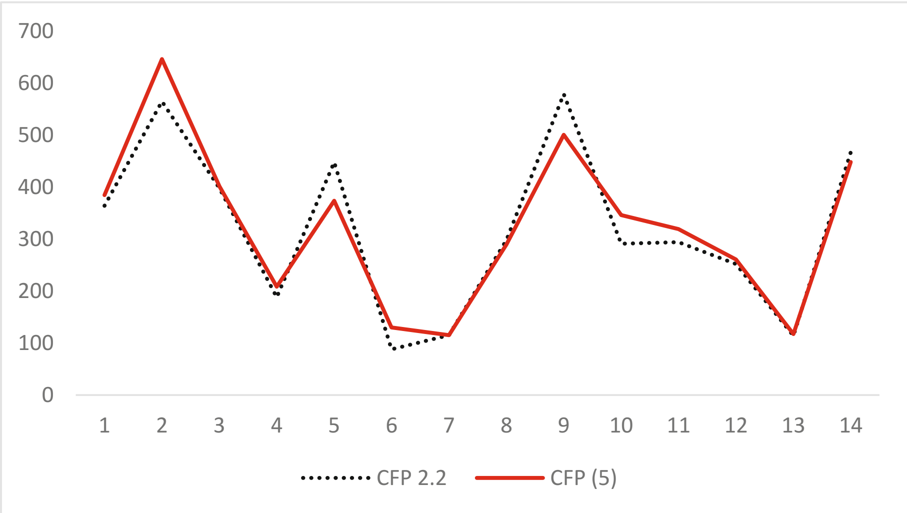

Fig. 2. Comparison of the results calculated using the conversion formula (5) with the results of measurements as presented in [3].

i.e. smaller than 0.25, and the Pred(0.25) value is greater than 0.75. Thus, of 14 projects, as many as 13 were estimated with an error below 25% and Pred(0.25) = 0.928 is only slightly smaller than 1, which implies a reliable (at the accuracy level of 25%) estimation of CFP on the basis of UFP, after using conversion formula (5).

4 Conclusion

The presented research results indicate that a strong correlation exists between the size of functional requirements measured with the FPA and with the COSMIC methods and the statistically calculated coefficient of determination is close to 1. The obtained accuracy rate for the CFP estimations using this formula is acceptable and the Pred(0.25) factor is close to 1.

The discussion of the monotonicity of the UFP measure due to partial restriction of the influence of variables RET/FTR and DET on the UFP value showed that in such case the measurement result is sufficiently dependent on variable z_{ij}. At the same time, the suggested correlation between UFP(H) and the deviation of the CFP value from the UFP value has not been statistically confirmed.

Although the FPA and COSMIC methods belong to the same group of FSM methods, depending on the employed requirement modeling methods, as well as on the domain of the information system, the differences that occur may be not only interpretation- but also domain-related and have a significant impact on the measurement results. Since the usage of the two methods requires the understanding of requirements analysis techniques, and especially of function and information modeling, the employment of the two methods may also cause difficulties related to proper classification of the components of a requirements specification, as well as to ensuring an adequate and uniform complexity level in such documentation. The presented conversion formula offers a solution to these problems.

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Developing Conformance Between Project Management and Enterprise Architecture Governance on the Basis of a PMBOK Case

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Abstract. Enterprises seek to improve their functions. This is not an easy task because the spectrum of their activities is very complex. One of the ways of untangling the complexity of enterprise activities is to describe them in a coherent and - to some extend - uniformed way. An important part of enterprise functionality is project management. Mapping the project management function onto enterprise architecture concepts is of great importance. In the paper the case of the PMBOK project management standard is considered. The main concepts of PMBOK are mapped to ArchiMate, an enterprise architecture modelling language. The obtained results indicate that such mapping is important for an enterprise and also show possibilities of improving the consistency of project management methodologies. The presented approach may be adapted for the agile approach.

Keywords: Project management · Enterprise architecture · Architecture governance · System modeling · PMBOK · ArchiMate

1 Introduction

Enterprise architecture occupies a central position in integrating different management functions, such as strategic planning, project portfolio management and project management. The project management function implements architectural changes on the basis of goals and directives of enterprise architecture. The development of enterprise architecture accounts for the structure of the organization, motivation, business, application and technology processes. The description of all components and relations requires a coherent approach (Lankhorst 2017), necessary in building integrated architecture models, which should be based on enterprise architecture modelling language. Enterprise architecture is used to obtain a holistic view of a company, and it can be adapted to a specific company as described in (Jamróz et al. 2014).

The functions and processes of a company are supported by different frames, such as methodologies, standards, and methods. The problem is that all these frames are described by different presentation approaches. The idea of the paper is to provide mapping of company project management operations to enterprise architecture governance on the basis of meta-models and ArchiMate, an enterprise architecture description language.

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The software development industry is a branch which uses a mix of different project management methodologies. An important portion of activities in software development companies (software houses) is software product development, usually organized into projects. The most popular project management methodologies are PMBOK for the classic and Scrum for the agile approach. PMBOK (Project Management Body of Knowledge) (PMI 2013a) is a classic project management methodology developed by PMI. The main problem in applying classic and agile methodologies like PMBOK or Scrum is caused by difficulties with understanding the difference between them, due to extensive texts based on descriptions containing many not self-explanatory terms. The method proposed here is based on enterprise architecture models and concepts of ArchiMate, a language which is used to describe enterprise architectures. To reduce the time of learning for both classic and agile methodologies, a meta-model was introduced enabling mutual mapping between them. The paper concentrates mainly on PMBOK, and it should be underlined that the proposed approach has not been described in the literature yet.

Enterprise architecture models can be used to describe activities of a company. Developing enterprise architecture is supported by different frameworks, out of which TOGAF (The Open Group 2011) is most frequently citied. In the TOGAF description, conformance means that all features described in the architecture specification are implemented in accordance with the specification, but some features not described in the specification may be implemented in a different way. The best way to specify architecture is to describe it in an enterprise architecture language, such as ArchiMate, which is also supported by The Open Group (The Open Group 2016). There are many software tools certified by The Open Group that may be used for modelling in ArchiMate. The ArchiMate models presented in the paper are developed using Archi (Beauvoir 2015), a free and open source modelling tool for creating ArchiMate models and sketches.

IT companies use different approaches for organizing their activities. They may include self-made solutions, a hybrid implementation of different methods, and tailored or fully implemented standard methodologies. Some well-known approaches will be briefly discussed below.

COBIT (Control Objectives for Information and Related Technologies) is a framework (ISACA 2012) for the governance and management of IT enterprises. COBIT is used to improve (Radovanović et al. 2011) the management of IT in accordance with regulatory requirements, and the key areas of IT governance include: business IT strategic alignment, new value delivery through IT, IT resource management, IT risks management and IT performance management.

ITIL (Information Technology Infrastructure Library) is a standard aimed at supporting IT services for business, on the basis of definitions of processes, which should be implemented in organizations delivering IT services. (Vicente et al. 2013b) present a proposal of integrating ITIL with the Enterprise Architecture approach by mapping ITIL to the ArchiMate concepts. The goal of their paper is twofold: on the one hand, to offer architects the elements, relationships and models representing best practices in IT service management, and, on the other hand, to create a formal model for knowledge sharing and communication with stakeholders. Another paper by the same authors (Vicente et al. 2013a) concentrates on representing motivation behind ITIL expressed in ArchiMate motivation concepts.

The problem considered here is connected with the fact that software developing companies are confronted with different standards and methodologies they should use. Some examples of such standards include PMBOK, Scrum, KANBAN for project and product management, COBIT and CMMI for software development governance, ITIL for IT service support, ISO, and TOGAF for more general usage. These standards are based on different presentation approaches, terms and motivations. The employees working in a given company may find it difficult to understand the main differences between all these standards. The proposed hypothesis states that using a common model based on enterprise architecture concepts will make it easier for them to understand and compare all these standards. The proposed solution recommends the application of enterprise architecture solutions, meta-models and ArchiMate, an enterprise architecture language.

The paper is organized as follows. The introduction describes the problem of project management conformance and reviews existing solutions in this area. In Sect. 2 a meta model of project management methodologies is proposed which allows for comparing methodologies and aligning them to enterprise architecture. In Sect. 3 a PMBOK process concept is described using ArchiMate notation. On the basis of the PMBOK flow model between processes (DFD based), in Sect. 4 artifacts modelling is proposed. The roles in PMBOK are not explicitly described, so the role-based collaboration is introduced in Sect. 5. For each process in PMBOK, a set of proposed tools and techniques is given. In Sect. 6 a workshop proposal is introduced including tools and techniques as a resource asset that may be used in the process. An example of a stakeholder process management group is presented in Sect. 7, with an application layer added. Concluding remarks are given in Sect. 8.

2 Meta-Model of Project Management Methodologies

In the IT branch, agile (Scrum) and classic (PMBOK) project management methodologies are the most popular ones. For describing, mapping and integrating such different methodologies, it is necessary to develop a general model (a meta-model), which will be used for modelling methodologies. The goal of building a meta-model is to develop a notation suitable for users of the developed models. A meta-model will be a constraint in defining terms representing different methodologies. On the other hand, a meta-model must be general enough so as not to limit correct definitions of methodologies.

The proposed meta-model will be simple and will be based on concepts and schema concepts (a set of concepts of a given structure). Different relations can occur between the concepts of different concept schema, and they will be denoted as semantic mapping. On the basis of the concept schema, a meta-model - common for project management methodologies - can be build. The following concepts are introduced for project management methodologies (Werewka et al. 2010):

- Universal principles. The activities in the methodologies should conform to principles.
- Artifacts. Everything that is produced during project execution (e.g. products, documents, software, new organization of a team, etc.).

- Role. Role means a virtual person or organization which is able to perform a set of activities.
- Process. Process consists of activities leading to the creation of artifacts.
- Events. Phenomena which occur during project execution.
- Workshop. A combination of elements used by project roles in order to perform activities leading to the creation of artifacts.
- Discipline. Knowledge areas of various project management fields.

An enterprise performs many functions, and one of them is project or product management using different project management methodologies. In the above mentioned work a solution is proposed for the alignment of project management methodologies based on two ontologies, a classic one represented by PMBOK and an agile one represented by Scrum.

Different notations or models may be used for enterprise architecture modelling. The ArchiMate notation is used because the elements of the notation seem self-explanatory and the notation is not very extensive. In the ArchiMate notation seven different layers are distinguished: motivation, strategy, business, application, infrastructure, physical, implementation and migration. In this paper mainly a business layer is considered. While modelling PMBOK in ArchiMate, it is important to distinguish basic concepts of PMBOK. In mapping PMBOK concepts to ArchiMate the following PMBOK concepts will be taken into consideration: process, inputs and outputs of the process, project role, and tools and techniques supporting the process of performing.

3 Process Concept in PMBOK

A process is a primary concept of PMBOK. Processes are performed by process roles. In PMBOK roles occur in an implicit way. Each process is characterized by its inputs and outputs. The inputs and outputs can be modelled with flow relations. An artifact is related to each flow. In each process some defined tools and techniques may be used.

The process concept in PMBOK is very similar to that in ArchiMate. In PMBOK each process is a member of two process groups (Fig. 1): project management process group and knowledge areas. The project management process group divides management functions into project initiating, planning, executing, monitoring and controlling, and closing. The grouping process according to a knowledge area has educating functions, and grouping processes according to project phases indicates a management function assigned to each process.

General management functions are defined as: planning, organizing, staffing, directing and controlling. In case of project management in PMBOK, the following general functions can be distinguished: project initiating, planning, executing (including organizing, staffing, directing), monitoring & control, and project closing. Naturally, in project management other functions can also be listed, connected e.g. with people or organization competency.

One of PMBOK drawbacks is the lack of the definition of process activities. The activities of a process can be determined on the basis of documentation analysis, produced outputs and tools and techniques used. Another issue is connected with the

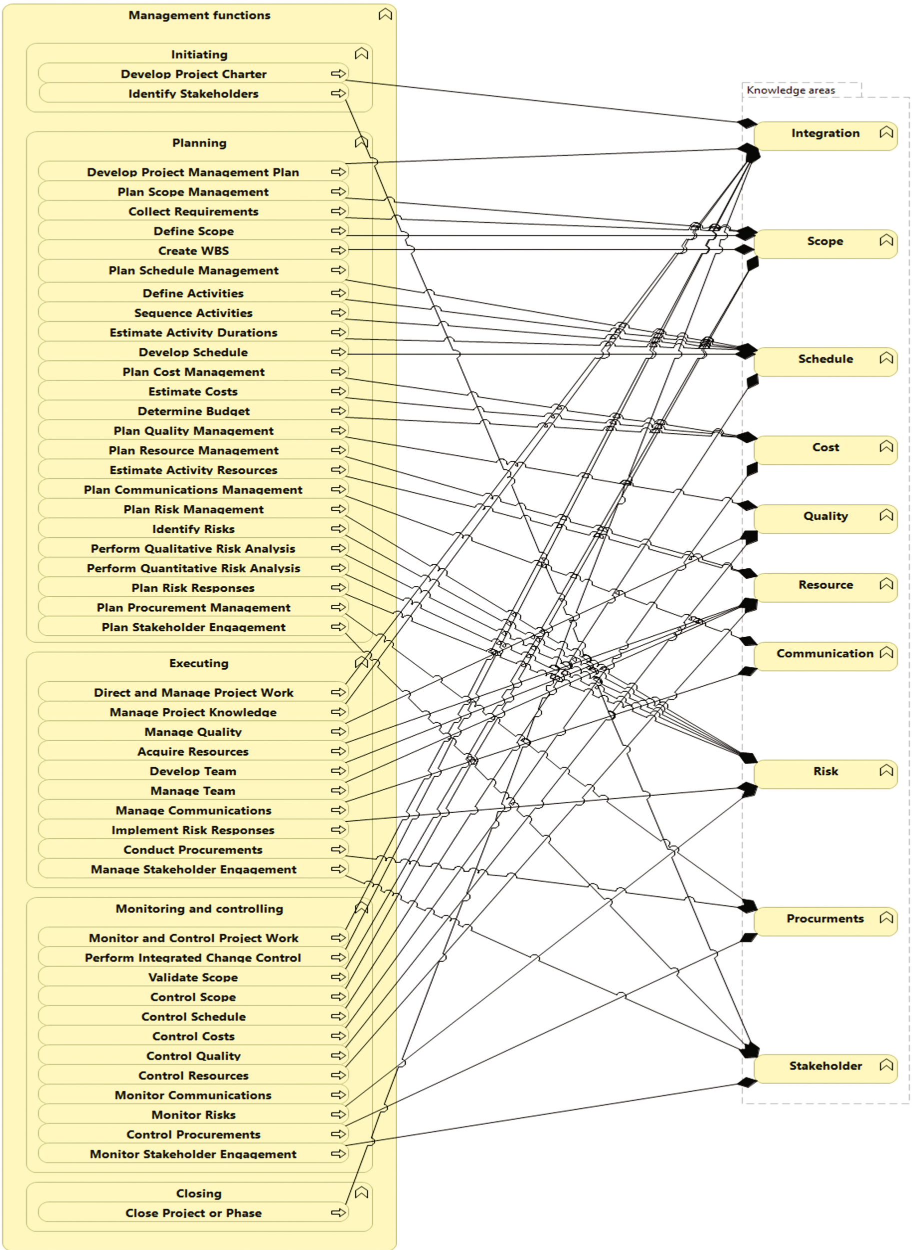

Fig. 1. PMBOK processes described in ArchiMate

fact that flow relations between processes are defined, but triggering relations are not. To some extent, it is possible to determine triggering relations on the basis of flow relations. Additionally, it is not explicitly defined when a process starts and stops.

4 PMBOK Artifacts Modelling in ArchiMate

Processes in PMBOK are well defined by their inputs and outputs. Every process is described as DFD (Data flow diagram). Inputs and outputs represent a flow between different processes. The flows can be grouped into different information types, like project plans or documents. The proposal is to treat inputs and outputs of processes as artifacts presented as ArchiMate business objects. Artifacts can be grouped as shown in Fig. 2.

The main group of artifacts are project plans and documents. Very often in PMBOK artifacts are used describe the project context. An important group of artifacts are project deliverables, which are the main concerns for customers. Generally, the model of artifacts does not seem consistent due to the fact that sometimes a single process input is composed of artifacts from different hierarchy levels or is a subset of other artifacts (e.g. outputs of other processes).

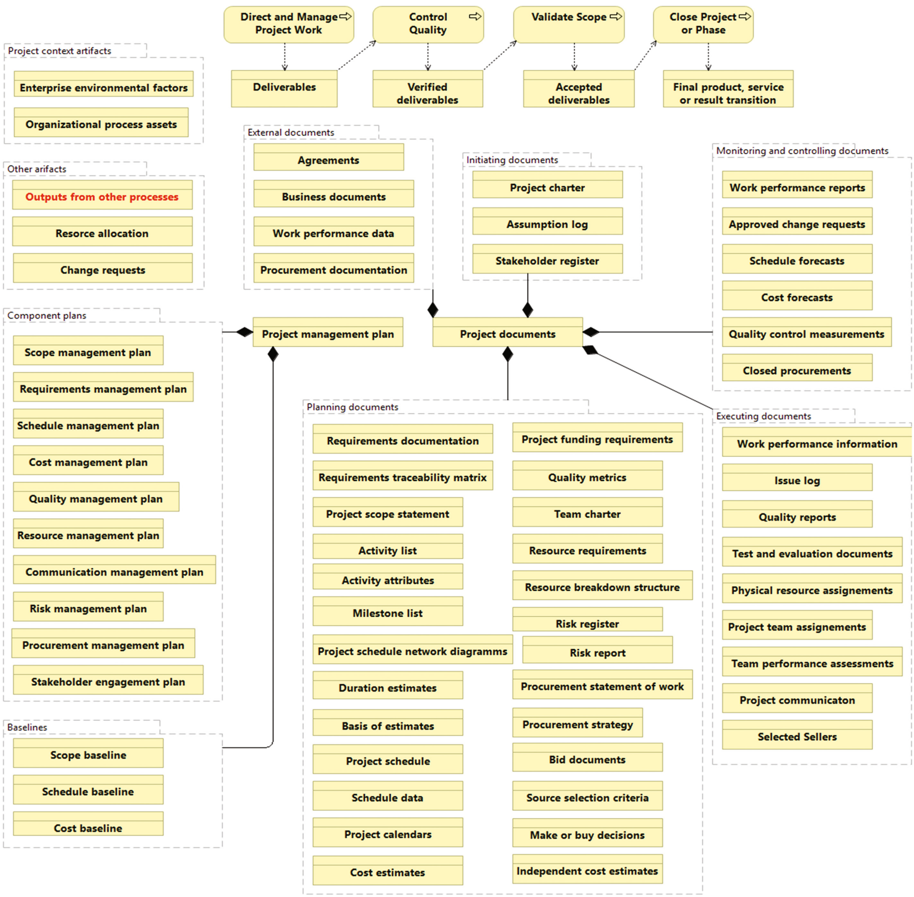

Fig. 2. Inputs and outputs of the MBOK processes as ArchiMate business objects

5 PMBOK Role Modelling in ArchiMate

One of the problems in PMBOK is connected with the fact that roles are not given in an explicit way. So, the first task was to go through PMBOK documentation and to identify all possible roles. Figure 3 presents the roles found through searching documentation.

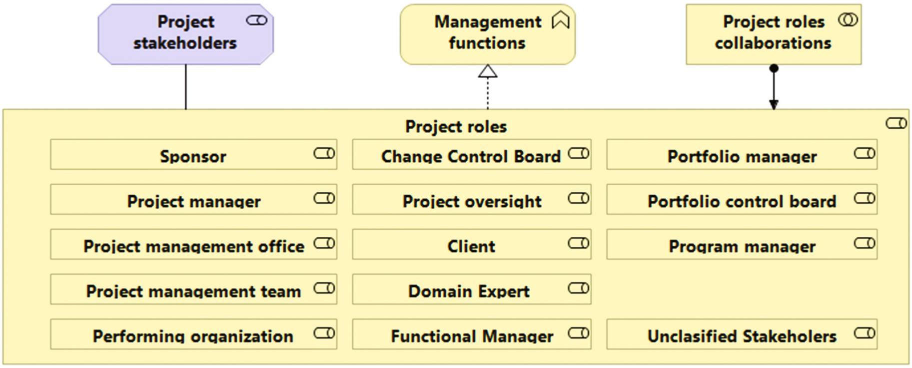

Fig. 3. Extracted roles from PMBOK documentation

The activities of the roles change during the project lifecycle. In PMBOK project management five process group are defined: initiating (IN), planning (PL), executing (EX), monitoring & controlling (MC), and closing (CL). The groups are the functions of project management and not direct the phases of the project. Analyzing PMBOK documentation yields 14 different project roles (Table 1). For each role and process group the participation importance is proposed as: 0 - role not necessary, 1 - role can occur, 2 - role should occur in business cooperation, 3 - role should occur, 4 - role must occur in business cooperation, and 5 - role must occur.

In ArchiMate a concept of collaboration of roles is introduced. Figure 4 shows an example of such possible collaboration. Each role is of different importance in process groups. For each process group the leading roles are proposed forming business collaborations:

- Business Collaboration (IN) = {Sponsor, Portfolio Manager, Program Manager, Project Manager, PMO, Client, Performing Organization}
- Business Collaboration (PL) = {Project Manager, PMO, Project Management Team, Sponsor, Functional Manager, Performing Organization}
- Business Collaboration (EX) = {Performing Organization, Project Manager, Project Management Team, Functional Manager,}
- Business Collaboration (CM) = {CCB, Project Oversight, Project Manager, Client}
- Business Collaboration (EX) = {Client, Project Manager, Performing Organization, Sponsor, PMO}

Table 1. Role assignments to project functions

	Role	IN	PL	EX	MC	CL
1	Sponsor	5	3	2	2	1
2	Portfolio Manager	3	2	0	2	2
3	Portfolio Control Board	3	2	0	2	2
4	Client	4	4	0	4	5
5	Program Manager	3	2	0	2	2
6	Change Control Board (CCB)	0	2	0	5	2
7	Project Oversight	0	2	0	5	4
8	Project Manager	3	5	5	4	5
9	Project Management Office (PMO)	3	3	2	3	3
10	Project Management Team	2	4	3	2	4
11	Functional Manager	2	3	3	2	2
12	Domain Expert	1	1	1	1	1
13	Performing Organization	2	3	5	3	4
14	Project Stakeholders	1	1	1	1	1

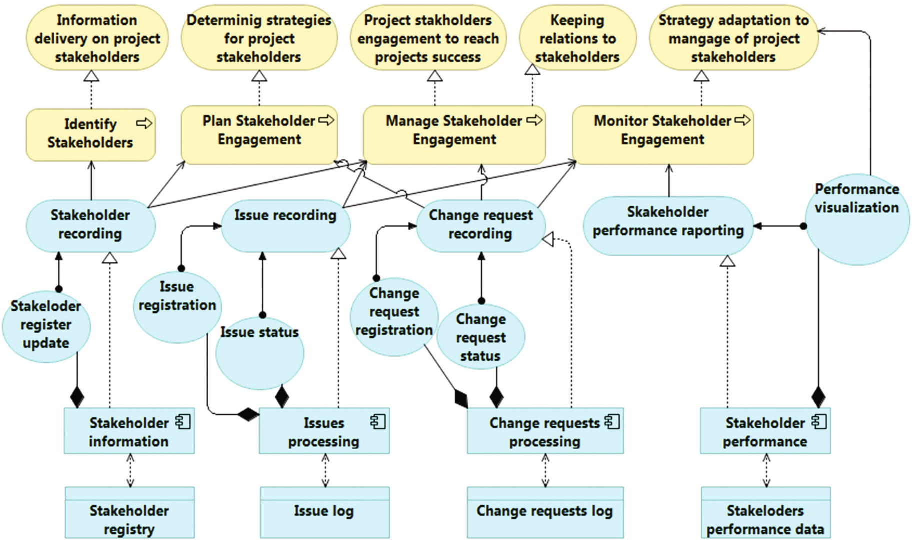

Fig. 4. Possible support of stakeholder management performed by application components

Because in PMBOK roles and activities are not defined in an explicit way, in the developed model no assignment between roles and activities is determined. Doing so, we can obtain a model which does not conform to PMBOK.

6 PMBOK Tools and Techniques Modelling in ArchiMate

In PMBOK each process realization can be supported by tools and techniques. PMBOK tools and techniques may be considered a methodology asset. In ArchiMate (The Open Group 2016) a resource represents an asset owned or controlled by an individual or organization. Resources can be classified as financial, physical, human and organization (e.g. technology, methods) assets. In PMBOK a set of tools and techniques is assigned to each process. Generally, in project management methodology for process a workshop can be defined. The workshop here means using different assets to support process execution. The workshop can consists of:

- Techniques (expert judgement, stakeholder analysis, analytical techniques, leader and interpersonal capabilities, etc.)
- Tools (meetings, communication methods, information management systems, etc.)
- Practices
- Rules (methods, instructions, terms of use, etc.)

With each process described in the paper tools and techniques will be considered as methodology assets. In PMBOK for each process a workshop is defined consisting of tools and techniques. The practices that may be used within the project are described in separate PMI standard as OPM3 (Organizational Project Management Maturity Model). The OPM3 (PMI 2013b, p. 3) is used to determine organization project management maturity on the basis of the level of use of best practices by project management organization. The usage of rules is not given in an explicit way. In PMBOK documentation methods and instructions to be applied for a general purpose or for purposes specific for each process are described in a general way, and the terms of use of different activities are mentioned.

7 Example of PMBOK Process Model

In the first step, the core PMBOK elements including all processes, artifacts, roles and workshop items are described in ArchiMate. A process group known as stakeholder management knowledge area will be considered as an example. The basic structure of this process group is presented in Fig. 4. The presented diagram consists of PMBOK processes which realize services for this group.

Additionally, in Fig. 4 possible support of these processes performed by application components is given. The application usage is not a part of PMBOK, but could be an enterprise architecture solution supporting business processes.

8 Conclusions

The paper proposes a way of aligning a basic PMBOK concept to enterprise architecture description. The proposed solution may be useful for common understanding of company operations and may be important for developing enterprise architecture governance. The proposed solution may be successfully adapted to agile projects and product development methodologies. In the paper only the core PMBOK concepts are considered. The future work will concentrate on alignment of motivation concepts to different organization levels: enterprise, project, process.

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Hazard Control in Industrial Environments: A Knowledge-Vision-Based Approach

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Abstract. This paper proposes the integration of image processing techniques (such as image segmentation, feature extraction and selection) and a knowledge representation approach in a framework for the development of an automatic system able to identify, in real time, unsafe activities in industrial environments. In this framework, the visual information (feature extraction) acquired from video-camera images and other context based gathered data are represented as Set of Experience Knowledge Structure (SOEKS), a formal decision event for reasoning and risk evaluation. Then, grouped sets of decisions from the same category are stored as decisional experience Decisional DNA (DDNA) to support future decision making events in similar input images. Unlike the existing sensor and vision-based approaches, that required rewriting most of the code when a condition, situation or requirement changes, our platform is an adaptable system capable of working in a variety of video analysis scenarios. Depending on the safety requirements of each industrial environment, users can feed the system with flexible rules and in the end, the platform provides decision makers with hazard evaluations that reuse experience for event identification and correction.

Keywords: Decisional DNA (DDNA) · Set of Experience Knowledge (SOEKS) · Industrial hazard control

1 Introduction

Hazards are present in all workplaces and can result in injuries, short and long-term illnesses, and even death. According to the Safe Work Australia SWA [1], from 2003 to 2015, over three thousand workers lost their lives in work-related incidents. In addition, still according to SWA in 2014–2015, there were 107,355 serious worker' compensation claims related to disease and injuries, resulting in productivity loss, human suffering and the cost of billions of dollars to the Australian Economy.

The Australian Work Health and Safety Strategy 2012–2022 aims at reducing the incidents related to occupational health and safety and has identified the manufacturing industry as a priority to reduce the work-related injuries, illnesses and fatalities -

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according to industry type, from 2003 to 2015, the manufacturing had the third highest incidence rate of serious claims and the fourth highest proportion of fatalities [2].

Hazard control is essential to ensure the occupational health and safety of workers [3]. In this context, monitoring of workers activities and identifying any risk present in the workplace emerged as a need. The use of sensors data and computer vision techniques support the fast and automated detection of potentially dangerous situations. This information can be used to provide feedback, and manage workers behavior to perform the work in a safe manner [4].

However, as stated by [5], the broad industrial environments and situations existing, result in rewriting most of existing applications code each time the circumstances or conditions change. In addition, as the system grows the scalability becomes an issue and the quantity of considerations required for each application in particular can easily lead to a rigid and inflexible structure [6]. Aiming at controlling hazards in industrial workplaces, in special for a wide diversity of environments in the manufacturing industry, it is proposed in this research an adaptable system capable of working in a variety of video analysis scenarios requiring little or no modification.

This paper is organized as follow: in section two, we present some relevant related work in sensor-based and vision-based systems as well as the use of knowledge representation approaches for the task of recognizing human activities; in section three, we introduce our proposed framework, explaining each layer of the overall architecture of the system; and lastly, in section four, we present conclusions and future work.

2 State of Art

We separated the state of art into two sections: (i) sensor and vision-based human activity recognition, and (ii) recognizing human activities using knowledge representation approaches.

2.1 Human Activity Recognition

Human activity recognition has become one of the most active research subjects in pattern recognition and image processing fields [7]. It can be a challenging problem, particularly in real world scenes, subject to illumination changes, difficult structured background, occlusion and variation of human body poses [8]. This is a significant problem with a broad range of applications such as video surveillance of train stations, airports and pedestrians in road traffic scenes; smart homes; human computer interfaces; sports video analysis and workspace monitoring [9–14].

Generally, approaches to recognize human activities can be divided into two groups: sensor-based and vision-based. Sensor-based systems use a combination of sensors, attached to the subject being monitored, whereas, vision-based activity recognition systems attempt to recognize human behavior from images and video sequences [15, 16].

Sensor-Based Systems. Activity recognition based on sensors is a growing area of interest given the advances in wearable sensors. With common use of smartphones, applications in various domains are taking advantage of the ease to monitor personal activities and behavior in order to provide dynamic and personalized services [17].

For daily activity recognition, Palumbo et al. [18] research introduced a flexible and robust multi-sensor data approach using data sampled by sensors embedded in a smartphone and the reciprocal values coming from worn wireless sensor devices with applications in smart homes. Moreover, Wang et al. [19] proposed a method for human activity recognition using a wearable inertial sensor, which achieved higher recognition accuracy for hierarchical classification even with few training samples; although, it presented the limitation of implementability, and porting the proposed algorithm would be, according to the authors, a "meaningful job". In the industrial context, Li et al. [20] described an intelligent system able to identify head motion, aiming to reduce accidents caused by fatigue and sleepiness of workers.

Despite the fact that several activity recognition systems have been developed over more than two decades, there are still unsolved issues to be addressed with new techniques [17]. One of the biggest limitations of sensor-based systems is the requirement of classifiers to work as fast as possible in order to be embedded in lower-power wearable devices [16]. Dohnálek et al. [16] tested the performance of several classifiers on multiple datasets and concluded that the computation power for real-time implementation, even when using the best performances, still remains a challenge. Additionally, in spite of sensor-based systems providing more accurate results than vision-based systems, it requires sensors or markers to be attached on the human body, which can be a difficulty because the device can disturb some movements [4].

Vision-Based Systems. The majority of previous work on activity recognition has focused on development of systems using 2D video cameras, which are, in general, sensitive to clutter and occlusion, resulting in low accuracy [21]. Aiming to solve this limitation, the use of the RGBD sensor has been proposed in recent researches. This sensor is composed by a RGB camera that works in association with a particular kind of depth sensing device and is capable of supplementing the conventional image with depth information [22]. The RGBD sensor was used, for example, in Sung et al. [21] research, which considered the problem of detecting and recognizing human activities in unstructured environments.

Additionally, Farooq et al. [23] presented an effective body skin joints feature identification system based on depth sequences, handling problems such as self-occlusion, overlapping among people and hidden body parts prediction. With applications to safety, Han and Lee [4] developed a supervised vision-based framework to detect critical unsafe activities of construction workers using 3D human skeleton models, aiming to provide workers with feedback on their behavior and to examine the impact of safety-related management actions.

Furthermore, Roitberg et al. [24] presented a two-step approach for activity recognition based on Random Forest and Hidden Markov Models for safe cooperation between humans and robots. In terms of accuracy, the systems performance when operating in real life remains limited. In Xu et al. work [25], vision-based activity recognition techniques are examined, and showed that it is still a challenging task for several reasons, such as variance in the appearance of particular events, similarity in the appearance of different events, lack of specific background information, scalability and in flexibility.

2.2 Knowledge Representation

Besides the significant improvements of human activity identification that has been done in the past few years, only a little research has focused on specific requirements for industrial applications and the commercial systems available that are able to run in real time (mostly using vision-based approach) currently perform far from satisfactorily [8]. In addition, the issues related to human detection such as occlusion, position accuracy, frame rate and background changes result in the necessity of adapting the algorithms for different conditions, clients and situations [6].

In this context, methods incorporating priori knowledge and context information are gaining interest. Zambrano et al. [6] developed an automatic semantic and flexible annotation service able to work in a variety of video analysis with little or no modification using SOEKS. With additional contextual information it was possible to enhance the speed and accuracy of the detection algorithms and reduce the scalability issues.

With our approach, we attempt to implement an analogous idea to Zambrano et al. [6]. The system is composed, basically, by the combinations of image processing techniques (e.g. segmentation, feature extraction and selection) and a knowledge representation approach: Set of Experience Knowledge Structure (SOEKS) and Decisional DNA (DDNA). The platform, unlike the sensor and vision based systems, has the flexibility to work in a range of manufacturing environments, without the necessity of recoding the whole system to each different industry. In addition, reusing the past experiences and contextual knowledge for future decisions improves the system performance in terms of computational time, accuracy and scalability, as well as gives support for self-learning; those factors make its implementation possible in a real time application. Though, in Zambrano et al. [6] approach, a lot of information contained in the classifiers is lost by separating the classification of the humans and objects from the event recognition. Also, the training of classifiers can be very time consuming. To overcome that issue, we propose representing the image feature vectors also as part of the SOEKS together with context variables.

3 Proposed Framework

Figure 1 shows the overall architecture of the proposed knowledge-vision-based hazard control system, which is divided into three main layers: Configuration Setup, Reasoning and Repository, and Monitoring.

The initial process for behavior-based worker observation is to develop a checklist of critical safety-related behaviors. Initially, it will consider general activities that may present risk such as non-use of Personal Protective Equipment (PPE) when required (e.g. when accessing certain areas, operating machines or interacting with robots), access to restricted area when not permitted, disregard to gap or safety distances to areas and machineries, among others.

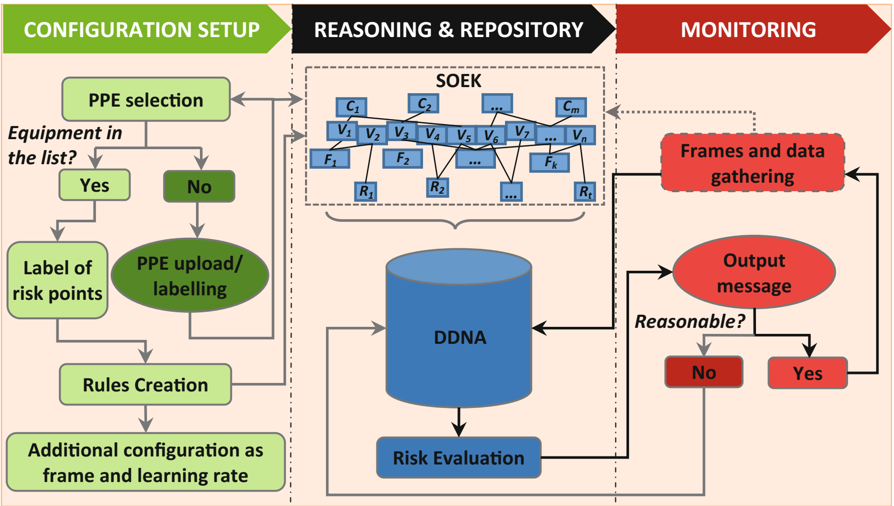

Fig. 1. Overall architecture of the proposed knowledge-vision-based hazard control system.

3.1 Configuration Setup

This layer comprehends the selection of the PPE according to industry requirements; labeling of machinery, areas and plants of the workplace being captured by the camera; creation of the rules and configuration of other functionalities such as frame and learning rate.

Through the application, the user is able to select the required PPE from a given list. In case of the desired equipment is not in the list, a new one can be added. To include a new equipment, which might be used future configuration setups, the user must upload an image containing the equipment and its label (name). It gives the system the ability to self-increase the range of possible workspaces' applicability. The resulting set of numeric features extracted from the new equipment is described by a feature vector and represented in the SOEKS as new variables.

Once the process of selection of equipment is finalized, the selection of areas and machinery is initialized. In this step, each single machine is manually select and labeled. The same process is repeated for the areas. Once all the areas and machinery are selected and labeled, and the all extra functionalities are configured, the configuration setup process is finalized. The features composed by the selected areas and machineries are also stored in the SOEKS for recommendations in future setup configurations.

Feature Extraction and Selection. A In Machine Learning and Pattern Recognition, 'feature' is a single computable property of a certain pattern that is being observed, such as color components, length, area, circularity, gradient magnitude, gradient direction, or simply the gray-level intensity value. For the feature extraction, a range of different approaches will be tested such as Histogram of Oriented Gradients [26], Speeded Up Robust Features [27], Local Binary Patterns [28] and Haar-like wavelets

[29]. To reduce processing time and data storage, a small set of features is selected (the ones whose values efficiently discriminate among patterns of different classes, but are similar for patterns within the same class). This process is known as feature selection. For feature selection, existing methods such as Principal Component Analysis [30], Adaboost [31], Random Forest [32] and Mrmr [33] will be explored.

Rules Creation. We propose to recognize workers activity under the organization and relationships of the context attributes. In this research, we consider, at first, four basic attributes to compose an activity: object (in this case the PPE), person, action (e.g. approaching, operating) and the risk point (e.g. machinery, plants and restricted areas). An activity may contain one or more attributes and may be composed by more than one attribute of the same type. Each of those attributes and other context data, as well as the rules created by the users, are represented as a SOEKS in our system. Once an activity is detected, its recognition and indication of hazards take into consideration the set of rules given by the user. They contain an explicit relationship among the context attributes, such as "Workers must wear gloves when operating machine 1" and "Workers must stay 2 m from the area 1". The rules can be changed according to each industry requirement and is able to adapt to different necessities by, simply, changing the entries.

3.2 Reasoning and Repository

The Reasoning and Repository layer is composed by the Set of Experience Knowledge Representation (SOEKS), Decisional DNA (DDNA) and the intelligence of the entire system. The SOEKS, DDNA and system operation are explained below.

Set of Experience Knowledge Structure (SOEKS). SOEKS is a knowledge representation structure designed to obtain and store formal decision events in an explicit way. It is based on four key basic elements of decision-making actions (variables, functions, constraints and rules). Variables are generally used to represent knowledge in an attribute-value form, following the traditional approach for knowledge representation. Given the set of variables, functions, constraints, the rules of SOEKS are different ways of relating knowledge variables. Functions define relations between a dependent variable and a set of input variables; therefore, SOEKS uses functions as a way to create links among variables and to build multi-objective goals. Likewise, constraints are functions that act as a way to limit possibilities, restrict the set of possible solutions and control the performance of the system in relation to its goals. Finally, rules are relationships that operate in the universe of variables and express the condition-consequence connection as "if-then-else" and are used to represent inferences and associate actions with the conditions under which they should be implemented [34].

Decisional DNA (DDNA). The repository is composed of experienced decision events, which are represented as SOEKS in our platform, grouped according to the areas of decision categories – the Decisional DNA. A SOEKS from a formal decision event represents a portion of an organization's DDNA (as a gene that guides decision-making). This gene belongs to a decisional chromosome from a certain type or category. A group of chromosomes from different kinds (e.g. hazard control decisions, production decisions, marketing decisions) comprise the DDNA, a decisional genetic code of an organization. The DDNA can be used to solve the scalability issues found in current vision-based approaches by introducing an experience-based approximation that aims to recognize events defined by the user using production rules, adaptable for different conditions, clients and situations [35].

System Operation. The visual information (vector of features) and other gathered data is stored as variables in the SOEKS. Those variables are connected by relationships, the functions, which describe the associations between the set of input variables and the dependent variable (in this case the hazard). These relationships provide uniqueness and reduce the ambiguity for decision-making.

As any other system, our platform is also composed of constrains, which is another way of describing relationship among the variables, but with the purpose of limiting the possibilities and restrict the feasible solution. Without the constraints, the system would have infinite performance. As an example, when the user configures the system and chooses the list of personal protective equipment and the risk points, constraints are created, which means, any another PPE or risk point different from the selected ones will not be considered for evaluation.

In addition, the SOEKS will be composed by the set of rules given by the user, translated and represented as if-then-else statements. Finally, each decision-making, i.e. evaluation of events, for each single SOEKS captured will be grouped and stored in the DDNA repository for reuse in future similar occurrences. In order to build a smart platform, the system will be trained, which means, it will run several times as a way to learn as much as possible before it is put into practical use.

When operating, the platform will compare the vector of information obtained from the application (monitoring layer) to the vector of variables existing in the repository. For the comparison, few methodologies may be tested to measure similarity between the input vector and the stored vectors. Initially, Euclidian distance and Cosine [36] techniques will be used. When comparing the vectors, the similarity is given along with the established solution contained in the SOEKS with the shortest distance. If the solution given does not fit the requirement of the user, then human intervention will be needed. In this case, if the SOEKS is not completely equal to any existing one, a new experience is created with the suggested solution given by the user; otherwise, the SOEKS is entirely equal to an existing one and, then, the suggested solution given by the user replaces the existing in that SOEKS.

In addition, when operating, the system creates new experiences even when the solutions given are reasonable and non-human intervention occurs. As stated before, the learning rate, which is the frequency of storage of experiences, is given by the user when configuring the system. The higher the learning rate, the smarter the system becomes. On the other hand, reusing information whenever possible without the necessity of creating a new experience reduces the complexity of the system, saving processing time and storage space. Thus, in order to achieve the desired performance, there should be a balance between capability and simplicity.

3.3 Monitoring

This layer represents the monitoring of workers' activities. For each captured frame, the visual information (features) and other context based gathered data are grouped into a vector of variables for comparison with the vectors of variables stored in each SOEKS of the DDNA repository. It might also be stored (depending on the learning rate), as previously explained. When a hazard is identified by the system, an alert message is shown on the application with some details about the existing risk. This information is useful to avoid creation of a mistaken SOEKS when there is an issue with the collecting of information (and not with the reasoning of the system). For instance, if it is required the use of helmets to operate a machine and the system fails in recognizing it, the alert message will provide the detail of why a risk was identified. Knowing that the given output message does not reflects the reality, the user will be able to manually annotate the equipment and the system can use that information to create a new experience which containing, besides all the other variables, the set of features extracted from the selected region. This is an additional way for the system to learn when operating in real time.

4 Conclusion

The research is still at its early stages. The related work has been extensively researched and helped us to propose an overall architecture for a knowledge-vision-based system to control hazards in workplaces, in particular in manufacturing industry. We intend to recognize, in real time, human activities that can cause hazards or accidents in industrial environments and overcome the problem of recoding when the system is applied to a variety of scenarios subject to different conditions, situations and specifications. For that purpose, the proposed system combines computer vision and knowledge representation technologies, which allows its adaptability to different necessities, requiring little or no modification.

In our future work we will implement the representation of the image features, context variables theirs relationships as a SOEKS and explore the available technologies for computation of vectors similarity. The goal is to analyze the performance of each approach in terms of accuracy and computation costs and choose the most reasonable option for our real-time application.

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The Adaptation of the Device Assessment Questionnaire ISO 9241-9 in the Polish Samples

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Abstract. The paper demonstrates the Polish version of Device Assessment Questionnaire. Adaptation process was made in order to create the universal tool for the assessment of pointing devices other than keyboard, as it is intended in ISO9241-9 standard. The authors' main purpose was to include in the adaptation process some of the problems of psychological rather than the content or language nature. These problems are associated with the uncertainty of those respondents, especially people with disabilities, in the subject of evaluation and excessive internal attribution (assessment of their own competencies and not the characteristics of the device).The results of three studies with an adapted diagnostic tool for comfort of work are presented. Obtained study results show compliance with the Standard, versatility and flexibility of the Questionnaire.

Keywords: Device Assessment Questionnaire ISO 9241-9 · Adaptation procedure · Users comfort of work · Face Controller

1 Introduction

The main goal of presented study was adapting the Polish version of Device Assessment Questionnaire prepared according to ISO 9241-9 standard entitled *Ergonomic requirements for office work with visual display terminals (VDTs) – Part 9: requirements for non-keyboard input devices* (International Organization for Standardization 2000). Moreover, the adapted versions of the Device Assessment Questionnaire ISO 9241-9 were checked for two different pointing devices: a standard wired optical mouse, and Face Controller system, which is a pointing device based on head movements and facial expressions only.

The main role of the ISO standard is to establish guidelines and testing procedures for evaluation of different pointing devices (Douglas et al. 1999). Even if the ISO 9241-9 standard originally applied to a close catalogue of mentioned devices, i.e. mice, trackballs, styli, joysticks with exclusion of eye-trackers, head-mounted controllers and devices for users with disability, some testing procedures described in the standard are used wider than it was assumed. According to the ISO 9241-9 standard, the evaluation of device needs take into account three main aspects: performance, effort and comfort. The performance is measured as a result of a combination of six different tasks

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proposed in the standard and the effort need to be assessed by biomechanical measurements of muscle load and fatigue during performance tests (Douglas et al. 1999). The Device Assessment Questionnaire is proposed in the standard as a metrics of users' comfort to measure after the performance testing (International Organization for Standardization 2000). The typical application of the questionnaire is the subjective evaluation of different pointing devices made by participants after usability testing i.e. different video game controllers (Natapov et al. 2009), a finger-controlled isometric joystick and a touchpad (Douglas et al. 1999), the device called Virtual Binocullar (Glowinski et al. 2011), eyetracker (Zhang and MacKenzie 2007), different head activating systems like the CameraMouse, the ASL Head Array mouse emulator, the CrossScanner, and the Quick Glance Eye Tracking System (Man and Wong 2007). The questionnaire is used in usability research with different modifications. For example Natapov et al. (2009) applied a short version with nine questions only and Zheng and MacKenzie (2007) used twelve items with significant modifications. Especially interesting for our purposes was the adaptation of the ISO 9241-9 Device Assessment Questionnaire made by Zheng and MacKenzie in 2007. As they applied the questionnaire for eye tracking systems evaluation, their modifications were similar to the ones presented in this paper. They deleted questions about body parts not involved during the operating with eyetracker (fingers, wrists) and added question about eye fatigue. Moreover, they changed the original proposed five-point scale into seven-point one, reversed the scale for some of the questions and added the 4 as the mid-point (Zheng and MacKenzie 2007).

A particular research and application purpose is to adapt the questionnaire for use in specific test groups and in different contexts of research into the usability and comfort of working with different pointing devices and systems. For the authors it was very important to adapt the Questionnaire as a diagnostic tool used by people with a high level of motor disability.

2 The Tool

The original version of Device Assessment Questionnaire was described in ISO 9241-9 standard and covers thirteen items referring to different aspects of user's comfort after working with the evaluated device. Items are divided into three parts. Four of them describe subjective opinion about the device's features (pointing accuracy, operation speed, smoothness, ease of use). Other three focus on requirements for a user (force, mental and physical effort required for operation). Last group focus on user's physical feelings after operation with the device described as fatigue of specific body parts and general statement about comfort. The original Device Assessment Questionnaire has a form of very simple statements. The respondent chooses the most appropriate answer for each item on five-points scale with descriptions on both ends. Items are evaluated on bipolar scale with optimum in the middle point or on unipolar scale with optimum in one of the ends.

2.1 The Procedure

The adaptation proceeded in the following steps: (1) forward-translation done by three independent experts, (2) formulation of the list of problems, (3) comparison of all versions of translation and synthesis of the translation, (4) procedure of collating (5) application of the adapted questionnaire for the assessment of two different pointing devices. Besides the 5. step, the procedure is consistent with test adaptation practices (Hornowska and Paluchowski 2004). As it is recommended with WHO, all three translators mother tongue was Polish (World Health Organization 2016). The list of problems found was made on the basis of all the translations. As most of the findings were not linguistic but connected with specified context of use, further modifications were focus on psychological aspects.

2.2 Respondents Oriented Modifications of Device Assessment Questionnaire

The authors' idea was to create a Polish version of the Device Assessment Questionnaire, which would be a flexible and adaptable tool in various research and diagnostic contexts. At the same time, the questionnaire should derive from the assumptions of the ISO 9241-9 standard and give the possibility of comparisons even in different projects and evaluations of different systems and devices.

In the first step, the English version was translated into Polish independently by several people, and the final version was jointly established. However, a fundamental change over the original version is the change of the format from the statements to the questions. The original questionnaire assumes the rating of the pointing device, but this is not in *expressis verbis*. Because this question structure appear to be ambiguous to the respondents (i.e. it does not emphasize that it is an evaluation of a system/device rather than its own competencies in using a system/device), it is assumed that the form is changed from simple statements such as *Operation speed was …* to a more elaborate form of questions: *How do you assess the operation speed at work?*. This assumption was confirmed in interviews with the respondents at the initial stages of construction of the questionnaire. The respondents declared that they were not sure whether they would judge the system/device or themselves as its users.

The problem with a clear distinction between self-evaluation as a user of the system or device and the assessment of it and of the comfort it gives the user is particularly important in the case of people with disabilities. The studies show some attributional bias of this group of respondents. In comparison to able-bodied, people with disabilities in the situation of an absence of success (i.e. due to problems with the use of devices or systems) tend to have a higher tendency to attribute themselves to these problems rather than external attribution of failure. Most research show people with disability reported lower self-esteem level in comparison to able-bodied. People with physical disabilities generally have more negative self-esteem than others (Martin 2006). For example, the research made on a sample of 475 women with a variety of mild to severe physical disabilities versus 406 without disabilities shown that women with disabilities had among others significantly lower self-cognition and self-esteem (Nosek et al. 2003). Other study shown that persons with disability, independent from its source, possessed lower self-esteem (both personally perceived and socially perceived) than able bodied (Bhattacharjee and Chhetri 2014). Moreover, people with disability opinions about their own capacities are not consistent with objective tests results and professional evaluation. For example, in the research of customers of Pomeranian Competence Center investigated by the set of objective physical tests and a questionnaire focuses on functional abilities, significant discrepancies were stated between objective test results and self-assessment of subjects, and between the same questionnaires fulfilled by the client and by the professional (occupational therapists). For persons with disability the consistency with professional assessment was stated for 30% only. The elevated self-assessment was observed among persons with disabilities with official statement of disability (42%). The low self-assessment was easy observed especially for persons with injuries, which affected their work capacity and it was stated for the half of persons with disability without any official statements of disability (Jach 2015).

In view of these data, the more efforts were made to ensure the correct, unambiguous interpretation of the subject of evaluation by the respondents. Our goal was to minimize the impact of a particular self-image and attribution model of persons with disabilities. Moreover, this approach can be observed in all usability testing projects, where the need of respondents awareness of the assessment of devices/systems rather than their individual effectiveness and competence is generally present.

Additionally, under the adaptation procedure, scales were extended. In the version designed to test the FC system, in addition to describing the extremities of the scale, a label of its central point has also been added. The extension of the scale from five to seven was intended to increase the discriminative power of the evaluations made by the respondents and was made in other studies too (Zhang and MacKenzie 2007; Glowinski et al. 2011; Man and Wong 2007).

2.3 Variations the Device Assessment Questionnaire ISO 9241-9

As a result of described adaptation procedures, two different versions of the questionnaire were produced, designed for two different pointing devices. Table 1 presents two versions of the questionnaire items in Polish along with the English item samples (see Table 1).

The scales used in Polish versions of the Device Assessment Questionnaire were analogous to English. As it is described above, for greater discriminant power seven-point scale was used with middle point added. The full content of the Questionnaire is shown in Appendix 1.

Table 1. Example items of the Questionnaire in the English and both Polish versions.

Item content original version	Item content universal Polish version I[a]	Item content Polish version for FC study[b]
The force required for actuation was	Jak oceniasz siłę fizyczną potrzebną do uruchomienia i działania urządzenia?	Jak oceniasz siłę fizyczną potrzebną do działania w systemie FC?
Operation speed was	Jak oceniasz prędkość wykonywania operacji za pomocą urządzenia?	Jak oceniasz prędkość wykonywania przez system operacji?
Arm fatigue was	Jak oceniasz swoje zmęczenie ramion w trakcie pracy z urządzeniem?	Jak oceniasz swoje zmęczenie ramion w trakcie pracy z systemem FC?
General comfort:	Ogólny komfort pracy z urządzeniem był	Twój ogólny komfort pracy z systemem FC był
Overall, the input device was	Ogólnie rzecz biorąc, urządzenie było	Ogólnie rzecz biorąc, system FC był

[a]Device Assessment Questionnaire (universal Polish version) used in the computer mouse evaluation

[b]Device Assessment Questionnaire (specific Polish version) used in the Face Controller system evaluation

3 The Study

The Polish adaptation of the Device Assessment Questionnaire ISO 9241-9 was checked for two different pointing devices. The first device tested with Device Assessment Questionnaire was a standard wired optical mouse, model Tracer TRM – S030. This is a simple, universal model operating with resolution 800 dpi.

The other pointing device used for tests was Face Controller system. This is a special software based on Microsoft Kinect game controller created by Polish enterprise Risenbit. The system allows a user for operating with a computer by head movements and facial expressions only. The head position is used for the cursor placement control, while chosen facial expressions (smile, mouth opening, eye blinking, duck face) emulate different mouse actions, like left, right or double click. The user can individually assign specific face expressions for specific actions as well as adjust different parameters (gesture recognition sensitivity, cursor speed etc.) (Bajcar et al. 2017).

Due to the Face Controller (FC) specificity in this study three items referring the face, mouth and eyes fatigue were introduced, while other three (fatigue of finger, wrist and arms) were cancelled as useless for the evaluation of this kind interface. This replacement allows for better tailoring the questionnaire to our needs and observed similar approach in other experiments (Zheng and MacKenzie 2007).

3.1 The Evaluation of Computer Mouse Device

The test of computer mouse was performed in the sample of 35 people (17 females and 18 males) aged from 21 to 24 years (M = 22.3, SD = .71). Participants assessed the

Tracer TRM – S030 mouse after 30 min continuous operating by filling out Device Assessment Questionnaire. The parameters of mouse evaluation are shown in Table 2. Participants rated the accurate pointing and smoothness during mouse operation, and general comfort and easy using above average. The speed operation and the level of the force, physical and mental effort required to mouse operation were assessed as below average. Furthermore, use of the computer mouse implied the low degree of the fatigue of finger, wrist, arm, neck and shoulder, maybe because of the relatively short time of work.

Table 2. The differences in Device Assessment Questionnaire items between three subsamples

	1. Mouse $n = 35$		2. FC without disabilities $n = 27$		3. FC with disabilities $n = 33$		1–2	2–3	1–3
	M	*SD*	*M*	*SD*	*M*	*SD*	U^a	U^a	U^a
1. The force required for actuation	3.81	.92	4.23	1.03	4.24	1.06	372.5	441.0	459.0†
2. Smoothness during operation	4.33	1.17	4.38	1.47	4.67	1.65	469.5	386.0	491.0
3. The mental effort required for operation	3.56	1.08	4.19	1.30	4.33	1.16	298.0**	418.5	393.0*
4. The physical effort required for operation	3.67	1.22	4.38	.98	4.30	1.05	318.0*	421.5	412.5*
5. Accurate pointing	4.75	1.56	2.96	1.66	4.18	2.02	178.5***	283.5*	468.0
6. Operation speed	3.47	1.03	3.15	1.26	3.45	1.60	392.0	406.5	535.0
7. Finger fatigue[a]	3.09	1.58							
8. Wrist fatigue[a]	3.23	1.82							
9. Arm fatigue[a]	2.66	1.59							
10. Eyes fatigue[b]			3.73	1.71	2.52	1.70		287.0*	
11. Mouth fatigue[b]			3.19	1.79	2.27	1.53		307.5*	
12. Face fatigue[b]			3.58	1.50	2.61	1.84		296.5*	
13. Shoulder fatigue	2.75	1.48	1.73	1.22	2.55	1.89	284.5**	367.5	535.0
14. Neck fatigue	2.81	1.60	2.88	1.84	3.58	2.02	468.5	360.5	495.5
15. General comfort	4.56	1.18	4.04	1.25	5.15	1.62	329.0*	239.0**	459.0†
16. Ease of device use	5.92	1.20	4.46	1.56	5.27	1.88	197.0***	305.0*	480.0

Note: [a]items in mouse device evaluation; [b]items in FC system evaluation.
$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

3.2 The Evaluation of Face Controller System

To examine the universality of the presented measurement tool the Device Assessment Questionnaire ISO 9241-9, the other pointing device used for tests was Face Controller system described above. 30 persons with physical disabilities (4 females and 26 males, aged from 20 to 58 years, M = 33,0, SD = 9.38) assessed Face Controller (FC) system by completing the Device Assessment Questionnaire. According to the evaluation of disability by Gross Motor Function Classification System (GMFCS) (Palisano et al. 2008), all the participants were assessed on 4 or 5 disability level, which does not allow them for independent use a computer mouse as a typical pointing device. For comparison, in the evaluation of the FC system, 27 able-bodied persons (14 females and 13 males, from 18 to 34 years old, M = 23.3, SD = 3.83) took part. The Face Controller system evaluation is shown in Table 2.

Data analysis shows that people without disabilities assessed the smoothness during FC operation above average, but accurate pointing and operation speed as too low. Moreover, the force and mental and physical effort during FC using was rated above average (as a bit too high). The fatigue of the all body parts was rated on the low or moderate level (although face and eyes fatigue were relatively the highest). Compared to mouse evaluation in the FC operation participants indicated their mental and physical effort as higher, but accurate pointing, general comfort, ease of device use, and shoulder fatigue as lower.

Compared to able-bodied people, participants with disabilities assessed general comfort and overall input as higher. They indicated also higher accurate pointing of FC than persons without disabilities. There were no significant differences in the FC smoothness (both scores above average), speed (both scores below average) the force and effort required to FC system operation (above average scores). Moreover, participants with disability assessed lower fatigue of eyes, mouth, and face after operating with FC system than those without disabilities. No significant differences between these groups were stated for neck fatigue only (both scores were below average).

3.3 Discussion

The above comparisons do not exhaust the possibility of further analysis of collected data. It is worth noting that the computer mouse is a typical pointing device for able-bodied people, while our specific participants with disability use different other types of pointing devices or use a computer mouse in a nontypical way due to restrictions with upper limbs movements. We can assume that FC is one of the typical pointing devices for this group.

There were significant differences in ratings of the computer mouse (assessed by able-bodied people) with FC system (rated by people with disability) in the force, efforts required to operation, and general comfort, and ease of device use (see Table 2). Participants with disabilities assessed FC system as slightly more comfortable, but requiring higher force and efforts to operation in the comparison to mouse operation (assessed by able-bodied people). In the remained aspects of device evaluation people both with and without disabilities assessed similarly (no significant differences; see Table 2). The ease to use and smoothness of the pointing devices were above average, but operation speed, accurate pointing, neck and shoulder fatigue reached below average scores.

4 Summary

Just after few years of ISO 9241-9 standard obtaining, Soukoreff and MacKenzie (2004) showed an evidence of higher agreement in throughput values in nine investigations provided according to the recommended procedure in comparison to other twenty two research done without this frame. Therefore, the application of procedures, tests and the Device Assessment Questionnaire seems to be the appropriate research approach. Moreover, the Device Assessment Questionnaire demonstrated significant correlation between the level of comfort and performance as other aspects verified in ISO9241-9 standard i.e. by movement time and accuracy (Man and Wong 2007).

We produced two different versions of the Device Assessment Questionnaire. The first one is universal and was checked by the evaluation of a computer mouse. The other, specific version of the Questionnaire was intended to assess a nontypical pointing device – Face Controller system. As empirical evidence – our study results - has shown, the Device Assessment Questionnaire is a universal tool for evaluation of different pointing devices. Thanks to the possibility of individual adaptations for specific purposes by item selection and modifications for specific device evaluation, it is useful and versatile tool. Given the problems that the authors predicted and the subjects reported at the very beginning of the procedure, should be emphasized that the questionnaire in the course of the subsequent examination procedure of adaptation, does not cause any problems and did not raise doubts of the respondents.

Moreover, the presented questionnaire adaptation procedure and the results of the studies with its use, clearly show the area of problems that are overlooked in the study of usability and comfort of working with devices. This area consists of the attitudes, evaluations and attributions of the respondents, which can significantly influence the assessments of systems and devices.

For this reason, so much effort has been put into adapting the form of the Question-naire to the needs of testing people who are not always well-behaved in the evaluated devices. A particular challenge were also people with disabilities, whose specific functioning, slightly lower self-esteem and internal attributions can significantly biased the results of studies using this questionnaire (the tendency to judge their own competencies, and not the utility and comfort of working with the device).

The results presented in this paper, i.e. the evaluation of the pointing device and FC system performed by non-disabled and physically disabled respondents, clearly indicate the achievement of the intended purpose. The aim was to adapt the Questionnaire of assessment the comfort of working with devices and systems based on the ISO Standard. In addition, the authors attempted to demonstrate the flexibility of this diagnostic tool and its applicability in various research contexts - in the study of the various devices and in the various test groups.

4.1 Limitations of the Research

Both presented investigations were made on a relatively little sample (around 30 persons) due to restricted access to Face Controller users, both able-bodied and physically impaired. Additionally, among participants with disability, huge gender discrepancy can be observed. It should be emphasized that the adaptation of the questionnaire has resulted in a universal tool, however, modifications applied to specific projects (e.g. evaluation of the FC system), the results of these different studies are not directly comparable.

Acknowledgments. The research was conducted at Wroclaw University of Science and Technology, Poland partially in cooperation with Polish society "Association for Your New Opportunities".

Appendix 1

Kwestionariusz oceny urządzenia wskazującego ISO 9241-9

Oceń swoją pracę z urządzeniem, zakreślając odpowiednią odpowiedź przy każdym pytaniu. Pamiętaj, że oceniasz działanie systemu. Nie ma odpowiedzi złych ani dobrych. Zaznacz odpowiedź na każde pytanie.

1. Jak oceniasz siłę fizyczną potrzebną do działania urządzenia?

❒	❒	❒	❒	❒	❒	❒
Zbyt mała			Odpowiednia			Zbyt duża

2. Jak oceniasz płynność działania urządzenia?

❒	❒	❒	❒	❒	❒	❒
Bardzo mała			Przeciętna			Bardzo duża

3. Jak oceniasz swój wysiłek umysłowy podczas pracy z urządzeniem?

❒	❒	❒	❒	❒	❒	❒
Zbyt mały			Odpowiedni			Zbyt duży

4. Jak oceniasz swój wysiłek fizyczny podczas pracy z urządzeniem?

❒	❒	❒	❒	❒	❒	❒
Zbyt mały			Odpowiedni			Zbyt duży

5. Jak oceniasz precyzyjność urządzenia we wskazywaniu elementów na ekranie?

❒	❒	❒	❒	❒	❒	❒
Bardzo mała			Przeciętna			Bardzo duża

6. Jak oceniasz prędkość wykonywania przez urządzenie operacji?

❒	❒	❒	❒	❒	❒	❒
Zbyt mała			Odpowiednia			Zbyt duża

7. Jak oceniasz swoje zmęczenie palców w trakcie pracy z urządzeniem?

❒	❒	❒	❒	❒	❒	❒
Brak			Średnie			Bardzo duże

8. Jak oceniasz swoje zmęczenie nadgarstków w trakcie pracy z urządzeniem?

❒	❒	❒	❒	❒	❒	❒
Brak			Średnie			Bardzo duże

9. Jak oceniasz swoje zmęczenie ramion w trakcie pracy z urządzeniem?

❒	❒	❒	❒	❒	❒	❒
Brak			Średnie			Bardzo duże

10. Jak oceniasz swoje zmęczenie szyi w trakcie pracy z urządzeniem?

❒	❒	❒	❒	❒	❒	❒
Brak			Średnie			Bardzo duże

11. Jak oceniasz swoje zmęczenie barków w trakcie pracy z urządzeniem?

❒	❒	❒	❒	❒	❒	❒
Brak			Średnie			Bardzo duże

12. Twój ogólny komfort pracy z urządzeniem był:

❒	❒	❒	❒	❒	❒	❒
Bardzo niski			Przeciętny			Bardzo wysoki

13. Ogólnie rzecz biorąc, urządzenie było:

❒	❒	❒	❒	❒	❒	❒
Bardzo trudne w użyciu			Przeciętne			Bardzo łatwe w użyciu

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Special Session: Modeling of Manufacturing Processes

Improvement of Production Processes with the Use of Simulation Models

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Abstract. The paper presents results of the studies aimed at improving the production process by performing a reorganization of workstations. The purpose of this reorganization was to increase the rate of utilization of machines in the production process. The studies were carried out with the use of an IT package for modeling and simulation of production systems – ProModel. The paper describes a plan of optimization of the layout of workstations, which consists in grouping them into functional work centers and determining the best arrangement of the workstations using the Schmigalla method of triangles. The arrangement was assessed by comparing the simulation models prior to and after the reorganization.

Keywords: Process improvement · Modeling and simulation of production systems · Layout · Schmigalla method of triangles · Simulation packages

1 Introduction

Simulation models belong to the group of symbolic models based on mathematical notation, in which the reality is represented with the use of symbols and mathematical relations [8]. Modeling and simulation of manufacturing processes make it possible to analyze them and trace the way they have been functioning, sometimes for many years, in just a few minutes. This allows verifying the assumptions made and identifying the irregularities that may occur during the operation, particularly the weaknesses of a production system that is being designed or operated [2, 3, 6, 7].

Due to the fact that production systems are very complex and vary in individual industries, as well as due to different applications for computer simulations of production systems, there is no single, universal software that could be deemed to be the best in the market. An appropriate package should be selected each time depending on the purpose of modeling and the type of the system analyzed. Figure 1 shows the percentage share of the use of computer modeling and simulation methods in the selected areas of production system management. The most commonly used commercial computer tools were assigned to each area.

A computer simulation of a production system consists in building a computer model of the system to be analyzed, and then examining the influence of input

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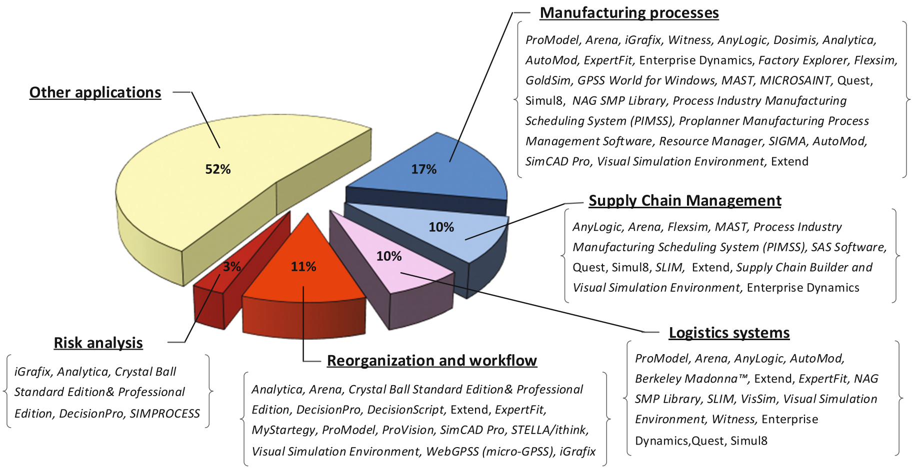

Fig. 1. Application of computer modeling and simulation methods in selected areas of production system management and the commercial tools that are used in these areas [1, 5, 9]

parameters (signals) on the behavior of the model with the of simulation experiments. Typically, many simulation experiments are carried out on the model for different sets of the input parameter values. An analysis of the reports with simulation results allows selecting the best (optimal) input parameters from the viewpoint of building a model of a set of input parameters. In addition, the model can be improved and further simulations may be carried out for different variants of the model.

Computer simulation and modeling methods are used when obtaining a solution by analytical methods is too complicated, while direct experiments on the real system consume too much time or cannot be carried out. Such a situation took place in P.P.H. U. Packer company and the problem concerned a method for increasing the utilization rate of machines. In this case, the improvement of the production process consisted, among other things, in the reorganization of the layout of the workstations. It was achieved using the Schmigalla method of triangles and the heuristic method for layout planning [4].

2 The Profile the Company and an Assessment of the Utilization Rate of Workstations

P.P.H.U. Packer company manufactures flap cardboard boxes and is located in the Opole province. The company's production program is built on the basis of orders from customers. The products manufactured and the volumes of standard orders are shown in Table 1.

In the case of traditional flap boxes made with the use of traditional methods, the main stages of the production process include cutting and creasing (bending the edges of the packaging) performed on the cutter-creasing machines, as well as gluing and stitching of boxes. The process is different in the case of packaging made using

Table 1. Standard orders executed in P.P.H.U. Packer

Item	Product	Order volume [pcs]	Transport batch [pcs]
1.	Flap box (traditional method)	10,000	20
2.	Flap box (BoxMaker)	1000	20
3.	Printed flap box	10,000	20
4.	Die-cut box	1000	20

BoxMaker (a machine that allows making a ready-to-use packaging) which is used in the same stages except for gluing. The process of manufacturing the die cut boxes differs primarily in the method of cutting, in which special punching dies prepared according to the customer's order template are used instead of standard cutters. The layout of the production floor is shown in Fig. 2, where the numbering corresponds to the numbers of machines from Table 2.

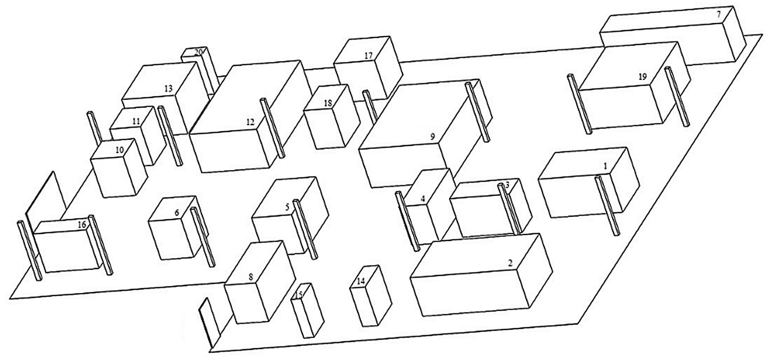

Fig. 2. Layout of the production floor in P.P.H.U. Packer

The main problem of the company is the need to perform multiple transport operations during the production process. This is due to the fact that the development of the company and consequently the development of its machinery resources took place in stages. The placement of further workstations in the production floor at different time intervals was dictated mainly by the free space in the floor rather than by production organization and technology. Currently this fact causes that some work centers are not sufficiently used due to a too long distance. This results in an uneven use of the machinery resources, an extension of the production time and increased costs of executing production orders.

2.1 Assessment of the Utilization Rate of the Workstations

In order to assess the utilization rate of the workstations, it was proposed to group them into work centers first (Table 3).

Table 2. List of machines

No.	Machine	No.	Machine
1	Cutting-creasing machine 1	11	Crucible 3
2	Slotter	12	Roller press
3	Cutter 1	13	Guillotine
4	Cutter 2	14	Stitching machine 1
5	Cutting-creasing machine 2	15	Stitching machine 2
6	Cutting-creasing machine 3	16	Stitching machine 3
7	Screen printing unit	17	Sticking workstation 1
8	Laminating machine	18	Sticking workstation 2
9	Crucible 1	19	BoxMaker
10	Crucible 2	20	Band saw

Table 3. Grouping the machines into functional work centers

Work centre no.	Work centre name	Machine no.	Operations performed
1	Sticking work centre	17, 18	Sticking, gluing of parcels
2	Stitching work centre	14, 15 and 16	Stitching of parcels
3	Die cutting work centre	9, 10 and 11	Die cutting with the use of a punching die
4	Screen printing work centre	7	Printing, drying
5	Creasing work centre	1, 5, 6, 2	Cutting, creasing
6	Cutting work centre	3, 4	Cutting, cutting out
7	BoxMaker work centre	19	Ready-made packaging
8	Laminating machine	8	Laminating
9	Cutting centre	13, 20	Cutting, cutting off, cutting through
10	Roller press	12	Rolling

Then a simulation model of the production system reflecting the present state was built to assess the current utilization rate of the machines. The model of the present state includes process and organizational data such as volumes of production orders, a typical production schedule, manufacturing technologies of individual products, cycle times and transport times. The ProModel package for modeling and simulation of production systems was used to build the simulation model. Thanks to this tool it was possible to take into account the actual dimensions of the production floor, machines, the distance between the workstations, the length of the transport routes, as well as the transport times.

Due to the fact that four machines are not used for executing standard orders, they were omitted in the model. These machines are not the subject of the improvement and their layout does not affect the results of the study in any way. A graphical representation of the process modeled in the computer program is shown in Fig. 3.

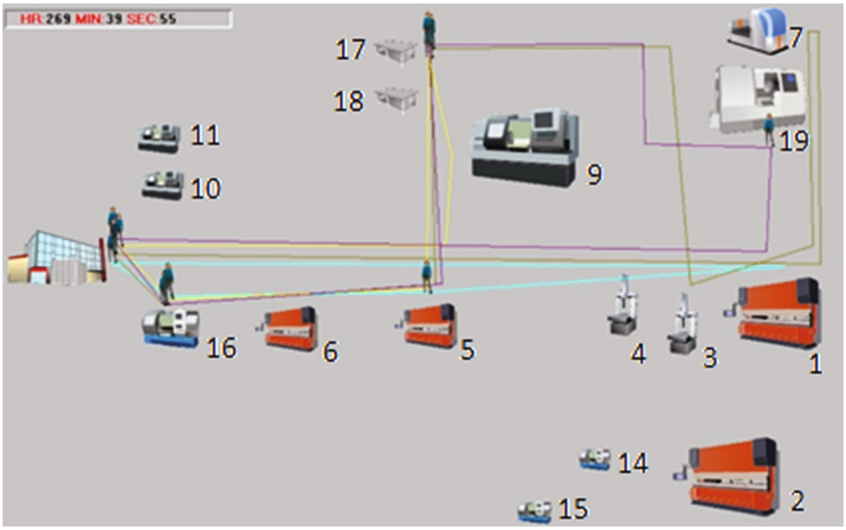

Fig. 3. Screenshot of the simulation model of the production process – present state

As a result of the simulation of the process subject to the studies described in this paper, data concerning the percentage degree of the current utilization of machines and equipment in the company were obtained. These results are shown in Fig. 4.

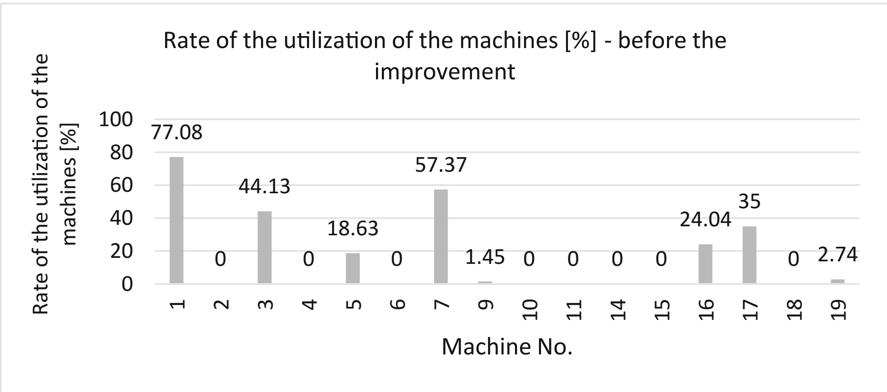

Fig. 4. The utilization rate of the machines, which was obtained from the model of the present state

The first clearly noticeable issue is a huge disproportion between the utilization rates of the machines. As many as eight machines are not used despite the fact that they are in good working order. This is caused by the ill-judged layout of the workstations, which was described earlier in the paper. Attention should be paid to the fact that these machines are in good working order and can perform their tasks to relieve the strongly worn out machines such as cutting-creasing machine 1. The fact that they are not used is results only from a poor spatial organization. Such disproportions between the utilization rates of the machines that perform the same functions lead to a faster wear of the machines in use, the need to perform maintenance and inspection activities on the machines not in use, as well as an unnecessary occupation of space. All these aspects generate losses in the company – not only financial ones, but also losses in terms of performance and logistics.

3 The Concept of the Reorganization of Workstations and Its Assessment

When planning the reorganization in the layout of workstations with the use of the Schmigalla method of triangles, a material flow matrix should be created to determine relationships between the workstations [4]. The flow of materials is constructed by writing down the individual workstations (here: work centers) and summarizing the batches that are transported between them, and then presenting this in a form of matrix. A matrix created in such a way is shown in Table 4.

Table 4. Matrix of the material flow between work centers

Work centre no.		Transport from						
		1	2	3	4	5	6	7
Transport to	1	X		50			500	50
	2	600	X			500		
	3			X				
	4				X	500		
	5					X		
	6				500		X	
	7							X

In accordance with the matrix, the centers 1 and 2, i.e. gluing and stitching, are the pair of work centers with the highest flow intensity, while the flow for the orders in question is 600 transitions. According to the Schmigalla method of triangles, this is just the first pair placed in the vertices of the central triangle of the network [4]. Then, there should be placed the work centre with the highest intensity of relations with the work centers already placed in the adjacent vertices of the triangle. In order to determine, in which of the free vertices the next centre should be placed, calculations should be performed according to the formula :

$$W = Ip\,x\,M \tag{1}$$

where:

W – value of potential vertex
Ip – intensity of relations
M – modular distance

The modular distance is an integer that determines how many modules (graphically: dashes) are located between the already placed workstation and a potential vertex. After the calculations have been performed, the vertex with the highest value should be selected and the element should be placed in it. If the intensities of relations for a number of work centers are the same, the intensity of the relations between the subsequent work centers that have already been placed should be taken into account first, and then the intensity of those that have not been placed yet. If they are also the same, then the work centre being placed can be selected freely. By repeating those steps until all the objects have been placed, we obtain a triangle network showing how the spatial arrangement of the objects should be designed. In this case, the layout of the work centers in the Schmigalla triangle network is shown in Fig. 5.

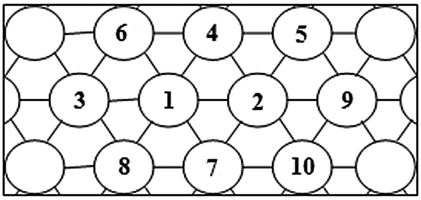

Fig. 5. Layout of the work centers in the triangle network

The layout of the production floor planned in such a way will allow using all the machines available in the company, which will be discussed in more detail further in this paper. Thus, in addition to grouping the machines into functional work centers, the changes include the arrangement of all the machines in accordance with the flow taken into account in the Schmigalla method of triangles.

3.1 Improvement – Computer Simulation Model

After the new layout had been developed, the second simulation model was built. The only change within the company was a change in the layout of workstations, which enabled the use of the remaining machines. Graphical representation of the process after the changes is shown in Fig. 6.

The utilization rate of the machines was changed as a result of placing the machines closer to the warehouse, which is shown in Fig. 7.

The fundamental change is that out of the eight machines that have not been used, as many as seven machines are now in use. One of them is still not used, which results from the fact that the company's production capacity is much bigger than that currently used. This can be understood in two ways: either the machine is redundant or the company can afford to execute larger orders.

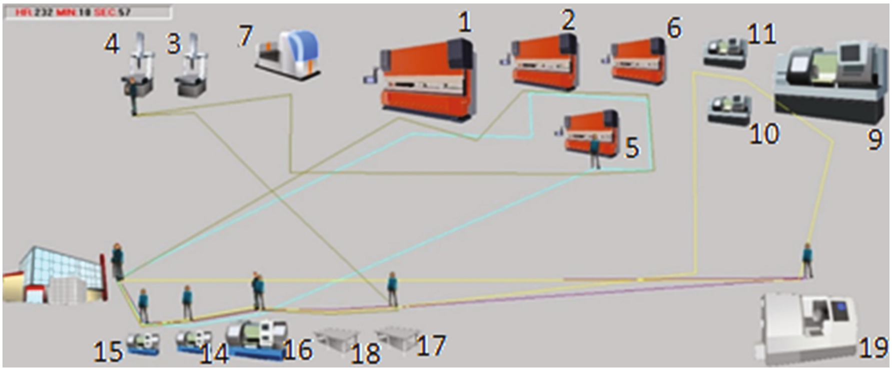

Fig. 6. Screenshot from the simulation model – after the reorganization

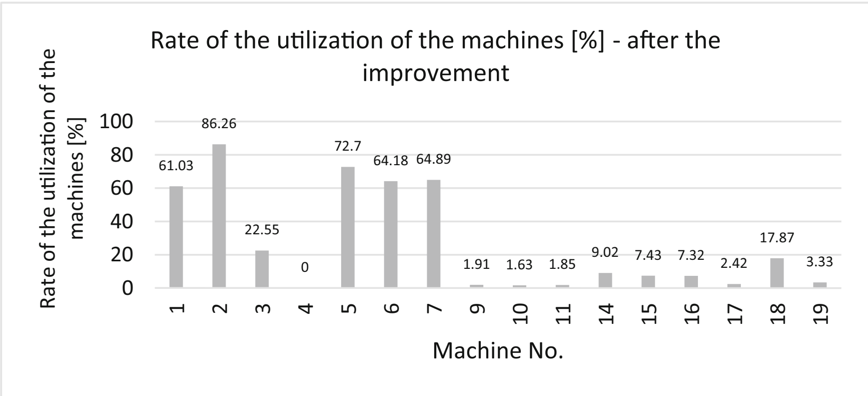

Fig. 7. The utilization rate of the machines after the improvement

3.2 Results of the Reorganization

As a result of the reorganization of the production system, the utilization rate of the machines has changed. This change for each machine was presented in Table 5.

In some cases the utilization rate of the machines increased, but in the case of the workstations intensively used before the reorganization, it decreased. This is caused by the distribution of work to other machines that perform the same function but were not available before. So the most important change in this improvement project is that the machines, which have not been used earlier in the production process, work simultaneously with other machines after the reorganization. Only in the case of the second cutter the result was still 0%, which indicates that the remaining two cutters are sufficient to execute the sample order adopted for the needs of the studies.

Table 5. Change in the rate of the utilization of the machines for execution of orders

Machine name, number (number in the drawing)	Utilization rate [%] before the reorganization	Utilization rate [%] after the reorganization	Change [percentage points]
Crucible 2 (10)	0	1.63	1.63
Crucible 3 (11)	0	1.85	1.85
Sticking workstation 1 (17)	35	2.42	−32.58
Sticking workstation 2 (18)	0	17.87	17.87
Crucible 1 (9)	1.45	1.91	0.46
BoxMaker (19)	2.74	3.33	0.59
Screen printing unit (7)	57.37	64.89	7.52
Stitching machine 3 (16)	24.04	7.32	−16.72
Cutting-creasing machine 3 (6)	0	64.18	64.18
Cutting-creasing machine 2 (5)	18.63	72.7	54.07
Cutter 2 (4)	0	0	0
Cutter 1 (3)	44.13	22.55	−21.58
Cutting-creasing machine 1 (1)	77.08	61.03	−16.05
Stitching machine 2 (15)	0	7.43	7.43
Stitching machine 1 (14)	0	9.02	9.02
Slotter 2	0	86.26	86.26

4 Conclusions

The purpose of the studies described in the paper was to improve the utilization rate of the machines and equipment available in the company in question. This goal was achieved and the total change (for all the machines) is almost 164 percentage points of the increase in their utilization. In addition, the load on the machines was distributed more evenly among different workstations performing the same function in the manufacturing process. It should also be noted that the change modeled under the study requires from the company only a reorganization of its existing resources without a need to purchase new equipment. Of course, this is also an investment associated with costs, but it is not possible to analyze the financial side of the project within this paper. It should also be taken into account that certain volumes of orders were assumed for the needs of this study in accordance with the opinion of the Production Engineer from the company in question. These are only standard orders that constitute the majority of the production, but not whole production. Therefore, the analysis indicates that there are still machine resources that allow executing the remaining orders, since the utilization rate has not increased to more than 90% in the case of any of the machines.

Of course, it is important to consider the limitations resulting from computer methods for simulation of production processes. One of them is the limitation imposed by the tool used, which requires making simplifications specific to a given program.

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Optimization of Production Support Processes with the Use of Simulation Tools

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Abstract. The paper presents a concept for improving production support processes of ordering tools, parts and consumables for machines. In this concept, there were used selected Lean Manufacturing (LM) tools and the simulation models of primary and secondary processes created in iGrafx Process for Six Sigma software. The performance of the analysis of the secondary processes aimed at the identification of waste was possible, inter alia, thanks to the use of the following methods: Value Stream Mapping (VSM), Failure Mode and Effects Analysis (FMEA). Based on the results of the simulation studies, there was proposed an implementation of the scheduling method along the stream of values. The combination of LM methods with simulation tools allowed refining the method in such a way, so that it gives results satisfactory to the company.

Keywords: Production support processes · Lean management · Scheduling · Value stream management · Computer model · Simulations of processes

1 Introduction

The concept of Lean Management (LM) has been functioning in Poland since the end of the 1990s. From that time, many production companies have implemented the LM principles in their management systems. Now the idea of management based on the LM philosophy is being implemented more and more often in maintenance (Lean Maintenance) [1], in external logistics (Lean Logistics) [2], in product development (Lean Product Development) [3], in offices and administration (Lean Office/Lean Administration) [4], in accounting (Lean Accounting) [5], in mining (Lean Mining) [2, 6] and in healthcare (Lean Healthcare) [7]. LM tools and methods are universal.

However, the implementation of LM does not bring desired effects in any sector, if it is carried out partially and thus inconsistently with the concept of a system approach. In order to maintain the competitive advantage it is necessary to go beyond a given area – in accordance with the Lean Enterprise concept [8]. In the case of production companies this means, inter alia, that along with optimization of production processes there should also be performed an optimization of production support processes.

The implementation of the concept of lean management in production support processes provides great opportunities for improving the functioning of the entire company. It is estimated that approx. 70% of the waste elimination potential can be

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found in such processes [9] and that by reducing the transition time by at least 25% it is possible to double the productivity and working capital of a given organization [10]. A correct implementation of the continuous flow in production support processes allows reducing the transition time by up to 90% and the processing time by up to 40%, as well as improving the quality up to 75% [11]. A change of the strategy in the work and time management from the focus on operating activities (typical of administrative processes that generate and process any information in an excessive amount) to the focus on strategic activities translates into better results and thus a higher customer satisfaction. It often happens that the potential for improvement in administrative processes is even greater than in processes of typically production character. Production is evolving all the time, while the processing in individual production floors is easier to observe and much more tangible than in the case of the "on desk" manufacturing. In turn, the secondary processes are adapted to a certain organizational structure that was established at the beginning of the company's operation and has been functioning up to now.

LM in production support processes focuses on defining the value and the value stream, then creating conditions for its smooth flow generated by customer needs, as well as on continuous improvement. Value is defined in the same way as in sectors of typically production character. Frequently it is not something tangible, but still is what the customer expects and for what the customer is willing to pay.

The aim of this study is to examine the possibility of optimizing the process of ensuring the continuity of supply of production support materials in the selected production company using Lean Management and simulation tools. Figure 1 shows the adopted flow chart of the test plan.

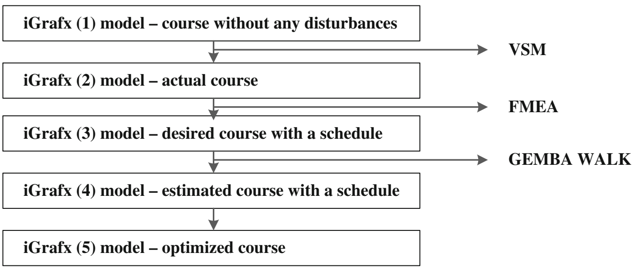

Fig. 1. Flow chart of the test plan

All the simulation models have been created in iGrafx Process for Six Sigma software. The iGrafx model (1) is the base model of the process being analysed, which does not take into account any disturbances occurring in the process. It is a reference point for comparison of results of the subsequent models. The second model – iGrafx (2), the actual course, was built by adding to model 1 the waste identified in the process. The Value Stream Mapping (VSM) method was used to identify sources of waste. The root causes were identified using Failure Mode and Effects Analysis (FMEA). This was a reason that the use of scheduling for the optimization of the processes analysed was considered. It was taken into account in the iGrafx (3) model. iGrafx (4) model was built in order to examine the effectiveness of the selected solution in the real conditions that has been forecast with the use of Gemba Walk. The analysis of results of the simulations carried out on these models resulted in a modification of the schedule in order to achieve measurable outcomes.

2 Problem of Waiting for Acceptance and Execution of Orders

The company being analysed is a global manufacturer and supplier of high quality components and tools for production of electric machines. The company is developing continuously both through the use of the latest technologies and by implementation of improvements based on Lean Management tools.

Up to now, LM tools have been used only in processes of typically production character. Over time an observation was made that the optimized production processes did not lead to measurable outcomes, if they were restricted by the secondary processes correlated with them. Earlier they had been neglected due to the fact that they were not essential for the core business activity of the company, but in the end it was admitted that their proper functioning is necessary for adequate implementation and development of production processes.

One of the processes subjected to observation was the process of ensuring the continuity of non-cyclic supplies (more expensive, ordered sporadically) of production support materials. This process is responsible for responding on a current basis to emerging demand for the materials which are not processed, but enable proper functioning of the production in the company (including tools, materials used for machine operation, etc.). The process is supported by a computerised management system that improves the information flow within the company. In connection with the fact that an analysis of the internal value stream is considered to be a key activity in terms of improving the efficiency of the company, value stream mapping was used to describe the process being analysed (Fig. 2).

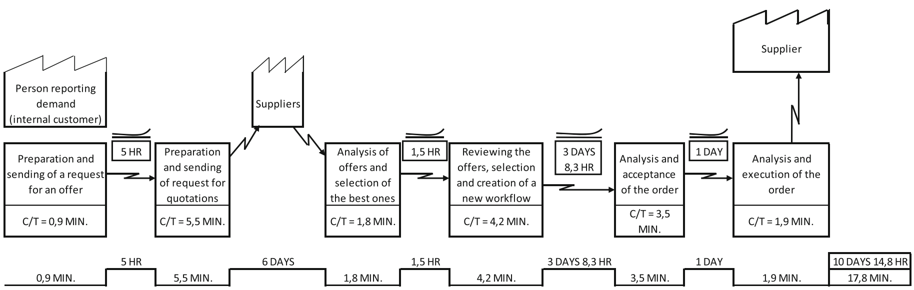

Fig. 2. Pictorial map of the current state of the process

The process begins when a worker notices any deficiencies. Then the worker sends a request for an offer to the purchasing department, which in turn sends the request for quotation to a group of potential suppliers. After the offers have been received, they are analysed and the most favourable of them are sent back to the person concerned, who makes selection and then enters a new workflow to the system (i.e. a certain item in the computerized management system that represents the initiation of an order). Before the final execution of an order (understood as sending a complete order to the supplier), an acceptance from the supervisor, chief manager, category manager, controlling department and the chief financial officer is required. Next stage of control takes place only after the acceptance of the previous one. Finally the order gets to the purchasing department where it is executed. Correct operation of the process appeared to be important insofar as the lack of supporting components caused even temporary production downtimes. Considering the above, a decision was made to examine the functioning of the process. Data have been collected for 3 months through the access to the company's internal system. Over this period, the authors participated in execution of approximately 200 orders.

The waiting is caused by different types of irregularities and waste in the process. Possibilities of optimizing the process at different stages with the use of LM methods were proposed. It appeared that the most problematic area was the management of the workflow unit in the system and more attention was paid to it in the paper (Fig. 3).

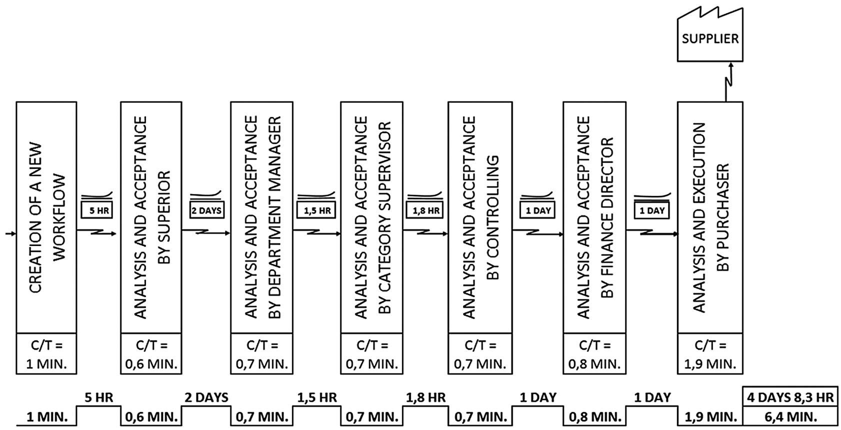

Fig. 3. Pictorial map of the current state of the analysed fragment of the process

When analysing the process, there was observed waste in the form of waiting in connection with the fact that a workflow must pass through all the required stages. It was estimated that the time needed for all the stages was over 4.3 days, while the activities that add value took less than 10 min.

The collected data resulted in the need to compare the real outcomes of the process with the planned outcomes. For the needs of the analyses in the iGrafx Process for Six Sigma software, a model of the perfect process, without confounding factors, was built and simulations were performed. The results obtained in this way allowed assessing that the time of complete execution of an order was approx 4–5 days, while the time required only for acceptance of the workflow units was approx. 2 days, which shows that there is a possibility to shorten the duration of the process more than twice by eliminating the disturbances. In order to validate the model, a model of the actual state that includes the disturbances was also built. The results of the simulations carried out on the second model confirmed the earlier concerns and showed that the time of execution of an order was 9–12 days, while the time of its acceptance was 4–6 days.

In connection with a significant discrepancy between the desired state and the actual state, observations of irregularities occurring in the process were commenced. The results are shown in Table 1.

Table 1. The deficiencies identified in the order acceptance and execution process

Deficiency	Frequency
Independent execution of an order outside the purchasing department	1/10 cases
Doubled orders	1/1.5 month
Outdated offer	1/50 cases
Lack of a range of products	1/30 cases
Acceptance of the same order several times	1/5 cases
Execution of the same order several times	1/25 cases

Then, the FMEA analysis was performed. It has been found that all errors occurring in the analysed fragment of the process are closely related to the problem of long-lasting order execution procedure. Independent execution of orders outside the purchasing department and related doubled shipments result from the attempts of avoiding too long procedure which would not ensure obtaining necessary components on time. The outdated offer and a lack of a range of products are also associated with the fact that the time between preparing the offer by a supplier and sending the order is too long. Other irregularities result from the errors of the system itself and from a lack of division of work between the two persons responsible for execution of orders.

The outcomes of the work performed indicate that the computerized management system has led to automation of waste instead of its elimination. It appeared that the root cause was incorrect management of the subprocess in connection with a lack of synchronization between its successive stages. A difficulty in management results from the fact that this fragment of the process involves representatives of different organizational units located even in different buildings. The process is simplified for each of the units, however there is a lack of a process approach. Guidelines between successive links of the chain links are not properly synchronized with each other.

3 Scheduling

In an attempt to reduce the waste identified, a decision was made to assume that a proper process management should be synonymous to the value stream management. Observing what is happening in office processes and understanding the essence of added value, two basic issues can be noticed:

- there was a variability of processes resulting from multitasking and arbitrariness in the sequence of the tasks executed, and
- there was waiting time practically between all successive stages due to a lack of synchronization among the employees responsible for them.

A properly organized value stream may be a solution here. From among various methods for organizing the stream of values suggested for both production support and non-production processes [11], the organization of activities according to the value stream for each unit has been selected. This is a method for a proper synchronization of the work of people from different departments (also quite far away from each other) without disturbing the existing structure (which is essential for the optimization of the secondary processes).

Organization of activities according to the value stream for each administrative unit consists in a maximum synchronization of the moment of completion of the previous stage of the process with the moment of starting the next one. This makes it possible to introduce a relatively simple tool, i.e. schedules, however not within a department but along the value stream. Such scheduling of a work week in a breakdown by hours and tasks offers a possibility to maximize the flow of information and thus improves also the productivity. Introduction of a schedule for each unit should stabilize the variable system and ensure its predictability, and then speed up the response to needs of customers (also internal ones).

The company decided to check the possibility of improving the process by preparing schedules for the persons taking part in the acceptance of workflow units in the system. Time intervals were assigned to each of them (Table 2), during which a given person should redirect orders further in the system.

Table 2. Workflow implementation schedule

Introducing of workflow	Acceptance by the superior	Acceptance by the chief manager	Acceptance by the category	Acceptance by the chief financial	Acceptance by the controlling	Execution of the order	
8:30 am	08:45 am	09:00 am	09:15 am	09:30 am	09:45 am	08:45 am	10:00 am
11:00 am	11:15 am	11:30 am	11:45 am	12:00 noon	12:15 pm	11:15 am	12:30 pm
01:30 pm	01:45 pm	02:00 pm	02:15 pm	02:30 pm	02:45 pm	01:45 pm	03:00 pm

There also appeared an idea of introducing an additional signal, i.e. a message from the system about striking a given hour. The hours in the schedule were proposed according to the observation about when most new workflows were getting to the system, while the time between successive stages was proposed adequately to the time required to get acquainted in detail with several different workflows. More dates were foreseen for execution of the order to synchronize them both with cyclical orders (concerning cheaper materials, consumed and replenished on a current basis, which get directly to the purchasing department) and non-cyclical orders (analysed in this study), but also to divided the work between two persons responsible for non-production purchases.

3.1 Analysis of the Potential Time of Execution of a Production Support Order After the Introduction of Schedules – Model (3)

The implementation of the proposed method requires the involvement of high-level personnel, which caused that the permission to test it in real conditions was declined. In order to investigate the potential of the method and estimate its capabilities, another model, i.e. model (3), was built in the iGrafx Process for Six Sigma software. The basis for it was provided by the basic model, i.e. model (1), to which the proposed schedule was introduced by assigning time limits for execution of the order to each of the units involved. Simulations were carried out to check what minimum time can be achieved by implementing the proposed improvement. The results of the simulations have shown that the use of the scheduling method proposed (at the assumption that it will be followed in 100%) makes it possible to execute orders in approx. 1.5 h. Similar results were obtained with the use of mapping of the value stream of the future state (Fig. 4).

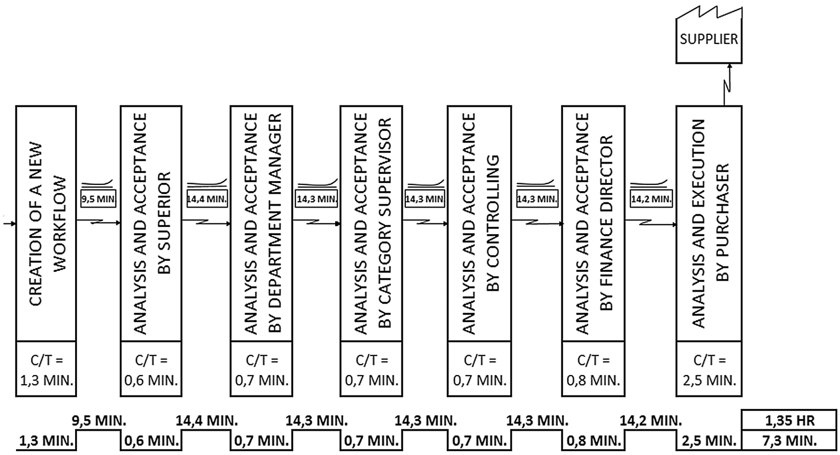

Fig. 4. Pictorial map of the future state of the analysed fragment of the process

It has been estimated that due to a significant reduction in the waiting time it will allow reducing the time of execution of the analysed subprocesses by over 98%.

3.2 Analysis of the Estimated Time of Execution of a Production Support Order After the Introduction of Schedules – Model (4)

After demonstrating the potential of the analyzed method using the model (3), a decision was made to examine its effectiveness in real conditions. Considering the fact that office processes are characterized by high variability [11], it is important to consider that it is sometimes impossible to respond to every single sound signal informing about the need to accept orders. Model (4) has been built in accordance with the above and takes into account the fact that the schedule is not followed fully by the employees. It is based on model (3) which was modified by designating certain schedule points as inactive.

In the first turn there were performed simulations, in which the number of such points was increased until the average actual time of order execution was exceeded. The results of the simulation have shown that even if a given workflow unit encounters in the acceptance route 14 schedule points that will not be properly completed and will generate additional waiting, it will be executed faster than in the present system functioning in the company.

In order to determine the most probable scenario for the execution of workflow units with the use of the proposed scheduling method, interviews were conducted with employees in order to gather information on the probability of observing the designated hours. Based on the data collected, the number of the schedule points skipped by each employee during 1 working week has been estimated. The probability of the occurrence of inactive points in a given working week was entered into the model (4). Then simulations of a few next working weeks were carried out. The results of the simulations indicate a fairly low predictability of the process, taking into account the predicted degree of compliance with the schedule. Although there were achieved shorter times of order execution (43 h on average) as compared with the current system functioning in the company, the stability of the system was not ensured (standard deviation for the average cycle of order execution at 10 trials is over 30 h). The number of workflows completed in a week varies from 30% to 100%, which means a relatively large spread. The time of execution of order from a full working week also has very different values: from 4 to 10 days. The results of the simulations performed show that the method can be effective, but it should be modified accordingly, taking into account the capabilities of the employees.

3.3 Analysis of the Estimated Time of Execution of a Production Support Order After the Introduction of Modified Schedules – Model (5)

The analysis of results of the simulations carried out on the previous models (1), (2), (3) and (4) has led to the development of another model (5) that will allow integrating the scheduling tool with the company's capabilities. The basis for the last model is provided by the model (4), in which time frames for execution of the workflow for the units involved were modified. For each new proposal of the schedule, there were collected data concerning whether the employees followed it and simulations were carried out in the strive to obtain an optimal solution. The results of the subsequent simulations led to reorganization of the schedule in order to increase the control over processes and shorten the average order execution time at the cost of extending the shortest possible time of execution of a workflow unit. The solution is therefore a schedule with a fewer number of the acceptance points, but with longer time for their execution. Employees would then have to keep tabs on one deadline a day only (which would be much simpler), and also would have more time (1 h) to comply with it (so they would not have to suddenly interrupt other activities).

To illustrate the effectiveness of the method, the results of simulations of the models were summarized (Fig. 5). A random unit taken from each of the 10 consecutive working weeks was included in the comparison.

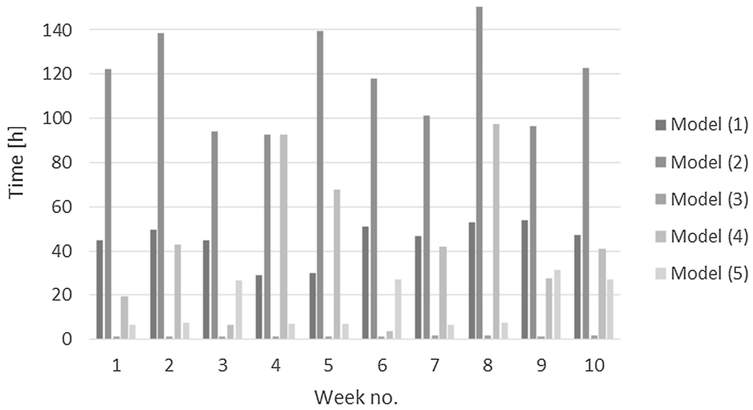

Fig. 5. The processing time of a workflow unit in successive working weeks

In accordance with the results of the simulations carried out on the model (5) with the modified schedule, the introduction of the proposed solution will extend the minimum order execution time to approx. 6.5 h, but the average time will be at a level of a dozen or so hours.

4 Summary

The use of simulation tools supported by LM methods enabled examining the possibilities of optimizing the process of ensuring the continuity of supply of production support materials in the production company in question. Irregularities in functioning of the process were demonstrated and their causes were identified. On their basis, there was proposed an optimization tool – scheduling along the value stream. An analysis of the improvement considered by the company was possible thanks to the computer models. The simulations performed on the models allowed checking the capabilities of the selected method and its efficiency in the estimated real conditions (Table 3).

Table 3. Summary of results of the simulation of the process

iGrafx model number	Average time of order acceptance and execution	Conditions of execution
(1)	2 days	Possible after elimination of disturbances
(2)	4–6 days	Actual with the existing waste
(3)	1.5 h	Impossible in the real conditions
(4)	1–4 days	Possible after the introduction of the schedule
(5)	1–2 days	Possible after a modification of the schedule

The studies confirmed the potential of the method, however they indicated that it is not utilized fully due to insufficient capabilities of the units involved. The conclusions led to a modification of the solution by adjusting the schedule to the daily work plans of employees, which allowed achieving better results than in the case of the previous solution.

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An Artificial Bee Colony Algorithm to Solve the Single Row Layout Problem with Clearances

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Abstract. The single row layout problem (SRLP) is defined as the optimal arrangement of n machines with varying length along a straight line in order to minimize the weighted sum of distances between all machine pairs. In this paper, an artificial bee colony (ABC) metaheuristic is proposed to solve the SRLP considering sequence-dependent, asymmetric clearances for the first time. The algorithm is evaluated on several benchmark instances selected from literature as well as random generated ones involving up to $n = 60$ machines. By comparing the computational results, either to optimal or best known solutions, it is revealed that our ABC performs efficiently, especially for instances with sequence-dependent asymmetric clearances.

Keywords: Single row layout · Artificial bee colony algorithm · Asymmetric clearances · Machine layout problem · Combinatorial optimization

1 Introduction

A thorough planning of the facility layout is an essential contribution to the companies' competitiveness due to the beneficial effects upon work in process, lead times, manufacturing costs, and the overall productivity. It has been shown that an efficient machine layout is able to reduce the material handling cost by 10–30% (cf. [21]). One layout configuration frequently adopted in modern manufacturing systems is the single row layout where machines are arranged along one side of the material transportation path. In practice, a single row layout may assume different shapes such as linear, semicircular, U-shaped, or serpentine patterns.

The corresponding single row layout problem (SRLP) is an $\mathcal{NP}$-hard optimization problem that necessitates robust and effective heuristics. Therefore, a number of metaheuristics have been applied to the SRLP including genetic algorithm (e.g. [4,10]), taboo search (e.g. [1,9]), scatter search (e.g. [11]), simulated annealing (e.g. [15,16]), and swarm intelligence optimization approaches such as ant colony algorithms (e.g. [20]) and particle swarm optimization (e.g. [17]). One

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recently proposed algorithm based on swarm intelligence optimization is the artificial bee colony algorithm (ABC) introduced by [7] who adopts the intelligent foraging behavior of a honey bee swarm to numerical optimization problems. To the best of our knowledge, [18,19] are the only ones who refer to the ABC technique in the research area of machine layout. The former describes the heuristic only in general without any specific application to the machine layout problem, whereas the latter solve a multi-row layout problem with predefined locations.

In this paper, an ABC algorithm is introduced and applied to the SRLP considering asymmetric and sequence-dependent clearances for the first time. Based on the work of [20], the respective mathematical formulation for SRLP is presented in Sect. 2. To solve this optimization problem, we have proposed an ABC heuristic which is described in detail in Sect. 3. Furthermore, we conducted extensive tests on several benchmark instances from literature as well as new generated ones. The results and the performance are reported in Sect. 4. Finally, Sect. 5 recapitulates our findings and suggests directions for future research.

2 Mathematical Model Formulation

To fulfill more real-life manufacturing requirements, Solimanpur et al. [20] introduced a continuous model formulation for the SRLP. This model overcomes a series of shortcomings such as (a) neglected or equal-sized machine dimensions, (b) neglected or constant clearances between machine pairs as well as (c) locations that have to be defined in advance. Instead of that, the following assumptions closer to reality are considered:

- Machines are of varying dimensions, but all are considered to be rectangular.
- Clearances between each pair of machines are variable and dependent on the machine sequence in the single row.
- Orientation of machines is predetermined in respect of the transportation path, and
- Distances between machines are measured with respect to their centroids.

The required size of clearances are affected by several factors, especially production volume and routing of components, processing times, shape and size of components, type of material handling equipment, and type and size of pallets used by the material handling device (cf. [20]). Based on these considerations, the respective SRLP is concerned with finding an optimal arrangement of a given set N of machines placed along one side of the material transportation path. Given the flow $f_{\pi_i \pi_j}$ as well as the clearances $e_{\pi_i \pi_j}$ between two machines π_i and π_j and the known lengths l_{π_i} $(i = 1, \ldots, n)$, the objective is therefore to find a feasible permutation $\pi = (\pi_1, \ldots, \pi_n)$, which minimizes the summed products of flow and center-to-center distances travelled by the material-handling device. Additionally, let Π denotes the set of all possible permutations π of $N = (1, \ldots, n)$, i.e. $\pi \in \Pi$, then the problem can be stated as:

$$\min_{\pi \in \Pi} \sum_{i,j \in N} \left(f_{\pi_i \pi_j} + f_{\pi_j \pi_i} \right) d_{ij}^{\pi} \qquad (1)$$

s.t.

$$d_{ij}^{\pi} = \frac{l_{\pi_i}}{2} + \sum_{k=i}^{j-1} e_{\pi_k \pi_{k+1}} + \sum_{k=i+1}^{j-1} l_{\pi_k} + \frac{l_{\pi_j}}{2}, \tag{2}$$

where d_{ij}^{π} is the minimal distance between two machines π_i and π_j which are arranged at position i and j in the particular solution π as depicted in Fig. 1.

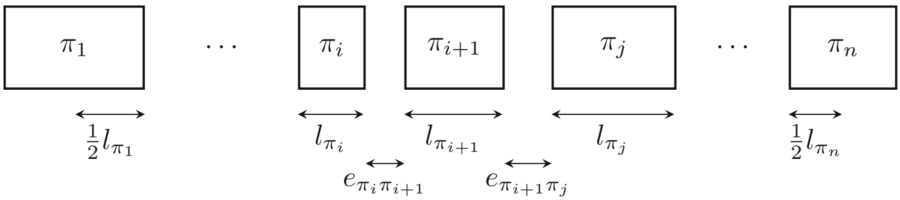

Fig. 1. Declaration of variables for SRLP with sequence-dependent, asymmetric clearances

Considering unequal, asymmetric clearances, the symmetry of the single row layout is cancelled out, since the distance between machine pairs depends on the clearances. That means the distances of permutation $\pi = (\pi_1, \ldots, \pi_n)$ may not equal the distances of the reverse permutation $\pi = (\pi_n, \ldots, \pi_1)$. To the best of our knowledge, this model is the only one which can handle this special kind of clearances (cf. [8]).

3 The Artificial Bee Colony Algorithm for the SRLP

Artificial bee colony algorithms belong to the research field of swarm intelligence. This phenomenon arises in multi-agent systems where colonies of non-sophisticated individuals cooperatively achieve complex tasks (cf. [2]). Such systems are comprised of autonomous agents that interact with each other and the environment in such a fashion that certain patterns emerge without central control (cf. [12]). The scientific field of swarm intelligence arose from the study of social insects such as ants, bees, wasps and termites as well as fish schools and bird flocks. Since swarm intelligent systems operate in both a flexible and robust manner, they are almost predestined to the field of optimization. Thus, a social insect colony can be understood as a decentralized problem-solving system (cf. [3]).

A wide variety of algorithms has been developed to apply swarm intelligence to optimization problems. Most famously these include particle swarm optimization (PSO) and ant colony optimization (ACO). However, in this paper, we focus on the more recently developed ABC algorithm that mimics the foraging behavior of honey bee swarms. It consists of at least three integral components: food sources, employed and unemployed foragers (see [7]). In this configuration, *food sources* are characterized by a certain profitability that is dependent on their proximity to the nest, the energy contained within and the ease with which energy can be extracted. *Employed foragers* are associated with a certain food source they are exploiting. They share the location of this source with other bees with a probability which depends on the profitability of the source. *Unemployed foragers* can be divided into *scouts* and *onlookers*. The former search the surrounding area of the nest for new food sources while the latter wait in the nest and can be recruited to known food sources by employed foragers.

The classification of bees into certain groups according to the behavior they are exhibiting is dynamic. A certain bee may be classified as a scout and an employed forager at different points in time. To maximize the nectar obtained by the whole colony, the bees share information amongst each other to exploit the most profitable food sources. In this case, the most important mechanism that facilitates the emergence of collective intelligence is the exchange of information which is conducted by performing a waggle dance.

An employed forager will share the information about the food source it is currently exploiting with a probability depending on the profitability of the source. A more profitable source leads to a longer duration of the dance. An employed forager has three options after unloading nectar: (1) abandon the food source if no more energy can be extracted, (2) recruit onlookers by waggle dancing and return to the food source or (3) continue exploiting the food source without recruiting others. An unemployed forager on the other hand has two options: It can either spontaneously become a scout and search the nest' surroundings for possible food sources or it can become a recruit after watching waggle dances. After locating and exploiting a food source, it becomes an employed forager. Since more information is circulated about profitable sources (longer dances), onlookers are more likely to choose lucrative sources.

Applying the observations made about natural bees to the field of optimization, several analogies can be drawn: In the algorithm by [7], a food source corresponds to a feasible solution to the problem and the quality of the associated solution matches the sources profitability. In ABC algorithm, half of the bees are employed bees and the other half onlooker bees, where each employed bee is associated with exactly one food source. If a given solution cannot be improved within a predetermined number of trials (= all of the sources energy has been extracted), the associated forager becomes a scout. Scouts introduce an aspect of randomness to the optimization, while onlookers choose food sources with a certain probability.

In the case of the ABC algorithm, scouts employ random processes (exploration), while employed and onlooker bees try to improve given solutions (exploitation). The algorithm proposed by [7] has three control parameters:

- SN is the number of food sources or employed bees and equals half the population size.
- *Limit* is the parameter which determines whether a food source is to be abandoned or not. It thereby regulates the creation of scouts.
- $Maximum\ Cycle\ Number$ (MCN) regulates how many cycles the whole algorithm is run before it terminates.

After initialization, each cycle of the ABC algorithm consists of three distinct steps (see Algorithm 1): measuring the quality of the solutions in memory (employed bees phase), determining which solutions could not be improved over a given number of trials and generating new solutions for the associated bees randomly (scout bees phase), and calculating the probability with which onlooker bees will choose these solutions (onlooker bees phase). To illustrate the mechanisms of the ABC algorithm, the three steps will be explained in more detail.[1]

Algorithm 1 Pseudo-code for the implemented algorithm

```
procedure ABC (SN;Limit;MCN)
    Initialize
    Create SN solutions
    while cycle < MCN do
        Employed bees phase (SN)
        Scout bees phase:
            if trial i > Limit then
                create random solution
            end if
        Onlooker bees phase (SN)
    end while
end procedure
```

Initialization. At the start of the algorithm, SN possible solutions (food sources) were initialized by generating SN random permutations π^i, $i = 1, ..., SN$. Each permutation $\pi^i = (\pi_1^i, \ldots, \pi_n^i)$, $\pi^i \in \Pi$, consists of n machines.[2] Its respective objective value $F(\pi^i)$ is determined and memorized. Since the SRLP considered is a minimization problem, the fitness of a solution is measured by:

$$fitness^i = \frac{1}{F(\pi^i)}. \tag{3}$$

Employed Bees Phase. An employed bee produces a modification on the food source it is associated with and compares the fitness of the resulting neighboring solution with its original food source. This is repeated for each of the SN permutations. To obtain a neighboring solution $\pi^{i\prime}$, two indices r and s were randomly chosen and the machines at the r^{th} and s^{th} index in π^i were switched: $\pi_r^i = \pi_s^{i\prime}$, $\pi_s^i = \pi_r^{i\prime}$, with $r, s \in \{1, \ldots, n\}$, $r \neq s$. After calculating the fitness of the new solution $\pi^{i\prime}$, it is compared to the fitness value of the former food source π^i. If the neighboring solution exhibits a better fitness than the former

[1] Here we are following the recommendation of [13] to conduct the scout bees phase before the onlooker bees phase in order to limit the maximum number of fitness evaluations per cycle. That is contrary to [7] who proposed the reverse order.

[2] Please note that π^i (superscript) denotes one of the SN permutations in the ABC algorithm, whereas π_i (subscript) and π_i^i denotes a machine in the permutation π and π^i, respectively.

one, π^i is overwritten by $\pi^{i\prime}$ and the i^{th} trial counter associated with permutation π^i $(i = 1, \ldots, SN)$ is set to 0. Otherwise, π^i is kept and the trial counter is incremented by 1.

Scout Bees Phase. During this phase, all trial counters are checked to see if any have reached the limit. If they have, the corresponding food source is abandoned and a random new solution is generated and its trial counter is set to 0.

Onlooker Bees Phase. The employed bees share the information about the food sources they have been exploiting with onlookers. The onlooker bees choose a solution among the presented ones with a probability that depends on the fitness. For this purpose, a roulette wheel selection scheme is employed, whereby a probability is assigned to every solution π^i:

$$\theta^i = \frac{fitness^i}{\sum_{k=1}^{SN} fitness^k}. \tag{4}$$

This equation ensures that on average more lucrative sources are chosen by more onlookers. Then a random real number $q^i \in [0;1]$ is generated for each source. If $\theta^i > q^i$, a modification is run on π^i and evaluated as in the employed bees phase. This process is repeated until all onlooker bees have been assigned to a food source.

4 Computational Results and Comparisons

Several problems from literature as well as new generated ones are used to demonstrate the efficiency of our ABC heuristic for the SRLP. The algorithm was coded in python programming language, and was executed on a desktop PC equipped with AMD A10-6700 APU 3.7 GHz and 16 GB RAM. The (near)optimal solutions were obtained by CP Optimizer, part of IBM ILOG CPLEX Optimization Studio v12.6.0.0 and were run on an Intel® Xeon® CPU E5-4627 v2 with 3.30 GHz and 768 GB RAM. A 1 h time limit was imposed for each solution of the problem.

4.1 Test Instances

Initially, our metaheuristic is successfully tested on 49 instances for the equidistant SRLP (SRELP) with up to 35 machines used by [6] and provided in the FLPLIB Facility Layout Database. Here, all machines are assumed to be of equal size and clearances are set to be zero. A second set is composed of eight problems proposed by [14] where machines lengths are obtained from [5]. These instances with constant clearances were solved by [17,20]. Finally, since no benchmark instances with sequence-dependent and asymmetric clearances are available, we have generated new instances with 6, 7, 9, 10, 11, 12, 15, 20, 30, 40, 50, and 60 machines adopting the flow matrices from set one. In these instances, the lengths are integer numbers drawn uniformly at random from the interval $[1; \lfloor 0.5\, n \rfloor]$ and the non-diagonal entries of the clearance matrix from the interval $[0.5; 0.5 \lceil \alpha(l_i + l_j) \rceil]$ with $\alpha \in U(0, 1)$.

4.2 Performance Evaluation

Due to the random characteristic of the algorithm and to obtain robust solutions, each instance in the dataset is run 30 times. For comparison purposes, we measure the solution quality in terms of the relative percentage deviation (RPD) from the optimal objective value over all 30 runs of each instance that is defined as:

$$RPD = \frac{H - B}{B} \times 100\%, \qquad (5)$$

where H describes the solution obtained by our ABC heuristic and B is the optimal or best known solution regarding the associated instance. Additionally, in order to evaluate the performance of the algorithm with respect to the control parameters SN, $Limit$, and MCN, we conducted preliminary tests considering different adaptive parameter settings. These tests revealed that low values for SN and high values for MCN should be chosen. The most promising combinations are used in the following analysis: (I) $\{n; n^2; 1000\}$ and (II) $\{n; 100; 500\}$ (in the order $SN, Limit, MCN$).

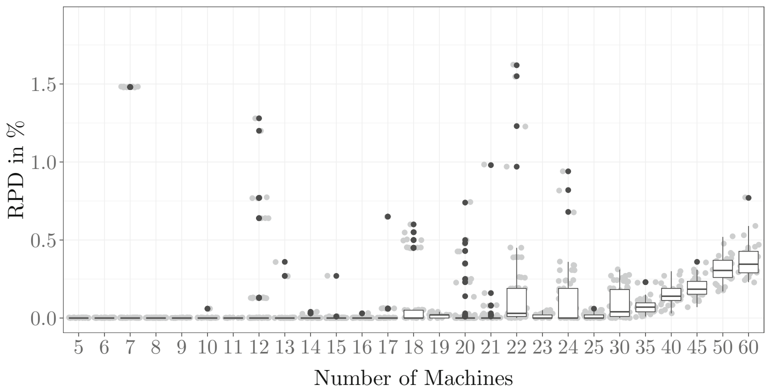

Fig. 2. RPD for set 1 and 2 with parameter setting $\{n;\, n^2;\, 1000\}$

Set 1 and 2. The optimal or best known solutions of set one and two are reported in [6,20], respectively. Compared to those, Figs. 2 and 3 show the RPDs over all instances of both sets. In the boxplot, each line indicates the median RPD of the instance considered. The box itself ranges from the first to the third quartile and the whiskers terminate at the largest data point within the 1.5 interquartile range. While all data points of each instance and each run

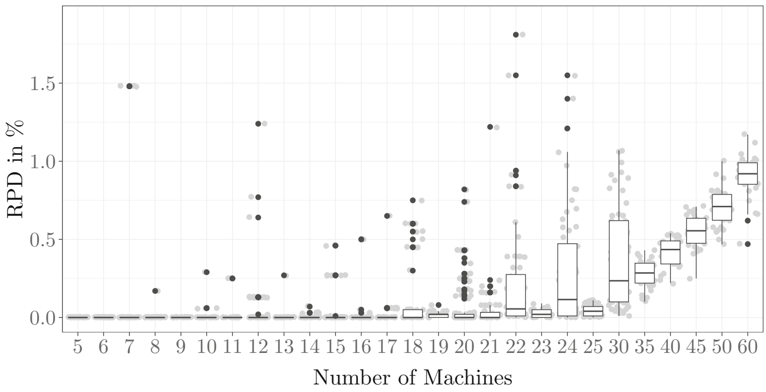

Fig. 3. RPD for set 1 and 2 with parameter setting $\{n; 100; 500\}$

are represented by grey dots, outliers are marked with black dots. Although our heuristic is developed for the SRLP with sequence-dependent, asymmetric clearances, it can be seen that the ABC is still promising for these sets. For both parameter settings, the algorithm found the optimal solution for instances with up to 25 machines. Results of larger instances deviate from best known solutions by 1.62% (I) and 1.81%[3] (II) at most. Even for the largest problem size tested ($n = 60$), 75% of all data have an RPD less than 0.43% (I) and 0.99% (II) as indicated by the box' top. Comparing both parameter settings, it is notable that the ABC heuristic controlled by the first setting exhibits a better performance, irrespective of the instance size. This corresponds to the observation based on our preliminary examinations that higher values of the control parameter MCN seem to strongly affect the results positively, whereas *Limit* has no significant effect. Furthermore, in Fig. 3 (setting (II)), the interquartile range of each box is comparatively large which suggests higher variation in the different runs. On this account, it can be deduced that setting (I) is more robust than setting (II).

Set 3. Since no comparison values for set 3 are available, the performance of the ABC algorithm with parameter setting (I) is compared with the (near)optimal solution of the presented model obtained by the CP Optimizer (column CP). The results are presented in Table 1. Instances larger than $n = 10$ are computational expensive so that the optimal solution process was aborted due to a time limit of one hour. It is depicted that the ABC heuristic hits the optimal objective value for small-sized instances and produces even better solutions for larger instances (column Best OFV). The differences between the two approaches strongly grow up to 35% with increasing instance sizes revealing that our ABC heuristic clearly outperforms the CP, especially for large-sized problems. This observation holds even when the mean OFV is taken into account ($n = 20$ to 60). Additionally, comparing best and mean results, the algorithm seems to perform very robust,

[3] An outlier with an RPD of 3.38% was neglected.

Table 1. Comparison of OFV and RPD for instance set 3 with parameter setting $\{n; n^2; 1000\}$

Instance	CP		Artificial bee colony algorithm				
	OFV	Time	Best OFV	Best RPD	Mean OFV	Mean RPD	Time
O-6	966.0	0.48 s	966.0	0	966.13	0.01%	1.7 s
Y-7	4,795.0	1.63 s	4,795.0	0	4,814.93	0.42%	2.9 s
O-9	3,498.0	3,001 s	3,498.0	0	3,655.17	4.49%	5.9 s
O-10	5,293.0	3,600 s	5,293.0	0	5,385.20	1.74%	9.3 s
Y-11	13,604.0	3,600 s	13,604.0	0	14,101.08	3.65%	12.4 s
S-12	17,764.0	3,600 s	17,764.5	0	18,485.82	4.06%	15.8 s
N-15	11,210.0	3,600 s	11,210.0	0	11,428.93	1.95%	32.6 s
O-20	70,079.0	3,600 s	66,519.0	−3.6%	68,566.47	−2.16%	84.9 s
S-30	80,065.5	3,600 s	67,577.0	−16.53%	68,064.68	−14.99%	257.1 s
Y-40	571,704.0	3,600 s	512,975.0	−19.95%	468,582.22	−18.04%	766.8 s
Y-50	1,402,370.0	3,600 s	1,243,914.0	−25.07%	1,053,429.75	−24.88%	1,719.6 s
Y-60	2,552,070.0	3,600 s	1,656,143.5	−35.11%	1,681,569.22	−34.11%	3,273.8 s

since only small variability in the different runs occurs and both values differ in 4.5% (O-9) at the most. Regarding the average computational time, our heuristic requires significantly less time to obtain a solution compared to the optimal approach. Only for O-6 and Y-7 a slightly longer time is needed. According to that, our ABC algorithm is very competitive referring to computational requirements.

5 Conclusion

In this paper, an ABC algorithm is proposed to solve the more practical variant of SRLP in which variable and asymmetric clearances between each pair of machines of unequal size is assumed. The performance of our metaheuristic is tested on several well-known data sets taken from literature supplemented by new instances tailored for the SRLP considered. Preliminary tests reveal that an appropriate parameter setting should consist of low and high values of SN and MCN, respectively, since a proportional correlation between SN as well as MCN and the computation time was observed. Additionally, higher number of cycles (MCN) provide lower objective values. The control parameter *Limit* seems to have a marginal effect on the objective values and computation time. In accordance with this, the results indicate that the proposed metaheuristic algorithm possesses a competitive effectiveness and efficiency for solving the SRLP with sequence-dependent, asymmetric clearances as studied in this paper. In general, ABC algorithms are comparable to those of other population-based metaheuristics, but with the advantage of tuning fewer control parameters. Nevertheless, more thorough studies on the effects of different parameter settings are needed, particularly in order to optimize the trade-off between RPD and time.

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Measurement Center Processes Support in the Automotive Industry

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Abstract. Nowadays, business process management and process modeling is an important part of business management and business process improvement. Resulting from the increasingly fast growing customer requirements for the final product, organizations need to introduce process management. The work presented in this paper was situated in the area of the automotive industry, which is the most important sector of the world economy. Technical development is progressing with rapid fashion, and even in the automotive industry, there is a need to monitor, manage and improve production processes. This is related to the deployment and use of information systems that support and automate these processes. The main goal of the work described in the paper is to provide a brief overview of the field of business process management, process modeling, related technologies, and the situation of the automotive industry in general. This work also analyzes the current situation in one of the measurement centers, selected processes, and user requirements for the application supporting those processes. Based on the analysis, we proposed an improvement of the selected processes and also designed a web application that supports these processes. The application was built using current technologies such as ASP.NET Core Framework, MVC architecture and the available libraries. Results of testing proved that the solution meets all requirements and in terms of key performance indicators surpassed the expected results. It is suitable for real use in practice and in the future, it is recommended its deployment to all measurement centers.

Keywords: Business processes · Process modeling · Process optimization · Automotive industry · Measurement center

1 Introduction

Nowadays, the automotive industry is one of the most important sectors of the world economy and even of the economy of the Slovak Republic. Slovakia is currently one of the top automotive manufacturers in the world. Measurement centers play an important role in the whole production process. The main objective of the measurement centers is to detect the smallest variations between the real parameters of the manufactured automotive parts and the required ones, thus preventing the errors of the final vehicles. The work presented in this paper was performed in the environment of one particular measurement center in chosen car factory. The work is dedicated to a thorough analysis

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of the current situation at a specific measurement center and based on the analysis we propose the most suitable solution for improvement of the selected processes deployed at this measurement center.

2 Automotive Industry and Manufacturing Process

In general, automotive industry involves a cooperation of a large number of companies and different organizations in various stages of the production of the motor vehicles such as design, development, production, marketing, and sales [1]. It is one of the largest and most important sectors of the world economy, especially in Slovakia. Nowadays Slovakia belongs to the 20 biggest car producers in the World. In Slovakia, there are 3 big world car manufacturers, and since 2018 one more will start the production there [2]. According to production statistics [3], since 2015, Slovakia has reached 1 million vehicles produced per year. Taking into consideration the number of inhabitants, Slovakia is by far the global leader in car production per 1000 inhabitants [2]. Figure 1 depicts the number of cars produced in Slovakia per year with the forecast for the year 2020 when the estimated number of cars produced in the country will reach 1 350 000 units per year.

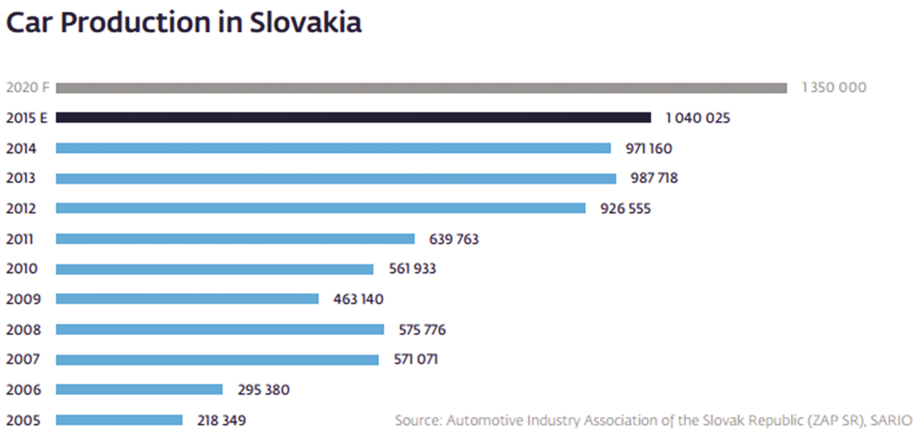

Fig. 1. Car production in the Slovak Republic

In general, the car manufacturing process can be described as follows: everything starts with the metal sheets and the handling process that takes place in the press shop. The sheets are cut to the required dimensions, then pressed and bent. The first moldings, after each mold change, are scanned measured at the measurement centers. From these moldings, the car body is then welded and goes to the paint shop, where all its parts are thoroughly painted with the desired color. In this final car body, there are cable networks located and the dashboard is put together. Then, there are put together all necessary car parts (such as engine, drive mechanism, wheels, etc.). This is where the production process ends and the car passes from the production hall to the test track where the car goes through the testing. After success in the testing phase, the car can be shipped to the customer.

3 Current Situation at Measurement Center

All manufactured car parts must pass through the Measurement center. Only those that meet all the necessary standards and strict criteria can be returned to the production process. The measurement center for which the output of this work is designed and developed is one of the three measurement centers that are located in the selected automotive production. This particular measurement center includes four touch measuring machines (KMG). Currently, they are delivered, measured, and analyzed on an average of 500 pieces per month. The current process of the transport of the measured vehicle parts is depicted in Fig. 2.

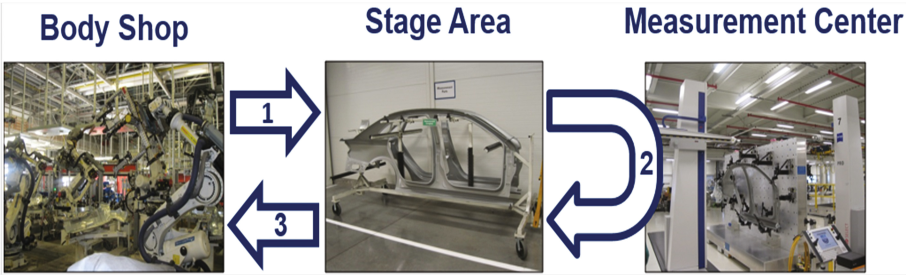

Fig. 2. Transport process of the measured parts

According to the pre-established measurement plan, the production workers move the necessary parts to the Stage area. The Stage area is a place that temporarily stores the parts that need to be measured or that have already passed the measurement process. From this place, the workers of the measurement center move the necessary parts to the measuring machines, where the particular measurements and analyses will be carried out. Upon completion of the measurements, the parts that have successfully passed through will be moved back from the measuring center to the Stage area. Finally, production workers will pick up the measured parts from the Stage area and move them back to the Body Shop. This process is currently not formalized (in any way) and not supported by any software in the measurement center. The staff of individual centers is not sufficiently informed about the actual status of the parts at the measurement center, which often causes problems. One of the most important ones is that the Stage area is filled with the temporarily stored parts too fast. Because of the lack of space there, there is a need to expand this area. At present, 1,233.94 m^2 space is used for the Stage area. Measurement center managers estimate, that the expansion of the center would cost more than 1,200 EUR per square meter.

3.1 Current Problems in the Measurement Center

The main reason of the problems is the lack of information and communication between the Body Shop and the Measurement center. In this case, especially the obsolete, “paper” way of creating, approving, and distributing measurement plans is implemented. This method does not allow any real-time information exchange when operational changes apply to these plans. Plans themselves are currently being created in the Excel spreadsheet environment and, once created, they need to be approved by responsible workers, printed and distributed to the individual centers.

Because of the reasons mentioned above, it is necessary to create and deploy an appropriate information system and process support mechanism that will effectively support not only the transport of measured parts but also the creation, approval, and distribution of the measurement plans. Support for these processes should include the possibility of creating, approving and making available of measurement plans by several workers of different centers immediately. In addition, it should include the possibility of monitoring the status at the measurement center including production and logistics. It should enable the users to perform immediate notifications to all involved workers in case of a change in the measurement plan. Based on the information provided, it is possible for the production to effectively adapt to the changes. All this should be done in real-time and without unnecessary delays.

4 Proposed Solution

We proposed a solution, which automates certain stages of the current process and the workflows that take place at the Measurement center. The solution aims to optimize the existing processes [4] and to provide real-time communication between production, logistics and the Measurement center. Staff will exchange the necessary information through the proposed software solution supporting the designed and optimized processes. Such implementation will result in more readable generation of measurement plans on a daily, weekly and monthly basis.

4.1 Processes Re-engineering

Process of Transportation of the Parts to the Measurement Center

The process of the transportation of the parts to Measurement center was not formalized in any standard or notation. Therefore, we decided at first to design the process models and identify the concrete activities that could be supported by a kind of software solution in order to optimize the process or resources. The process is designed in a way, which enables the elimination of the issues mentioned in Sect. 3.1. The process was designed in the BPMN (Business Process Modeling Notation), which is a standard for modeling of the business processes [5] and is depicted in Fig. 3. The process starts when Measurement center staff receives the weekly measurements plan. The first step is to check, whether the actual state in the Measurement center is aligned with the plan. If not, the warning is issued and staff is notified. Notification has to be confirmed (staff has to confirm, that they are informed about the change). In the next step, the parts are ready for measurement and transported to the Stage area. Measurement center staff pick up the parts, update the information in the system, and move the part to perform measurements. When the part is located at measurement machine, staff changes the status of the part in the system and starts the measurement and analysis. The part remains in this state until the measurement in completed. After that, the part is moved back to the Stage area, its status is changed to "ready" and production staff is notified, that the part can be picked up from Stage area. Production staff confirms when the part is actually picked up from Stage area and moved back into the production. Figure 3 also shows the tasks directly supported by proposed software solution.

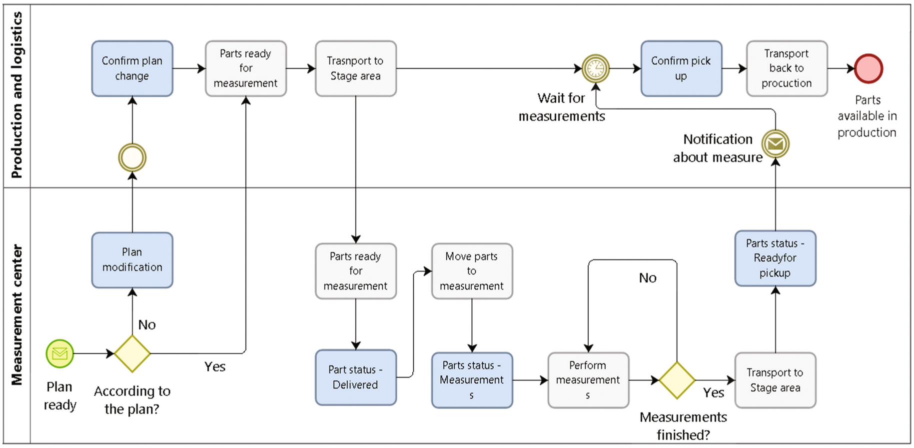

Fig. 3. Process of the transportation of the parts to the measurement center

Process of Measurements Planning

The planning phase is required to correctly perform the measurement process. In general, this process is performed on weekly basis and it results in the measurement plan which can be changed during the operation. The plan then orchestrates the all involved parties including Measurement center staff, Production staff, and Logistic staff. Changes during the operation can be made by the Measurement center designated staff members. Such operative changes should reflect the current requirements.

Designed and formalized process model is depicted in Fig. 4. Highlighted tasks are the ones supported and partially automatized by designed software solution. In general, the process starts weekly, when Measurement center staff member starts to create the plan, either from scratch or using the existing template. The template has to be checked, if it is ready to be used, in case when a new template is created, staff member has to fill all needed information (about the measuring machines and measurements) until all information for all machines is provided. When all information are provided and all fields correctly filled, designated worker sends the created plan for approval. In case of plan dismissal, designated worker performs the needed corrections (e.g. to remove errors) and again sends the plan for approval. When the plan is approved, it can be printed out or just stored in the database without printing. In both cases, the plan is available in the application for all involved parties.

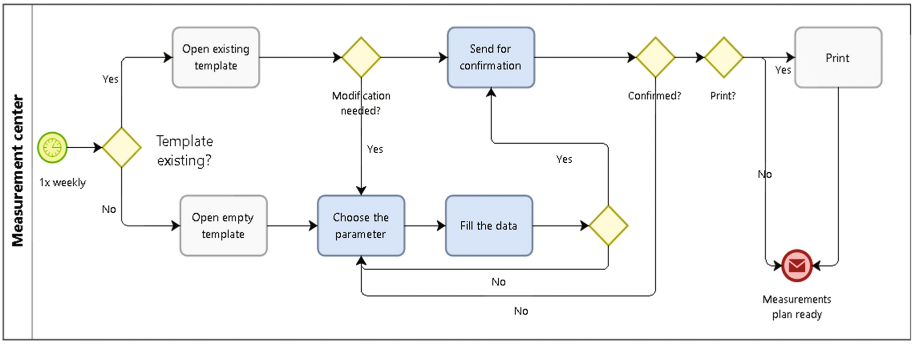

Fig. 4. Modified process of the measurement planning

4.2 Design and Implementation of the Supporting Application

The required functionalities of the proposed solution can be summed up:

- Definition of a measurement plan according to the process standard: possibility of defining a measurement plan for a particular measuring machine according to the type of measured parts. It is possible to enter the number of measured parts on a given measuring machine, to determine the time of measurement from - to, the possibility of adding, removing and adjusting the measurements.
- Approve and view the created plan.
- Possibility to make operational changes in an already generated and approved plan: adding a measurement, removing measurement and adjusting the measurement.
- All changes are immediately visible to all employees in real time: alerting workers to changes.
- Changing the status of the measured part: not delivered, delivered, done, measured, finished, picking up, transport to production.
- Search for possible measured parts.
- Application administration: setting permissions for individual application users, administration of the lists - vehicle model list, list of the types of measured parts, list of measuring machines.

After the initial analysis, we identified the three major user roles of the proposed system:

- Production and logistics staff.
- Measurement center staff.
- Administrators.

The main data model of the application is depicted in the Fig. 5. There are also more tables in the database that provide the functionalities of the user accounts management and roles support.

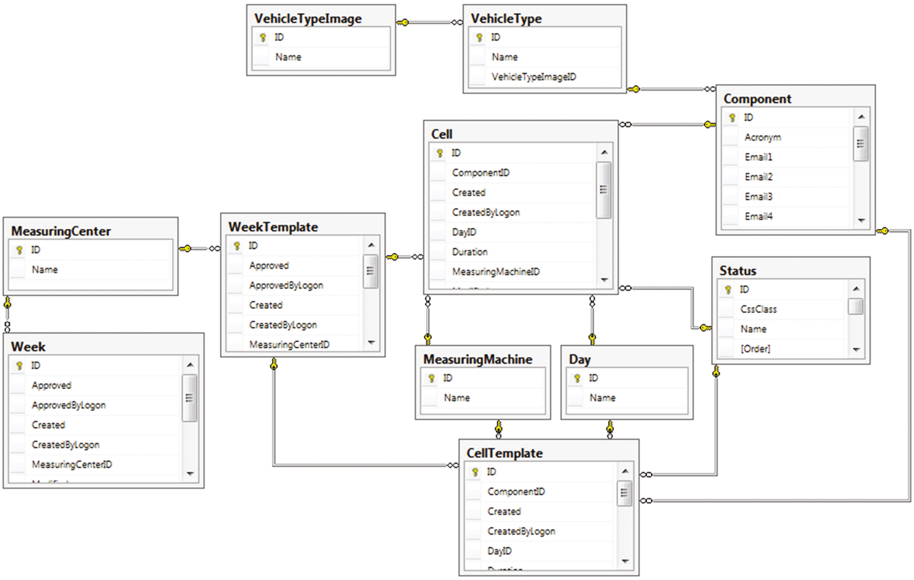

Fig. 5. Data model of the proposed solution

There are two main views that will provide the required functionality and one view for administrator that will manage lists. The first view is dedicated to the Production and Logistics staff as well as the staff of the Measurement center. All staff is able to view the current measurement plan for the particular day or week and set the status of individual measurements. This view also provides the alerts when the measurement plan has been changed.

The second view is dedicated for the staff of the Measurement center and provides the functionality to define and modify the measurement plan, search in existing records and lists. Users can create alerts displayed to the Production and Logistics staff at first view. We developed this application using Visual Studio 2017, the ASP.NET Core MVC framework [6] as the framework for web applications development. It leverages the MVC (Model-View-Controller) architecture [7]. We used Microsoft SQL Server 2014 database server. From programming languages, we used C#, HTML, CSS, ASP.NET, JavaScript and jQuery, DataTables and Bootstrap libraries.

5 Evaluation

To evaluate the proposed solution, we chose three key performance indicators (KPIs) [8]:

- The time needed to create, approve, and distribute the measurement plan (KPI I): currently, this time can climb to more than 3 h. We will consider the application to be successful if this time is reduced by at least 30%.
- The time in which the Stage area is filled in case of an operational change of the measurement plan (KPI II): when a delay occurs - at present if there is a delay of approximately 2 h, this space will be filled within one hour. We expect the application to be successful if this delay time is reduced by at least 30%, but it is best to avoid filling the Stage area.
- The time for which the Stage area is emptied in case of an operational change of the measurement plan (KPI III): at the present time, if the measurement is completed approximately 2 h earlier, this space begins to be emptied for up to two hours, as determined by the original plan. We will consider the application as successful if the Stage area is emptied within half an hour after the measured parts are delivered to this space.

6 Testing and Evaluation

Application testing took place in a simulated environment of the Measuring center for a period of three weeks. During the testing, the application was deployed to a test server where it was evaluated by chosen employees of the Measurement center. Server deployment, testing, and communications with the Measurement center has been provided by the company BSP Applications. The whole testing process took place in the form of Black-Box testing.

The first phase of the test trials lasted approximately two weeks. During this phase, we focused mostly on the detection of errors that would cause the application to crash, to specify the functionalities that would be missed in the real environment of the Measurement center by its end users.

The second phase of testing lasted approximately one week and this phase was mainly focused on tracking and estimating times for the predefined KPIs. User requirements were met, as the solution provided all the required functionalities and interfaces. KPI were evaluated by the staff of the Measurement center. Staff members were involved in a set of simulated processes and we measured the particular KPIs in several trial runs. The evaluation results proved that the KPI I was fulfilled as the expected time was peaking at 1 h 45 min, which represents the time reduction of 40% (30% planned). KPI II and KPI III metrics were tested in scenarios of the measurement delay of 2 h. During the simulations, the KPI II times were reduced by 40% and KPI III times by 70%.

7 Conclusion

The test results clearly indicate that the application met all user requirements and its measured performance based on predefined key performance indicators exceeds the expected results by at least 40% in each of these indicators. For this reason, we consider the solution to be successful and we can recommend that the solution is ready to be deployed to the real environment of the Measurement centers. In the future, it is possible to add the possibility of displaying images for individual types of cars in an aesthetic and design aspect. Also, it is recommended to extend the possibility of exporting weekly templates and plans to the SharePoint corporate environment as well as the possibility of sending SMS and emails with notifications in case of an operative change in the currently running weekly schedule.

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Ergonomics Analysis in the Context of a Digital Factory

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Abstract. The paper deals with possibilities of using ergonomics analyses in the area of a digital factory with the focus on the load on the human musculoskeletal system. The emphasis is put on results of research aimed at connecting simulation software with inertial and optical MoCap systems. The importance of such analyses is to achieve the most exact estimation of consequences on human health, already within the stage when the work systems design begins. The paper comprises theoretical starting points, results of laboratory verification and results of realisation outputs.

Keywords: Ergonomics · Digital factory · Production systems

1 Introduction

One of the basic elements of the assembly system is the operator and his or her workforce. The workforce is the sum of our physical and mental abilities. The aim of ergonomics is to adapt human workplaces, thus optimising all the physiological and psychological aspects of the work. The concept of ergonomics first appeared after the Second World War in 1949, when it was defined as a new branch of science dealing with the whole complexity of relations: man - technology - working environment. Ergonomics is a classical interdisciplinary science that uses knowledge of anthropometry, occupational medicine, physiology and hygiene, biomedicine, psychology, sociology, labour education, labour law, philosophy and other disciplines. In terms of the application of ergonomics, we distinguish two basic approaches [1]:

- Reactive ergonomics – focused on the evaluation of the existing system. The evaluation result is a selection of the risks in the work process and a proposal of new measures to eliminate or reduce their harmful effects on human beings at work,
- Proactive ergonomics – this is the application of ergonomics' principles in the design and development of future products, departments, systems, installations, but also of the entire factories. The aim is to eliminate shortcomings in terms of ergonomics at the proposal stage.

Work is a goal-seeking human activity resulting in immediate or potential benefits. From the physiological point of view, it is an activity involving muscles and nerves, which can be made on the basis of the stored energy. The energy is consumed during

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physical work, and information - in sensory or mental work. During work, certain load is applied to the operator, which can be divided into physical, mental and sensory load. Depending on the type of work the operator performs, a particular part of the human body is mainly affected. However, all three types of load influence the body simultaneously [21]. Ergonomics provides a number of rules and recommendations how to design a workplace so that it is harmless to health and does not cause health problems to the operator even in older age. There are several procedures that should be considered when designing a workplace, for example: [20]

1. Selection of a worker (gender, age, size restrictions such as: max. height).
2. Determination of prevailing working position (standing, sitting).
3. Proposal of workplace layout based on the size and weight of the product, number of operations, assembly process and joining technologies, appropriate technologies, the number and size of machinery and equipment, and physical and psychological load on the operator.

Basic principles of ergonomics in the workplace are connected with [6, 22]:

- working position,
- physiology,
- repetitive movements,
- excessive force,
- hand tools,
- lighting,
- noise,
- temperature,
- humidity, etc.

In developed countries, an increasing importance is nowadays attached to proper design of manufacturing and assembly systems as well as their ergonomics site. Proper design needs information about what the operator will do at a particular workplace, and how he or she will perform the activities. Design and assessment of spatial arrangement of workplaces, as well as design of ergonomically correct tools and machines, must take into account dimensions and power capabilities of the human body. Anthropometry is a science that specifies average values of body parts in a given geographic area. This discipline of science provides the designer with dimensional data, possible load and mobility of the human body parts which must be respected in the design of production and assembly systems [8].

Optimal workplace areas and manipulation space, optimum working plane height for sitting and standing, handling and pedipulation space, etc. are defined on the basis of the aforementioned dimensions [2, 3].

2 Current Opportunities of Supporting Workplace Design

Thanks to the development of technology, methods of workplace design have significantly changed. The biggest changes have occurred in the last twenty years. The rapid development of computer technologies and advanced software solutions support the area of design and allow for testing things in a virtual environment. This way it is possible to save considerable funds for prototyping and implementing corrective actions caused by wrong decisions. Extending modern technology usage to almost all areas of business activities has led to defining the concept of a digital factory.

A digital factory is a broad and rapidly changing notion, therefore, there are no precise definitions. Various authors give their views and opinions on this concept. If we generalise them, we can say that a digital factory is a virtual view of manufacturing and production systems, processes and resources for the purpose of design, planning, testing and optimisation [4, 5].

This concept is one of the newest approaches used in industrial production. Its applications are now limited due to high acquisition costs. It is mainly used in the auto-motive, electronics and aerospace industries. Virtual reality has become an area of great dynamism of development and new applications. Over the last few years it has found usage mainly in companies that operate within high technology business.

If a digital factory is "alive" and working properly, it offers rapid feedback to the planning, analysis and optimisation of production based on multifunctional team results. The importance of the concept of digital factory is shown in Fig. 1. It shows the differences between real and virtual verification in the change of costs and possibility of its implementation.

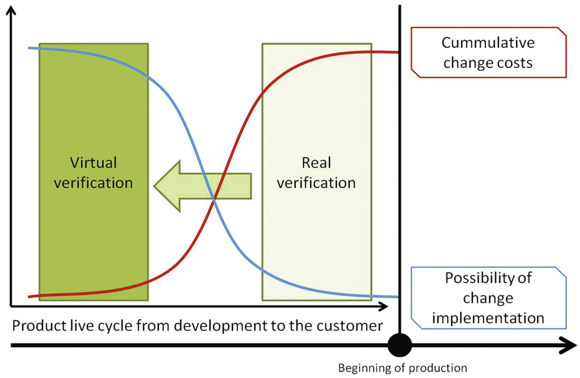

Fig. 1. Importance of digital factory

If we want to optimise current workplaces in a virtual environment, we must have 3D models of all important workplace elements. The problem often is that these 3D models do not exist because 3D design is a new approach. If parts of the workplace are not very complicated, the situation is not problematic. Problems appear when we want to measure complicated or huge components or we have to measure a large number of them. In such a case, we should use reverse engineering techniques.

Reverse engineering covers methods dealing with transfer of physical objects dimensions into a 3D model. This is made with the aim to make further adjustments more quickly and efficiently. This type of modification in the final physical model is currently the fastest and cheapest method, especially if adjustments are very extensive [13, 15] (Fig. 2).

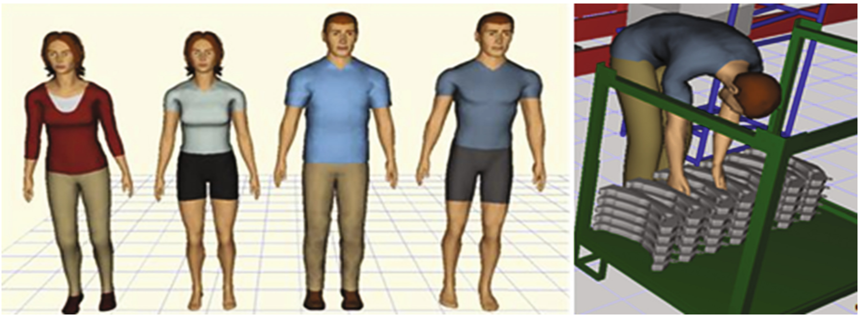

Fig. 2. Mannequins in working postures

The software provides several options for adjusting working postures. It is possible to use a library with 30 basic postures and 27 basic grips. Alternatively, it is possible to modify these basic postures in several ways. The program enables to adjust the mannequin posture to the last fingertip. When the posture is set, it is possible to evaluate the visual field, view the cone for one or both eyes or evaluate reach-zones of the operator based on several rules [18].

All well-known ergonomics analyses as OWAS, RULA, NIOSH, Low Back Analysis, Static Strength Prediction or MTM can be found in Technomatrix software in Task Analysis Toolkid. For example, RULA is an analysis which does not give specific advice how to change the work procedure. It is designed for quick assessment of a working posture and determination whether it will be necessary to use more detailed analysis of the evaluated work. An OWAS-based analysis shows us the four-digit code indicating the back position, hands position, feet position and load level for the selected working posture and shows the result of corrective recommendations [23].

As for software solutions, there are more alternatives. The first alternative are simple 3D model viewers that are able to display a 3D image. The second alternative is software programmed primarily for the CAVE environment, as, e.g. VDP developed by the company ICIDO. These software products are very costly. The third alternative are graphic programs which are able to general stereo display. These programs include also modules of Technomatrix Teamcenter Visualization Mockup and Jack. They contain various display settings to display a stereo image [12].

3 Proposals of Supporting a Workplace Ergonomics Analysis

3.1 Detailed Design Using Tecnomatix Jack

The use of the tracking technologies and Tecnomatix Jack presented in the previous chapter, can significantly shorten the time of creating an animation and of dynamic load evaluation. They can save hours of time when evaluating longer movements, because we do not have to create movement manually. We can create it thanks to saving our own movements.

These technologies do not always work properly, but they are rapidly developing. We believe that in the future this type of operator load evaluation will be common and often used.

Assembly is a collection of activities aimed at creating a functional unit (machine, equipment, etc.) by means of joining various components. It is usually the last stage of production, followed by functional testing. It has a decisive impact not only on quality and reliability of products, but also on productivity and efficiency of the whole assembly and production system. The assembly of difficult products is still manual work even in the automotive or mechanical industries. Therefore, it is necessary to ensure suitable working conditions during assembly workstations design.

When the operator manipulates a hand tool or another object (e.g. a drilling ma-chine) in an incorrect way many times per day, it can cause serious health problems. That is the reason why we have to know how to measure the load.

Tecnomatix Jack is one of the several software packages that allows to evaluate load of the operator during work or assembly. For load evaluation we can use several well-known ergonomics analyses, each of which has a special menu and a possibility of entering different data. For example, OWAS of RULA evaluates a working posture only. When we add load to the figure in evaluating posture the results will not change. But there are other analyses that change the results very significantly when load is added.

We can add load into this program in two ways. The first way is to add the weight of bur in kilograms. In this way, the direction of loading always aims downward. The second way is to add a load vector. We can specify x, y, z coordinates of this vector and the load level is defined in newtons. These variants can be seen in the figure above.

As has been already said, this load significantly changes results of ergonomics analyses. We can see it in Fig. 3 where the same situation, at first without load, (the operator is bending down to the bur) and then again with load of 15 kg (operator is lifting a 15 kg heavy object) is compared. In this working sequence, the operator is lifting a work piece and then he is flattening it at the worktable.

3.2 Load Measurement Using ErgoPAK

When we solve a real project, we have no problems to detect real weight of components or work pieces, but there is a problem how to detect a real load while pushing or pulling something [14].

There are several possibilities how to measure this load. One of them is ErgoPAK. It is a tool kit for collecting and analysing data under real job conditions. It can measure force, velocity and also angle. It has few sensors that can measure pushing or pulling. Each sensor is calibrated independently and has a wireless hub with eight ports so you can use more sensors at the same time. For collecting and processing data, it is necessary to install special, very user-friendly ErgoPak data acquisition software [23].

ErgoPAK tool kit includes the following sensors:

- A handle sensor for measuring push or pull for both hands,
- A handle sensor for measuring push or pulling for one hand,

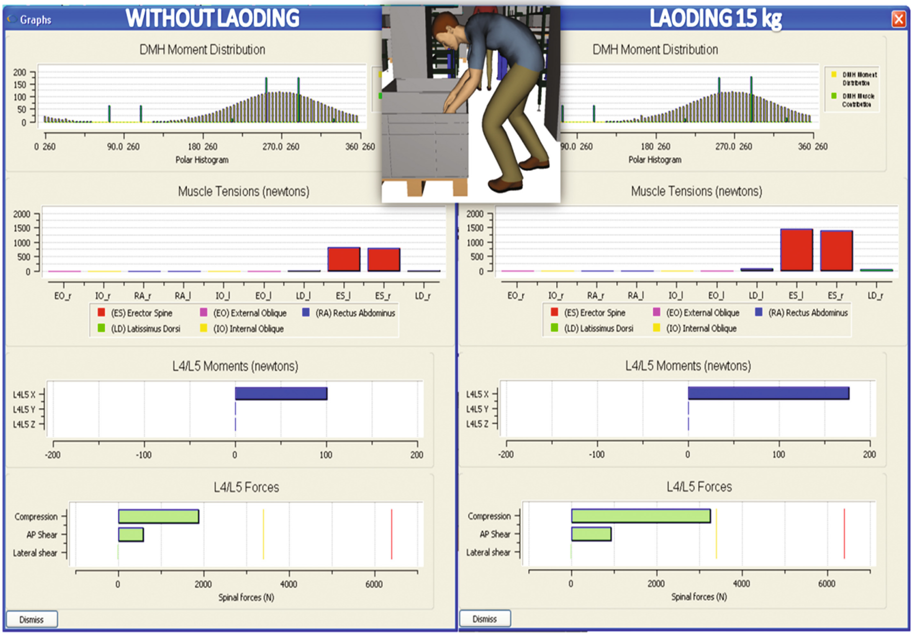

Fig. 3. Comparison of loading with and without bur

- one finger sensor for measuring push,
- two finger sensors for measuring push,
- a “mushroom” sensor for measuring push of the whole hand,
- gyroscopes for angle measuring,
- accelerometers for measuring acceleration,
- a special glove with four push sensors measuring each finger independently (Fig. 4).

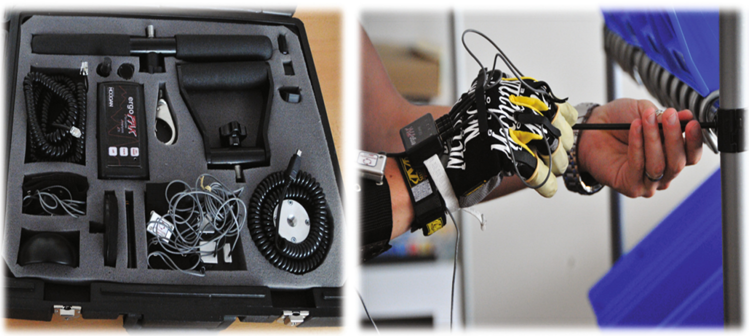

Fig. 4. ErgoPAK tool kit

This device is able to capture one hundred elevations per second. It means that we get about one thousand values in ten seconds. Push values are captured in positive numbers and pull values are captured in negative numbers. In Fig. 5 we can see a sample of the pushcart pulled with two hand handles. In the graph we can see push forces at four fingers and pull force needed for moving the pushcart.

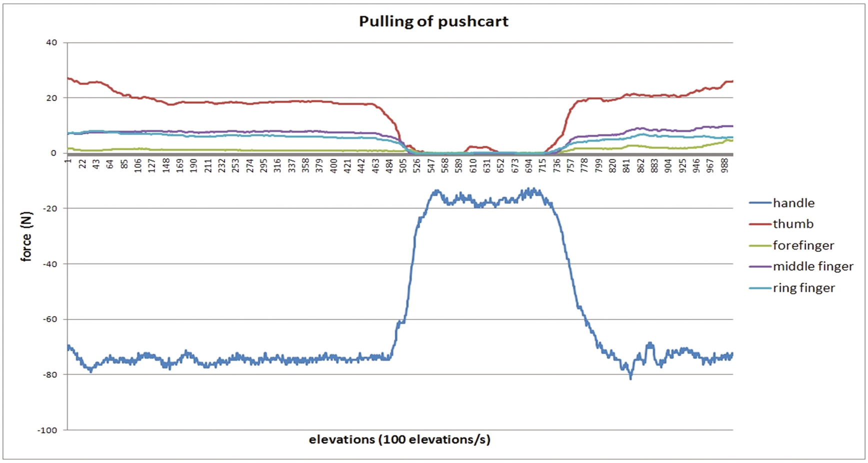

Fig. 5. Pulling a pushcart – measured values

It is very important to know the right load values especially in the assembly processes where the same movements are repeated very often. Because when they have some harmful influences they can cause serious health problems. This part describes possibility of measuring push and pull forces in working and assembly processes using the ErgoPAK tool kit and of using these values in load evaluation. This evaluation can be also done in many other ways. We will present load evaluation by means of ergonomics analyses in Tecnomatix Jack software as an example of many possibilities [24].

3.3 Arrangement of Proposals and Choice of the Final Proposal

When the user is surrounded by a virtual environment and can see displayed elements of the future workplace in the real dimensions, he or she can very exactly imagine the work space and reveal possible limitations and disadvantages of components arrangement. Individual software packages also offer tools for detecting collisions, generating outreach zones and many other ergonomics analyses, using which we can efficiently and quickly assess the proposal of component placement in the workplace. Thanks to these tools we arrange the placement of basic components in the workplace and specify their precise dimensions. If there is no CAVE environment at our disposal, we can make arrangements with the support of a 3D projector or a 3D monitor [11, 17] (Fig. 6).

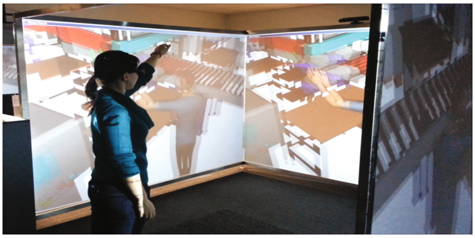

Fig. 6. Placement of components in the workplace using the CAVE

HMD displays can also be used for displaying individual variants in the virtual environment and for supporting the decision making process. In the past, these devices were relatively defective; however, at present they offer convincing experience and are visibly smaller. Currently, one of the best solutions is the glassed Oculus Rift developed by Oculus VR®. The company started selling the first version of glasses under the name "Development Kit" and is currently offering a new version with HD resolution. The company also offers accessible development environment and users can test new possibilities of the device and prepare their own applications [7].

The device contains a gyroscope; thus it can interactively react to head movements and automatically recalculates an image in the displays as if the user moved his/her head also in a virtual environment [19]. The device is connected via HDMI or a DVI cable and is considered to be an external monitor. When the device is used, the monitors have to be set to image cloning. This is the reason why the generated image can be seen also on the monitor screen. There are two separate windows with a shifted image. 3D impression and immersion into a virtual environment can be achieved only with the support of a HMD device [16].

If all the proposals for the workplace arrangement have been optimised in the previous design step, we choose the best variant. With more complex projects it is necessary to take into account different aspects of proposals and, therefore, a multi-member team is to be created. The decision-making team consists mostly of the project team members, but it is possible to add a specialist from a particular area of activity. The resultant variant then moves to the stage of detailed design, in which a detailed

Fig. 7. View of the future workplace using AR in 1:1 scale

placement of all – also less important – workplace elements is done: placement of tools, visual management, maintenance, working and assembly procedures, etc. (Fig. 7).

This variant can be visualised before the detailed design phase with the use of AR in real size and real position in a layout where it will be placed in the future. Such a display can be used as visualisation of the final concept solution presented to company management, etc. [9, 10].

4 Conclusions

In the time of rapid changes in demand, it is necessary to flexibly react to customer requirements. Thus, it is necessary to rebuild and change the existing working and assembly workstations. Modern information technologies and software solutions offer a range of possibilities to try new ways how to design or evaluate a workstation. We have introduced one possible software solution Tecnomatix Jack and its features in the CAVE environment. The aim was to design and implement the CAVE environment with the possibility of special use of Tecnomatix Jack software. The new solution was adding plug-in for possible cooperation between the CAVE and Tecnomatix Jack. To be able to implement the new solution, we suggest using Kinect for Windows devices.

These technologies are not without defects or disadvantages, but they are constantly developing. The assumption is that these technologies will become more and more common and widely used. They will be very helpful because already the current versions shorten the time of the design process and significantly reduce costs.

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Multiple Criteria Decision Support System for Making the Best Manufacturing Technologies Choice and Assigning Contractors

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Abstract. The article presents a conceptual framework of Multiple Criteria Decision Support System for choosing technology and contractors. It consists of two modules which conduct the decision process in two phases. The first one equipped in Analytical Hierarchy Process (AHP) method indicates which technology has a priority for a given part to be produced. The solution space contains Addictive Manufacturing, Conventional Manufacturing, and the combination of both. The second phase aids decision-maker in the NP-hard problem which is choosing the best (in multiple criteria sense) configuration of contractors to the order realization with the technologies suggested theretofore. For this phase, a mathematical model and problem formulation are presented. The solution applied for the first phase was tested on the example of data extracted from a real order giving promising results. For the second phase, a solution procedure is proposed, which involves usage of metaheuristic (NSGA II algorithm) and the reference point method. The research for this approach is not a subject of this paper.

Keywords: Decision support systems · Additive manufacturing technologies · Multi-criteria analysis · Multi-criteria optimization · AHP · NSGA II

1 Introduction

The recent research and trends in the industry indicate that there is a noticeable trend towards Additive Manufacturing (AM) technologies. It is visible that it over crossed its root domain which was single part production for very individual purposes like in medical implants and now it is seriously considered or already used in serial production. The insight in reports and analysis [1–6] regarding dynamic of development in this field indicates that there are particular obstacles in their faster and more extensive deployment with a positive impact on the economy. This is a lack of appropriate support of decision processes and deficiency of new business models. The popularization of 3D technologies naturally causes new challenges in the field of production engineering. The Solid Free Fabrication processes often do not lead to making final goods, so they have to be integrated with conventional processing. Moreover, there

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appears a very complicated decision process for executive leaders who have to indicate which elements of workflow has to be redesigned and shifted to the Additive Manufacturing field. It can be either particular machine stands, a group of products or series of products/parts. Despite the type of dilemma cost is always a key factor in this kind of analysis. For small and medium enterprises which do not have such an investment potential as big corporations, it might be crucial to find new business models enforcing cooperation. Producing within manufacturing networks or clusters, they may diversify the range of their technologies including different types of AM technologies nowadays still relatively expensive despite the increasing popularity.

During the next ten years, there may occur significant changes in the organization of production process surprising those who stacked in the traditional manufacturing paradigms. The history seems to come full circle. The products have been produced in accordance with the individual customer order and tailored to meet his needs [7]. Today we can talk about getting into the age of mass customization thanks to the exponential development of AM technologies. It enables manufacturing of customized products on the mass scale simultaneously dispersing production systems and creating well-communicating network of small production units.

The article contains the concept of Multiple Criteria Decision Support System (MCDSS) equipped with the appropriate algorithms and procedures which enable to make decisions on two levels. First one leads to making a choice regarding the best technology of production for components consisted in a given order. In this phase, the system suggests whether the part should be produced with conventional manufacturing (CM), additive manufacturing or a mix of both technologies AM and CM. While in the second phase the designed application suggests the best combination of contractors who could realize the order using the technologies suggested accordingly for each element in the first phase.

2 Multi-criteria Analysis Method Dedicated for MCDSS

The crucial aspect of the effectiveness of MCDSS is applying and tailoring the appropriate algorithm and reasoning rules corresponding to the type of problem to be solved. In the analyzed case it was obvious that the befitting multi-criteria approach has to be applied. It was necessary to take into consideration fact that choosing between AM and CM technologies requires the participation of experts team where design engineer, process engineer, and AM expert has to be involved. Moreover, some of the given criteria are more qualitative than quantitative, which makes the evaluation process even harder. Having this aspects in mind a multi-criteria decision analysis (MCDA) method called AHP (analytic hierarchy process) was applied in the first phase of the decision process. The method developed by Saaty [8] is based on making judgments by pairwise comparisons of elements composed hierarchically. The conclusion is made by establishing the preference relation, together with its degree between elements. Based on this knowledge, the ranking of variants are calculated. The method can be described by the following procedure:

Step 1. Describing the problem in hierarchical way containing decision goal (in this case the best manufacturing technology for the process is being chosen), the alternative variants of the problem solution and criteria for evaluating alternatives.

In this step, the tree picturing hierarchy is built. The top element which is the main goal is followed by the criteria and sub-criteria placed in the chosen order. It is recommended that each element has no more than 5–7 sub-elements so that each node of the tree has no more than 5–7 children. This assumption results from the limited ability to make consistent judgments by a human being.

Step 2. Establishing relations between elements of the hierarchy by making a series of judgments based on pairwise comparisons of them. The judgments are made by pairwise comparisons of sub-elements against the element (sub-criteria, criteria or main goal). The judgments establish the preference relation of one element against the other. The relation degree is expressed using scale suggested by Saaty in [8], where the main values used are 1, 3, 5, 7, 9 to express the degree, where 1 corresponds to equal importance of the elements, 3 – weak preference, 5 – moderate preference, 7 – very strong preference, 9 – extreme preference. The even numbers can also be used to reflect the semi degrees of the main ones. The opposite relation is also used if the second element is more preferred then the first, then inverse numbers are used, i.e., 1/3, 1/5, 1/7, 1/9 (and if necessary 1/2, 1/4. 1/6, 1/8).

Step 3. Checking consistency of the judgments (if necessary, the consistency has to be corrected). The calculation of consistency is used to check if expert judging elements gives coherent information. From judgments, for each hierarchy element (except solution alternatives) a "comparison matrix" is build (it consists of numbers reflecting the degree of preference relation between elements), which then is normalized. Based on the own value of the matrix and "random index" value, a "consistency index" is calculated. If its value is greater than 0,1, it is assumed that the judgment is inconsistent, and should be amended.

Step 4. Calculating local priorities of elements for each hierarchy level on the base of judgments. To compute the local priorities of the elements, the normalized "comparison matrix" is used.

Step 5. Calculating the final overall priorities of the alternatives. The final overall priorities of the alternatives are calculated using local priorities and hierarchy structure of the model.

The AHP method is a great tool for ranking alternatives when more than one expert is involved in the evaluation process. Each expert may have his own set of criteria composed in the hierarchy, that he uses for evaluation. The main expert may set priorities of the experts' judgments explicit or by using pairwise comparisons. The resulting priorities take into account the opinion of every expert involved.

3 Dedicated Multiple Criteria Decision Support System

It is very important to systematize and rationalize decision process regarding the type of technology that should be used in the production of each part from a given order. The decision process is very complex due to the extensive criterion collection and their different weight depending on the analyzed case, expert competence scope, knowledge, and preferences. Once the decision regarding the best way of producing given part is made in the next step, the appropriate resources for the process have to be found. Since the AM technologies still belong to a group of new or being developed in the industry it is recommended to realize orders with their usage within manufacturing networks or cluster which integrate many production units having at disposal diversified technologies and machines. This in turn also require the application of an MCDSS to find the best configuration of Virtual Organization which will be most profitable realizing particular order. Here the list of criteria is quite standard (time, cost, risk, quality) but there is a significant number of possible combinations in solution space which induces designing an appropriate method of their search.

The conceptual framework of MCDSS which would answer the need of straightening and formalizing the decision procedure in described scope is presented in Figs. 1 and 2. Module 1 of the developed MCDSS executes the first phase of the decision process when it is necessary to prioritize conventional manufacturing (CM) methods (machining) and Additive Manufacturing. The collection was divided into four categories:

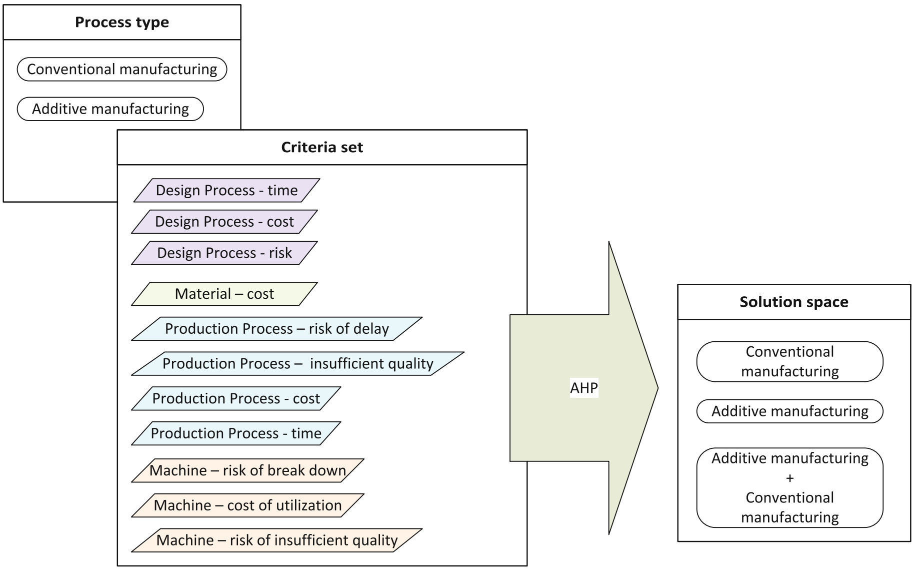

Fig. 1. The conceptual framework of MCDSS for choosing technology – Phase I.

1. The factors resulting from design process (time, cost, risk),
2. Cost of material,
3. The factors connected with production process (risk of delay, insufficient quality, cost, time),
4. The factors that are tied to the machine (the risk of breakdown, the cost of utilization, the risk of insufficient quality).

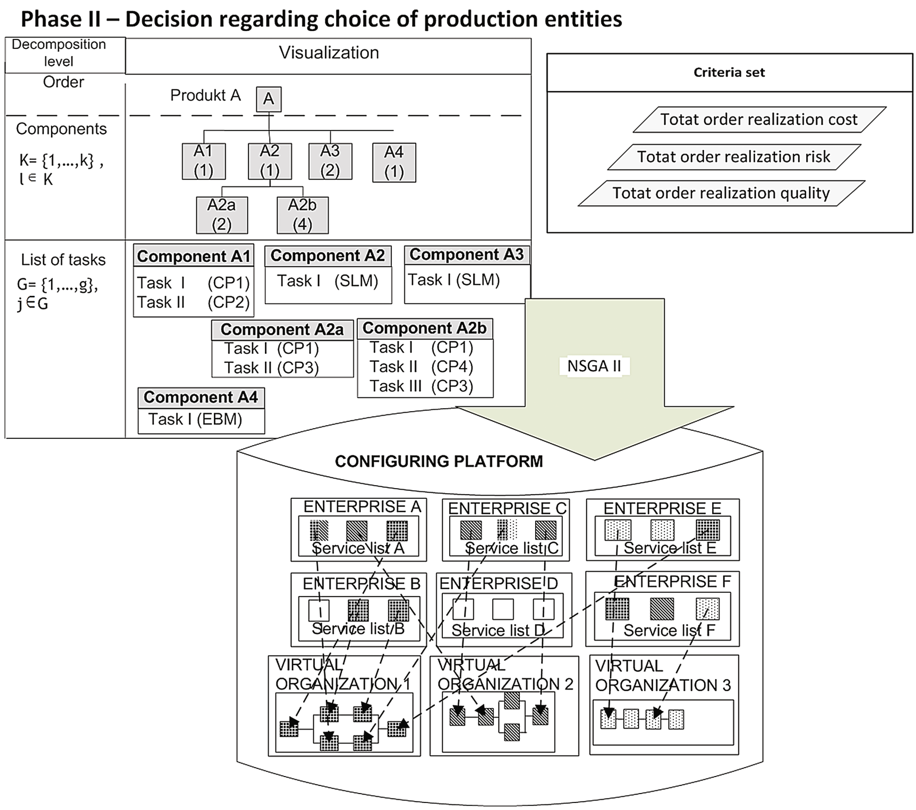

Fig. 2. The conceptual framework of MCDSS for choosing contractors – Phase II.

The engine of the reasoning in *Phase I* is AHP (Analytic Hierarchy Process) method. The solution space consists of the three options: Conventional Manufacturing, Additive Manufacturing and the combination of both CM and AM.

Phase II consists of assigning work to the contractors taking into consideration optimal time, cost, risk, quality for the entire order, fitting their competencies with technologies which are the best for the process (according to priorities obtained in Phase I). In the initial phase of building the MCDSS system, it will not be able to divide work necessary for producing one component between different contractors.

4 Mathematical Model for the Decision Problem in Phase II

Let us denote the following notation referring to the main elements of the model:

Contractors

Let us denote by $\boldsymbol{Q} = \{1, 2, \ldots, Q\}$ a set of contractors numbers, where Q is the number of all contractors available. With each contractor, a processing capacity, and a level of risk characteristic are bounded and given by vectors $\mathbf{PC} = [PC_q]_{q \in \boldsymbol{Q}}$, and

$\mathbf{CR} = [CR_q]_{q \in \boldsymbol{Q}}$, respectively, where $PC_q \in N$ is the processing capacity, and $CR_q \in [0,1]$ is the risk inherent with processes realized by the contractor q.

Orders

Let us denote by $\boldsymbol{P} = \{1, 2, \ldots, P\}$ a set of orders numbers to be assigned to the contractors, where P is the number of all orders. With each order, a number of processing capacity required, and minimal quality are connected and represented by vectors $\mathbf{V} = [V_p]_{p \in \boldsymbol{P}}$, and $\mathbf{Q}^{\min} = [Q_p^{\min}]_{p \in \boldsymbol{P}}$, respectively, where $V_p \in N$ is the number of processing capacity required for realization of order p, and $Q_p^{\min} \in N$ is the minimal order realization quality needed for the order p.

Technologies

The orders may be realized in different technologies denoted by the set $\boldsymbol{T} = \{1, 2, \ldots, T\}$, where T is the number of all technologies specified.

The technology chosen as the best for each order is given by a matrix $\mathbf{TN} = [TN_{p,t}]_{p \in \boldsymbol{P}, t \in \boldsymbol{T}}$, where $TN_{p,t} = 1(0)$ if the technology t is the best for order p (otherwise). From the other hand, each contractor has some experience with each technology, which reflects matrix $\mathbf{Q^L} = [Q_{q,t}^L]_{q \in \boldsymbol{Q}, t \in \boldsymbol{T}}$, where $Q_{q,t}^L \in N$ is the level of quality in which contractor q realizes orders in technology t. Contractors may have different wages for one processing capacity unit used for order realization in a given technology, which is treated as unit costs and given in matrix $\mathbf{C} = [C_{q,t}]_{q \in \boldsymbol{Q}, t \in \boldsymbol{T}}$, where $Q_{q,t \in R_+}$ is the unit cost of realization of one unit of processing capacity in technology t by contractor q.

Decision Variables

Let us introduce the following binary decision variable representing the assignment of orders to the contractors, and given by matrix $\mathbf{x} = [x_{p,q}]_{p \in \boldsymbol{P}, q \in \boldsymbol{Q}}$. ($x_{p,q} = 1(0)$ if the order p is assigned to the contractor q (otherwise)).

Constraints

The constraints imposed on the decision variable are as follows:

All the orders must be assigned to exactly one contractor

$$\forall_{p \in \boldsymbol{P}} \sum_{q \in \boldsymbol{Q}} \boldsymbol{x_{p,q}} = 1. \tag{1}$$

The production capacities of any contractor cannot be exceeded

$$\forall_{q \in \boldsymbol{Q}} \sum_{p \in \boldsymbol{P}} x_{p,q} V_p \leq PC_q. \tag{2}$$

The minimal order realization quality for each order must be reached

$$\forall_{p \in \boldsymbol{P}} \sum_{q \in \boldsymbol{Q}} \sum_{t \in \boldsymbol{T}} x_{p,q} Q_{q,t}^L TN_{p,t} \geq Q_p^{\min}. \tag{3}$$

Objectives

The evaluation of the decision is made with the use of the following criteria:

The total orders realization quality

$$TQ = \sum_{p \in \boldsymbol{P}} \sum_{q \in \boldsymbol{Q}} \sum_{t \in \boldsymbol{T}} \boldsymbol{x}_{\boldsymbol{p},\boldsymbol{q}} Q^{L}_{q,t} TN_{p,t}. \tag{4}$$

The total orders realization risk

$$TR = \sum_{p \in \boldsymbol{P}} \sum_{q \in \boldsymbol{Q}} \boldsymbol{x}_{\boldsymbol{p},\boldsymbol{q}} CR_{q}. \tag{5}$$

Total orders realization cost

$$TPC = \sum_{p \in \boldsymbol{P}} \sum_{q \in \boldsymbol{Q}} \sum_{t \in \boldsymbol{T}} \boldsymbol{x}_{\boldsymbol{p},\boldsymbol{q}} C_{q,t} TN_{p,t}. \tag{6}$$

This is the most standard and basic criteria set that can be used to the contractor's evaluation. In the future, it can be developed with more elements such as the experience of the contractor in cooperation, the level of pro-ecological politics implemented in production and many others specific to a given industry.

Problem Formulation
For the given data: P, Q, T, **PC**, **CR**, **V**, $\mathbf{Q}^{\min}$, **TN**, $\mathbf{Q}^{\mathbf{L}}$, **C** obtain values of decision variable $\mathbf{x}^{*}$ with respect to constraints (1)–(3), which minimizes the vector of objectives $\mathbf{J}(\mathbf{x}) = [-TQ, TR, TPC]$, i.e. $\mathbf{x}^{*} = \arg\min_{\mathbf{x}} \mathbf{J}(\mathbf{x})$.

The problem considered is a hard multi-criteria optimization problem. To solve it, we propose first to find a Pareto front of non-dominated solutions and then to choose one of them, which is the closest (in the sense of Chebyshev distance) to the reference point [9] (provided by a decision-maker). Because, the problem is too hard to be solved efficiently with the conventional methods (problem is NP-hard, while it can be reduced to multi-criteria multiple knapsack problem), we propose to use evolutionary algorithm NSGA II [10] to approximate Pareto front. This algorithm has quite good performance in this types of problems [11]. The application of this algorithm will be tested and developed in future research.

5 AHP Algorithm Verification

The procedures implemented in Phase I of the decision process were verified on the example of three chosen parts from the order that could be analyzed in the proposed system. Turbocharger (Fig. 3) used in automotive engines consist of the following components: 1 – Compressor Housing, 2 – Compressor impeller, 3 – Shaft, 4 – Bearing System, 5 – Centre Housing, 6 – Turbine Impeller, 7 – Turbine housing. Three components were analyzed in the proposed DSS system: Compressor Impeller, and Bearing system, Centre Housing. Figure 3 shows a fragment of the tree picturing criteria hierarchy and some of the results obtained during analysis made for Compressor Impeller.

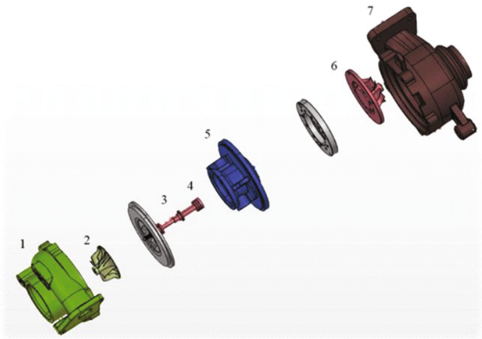

Fig. 3. Turbocharger expanded view [12].

The results of the analysis made for each part are presented in Tables 1, 2 and 3. The most recommended technology chosen has the lowest number in a row called rank number. Results obtained for compressor impeller (Fig. 4, element 2) are pictured in Table 1. In this case, the combination of Additive Manufacturing and Conventional Manufacturing gained the highest priority. The result is quite realistic. Due to the fact that this kind of part has complex geometry which influences working parameters of the part, it is possible to improve some parameters producing the part in AM technology and final surface processing in Conventional technology.

Table 1. AHP analysis results for compressor impeller.

Alternatives	CM (Conventional)	AM (Additive)	CM + AM
Priorities	0.120939869	0.40736482	0.471695311
Rank number	3	2	1

Table 2 presents results of AHP analysis made for the bearing system (Fig. 4, element 4). In this variant of analysis, the conventional machining was suggested with the highest rank. The choice, in this case,, is also very rational because the part construction is quite simple and requires a significant amount of solid material. The production with AM technologies would not be economically reasonable while using metal powder in the production process.

Table 2. AHP analysis results for the bearing system.

Alternatives	CM (Conventional)	AM (Additive)	CM + AM
Priorities	0.649496547	0.169022064	0.18148139
Rank number	1	3	2

Table 3 contains results obtained for the centre housing (Fig. 4, element 5). Again the choice is very reasonable due to the part construction and its modifications that can be easily implemented while designing for production in AM technology.

Table 3. AHP analysis results for the centre housing.

Alternatives	CM (Conventional)	AM (Additive)	CM + AM
Priorities	0.093814394	0.511539237	0.39464637
Rank number	3	1	2

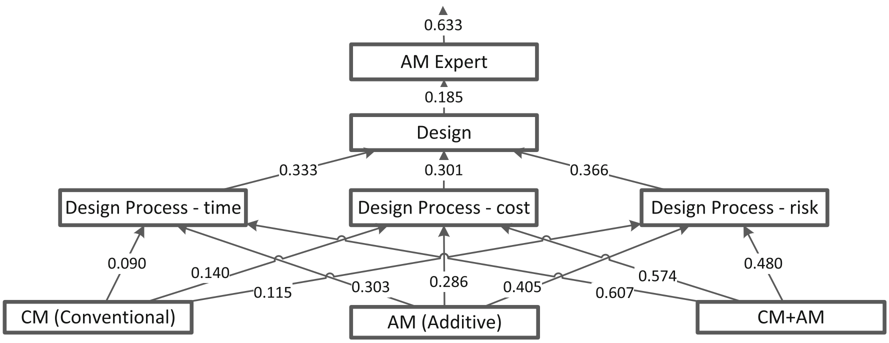

Fig. 4. Fragment of tree build for AHP method showing chosen results as priorities of elements.

All the suggestions made in Phase 1 using AHP algorithm have technological justification so the algorithm verification may be acknowledged as a successful.

6 Summary

The article presents the concept of a complex Multiple Criteria Decision Support System which was designed to work on two different levels. The first phase of its operation is based on AHP method which enables the involvement of experts in the decision process simultaneously making it more transparent than it is in a traditional environment without supporting applications. The tests made on the real order shows that the AHP implementation empowers the intelligence of designed system. The best technology for analyzed part production is suggested effectively. The second phase requires more thorough analysis which was presented in form of mathematical model. The proper choice of contractors for a given order realization will be made with the use of NSGA II algorithm, which approximates the Pareto front of non-dominated solutions. From the obtained set, the best one will be chosen based on the reference point method. This approach requires future testing to prove its accuracy in this application. The issue will be the subject of a future research.

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Sludge Volume Index (SVI) Modelling: Data Mining Approach

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Abstract. In this paper, statistical models to forecast based on the sludge volume index (SVI) with the continuous measurements carried out in the period from 2013 to 2016 for waste water treatment Sitkowka-Nowiny was developed at the same, for two variants of analyses. In the first one, a model of SVI predicting based on the quality indicators of wastewater flowing into the treatment plant, i.e. Biochemical (BOD) and chemical oxygen demand (COD), the content of total nitrogen (TN) and ammonia nitrogen (NH_4), total suspended solids, total phosphorus (TP) and the operating parameters of the bioreactor (pH, temperature, oxygen concentration in the nitrification chamber). In the second case, the possibility of replacing individual measurements of the quality of wastewater values calculated on the basis of daily sewage flows to the treatment plant was examined. The above mentioned models statistical analysis was performed using the method of k-nearest neighbor (k-NN), cascading neural network (CNN) and boosted tree (BT). To evaluate the predictive ability of these models the average relative error (MAE) and absolute error (MAPE) were used. The conducted analysis showed that based on the above mentioned indicators of effluent quality and technological parameters of the biological reactor it is possible to modeling of sediment volume index with satisfactory accuracy. In the case under consideration methods of lower values of the prediction error of SVI obtained using a cascade neural networks (MAE = 17.49 ml/g and MAPE = 9.80%) than for the method k-nearest neighbor (MAE = 27.85 ml/g and MAPE = 14.50%). Furthermore, based on the performed simulation, it was found that it is possible to model the analyzed work of the quality of waste water on the basis of the daily flow with reasonable accuracy, it is confirmed by the calculated value of the average and absolute and relative error, and the better ability predictive characterized by the models obtained on the basis CNN than k-NN. In examined cases, the MAP in a set of validation did not exceed 10.13%. The simulation results of quality indicators obtained by CNN were substituted in place of the explanatory variables of sludge volume index in the model for prediction index of sediment and conducted simulations SVI, set out the error MAE = 25.15 ml/g and MAPE = 15.26%. On this basis, it is possible to replace the measured values of the quality of the results of their simulation, thereby reducing the cost of testing, but also gives you continuous control of SVI and adjustments discussed in this work of technological parameters of the biological reactor.

Keywords: Sludge volume index · Cascade neural network · K–nearest neighbor method · Wastewater treatment

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1 Introduction

An effective method of communal sewage treatment is the biological treatment process using the activated sludge. Reaching the given level of pollution reduction depends then not only on the correctness of process planning and on the correct designing of process plan but also on the right operation of the treatment plant. The latter is not realizable without knowing the operational parameters of activated sludge chambers (ASC) and the sludge ability for sedimentation. This ability of activated sludge is calculated by means of Mohlman sediment volume index (SVI) which is defined as the quotient between the volume of sludge compressed by 30 min in one-liter Imhoff funnel and the dried mass of sludge sedimented.

The sludge sediments well when its SVI values are from the value range 50–150 ml/g [1]. The Mohlman index makes possible the successful prediction of unstable states of sewage treatment process which are arising when an excessive increase of filamentous bacteria in the activated sludge occurs what takes place for SVI > 150 ml/g [2, 3]. The presence of these bacteria in the sludge creates treatment problems especially during the sewage clarification in the secondary clarifiers of the plant. In the case of a SVI worsening an increase of total suspended solids as well as of organic carbon content in the sewage effluent arises. To avoid the problems the mathematical models predicting the Mohlman index shall be developed. To realize this aim different kinds of neuronal nets are commonly used, like hierarchical, probabilistic, compartmental or hybrid networks [4–7]. Previous analyses of Mohlman index and of its connection with the sludge ability for sedimentation showed [4, 8] that the index value depends strongly on the indicators characterizing the quality of sewage flowing into the treatment plant and on the parameters describing the operation of plant bioreactor (ASC). The concerned indicators are mostly biological and chemical oxygen demand characterizing the content of organic matters in the sewage as well as nitrogen compounds (ammoniacal and total nitrogen) appearing in total suspended solids; sometimes also total phosphorus is taken into consideration in such analyses. In the papers published the influence of only singular indicators or of their limited combinations on SVI value is analyzed [9] while an aggregated effect of all of them could be more interesting and cognitive. Apart from the factors mentioned also the sludge concentration, its pH value and temperature as well as oxygen concentration in nitrification chambers affect SVI value. An authorial approach to the sludge index prediction is presented in the papers of [10, 11], who considered in their works the sludge bioceonosis, quality of the raw sewage inflow and several technological ASC parameters. An interesting solution is presented also in the paper of [12], in which for SVI modeling the results of analysis of sludge flocs pictures were used. The SVI models discussed in the papers noted are accurate but their development requires application of expensive measurement devices (in case of sludge flocs observation) or carrying out the time consuming determination of sewage quality indicators what is often difficult or impossible from the technical point of view [7]. In the works mentioned neither the influence of dosing the chemical coagulant PIX on the sludge sedimentation ability has been considered what is a common practice by treatment plants operation.

In this paper the possibility of Mohlman index prediction by means of data mining methods has been investigated and by the works the daily sewage inflows, sewage quality indicators (i.e. chemical and biological oxygen demands, contents of total and ammoniacal nitrogen, of total phosphorus and of total suspended solids in the sewage) and the operational ASC parameters (pH, temperature, activated sludge and oxygen concentration in sludge chambers and amount of PIX coagulant dosed) were taken into consideration. Additionally the possibility of prediction of the sewage quality indicators while using only the sewage inflow measurements has been investigated in order to eliminate them from the SVI models.

2 Object Investigated

The analysed object is the communal sewage treatment plant (STP) localized at the Polish municipality Sitkowka–Nowiny into which the sewage from the wastewater systems of Kielce city, Sitkowka–Nowiny and partially of Maslow commune flows. The nominal capacity of plant equals to 72 000 m^3/d by its baseload equal to 275.000 ENI (Equivalent Number of Inhabitants). The raw sewage flowing into STP are mechanically pretreated on the stepped bars and in the aerated sand trap with the fats separator (see Fig. 1).

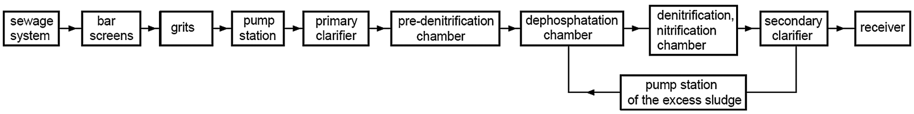

Fig. 1. Technological diagram of Sitkowka-Nowiny sewage treatment plant.

Afterwards the sewage is directed into the primary clarifiers from which it flows into the biological part of the plant (bioreactor with separated chambers of dephosphatation, denitrification and nitrification). The process of dephosphatation takes place firstly and then the processes of denitrification and nitrification occur consecutively. The sewage treated with the activated sludge together flows after that into four secondary clarifiers and from there it goes out already clarified into Bobrza river that is the wastewater receiver.

3 Modelling Methodology

In the paper some mathematical models for calculation SVI values while using three data mining methods have been developed. To do it measurements data concerning the sewage inflow Q, sewage inflow quality (like chemical oxygen demand COD, biological oxygen demand BOD_5 called farther as BOD, total nitrogen TN, ammoniacal nitrogen NH_4, total suspended solids TSS and total phosphorus TP) and bioreactor parameters (like temperature T_{os}, pH values, sludge concentration MLSS, amount of

PIX dosed and oxygen concentration in the chamber of nitrification OD) were used. The relations modelled can be written as follows:

$$SVI(t) = F\{Q, T_{os}, pH, OD, MLSS, PIX, BOD, COD, TP, NH_4, TN, TSS\} \quad (1)$$

Also modelling of the above indicators of sewage quality basing only on the sewage inflow measurements has been investigated. Possession of such the models is very convenient and useful for they enable the SVI calculation with the use of the measurements of only ASC parameters and of sewage inflow and its temperature what makes this calculation very easy and simple. Then Eq. (1) can be formulated following:

$$SVI(t) = F\left\{Q, T_{os}, pH, DO, MLSS, PIX, C(t)_j\right\} \quad (2)$$

where $C_j(t) = F\{Q(t), Q(t-1), Q(t-i), T_{in}(t), T_{in}(t-1), T_{in}(t-p)\}$, T_{in} means the inflow temperature and $j = 1, 2, \ldots, 6$ and $i, p = 0, 1, 2, \ldots, 7$.

That approach to SVI modelling is of importance from the practical point of view either for it makes possible to predict and supervise the Mohlman index event when the sewage quality meters are out of order, i.e. they are broken down or just calibrated. By that modelling the assumption is done that the sewage quality characterized by the pollutant load is influenced mainly by the sewage dilution what has been confirmed by [6] while investigating the wastewater network in Rzeszow city. In this paper the time delays of Q and T_{in} variables in Eq. (2) have been determined by means of the classification trees method (CTM) with the use of the predictor importance index (IMP) [13]. There was assumed that these variables could be taken into account while modelling the sewage quality indicators if IMP > 0.90 [14]. The first models developed were designed to predict the SVI parameter and they were calculated by use of the methods of Cascade Neuronal Nets (CNN), of k-Nearest Neighbour (k-NN) and of Boosting Trees (BT). To perform the calculation the available measurement data have been divided into learning, testing and validation sets in the proportions of 75%, 25% and 25% respectively and they were normalized by their min and max values [6, 12]. To ensure obtaining the proper models the process of their five-time cross-validation has been done.

The artificial neuronal nets are commonly used to model and simulate linear and nonlinear dynamic processes as well as for solution of optimization, classification and control tasks in the field of environmental engineering [4, 6, 12]. By process modelling the nets in form of Multi Layer Perceptrons (MLP) are used mostly and one of their modifications is CNN network owning the weight connections between the input layer and all internal layers and concurrently between the subsequent internal layers within the net. CNN networks with several hidden layers can be used to model complex nonlinear processes [15].

The optimal structure of neuronal nets designed to predict SVI index as well as COD, BOD, NH_4, TN, TP and TSS the parameters has been determined by using the error coefficients defined in (4). The CNN nets calculated consisted of only one hidden layer on which the neurons number changed from 3 to 10, the activation functions between the input and hidden layer have been taken optionally of linear, exponential, sinusoidal, sigmoidal and tangent-hyperbolical kinds and for the output layer the linear activation function was assumed. According to the works of [16, 17] only two connections between the input neurons and the following layers of CNN networks have been considered. The method of CNN nets have been applied till now for modeling treatment plants and for forecasting air quality but it has not been used to model the sludge sedimentation neither the sewage quality flowing into a STP. In the subsequent calculation of SVI modelling also some methods less complex as neuronal nets have been used. The first of them was k-NN method being the one of easiest nonparametric methods used commonly for modelling the sewage inflow quality and for prediction of efficiency of treatment plants operation. To calculate the variable predicted the following relation is used:

$$\hat{y} = \frac{1}{K} \cdot \sum_{i=1}^{N} y_i J(x_i, x_j) \tag{3}$$

where x_i is one of K nearest neighbours x_j when the distance $d(x_i, x_j)$ belongs to the smallest distances between them, N – number of all distances between the neighbours, $J(x_i, x_j)$ – a function equal to 1 (if x_i is one of K nearest neighbours x_j) or to 0 (otherwise). While using k-NN method mostly Euclid norm to calculate those distances is used what has been done also in our research and where K value was determined by successive approximation using the error coefficients defined in (4).

The last approach used in the paper to model SVI index was BT method that is an implementation of the method of stochastic gradient boosting applying commonly for the solution classification and regression tasks [18]. The main idea of the method relies on the creation of a sequence of decision trees and during the modelling process each following tree is used to determine the rests generated by the preceding trees. The choice of the trees number in the model developed has been realized by trial and error and this number was taken never bigger than 200 in order to avoid the overlearning of models calculated. The subsample proportion for building a tree was taken equal to 0.5 and the maximum number of levels was set to 10.

In the following analyses STATISITCA 12.0 software has been used to develop the models by means of BT and k-NN methods and MATLAB software was applied while using CNN method.

To assess the prediction abilities of models forecasting the values of sewage quality indicators COD, BOD_5, NH_4, TN, TP and TSS as well as the sludge volume index SVI the following error coefficients have been applied:

– relative average error:

$$MAPE = \frac{1}{n} \cdot \left| \frac{y_{i,obs} - y_{i,pred}}{y_{i,obs}} \right| \cdot 100\% \tag{4}$$

– absolute average error:

$$MAE = \frac{1}{n} \cdot \left| y_{i,obs} - y_{i,pred} \right| \cdot 100\% \tag{5}$$

– correlation coefficient:

$$R = \frac{\sum_{s=1}^{N} \left(y_{s,obs} - \overline{y_{obs}} \right) \cdot \left(y_{s,pred} - \overline{y_{pred}} \right)}{\sqrt{\sum_{s=1}^{N} \left(y_{s,obs} - \overline{y_{obs}} \right)^2} \cdot \sqrt{\sum_{s=1}^{N} \left(y_{s,pred} - \overline{y_{pred}} \right)^2}} \tag{6}$$

where: n – measurements data number, $y_{i,obs,pred}$ – measured or calculated data.

4 Results

Basing on the available measurements concerned the sewage inflow and quality and the ASC parameters the changeability of these variables has been determined in order to define the range of applicability of models under development (Table 1). An analysis of data listed in Table 1 shows that the pollutant load in the sewage inflow changed in a wide range what affected actually the ASC parameters and influenced strongly the SVI which values varied from 95 up to 320 ml/g.

Table 1. Summary of the range of variation of parameters describing the amount (Q), influent quality and the parameters of the biological reactor.

Variable	Minimum	Average	Maximum
Q, m^3/d	32.564	40.698	86.592
T_{os}, °C	10.0	15.9	23.0
pH	7.2	7.70	7.8
OD, mg/dm^3	0.55	2.56	5,78
MLSS, kg/m^3	1.19	4.26	5.89
PIX, m^3/d	0	0.80	1.93
SVI, ml/g	95	186	320
BOD, mg/dm^3	127	309	557
COD, mg/dm^3	384	791	1250
TSS, mg/dm^3	126	329	572
NH_4, mg/dm^3	24.4	49.31	65.9
TN, mg/dm^3	39.91	77.60	124.09
TP, mg/dm^3	4.3	7.80	12.6

The calculations done demonstrate that for the STP investigated the SVI values can be estimated with a satisfied exactness using for that the measurements of the sewage quality indicators (COD, BOD_5, NH_4, TN, TP, TSS) and of bioreactor technological parameters (pH, T_{os}, OD, MLSS, PIX) (Table 2).

Table 2. Comparison of CNN, k-NN and BT models calculated by SVI prediction.

Method	MAE	MAPE	R
CNN	5.08	3.01	0.965
k-NN	12.03	6.70	0.896
BT	11.25	6.37	0.904

The modelling results obtained (Table 2) show that the smallest errors by SVI prediction have been got for CNN model when the neurons number on the hidden layer of the network was equal to 6 and a tangent-hyperbolic function has been taken as the activation function between the input and hidden layer. By k-NN models the smallest error values have been got for K = 4 but they were more than two times bigger as by CNN model. In case of BT model the results received are alike as by K-NN model although its error values MAE and MAPE are slightly smaller. The results of modelling obtained with CNN method are similar to these ones reported by [19] (R = 0.97) who used for the SVI forecasts an ANN method and as the input variables the measurements of COD, TN, DO, TSS, MLSSV, pH and T_{os}. Some smaller error values MAE and MAPE and consequently a bigger correlation value (R = 0.99) the authors received using the ANN method modified by means of a genetic algorithm. A slightly smaller correlation value (R = 0.95) than in our work (R = 0.965) has been got by [5] who for SVI calculation used the following sewage quality indicators BOD, COD, TN, NH_4 and TP and ASC parameters MLSS, T_{os} and pH. Our results of modelling are alike as these ones got by [15] (MAE = 5%); they calculated SVI values by means of a modified neuronal network using as the inputs only the variables Q, BOD, COD, TN, OD and pH. An analysis of our current results shows that although the models calculated have got the satisfied prediction abilities but nevertheless there is problematic and difficult to gain the measurements of sewage quality indicators that are used in the calculation. Because of that an idea arose to replace them by their models calculated the formulas $C(t)_j = F\{Q(t-i), T(t-p)\}$, according to Eq. (2). The models of the indicators listed in Table 1 have been developed with k-NN and CNN methods using the measurements of the sewage inflow Q and sewage temperature T_{in}. By the modelling the method of classification trees has been applied to determine for particular indicators the coefficients of predictor significance (IMP); the results of this calculation are shown in Table 3.

Looking at the data recorded in Table 3 there is to note that the values of IMP are changing in a wide range from 0.56 up to 1.00. The biggest variation range is for COD and the smallest one is for BOD. The data show also that the values of all indicators BOD, COD, TN, NH_4^+, TSS and TP are similarly affected by the volume as well as by the temperature of sewage inflow. This conclusion is also supported by the results obtained by [6, 7] who performed similar investigation for communal treatment plants in Polish cities Kielce and Rzeszow.

In Table 4 coefficients of fitting the calculation results to the measurements (MAE, MAPE and R) in the wake of using the methods CNN, k-NN and BT are listed. By CNN method the smallest values of MAE and MAPE obtained for indicators COD, BOD, NH_4, TSS and TN have been got for 7 and 9 neurons on the hidden layer of the net and for the tangent-hyperbolic activation function between the input and hidden

Table 3. Calculation of significance coefficients for predictors of COD, BOD, TN, TSS, NH_4 and TP.

BOD		COD		TSS		NH_4^+		TN		TP	
Variable	IMP	Variable	IMP	Variable	IMP	Variable	IMP	Variable	IMP	Variable	IMP
Q(t)	1.00	Q(t)	1.00	Q(t)	1.00	Q(t)	1.00	Q(t)	1.00	Q(t)	1.00
Q(t − 1)	0.97	Q(t − 1)	0.94	Q(t − 1)	0.97	Q(t − 1)	0.98	Q(t − 1)	0.96	Q(t − 1)	0.96
T_{in}(t − 3)	0.95	Q(t − 6)	0.93	Q(t − 3)	0.95	Q(t − 2)	0.94	Q(t − 2)	0.95	Q(t − 2)	0.94
Q(t − 5)	0.94	Q(t − 3)	0.92	Q(t − 4)	0.94	T_{in}(t − 1)	0.93	T_{in}(t − 3)	0.94	T_{in}(t − 3)	0.93
Q(t − 6)	0.93	Q(t − 4)	0.92	T_{in}(t − 3)	0.93	T_{in}(t − 2)	0.92	T_{in}(t − 2)	0.93	T_{in}(t − 7)	0.92
T_{in}(t − 7)	0.92	Q(t − 5)	0.92	Q(t − 3)	0.92	T_{in}(t − 3)	0.91	Q(t − 6)	0.92	Q(t − 4)	0.91
T_{in}(t)	0.92	Q(t − 7)	0.91	T_{in}(t − 1)	0.91	Q(t − 4)	0.90	T_{in}(t)	0.91	T_{in}(t)	0.91
T_{in}(t − 5)	0.91	T_{in}(t)	0.90	Q(t − 2)	0.90	Q(t − 5)	0.90	Q(t − 7)	0.90	Q(t − 8)	0.90
T_{in}(t − 1)	0.90	T_{in}(t − 7)	0.90	Q(t − 7)	0.81	Q(t-3)	0.87	Q(t − 3)	0.85	T_{in}(t − 2)	0.81
Q(t − 4)	0.90	T_{in}(t − 3)	0.74	T_{in}(t − 5)	0.80	Q(t − 6)	0.81	T_{in}(t − 6)	0.73	Q(t − 11)	0.57
Q(t − 2)	0.82	T_{in}(t − 6)	0.71	T_{in}(t)	0.79	T_{in}(t)	0.80	Q(t − 4)	0.66	Q(t − 12)	0.55
T_{in}(t − 6)	0.81	T_{in}(t)	0.70	T_{in}(t − 4)	0.78	T_{in}(t − 5)	0.80	T_{in}(t − 4)	0.65	Q(t − 9)	0.53
Q(t − 7)	0.79	T_{in}(t − 4)	0.68	T_{in}(t − 6)	0.74	T_{in}(t − 6)	0.77	Q(t − 5)	0.64	Q(t − 14)	0.50
T_{in}(t − 4)	0.75	T_{in}(t − 1)	0.58	T_{in}(t − 2)	0.73	T_{in}(t − 7)	0.76	T_{in}(t − 5)	0.63	Q(t − 10)	0.48
T_{in}(t − 2)	0.72	T_{in}(t − 5)	0.56	T_{in}(t − 7)	0.66	Q(t − 7)	0.75	T_{in}(t − 7)	0.62	Q(t − 13)	0.47

layer. In case of TP indicator the smallest values of the errors were reached for 8 hidden neurons and for sigmoidal activation function. By the k-NN method the MAE and MAPE values were minimal for k = 6 in case of COS and BOD, for k = 5 in case of $NH_{4,}$ TN and TP, and for k = 4 in case of TSS. By the BT method the number of iterations while the tree parameters were corrected has not exceeded 100. There is to see from Table 4 that better prediction models for the sewage quality indicators have been achieved by means of CNN method than of k-NN and BT methods.

The correlation value for the BOD model received with the CNN method (Table 4) is bigger than that value obtained by [20] (R = 0.83) by means of an ANN method while as the inputs the sewage inflow parameters T_{in}, pH and TSS have been used. A better fitting of the BOD model to the measurements data (R = 0.92) than [20] was got by [21] who used as the model inputs the variables TN, TP, TSS and Q. On the other hand the correlation value for the COD model reached by [20, 22] was bigger

Table 4. Comparison of CNN, k-NN and BT models by COD, BOD, TN, TSS, NH_4 and TP prediction.

Indicator	CNN			k-NN			BT		
	MAE	MAPE	R	MAE	MAPE	R	MAE	MAPE	R
COD	66.90	8.88	0.90	83.21	11.05	0.76	76.79	10.16	0.82
BOD	23.58	8.11	0.94	41.00	14.11	0.82	38.84	13.19	0.85
NH_4	1.83	3.70	0.93	3.52	7.12	0.81	3.39	7.13	0.81
TN	4.37	5.62	0.82	6.45	8.30	0.75	6.08	8.14	0.77
TSS	22.93	7.81	0.91	32.84	11.19	0.79	32.26	10.84	0.82
TP	0.75	10.13	0.78	0.93	12.56	0.73	0.86	11.51	0.75

than in our work. As to the R values obtained for the TSS model they are smaller by us than these ones calculated by [23] (R = 0.93) who used for that also an ANN method. The MAPE values listed in Table 4 for TN and TP models developed with CNN method (5.62% and 10.13%, respectively) are in the first case smaller and in another one bigger than those values got with the method k-NN by [21] (5.79% and 8.87%, respectively).

In the following stage of investigation the results of modelling of the sewage quality indicators COD, BOD, TN, NH_4^+ and TSS that was done with the CNN, k-NN and BT methods have been put into Eq. (2) with which the SVI values could be now calculated in another way. The modelling errors received by this calculation are following: MAE = 17.43 ml/g and MAPE = 9.80% for CNN method; MAE = 22.72 ml/g and MAPE = 13.20% for BT method; and MAE = 24.35 ml/g and MAPE = 13.78% for k-NN method. In Figs. 2 and 4 the diagrams illustrated the comparison of the measurements and simulation results while calculating SVI values by means of Eqs. (1) and (2) are designed. From the Figures one can concluded that the maximal and minimal values of the SVI index calculated by BT and k-NN methods while using Eq. (2) are underestimated in the most calculation steps. A satisfied matching between the measurements and calculations can be stated only for CNN model (Fig. 3).

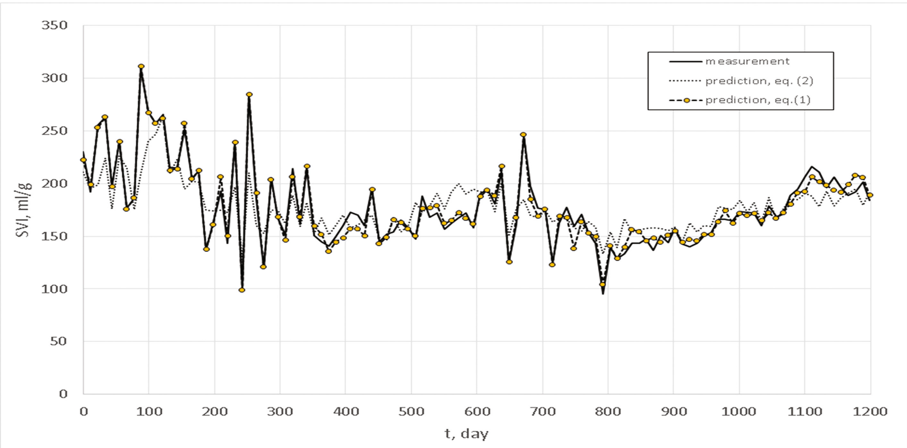

Fig. 2. A comparison of measurements and SVI model obtained with CNN method while using Eqs. (1) and (2).

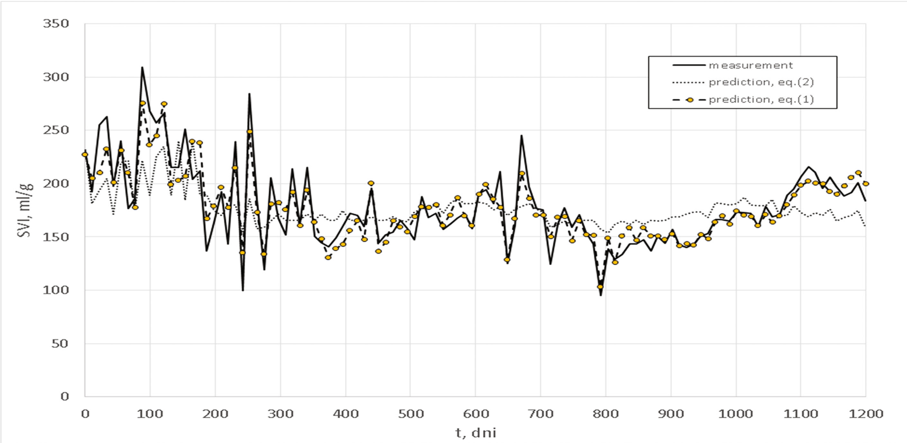

Fig. 3. A comparison of measurements and SVI model obtained with k-NN method while using Eqs. (1) and (2).

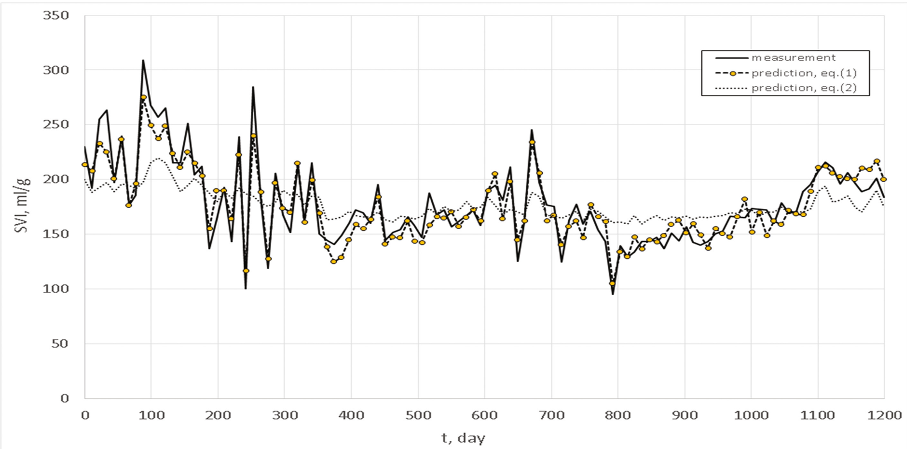

Fig. 4. A comparison of measurements and SVI model obtained with BT method while using Eqs. (1) and (2).

5 Conclusions

The results of investigation presented in the paper confirm that with the use of measurements concerning the volume of sewage flowing into a sewage treatment plant (Q) and the indicators of the sewage inflow quality (BOD, COD, TN, NH_4, TP and TSS) as well as the operational parameters of activated sludge chambers (pH, T_{os}, MLSS and OD) there is possible to calculate SVI index with satisfied exactness. An assessment of the results showed that the best prediction of SVI was achieved by means of CNN method that proved to be essentially better than k-NN and BT methods.

The results obtained demonstrated also that values of the sewage quality indicators can be determined with acceptable exactness with the use of only sewage inflow Q and its temperature T_{in}. It means that the quality of the raw sewage flowing into a STP is forming by biochemical processes occurring in the wastewater incoming from sewerage networks and by rainfalls determining the sewage dilution ratio. Because of that there was possible to replace the measurements data of COD, BOD, NH_4, TN, TP, TSS that were used to SVI calculation on the first stage of modelling by the results of solution of $C(t)_j = F\{Q(t - i), T_{in}(t - p)\}$ equation what has been done on the second stage of modelling. The modelling results received on this modelling stage confirmed that the SVI models calculated by means of $Q(t - i)_j$ measurements have got satisfied prediction abilities and they can be used successfully in operational practice. This statement is important from the economical as well as technological point of view because such the modelling way makes possible to eliminate the costs of on-line monitoring regarding the sewage quality indicators.

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Simulated Annealing Based on Linguistic Patterns: Experimental Examination of Properties for Various Types of Logistic Problems

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Abstract. The paper presents simulation experiment results regarding properties of linguistic pattern based simulated annealing used for solving the facilities layout problems in logistics. In the article, we investigate four different arrangements (02 × 18, 03 × 12, 04 × 09, and 06 × 06) comprising of 36 items. The examined layouts also differ in the links matrix density (20%, 40%, and 60%) and in defining distance between objects' pairs for the distance membership function (absolute and relative). We formally examine how these factors influence corrected mean truth values and average classical goal function values based on Manhattan distance metric. The results generally revealed a significant influence of all of the studied effects on the analyzed dependent variables. Some of the findings, however, were surprising and confirmed previous outcomes showing that the linguistic pattern approach is not a simple extension of the classic simulated annealing.

Keywords: Facilities layout · Optimization · Linguistic variables · Logistics · Fuzzy sets

1 Introduction

The main purpose of optimizing the placement of linked objects is to minimize the cost of their interoperability. In manufacturing engineering, one seeks such locations of machines and equipment in the production space that minimize the total cost of material flow, parts transportation, etc. between the objects. In the area of ergonomic research, the facilities layout problem is reduced to the arrangement of workplace elements that minimizes the overall cost of biological work such as energy expenditure. In the domain of human-machine interaction, the optimization could be based on the arrangement of the interface elements to ensure its maximum usability.

Since the layout optimization task is a combinatorial problem belonging to the NP-hard class [11], it is not possible to find optimal solutions within a reasonable time for large problems. Hence, the main research trend for years has been focused on developing heuristic algorithms leading to finding acceptable suboptimal solutions.

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Extensive reviews and classifications of such algorithms and optimization systems are presented, inter alia, in [1, 8, 9, 13] or [10].

An interesting research direction initiated, among others, by Scriabin and Vergin [12], focuses on the human ability to solve facilities layout problems. In general, studies conducted in this field has shown that intuition and experience allow experts to obtain very good solutions. Such results were a likely impulse for exploring the use of soft approaches in solving and modeling this type of problems. For instance, applications of fuzzy logic [14, 15] allow the use of experts' knowledge and experience in this respect. One of the possible approaches to modeling in such a manner was proposed by Grobelny [2–5]. The idea of linguistic patterns presented in these works enables the designers to take advantage of expert's intuition by expressing it in a form similar to natural language. The implementation of this concept in the simulated annealing algorithm [7] was proposed by Grobelny and Michalski in [6].

Although the overall nature of the approach and examples provided in this work are encouraging, the practical possibilities and limitations of the algorithm are not sufficiently examined and require further, systematic investigation. This paper presents the results of experimental studies on the influence of linguistic model describing the distance criterion and the links matrix density on the quality of solutions obtained by the proposed approach for a number of possible arrangements of 36 objects.

The following sections briefly discuss the idea of the linguistic pattern based approach, present the design of the experiment, the results along with discussion, and brief conclusions.

2 Overview of Simulated Annealing Based on Linguistic Patterns

The implementation of the linguistic patterns concept in the simulated annealing algorithm proposed by Grobelny and Michalski [7] implies the substitution of the classical goal function formula with the following pattern (1).

$$\textbf{\textit{If}}\ Link\_between\_objects_{(ij)}\ is\ STRONG\ \textbf{then}\ Distance\_between\_objects_{(ij)}\ is\ SMALL \tag{1}$$

When pattern (1) is true for all pairs of objects, we may assume that the solution is good. As it was demonstrated in a number of articles [2–6], it is possible to assess the truth level of formula (1) by means of the Łukasiewicz's implication formula (2):

$$Truth\_of(1) = minimum\{1, 1 - Truth\_of(l) + Truth\_of(r)\}, \tag{2}$$

where $Truth\_of(l)$ and $Truth\_of(r)$ denote truth values of left and right sides of linguistic pattern (1).

The overall idea of the simulated algorithm does not change, but the objects pairs changes are performed in each step based on the degree of mean truth for the solution.

3 Simulation Experiment

3.1 Method

Experimental Design. The experiment examines logistics problems comprising of 36 objects in various arrangements. The main three layouts include structures with two rows and 18 columns (02 × 18), three rows and 12 columns (03 × 12), as well as four rows and nine columns (04 × 09). For comparison purposes we also tested a typical square grid layout with 6 rows and columns (06 × 06). The layouts are schematically demonstrated in Fig. 1.

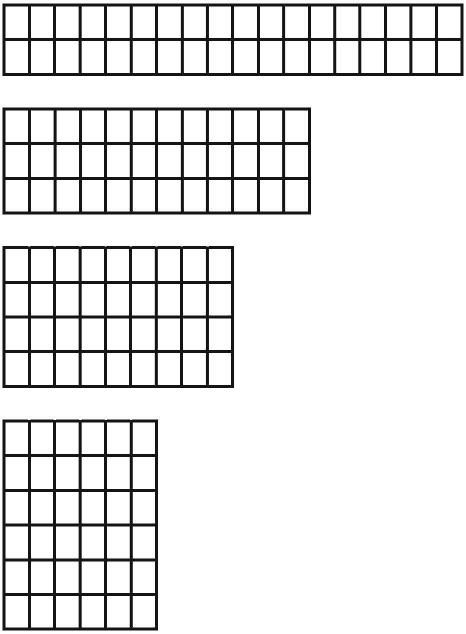

Fig. 1. Layout arrangements examined in this study. From the top: 02 × 18, 03 × 12, 04 × 09, and 06 × 06 layouts.

Relationships between objects were randomly generated from the 1–5 range. Their density was controlled and constituted the second independent variable specified on three levels 20%, 40%, and 60% of all possible links. The mean relationship value amounted respectively 2.90 (Standard Deviation, SD = 1.30; Flow Dominance, FD = 2.2), 2.96 (SD = 1.69, FD = 1.4), 3.19 (SD = 1.91, FD = 0.998).

The third factor investigated in this study was related with the way experts may treat the distance between objects. We tested two options: the relative and the absolute one. In the former approach, the membership function of the *SMALL* distance linguistic variable is linear starting from 1 for objects being next to each other and 0 when they were maximally far away. Such a case is symbolically illustrated in Fig. 5.

Naturally, the maximal distance varied along with the examined arrangements. Assuming the same, unitary distances between grid cells, the maximal Manhattan distance equals 10 for layout 06 × 06, 11 for 04 × 09, 13 for 03 × 12, and 18 for arrangement 02 × 18. In the absolute case, the distance memberships function is also linear and starts from 1 for adjacent items however, the zero value is assigned for all distances equal or bigger than 10. Thus, the function does not take into account differences in maximal possible gap between investigated arrangements. Graphical illustration of this idea is provided in Figs. 2, 3, 4 and 5.

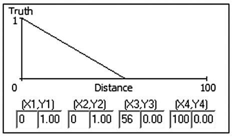

Fig. 2. Schematic presentation of the absolute distance membership function for 02 × 18.

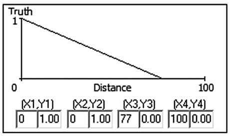

Fig. 3. Schematic presentation of the absolute distance membership function for 03 × 12.

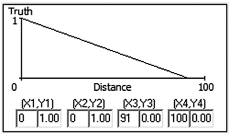

Fig. 4. Schematic presentation of the absolute distance membership function for 04 × 09.

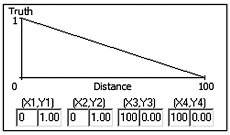

Fig. 5. Schematic presentation of the absolute and relative distance membership function for layout 06 × 06.

A full factorial, within subjects design gives 24 different experimental conditions, that is, arrangement {02 × 18, 03 × 12, 04 × 09, 06 × 06} × links density {20%, 40%, 60%} × distance function type {absolute, relative}. Since for layout 06 × 06 absolute and relative distance functions are exactly the same, the simulations finally included 21 variants.

The first dependent variable called corrected mean truth is based on goal function (3), which is related to the maximal possible mean truth value for a given arrangement (4) computed according to the theorem from [3].

$$mean\ truth = maximize\left(\frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left(Truth\_of(1)_{ij}\right)}{\frac{n^2-n}{2}}\right), \tag{3}$$

$$corrected\ mean\ truth = \frac{mean\ truth}{maximal\ mean\ truth}\cdot 100, \tag{4}$$

The second dependent measure included a typical goal function (5) based on Manhattan distance (6) that was computed for the best layouts obtained by maximizing mean truth (3).

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(D_{p(i)p(j)} \cdot L_{ij} \right), \tag{5}$$

where $D_{p(i)p(j)}$ is the standard Manhattan distance metric calculated by the formula:

$$D_{p(i)p(j)} = \sum_{k=1}^{N} \left| x_{p(i)k} - x_{p(j)k} \right|, \tag{6}$$

with N denoting the number of dimensions – here equal two, *and* L_{ij} specifying the link strength between two objects.

Procedure. For each of 21 problems defined by the experimental design, the linguistic pattern based simulated annealing algorithm was repeated 100 times. Every time, before applying the optimization algorithm, objects were randomly assigned on the grid. Taking advantage of the experimental results presented in [6], in all present study simulations, the epoch length multiplier was set at 20, the probability of accepting worse solutions equaled .8, while the cooling scheme .99.

3.2 Results and Discussion

Descriptive Statistics. Basic descriptive statistics regarding all examined experimental conditions both for mean truth values and classical goal function values are put together in Table 1.

Analysis of Variance. A series of analyses of variance were conducted to formally verify the influence of examined independent variables on two types of dependent measures. Summaries of essential results are provided in Figs. 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20.

Corrected Mean Truths. The analyses' results of mean truth value depending on the investigated factors are graphically illustrated in Figs. 6, 7, 8, 9, 10 and 11. These figures show mean truth values for the studied arrangements from the perspective of two factors – the way the membership function is defined for linguistic variable $Distance\_between\_objects_{(ij)}$ *is SMALL* and the link matrix density.

The obtained results were rather anticipated. The membership function for the relative approach treats bigger distances milder which makes it easier to obtain higher mean truth values for the same relationship matrix.

It is also understandable that the value of average truth increases along with the bigger and bigger concentration degree of the layout arrangement. For more concentrated layouts, the area of possible solutions is characterized by smaller, on average, distances and the bigger number of available pairs of locations with the same distances. This results in greater freedom for the simulated annealing algorithm in making changes in objects locations by pairs.

Table 1. Basic descriptive statistics for all experimental conditions and two dependent variables analyzed in the current study.

No.	Links density	Layout	Distance function type	Corrected mean truth			Manhattan based goal function		
				Max	Mean	MSE	Min	Mean	*MSE
1.	20%	02 × 18	Absolute	91.9	91.7	.0175	1387	1436	2.25
2.			Relative	98.6	98.5	.0095	1503	1532	1.94
3.		03 × 12	Absolute	96.4	96.2	.0111	1076	1123	2.08
4.			Relative	98.8	98.7	.0077	1113	1157	1.82
5.		04 × 09	Absolute	98.6	98.4	.0154	961	1005	1.71
6.			Relative	99.0	98.8	.0120	969	1007	1.70
7.		06 × 06		99.4	99.1	.0134	889	938	2.25
8.	40%	02 × 18	Absolute	85.0	84.9	.0096	3597	3646	2.74
9.			Relative	94.7	94.7	.0053	3655	3733	4.35
10.		03 × 12	Absolute	90.9	90.8	.0098	2722	2766	2.19
11.			Relative	95.0	94.9	.0069	2752	2817	2.87
12.		04 × 09	Absolute	94.1	94.0	.0111	2365	2428	2.69
13.			Relative	95.2	95.1	.0108	2383	2437	2.89
14.		06 × 06		95.6	95.5	.0088	2182	2257	2.26
15.	60%	02 × 18	Absolute	81.2	81.0	.0066	6499	6567	3.71
16.			Relative	92.0	91.9	.0029	6487	6558	4.97
17.		03 × 12	Absolute	87.9	87.8	.0088	4884	4940	2.36
18.			Relative	92.6	92.5	.0044	4871	4926	3.17
19.		04 × 09	Absolute	91.6	91.4	.0072	4235	4285.7	2.57
20.			Relative	93.0	92.9	.0060	4234	4286.4	3.36
21.		06 × 06		93.4	93.2	.0082	3941	4003	2.51

* MSE – Mean Standard Error

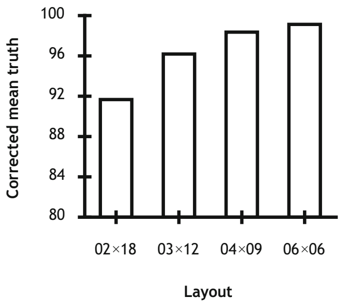

Fig. 6. Corrected mean truth depending on the layout. Links density: 20%, absolute distance membership function. F(3, 396) = 53 081, p < .0001.

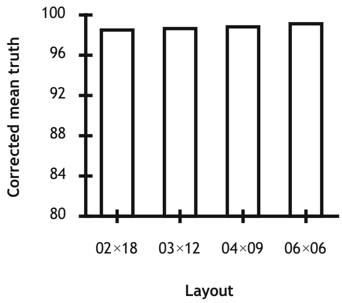

Fig. 7. Corrected mean truth depending on the layout. Links density: 20%, relative distance membership function. F(3, 396) = 601, p < .0001.

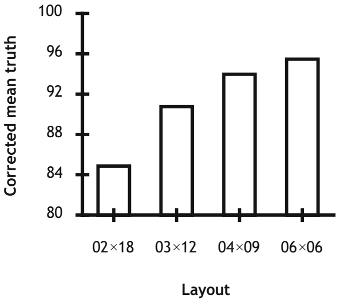

Fig. 8. Corrected mean truth depending on the layout. Links density: 40%, absolute distance membership function. F(3, 396) = 226 987, p < .0001.

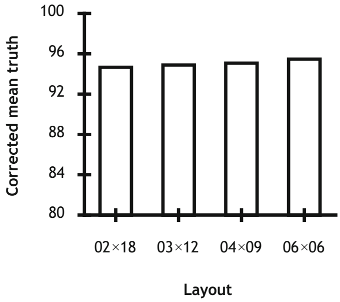

Fig. 9. Corrected mean truth depending on the layout. Links density: 40%, relative distance membership function. F(3, 396) = 1700, p < .0001.

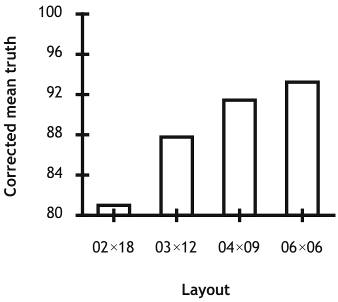

Fig. 10. Corrected mean truth depending on the layout. Links density: 60%, absolute distance membership function. F(3, 396) = 488 195, p < .0001.

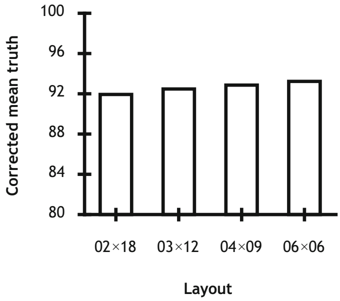

Fig. 11. Corrected mean truth depending on the layout. Links density: 60%, relative distance membership function. F(3, 396) = 9377, p < .0001.

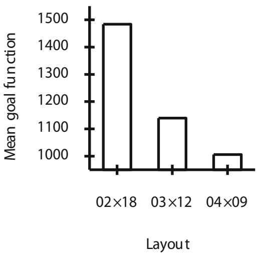

Fig. 12. Mean goal function depending on the layout. Links density: 20%. F(2, 594) = 32 660, p < .0001.

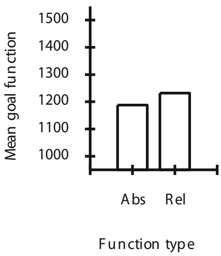

Fig. 13. Mean goal function depending on the function type. Links density: 20%. F(1, 594) = 783, p < .0001.

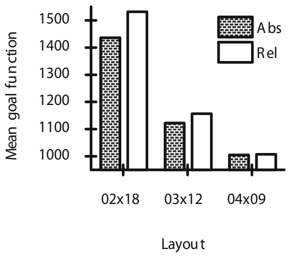

Fig. 14. Mean goal function depending on the layout × function type. Links density: 20%. F(2, 594) = 302, p < .0001.

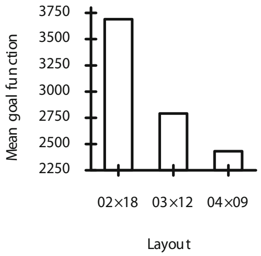

Fig. 15. Mean goal function depending on the layout. Links density: 40% $F(2, 594) = 91\ 506$, $p < .0001$.

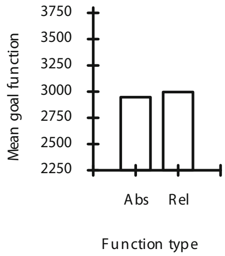

Fig. 16. Mean goal function depending on the function type. Links density: 40%. $F(1, 594) = 399$, $p < .0001$.

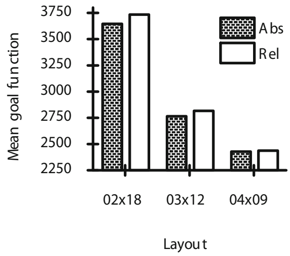

Fig. 17. Mean goal function depending on the layout × function type. Links density: 40%. $F(2, 594) = 83$, $p < .0001$.

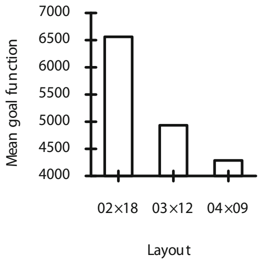

Fig. 18. Mean goal function depending on the layout. Links density: 60%. $F(2, 594) = 229\ 500$, $p < .0001$.

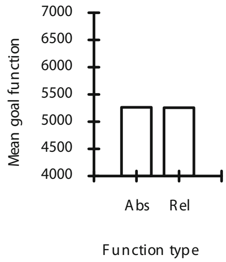

Fig. 19. Mean goal function depending on the function type. Links density: 60%. $F(1, 594) = 7.1$, $p = .0078$.

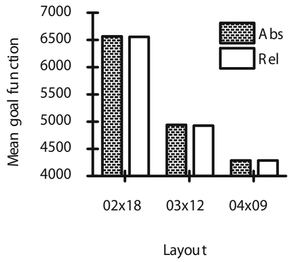

Fig. 20. Mean goal function depending on the layout × function type. Links density: 60%. $F(2, 594) = 2.3$, $p = .096$.

The relative decrease in mean truth values along with the higher matrix densities was also predictable. In general, facilities layout problem tasks are more difficult to solve for dense relationships between objects. It is worth pointing out that all differences in means presented in Figs. 6, 7, 8, 9, 10 and 11 are statistically significant.

Goal Function Based on Manhattan Distance. The outcomes for the classical objective function (5) are demonstrated in Figs. 12, 13, 14, 15, 16, 17, 18, 19, and 20. It seems that the most important relations were observed for definitions of membership functions in the absolute and relative conventions. One may be surprised while comparing these results with those presented in Figs. 6, 7, 8, 9, 10 and 11. Function values (5) express the overall cost and are to be minimized, so they should be interpreted inversely than corrected mean truths that supposed to be maximized. For small and medium densities, classic goal function mean values are better for distances treated in an absolute manner.

Comparison with the results from Figs. 6, 7, 8, 9, 10 and 11 clearly indicates that, in terms of mean truth of pattern (1), better solutions were obtained for the membership functions representing relative distances. This dependence disappears as the relationship density increases. For a density of 60% it becomes even, slightly but statistically significantly, reversed (Table 2 and Fig. 20). Such a reverse relation is strongly influenced by the shape of the available area modeled by the modular grid structure.

Table 2. Manhattan based mean goal function differences between absolute and relative membership function types

	Links density								
	20%			40%			60%		
	02 × 18	03 × 12	04 × 09	02 × 18	03 × 12	04 × 09	02 × 18	03 × 12	04 × 09
Absolute vs relative LSD probability	<.001*	<.001*	.34	<.001*	<.001*	.028*	.056**	.0045*	.88

* α = .05, ** α = .1

4 Conclusion

Grobelny and Michalski in [6] showed that the simulated annealing algorithm based on linguistic patterns is not a simple extension or generalization of the traditional approach where the function (5) is minimized. The results obtained in the current experiments empower the specifics of the approach and suggest that subtle analysis of its properties may lead to interesting outcomes.

The presented empirical data both in the present study as well as in the work [6] reveal that the behavior of the investigated algorithm with linguistic patterns is determined by many factors and interactions between them. In light of this, further research on the properties of the approach is justifiable and necessary.

Usually, in practical applications of the proposed approach, the actual relationships and distances are not known and are estimated in linguistic terms by an expert. Despite that, findings presented in the current study are an important indication for rational use of linguistic pattern based simulated annealing.

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Knowledge Sharing Using Customer Relationship Management Systems (CRM) in NPD Processes - Research Results from Polish and German Manufacturing Companies

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Abstract. Knowledge sharing in manufacturing companies is not an easy task. Our previous research conducted in Polish manufacturing companies in the construction and automotive industries, showed that 52% of respondents identified organisational difficulties which directly resulted from problems in knowledge sharing within the company, usually in the form of insufficient organization within the company and a lack of communication between company employees.

An NPD process in a manufacturing company needs innovative ideas supported by an information system. CRM systems are used to facilitate the creation of new knowledge about market demand and support an NPD process in a manufacturing company. This case study investigates how knowledge is shared through CRM use and explores how the use of this system supports New Product Development (NPD) process based on a data obtained from Polish Manufacturing Enterprises from Lubuskie region and from German Manufacturing Enterprises from Brandenburg region. Based on our research results it is stated that managers in German and in Polish companies perceive the importance of the knowledge sharing supported by CRM system in the context of the improvement of the new product development.

Keywords: Customer relationship management · Knowledge sharing · Manufacturing company · New product development

1 Introduction

Effectively managing knowledge in a manufacturing company, especially in an inter-organizational context, can improve New Product Development (NPD) configurations [10]. Knowledge sharing between company employees is a critical issue when managing the creation of a new product within an organization. Workers can exchange data through a database built on the infrastructure of information and communication technology [11]. For example, the implementation of a CRM system offers a common workspace in which product data can be shared. The data and information included in this system can enhance the robustness of new products at the conceptual design stage.

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IT solutions can play a role in effective knowledge sharing within an organization [1]. Our previous research, conducted in Polish manufacturing companies in the construction and automotive industries, showed that 52% of respondents were able to identify organisational difficulties which directly resulted from problems in knowledge sharing within the company, usually in the form of insufficient organization within the company and a lack of communication between company employees.

The analysis in this study also shows the relationships between useful knowledge sharing among employees who carry out an NPD process using a CRM system and explores how the use of this system supports this process.

Based on the research results from 69 Polish manufacturing companies from the Lubuskie region and from 23 German manufacturing companies from the Brandenburg region [9], it is possible to identify the most important knowledge which should be shared among employees and supported by CRM system. The research was intentionally carried out in the Lubuskie region of Poland and the Brandenburg region of Germany because these regions form a special joint cross-border area and the research results contribute to the achievement of an objective of European Territorial Cooperation.

The remainder of this paper is organized as follows. A number of related works are briefly introduced in the following section. Section 3 presents an overview of the design of a research model. Section 4 elaborates the research details. Closing remarks and a summary are then outlined in the last section.

2 Literature Review

New product development (NPD) has significant and positive effects with regards to competitive advantages [6]. NPD is a process of transforming market demands and opportunities into the knowledge necessary for production [2, 5, 7]. On the other hand, the process of new product development should be flexible and able to adjust to a company's needs and desires [3]. Moreover it is possible to define the following tasks in the process of the development of a new product in a manufacturing company (Fig. 1).

An NPD process needs innovative ideas supported by an information system. Moreover, communication mechanisms have important effects on knowledge sharing within a company [6]. Knowledge sharing within an enterprise refers to contact between employees by which one employee can help to transform the knowledge and skills of another [6, 8]. Customer relationship management (CRM) systems are information systems that enable organizations to gain a comprehensive view of their customers [4]. CRM systems are used to facilitate the creation of new knowledge about market demand and support an NPD process in a manufacturing company. The major contribution of this study is that it proposes the exploitation of a knowledge-sharing support tool (CRM) in an NPD process which can efficiently supply potentially useful knowledge to users in order to support their tasks in the process of NPD in a manufacturing company.

The following departments in a company are defined, from which employees share knowledge using a CRM system: sale department (SD), production department (PD),

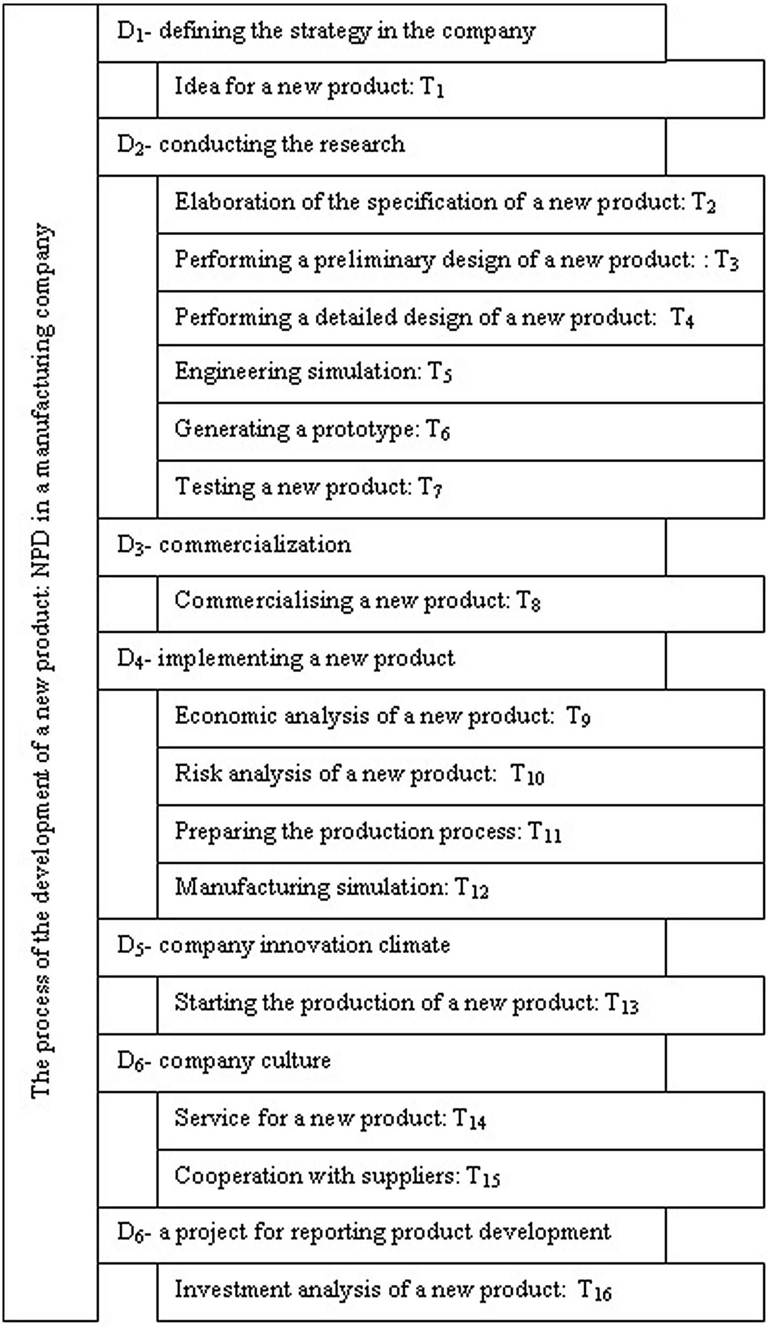

Fig. 1. An NPD process in a manufacturing company, own work

purchasing department (PRD), research and development department (RDD), service department (SD). The research model posits, from the preceding argument, that when workers who are involved in a NPD process in a manufacturing enterprise share knowledge using a CRM system, they are able to create an increased number of new products.

3 Research Method

Before the survey was carried out, it was assumed that those employees who took part in the research would realize at least 80% of the defined activities of an NPD process (Fig. 1) and use the CRM system to support this process. This study expects that knowledge sharing in Polish manufacturing companies supported by the CRM system, will positively influence NPD processes.

The survey data were collected between January to September, 2014 (69 Polish enterprises from the Lubuskie region of Poland - respondents: managers: 82%), between November 2015 to January 2016 (23 German enterprises from Brandenburg region of Germany - respondents: managers: 87%). The chosen 85 manufacturing companies from the “automotive” and “construction” sectors contribute about 20% of those enterprises in the cooperative, special joint cross-border region[1].

The respondents were asked to evaluate the degree the use of a CRM system in an enterprise facilitates knowledge sharing among the organization’s employees and influence NPD processes.

New product creation: The degree to which a company develops a new product from the use of a CRM system for knowledge sharing within the enterprise:

- NPD-factor1: I know that in my organization the use of CRM is not very important for new product creation.
- NPD-factor2: I know that in my organization the use of CRM is not important for new product creation.
- NPD-factor3: I know that in my organization the use of CRM is quite important for new product creation.
- NPD-factor4: I know that in my organization the use of CRM is important for new product creation.
- NPD-factor5: I know that in my organization the use of CRM is very important for new product creation.

The use of a CRM system: The degree to which the use of a CRM system in an enterprise facilitates knowledge sharing among the organization’s employees:

- CRM-factor1: I know that in my organization the use of CRM systems is not very important for knowledge sharing.

[1] This work was supported in part by the project realized by Justyna Patalas-Maliszewska: “Assessing the relationship between business strategy and knowledge transfer in German Manufacturing Enterprises” by the German Academic Exchange Service (DAAD), Bonn, Germany, Nr: 235585, 2016.

- CRM-factor2: I know that in my organization the use of CRM systems is not important for knowledge sharing.
- CRM-factor3: I know that in my organization the use of CRM systems is marginally important for knowledge sharing.
- CRM-factor4: I know that in my organization the use of CRM systems is important for knowledge sharing.
- CRM-factor5: I know that in my organization the use of CRM systems is very important for knowledge sharing.

For all kinds of characteristics which were measured, a five-point Likert scale was adopted in which 1 = strongly unimportant and 5 = strongly important.

4 Research Results

In our research results we can match the relationships between the use of the CRM system by the employees in the defined departments: sale department (SD), production department (PD), purchasing department (PRD), research and development department (RDD), service department (SD) which should support the knowledge sharing within a company and the improvement of the NPD process. The research results were defined using a correlation approach with Statistica ver. 12.5. The data were carefully examined with respect to linearity, equality of variance and normality. No significant deviations were detected. Tables 1 and 2 present descriptive correlations for the main variables levels of headings.

Table 1. Research results from Polish manufacturing companies, own work.

Construct (item: CRM-factor and NPD-factor)	Correlation	r2	t	p
Using CRM in the sale department (SD)/NPD	0.0128	0.0002	0.1015	0.9195
Using CRM in the production department (PD)/NPD	0.0640	0.0041	0.5088	0.6127
Using CRM in the purchasing department (PRD)/NPD	*0.3158*	*0.0997*	*2.6419*	*0.0104*
Using CRM in the research and development department (RDD)/NPD	0.1459	0.0213	1.1707	0.2461
Using CRM in the service department (SD)/NPD	0.2950	0.0870	2.4508	0.0170

Our research results present, that for managers of polish manufacturing companies from the Lubuskie Region the use of the CRM system by the employees in the purchasing department is important in the knowledge sharing process for the improvement of the new product development process (corr = 0.3158). To determine the nature of the significant interaction: the use of a CRM system in the purchasing department facilitates knowledge sharing among the organization's employees and New Product Development improvement, the study plots the effect (see Fig. 2):

Table 2. Research results from German manufacturing companies, own work.

Construct (item: CRM-factor and NPD-factor)	Correlation	r2	t	p
Using CRM in the sale department (SD)/NPD	–0.2218	0.0492	–1.0425	0.3090
Using CRM in the production department (PD)/NPD	–0.1828	0.0334	–0.8520	0.4038
Using CRM in the purchasing department (PRD)/NPD	–0.2598	0.0675	–1.2328	0.2313
Using CRM in the research and development department (RDD)/NPD	0.1555	0.0242	0.7211	0.4788
Using CRM in the service department (SD)/NPD	*0.2944*	*0.0866*	*1.4114*	*0.1728*

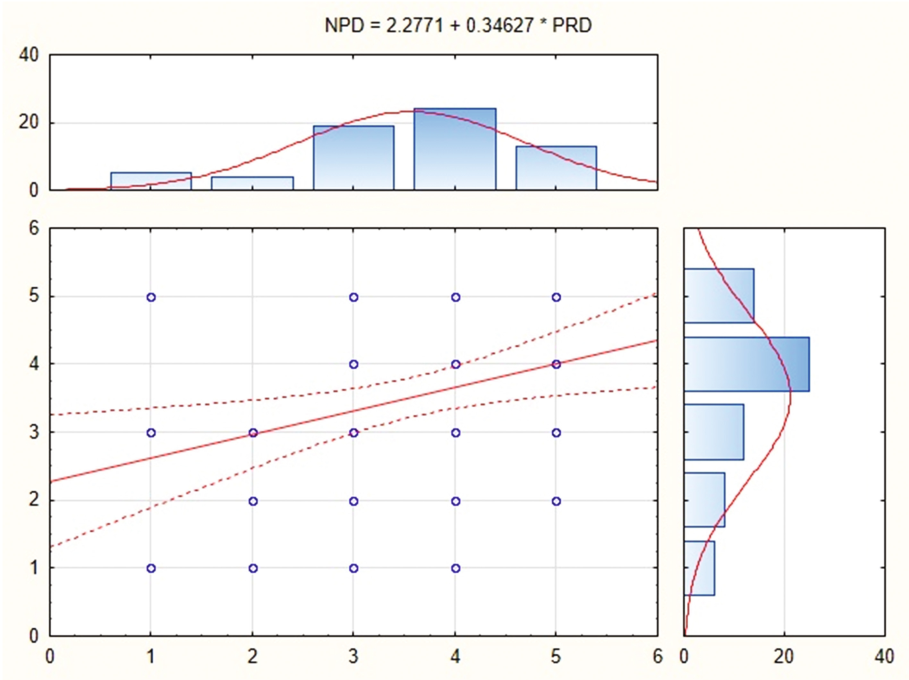

Fig. 2. Interactions involving New Product Development creation and knowledge sharing using a CRM – research results from Polish manufacturing companies, own work

$$\text{New Product Development} = 0.34627\,\text{PRD} + 2.2771 \quad (1)$$

New Product Development creation clearly increases with knowledge sharing using CRM systems by employees in the purchasing department. However, when given low frequencies of use the CRM, a decrease in company New Product Development is evident. So, we can state, that knowledge sharing supported by the CRM system within the purchasing department influences positive on the new products creation. Based on our research we can also define, that the knowledge from customers improves new products development process in the company, because customers communicate their needs for new solutions.

We can match also the second equal significant relationship: knowledge sharing within the employees by the use the CRM system in the service department and its effects on the improvement of a new product development (corr = 0.2950). This similar interaction we can observe in our research results from German Manufacturing companies (see Table 2).

We examine the effects on New Product Development that result from knowledge sharing using a CRM by employees in the service department, based on the research results from Polish Manufacturing Companies:

$$\text{New Product Development} = 0.31995\, SD_{PMC} + 2.4014 \quad (2)$$

and based on the research results from German Manufacturing Companies:

$$\text{New Product Development} = 0.27482\, SD_{GMC} + 1.9419 \quad (3)$$

As Figs. 3 and 4 show, the study plots the effects also in Polish and German manufacturing companies. New Product Development creation clearly increases with knowledge sharing in Polish and German manufacturing companies when faced with a high frequency of use of a CRM system by employee in the service department.

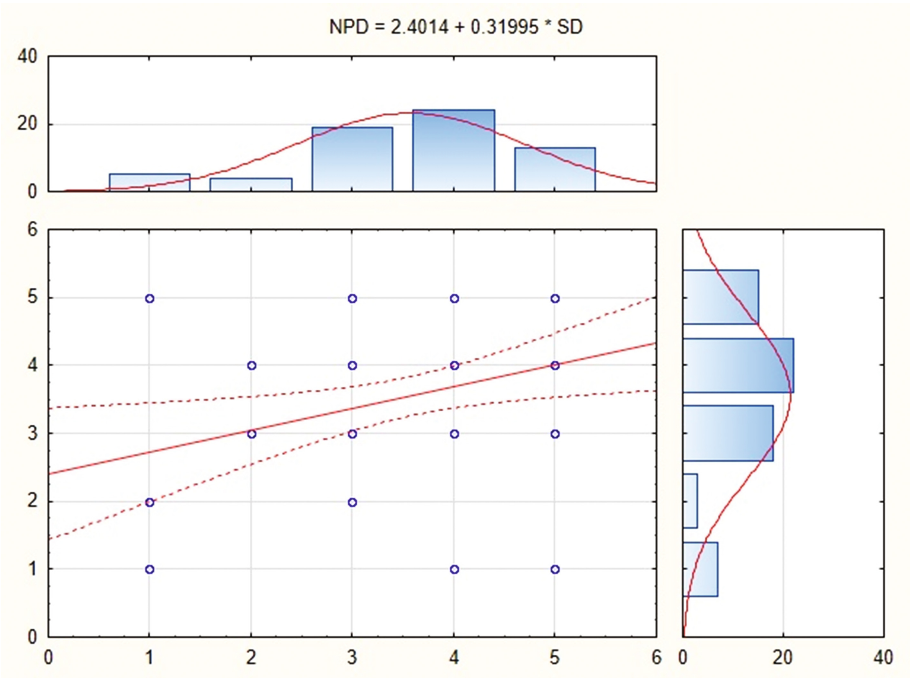

Fig. 3. Interactions involving New Product Development creation and knowledge sharing using a CRM – research results from Polish manufacturing companies, own work

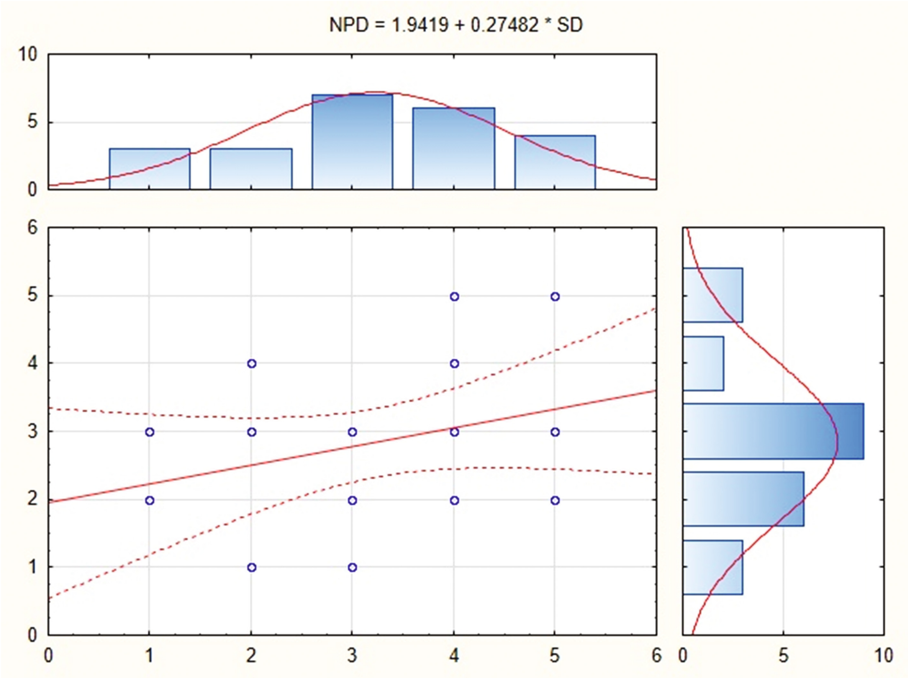

Fig. 4. Interactions involving New Product Development creation and knowledge sharing using a CRM – research results from German Manufacturing Companies, own work

In our research results we received similar research results from both German and Polish manufacturing enterprises. We can state, that knowledge sharing supported by the CRM system within the service department influences positive on the new products creation. In the service department we can match also the knowledge from customers (similar to the knowledge in the purchasing department), but this knowledge is mostly about the deficiencies in the products/services. This knowledge can also provide to the improvement of the new products in the company. Based on our research results we can state that managers in German and in Polish companies perceive the importance of the knowledge sharing supported by CRM system in the context of the improvement of the new product development.

5 Conclusions and Recommendations

This research analyzes the effects which occur on an NPD process in a manufacturing company when knowledge sharing, using a CRM system, takes place among employees in the enterprise.

It is based on using a comprehensive framework that integrates two research streams: knowledge sharing and an NPD process. Actually, Polish manufacturing companies tend not carry out their work in an innovative environment. It is necessary to support NPD processes in companies to increase the level of innovation of Polish industry. By proposing a model which addresses the influence of knowledge sharing among employees using a CRM system (ones who realize the effect of an NPD process on new product creation in enterprises), this study contributes to a filling of the gap which exists in the literature. The empirical findings suggest that it may be a good idea to share useful knowledge, because it could increase new product creation in Polish and German manufacturing companies.

Like all studies, this one has certain limitations that further research should aim to overcome. Firstly, because the intention is to analyze knowledge sharing, this study focuses on Polish and German manufacturing industries in the cooperative, special joint cross-border region which traditionally use defined functionalities of CRM systems. It would be unwise to generalize the findings too broadly to other enterprises. Furthermore, all the variables were measured at the same moment in time. So, it would be useful to provide such research over a longer time period and within different innovative environments of manufacturing companies. These conclusions and limitations suggest proposals for future research directions.

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An Analysis of the Impact of Buffer Allocation and Maintenance on the Effectiveness of a Manufacturing System Using Computer Simulation

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Abstract. Maintenance management is responsible for the effectiveness of automated manufacturing systems. The allocation of a certain number of employees to the servicing sector of a manufacturing system ensures that an enterprise's throughput is at a satisfactory level but of course, there is the 'cost' factor to be taken into account. The present paper concentrates on the impact of the number of maintenance staff employed, the availability of resources, the allocation of a capacity buffer and the topology of the manufacturing system on the throughput and average lifespan of a given product. Research has been conducted with the use of a computer simulation, using Tecnomatix Plant Simulation software. The model for the manufacturing system includes a parallel, serial production line with two separate manufacturing cells, connected by an intermediate buffer. Additionally the results obtained in simulations were subjected to statistical analysis. Performed analysis indicates that machines availability, size of buffer as well as number of operators have positive influence on value of throughput. Size of buffer has also positive influence on value of lifespan, while machines availability and number of operators have negative influence on value of lifespan.

Keywords: Discrete event modeling and simulation · Maintenance · Buffer allocation and associated problems · Availability of resources · Throughput · Average product lifespan

1 Introduction

The modelling and computer simulation of production, using manufacturing systems, plays an important role in industrial, engineering research. A variety of manufacturing systems, processes, and resources require computer simulation in order to facilitate dynamic analyses of the plethora of product variants and parameters. The main advantage of the computer simulation method is the possibility of carrying out many experiments using the various input parameters of a manufacturing system over a short period of time, thereby obtaining results showing the behaviour of the system. In the

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literature, there are many publications on the computer simulation of manufacturing [1, 2] as well as maintenance processes.

Negahban and Smith [3] provided a comprehensive review of discrete event simulations presented in publications which were published between 2002 and 2013 and are focussed particularly on simulations application, vis-à-vis manufacturing. The use of simulation methods to study maintenance processes is included in the paper. Ni and Jin [4] propose a decision-support system for effective maintenance operations. The proposed system supports data-driven, short-term identification of bottlenecks in throughput, the evaluation of “windows of opportunity” in maintaining it, the prioritisation of maintenance tasks, joint production and the maintaining of scheduling systems and maintenance staff management. To illustrate the concept of a decision-support system, mathematical algorithms and simulation tools are used. Mjema [5] used a simulation method to analyse the requirements of personnel capacity in the maintenance department. The ‘SIMPLE++’ simulation language was used to build a model. Input data included work orders with various throughput times, various personnel profiles, based on the requirements of work orders and various prioritisation rules. The effects of personnel organisational policies, vis-à-vis the full use of personnel, as well as on the time spent in this maintenance, were studied. The results of the simulation show that the best utilisation of maintenance personnel and the best throughput time spent on maintenance work was obtained when personnel was allowed cross-border departmental interaction.

Iassinovski et al. [6] presented a structure, along with the components of a shared decision-making system for complex, discrete systems and process control. The proposed model allows on-line simulations, state-graph search expert systems and other decision making methods to be used. Boschian et al. [7] compared two strategies for operating a production system composed of two machines working in parallel with a downstream inventory supply for an assembly line. Manufacturing resources are prone to random failure and are, therefore, subject to preventive and corrective maintenance operations. A simulation model for each strategy is developed to compare them and simultaneously determine the timing of preventive maintenance on each machine, taking into consideration the total average cost per unit of time as the performance criterion. Allaoui and Artiba [8] dealt with the scheduling of problems in a hybrid flow shop under maintenance constraints in order to optimise several objectives based on flow time and due dates. In this model, set-up, cleaning and transportation time periods have also been taken into consideration. Simulation and optimisation were integrated in order to tackle practical, NP-hard problems. They also illustrated that the performance heuristics applied to this problem can be affected by the percentage of breakdown times.

Maintenance specific, modelling decisions are of a component or system perspective and finite or infinite in the planning horizon [9]. In highly automated production systems, professional, maintenance department employees decide on how best to avoid, if not put an end altogether to breakdowns and production system failures. Maintenance departments usually employ specialists in the fields of automatic, electronic, robotic, production and mechanical engineering. Management of the maintenance staff is not easy because planning is often haphazard and, as well, there are breakdowns and damage to production resources [10]. System breakdowns are quite unforeseeable and it is not possible to predict whether a given repair will be ready in 10 min, 10 h or 10 days. To effectively manage a maintenance department, the 'motivational path' might be the best option for a company.

In the paper, the computer simulation method is used to analyse the effectiveness of maintenance in a series parallel production line where intermediate buffer capacity and the number of maintenance staff fluctuates. The production system investigated is fully automated but production resources need maintenance support. During the simulation, experiments on such as input values, intermediate buffer capacity, the availability of resources and the number of maintenance workers, are defined as output values, system throughput and the lifecycle of the average product.

2 The Buffer Allocation Problem (BAP)

The buffer allocation problem (BAP) is one of the most important questions facing a serial production designer. It is a combined, NP-hard, combinatorial, optimisation problem when designing production lines and the issue is studied by many scientists and theorists around the world. The buffer allocation problem is concerned with the allocation of a certain number of buffers P, among the N-1 intermediate buffer locations of a production line, in order to achieve a specific objective [11]. A production line consists of machines working in a sequence and being separated by buffers (Fig. 1) where the machines are denoted as $M_1, M_2, \ldots, M_N$, and the buffers as $B_1, B_2, \ldots, B_{N-1}$.

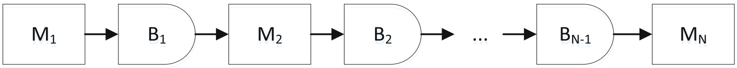


Fig. 1. A production line with N machines and N − 1 intermediate buffers.

Also, it is obvious that in each station, there might be a number of parallel machines that boost production and manufacturing systems (Fig. 2).

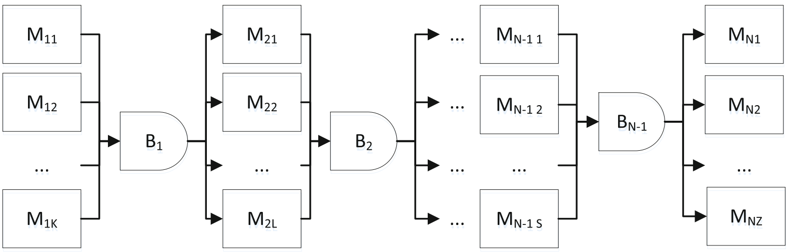


Fig. 2. A series-parallel production line; where: K, L, S and Z – number of machines working in parallel.

In the literature, several types of production lines are taken into account. The classification of production lines can be based on the blocking type, that is, those which block before or after service; job transfer timing, such as, asynchronous, synchronous, continuous; production control mechanisms, such as, push and pull; types of workstations and whether they are reliable or unreliable and career requirements, whether open or closed. BAP can be formulated in three cases depending on the function of the objective. In the first case, the main objective is maximisation of the throughput rate for a given fixed number of buffers. The first BAP case is formulated as follows (1)–(3):

find

$$B = (B_1, B_2, \ldots, B_{N-1}) \tag{1}$$

so as to

$$max\, f(B) \tag{2}$$

subject to

$$\sum_{i=1}^{N-1} B_i = P \tag{3}$$

where B represents a buffer size vector and $f(B)$ represents the throughput rate of the production line as a function of the size vector of the buffers and P is a fixed, non-negative integer denoting the total buffer space available in the manufacturing system. The second BAP case is formulated as follows (4)–(6):

$$B = (B_1, B_2, \ldots, B_{N-1}) \tag{4}$$

so as to

$$\min \sum_{i=1}^{N-1} B_i \tag{5}$$

subject to

$$f(B) = f^* \tag{6}$$

where f^* is the desired throughput rate. The third BAP case is formulated as follows (7)–(10):

find

$$B = (B_1, B_2, \ldots, B_{N-1}) \tag{7}$$

so as to

$$min\ Q(B) \tag{8}$$

subject to

$$f(B) = f^* \tag{9}$$

$$\min \sum_{i=1}^{N-1} B_i \leq P \tag{10}$$

where $Q(B)$ denotes the inventory of the average work-in-process as a function of the size vector of the buffers and f^* is the desired throughput rate. This formulation of the problems expresses maximisation of the throughput rate for a fixed, given number of buffers which achieves the desired throughput rate with the minimum total buffer size or minimisation of the inventory of the average *work-in-process* which is subject to the constraints of total buffer size and the desired throughput rate.

3 The Model of Manufacturing System

The model of the manufacturing system was prepared using Tecnomatix Plant Simulation software (see Fig. 3).

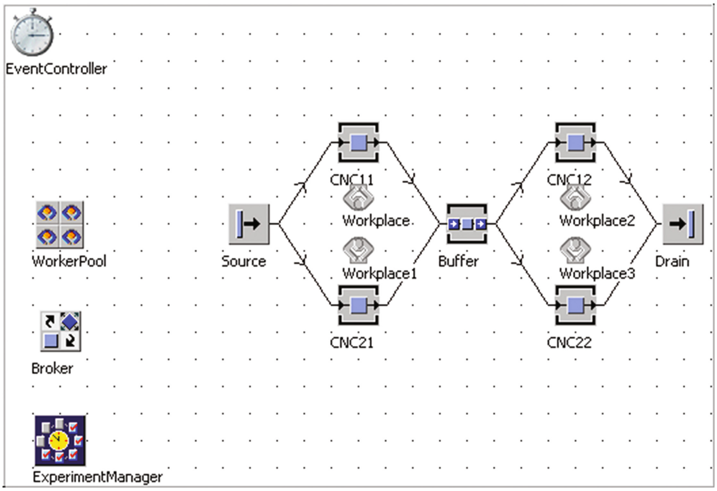


Fig. 3. A model of the manufacturing system created in Tecnomatix Plant Simulation software.

The model includes 4 CNC machines which work fully automatically; the workplaces are prepared for maintenance services. It is assumed that transportation system is failure-free and transportation times are negligibly small compared to the processing times. The WorkerPool object determines the number of maintenance staff which can, of course, vary. The number of maintenance staff is defined as between 1 and 3 workers. Operation times are determined as Uniform distribution which can be used for the modelling of random numbers which are located between the 'start and stop' interval limits. This is useful when little is known about the distribution of random numbers. The function of the density of the probability of distribution, for values between *start* < *x* < *stop*, takes the following form (Eq. 11).

$$f(x) = \frac{1}{stop - start} \tag{11}$$

where the average value of the distribution is (12)

$$\sigma^2 = \frac{(stop - start)^2}{2} \tag{12}$$

An example of uniform distribution is presented in the Fig. 4.

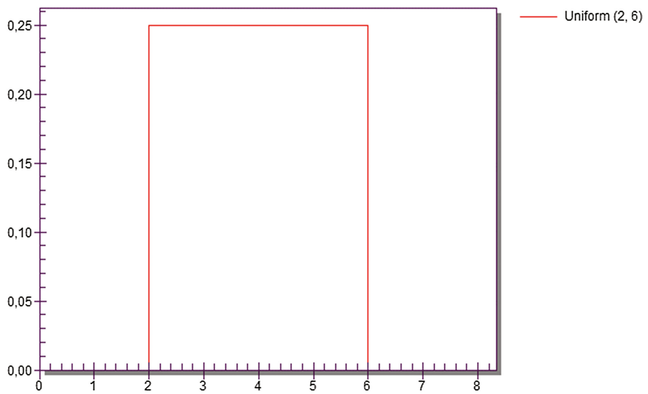


Fig. 4. Uniform distribution for the start value = 2 and for the stop value = 6 [12].

The processing times for each of the CNC machines are defined as *start = 1:00* and *stop = 5:00*. The production materials are delivered from the *Source*, to CNC11 and CNC21 objects on a *round robin* basis, dispatch format. Similarly, parts are distributed from the *Buffer* object into machines CNC12 and CNC22. The simulation experiments are prepared for different numbers of maintenance staff, different availabilities of manufacturing resources and different intermediate buffer capacities. For the manufacturing system model, here presented, the following research problem is formulated: '*Given is a simulation model of a manufacturing system which includes a series parallel production line. What is the impact of buffer capacity, the availability of resources and the number of maintenance workers on throughput and the average lifespan of the system*?'

The results of the computer simulation are presented in the next chapter.

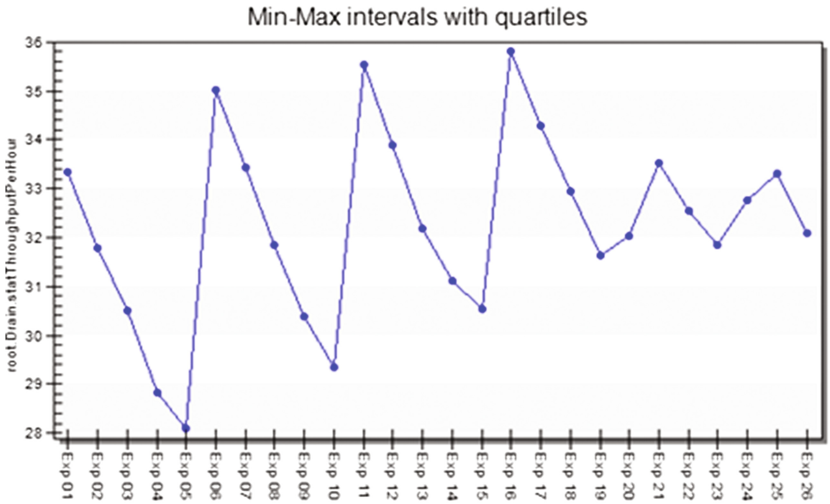
4 Simulation Experiments – The Results

As is the case with the input of the simulation experiments, the different values for the availability of manufacturing resources and intermediate buffer capacity are taken into account. The input values for simulation experiments are presented in Table 1. The availability of resources changes from 99% to 95% and the buffer capacity increases from 1 to 10. For different combinations of input values, 25 simulation experiments were prepared.

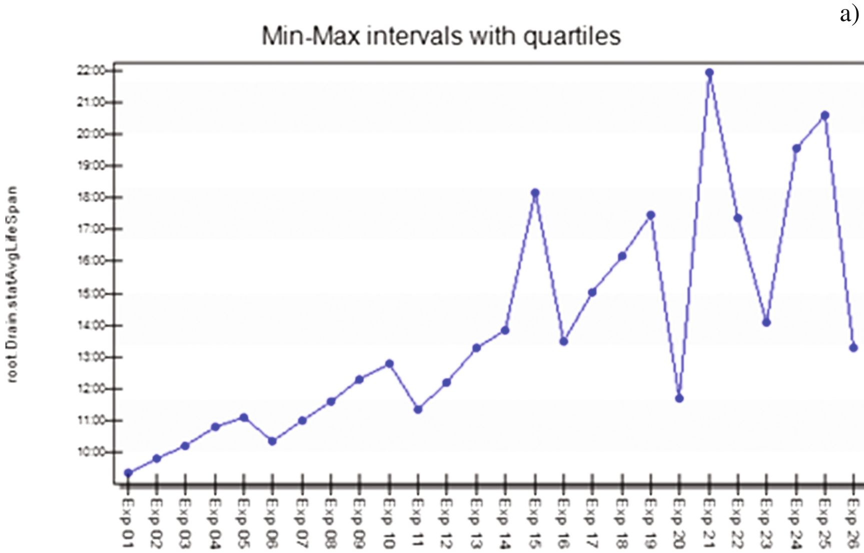
Table 1. Input values of the simulation experiments

Experiment	Availability of machines [%]				Buffer
	CNC11	CNC21	CNC12	CNC22	
Exp 01	99	99	99	99	1
Exp 02	98	98	98	98	1
Exp 03	97	97	97	97	1
Exp 04	96	96	96	96	1
Exp 05	95	95	95	95	1
Exp 06	99	99	99	99	3
Exp 07	98	98	98	98	3
Exp 08	97	97	97	97	3
Exp 09	96	96	96	96	3
Exp 10	95	95	95	95	3
Exp 11	99	99	99	99	5
Exp 12	98	98	98	98	5
Exp 13	97	97	97	97	5
Exp 14	96	96	96	96	5
Exp 15	95	95	95	95	10
Exp 16	99	99	99	99	10
Exp 17	98	98	98	98	10
Exp 18	97	97	97	97	10
Exp 19	96	96	96	96	10
Exp 20	95	95	99	99	10
Exp 21	99	99	95	95	10
Exp 22	95	99	95	99	10
Exp 23	95	96	97	98	10
Exp 24	99	95	96	97	10
Exp 25	99	98	96	95	10
Exp 26	95	96	98	99	10

Simulation experiments were conducted for 1 maintenance worker and also for 3 maintenance workers. The values of throughput and for the average lifespan of a product for 1 maintenance worker is presented in Fig. 5.



a)



b)

Fig. 5. Results of simulation experiments for 1 maintenance worker; (a) values of throughput per hour, (b) average *lifespan*.

The lowest throughput value was reached for Exp 05 (availability of resources 95% and buffer capacity 1) and was equal to 28.09 products per hour. The greatest throughput value was reached for experiments Exp 11 and Exp 16 (respectively 35.54 and 35.82 products per hour). For experiment Exp 11, the average lifespan of the products equalled 11:21, while for Exp 16, it equalled 13:29. From an analysis of the results of the throughput, it can be stated that buffer capacity impacts on this parameter. The throughput of the system, for buffer capacity 1 and for a 99% availability of resources, was 33.35 (Exp 01) while a buffer capacity of 10, with the same availability of resources, equalled 35.82, the difference equating to 2.42 products per hour per a maintenance worker (Exp 16).

The same simulation experiments were conducted for 3 maintenance workers. The results are presented in Fig. 6.

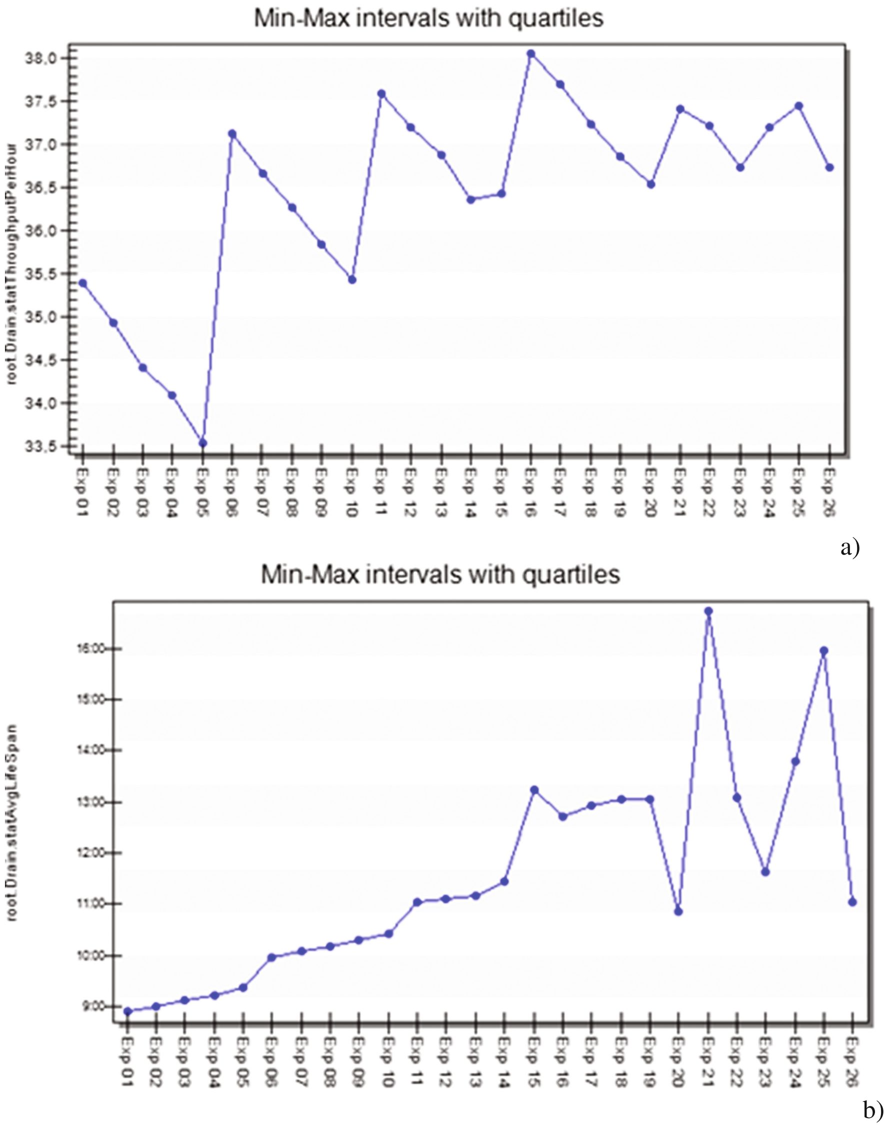


Fig. 6. Results of simulation experiments for 2 maintenance workers; (a) values of throughput per hour, (b) average *lifespan*.

An increase in the number of workers resulted in only minimal differences presenting, among the best throughput values, for the maximum availability of resources (99%). Maintenance can usually be continued, the average lifespan of the products being relatively smaller than for the first scenario. The best throughput values were reached for experiments Exp 11 and Exp 16 (respectively 37.60 and 38.06 products per hour). The difference between the system's throughput for buffer capacities 1 and 10 and for the availability of resources at 99% was slightly more than for the former case. The system's throughput for buffer capacity 1 and for the availability of resources at 99% was 35.29 (Exp 01) while for buffer capacity 10, with the same availability of resources (Exp 16), this equalled 38.06, the difference being 2.77 products per hour per 2 maintenance workers. Increasing the number of maintenance workers to 3 or even more, had no influence on the earlier increase in throughput or on the average lifespan of the product.

The average differences between the values of the output with the same buffer capacity, vis-à-vis the minimum/maximum availability of resources, were greater for the system with only 1 maintenance worker, at 4.93 products per hour, than for the system with 2 maintenance workers, at only 1.68 products per hour. The greatest throughput was reached with the maximum availability of all resources and with the greatest buffer capacity. The greatest value for the average lifespan of products was reached with a buffer capacity equalling 10, while the largest difference presented between the availability of resources (Exp 21). The main conclusions of the research are presented in the last chapter.

5 Statistical Analysis of the Results

The obtained results (Table 2) were subjected to statistical analysis. Availability of machines was on five levels (A1 – 99%, A2 – 98%, A3 – 97%, A4 – 96%, A5 – 95%), buffer size was on four levels (B1 – 1 pcs, B2 – 3 pcs, B3 – 5 pcs, B4 – 10 pcs), number of operators was on wo levels (O1 – 1 operator, O2 – 2 operators). The analysis were performed to verify the hypotheses presented in Table 3. P-values being the results of performed Anova analysis on the confidence level equalled 95% are also presented in Table 3. The analysis were performed in Minitab 16.

All presented hypotheses were rejected. It means that levels of machines availability, size of buffer and number of operators have significant influence on Throughput as well as on average Lifespan. The next question is what is the influence of inputs on outputs. To answer this question a regression analysis on the base of data from planed experiments were made.

Experiments were made according to 2^3 full factorial design, where availability were taken on levels 99% and 96%, buffer was on levels 1 pcs and 10 pcs and number of operators was 1 operator and 2 operators (Table 4). On the base of the performed experiments the regression Eqs. (13) and (14) were derived.

$$T = 0.947\,A + 0.3\,B + 3.61\,O - 65.1 \tag{13}$$

Table 2. Coded inputs and values of outputs of the simulation experiments

No of experiment	Availability of machines (A) [%]	Buffer (B)	No of operators (O)	Throughput (T) [pcs/hour]	Lifespan (L) [min]
Exp 01–01	A1	B1	O1	33.3542	561
Exp 02–02	A2	B1	O1	31.7833	589
Exp 03–03	A3	B1	O1	30.4917	612
Exp 04–04	A4	B1	O1	28.8417	648
Exp 05–05	A5	B1	O1	28.0917	665
Exp 06–06	A1	B3	O1	35.0292	621
Exp 07–07	A2	B3	O1	33.4458	660
Exp 08–08	A3	B3	O1	31.8625	696
Exp 09–09	A4	B3	O1	30.3708	736
Exp 10–10	A5	B3	O1	29.3375	766
Exp 11–11	A1	B5	O1	35.5417	681
Exp 12–12	A2	B5	O1	33.8958	733
Exp 13–13	A3	B5	O1	32.1833	797
Exp 14–14	A4	B5	O1	31.1083	831
Exp 15–15	A5	B10	O1	30.5333	1090
Exp 16–16	A1	B10	O1	35.8167	810
Exp 17–17	A2	B10	O1	34.2875	902
Exp 18–18	A3	B10	O1	32.9583	972
Exp 19–19	A4	B10	O1	31.6250	1047
Exp 01–20	A1	B1	O2	35.2958	535
Exp 02–21	A2	B1	O2	34.9125	541
Exp 03–22	A3	B1	O2	34.4125	548
Exp 04–23	A4	B1	O2	33.9583	555
Exp 05–24	A5	B1	O2	33.4625	563
Exp 06–25	A1	B3	O2	37.1125	597
Exp 07–26	A2	B3	O2	36.6458	604
Exp 08–27	A3	B3	O2	36.2167	613
Exp 09–28	A4	B3	O2	35.6958	619
Exp 10–29	A5	B3	O2	35.1875	630
Exp 11–30	A1	B5	O2	37.6000	662
Exp 12–31	A2	B5	O2	37.1417	665
Exp 13–32	A3	B5	O2	36.8292	671
Exp 14–33	A4	B5	O2	36.2708	685
Exp 15–34	A5	B10	O2	36.2625	791
Exp 16–35	A1	B10	O2	38.0625	767
Exp 17–36	A2	B10	O2	37.6292	788
Exp 18–37	A3	B10	O2	37.1750	790
Exp 19–38	A4	B10	O2	36.7458	779

Table 3. Hypothesis and results of Anova analysis

No	Hypotheses	P-value
1	H0: There is no statistically justified difference between values of Throughput obtained for different levels of machines availability	0,000
2	H0: There is no statistically justified difference between values of Throughput obtained for different size of buffer	0,000
3	H0: There is no statistically justified difference between values of Throughput obtained for different number of operators	0,000
4	H0: There is no statistically justified difference between values of average Lifespan obtained for different levels of machines availability	0,001
5	H0: There is no statistically justified difference between values of average Lifespan obtained for different size of buffer	0,000
6	H0: There is no statistically justified difference between values of average Lifespan obtained for different number of operators	0,000
7	H0: There is no statistically justified difference between values of Throughput obtained for different levels of machines availability	0,000

Table 4. Values of input and outputs of the simulation experiments according to 2^3 full factorial design

No of experiment	Availability of machines (A) [%]	Buffer (B)	No of operators (O)	Throughput (T) [pcs/hour]	Lifespan (L) [min]
Exp 01–01	99	1	1	33.3542	561
Exp 04–02	96	1	1	28.8417	648
Exp 16–03	99	10	1	35.8167	810
Exp 19–04	96	10	1	31.6250	1047
Exp 01–05	99	1	2	35.2958	535
Exp 04–06	96	1	2	33.9583	555
Exp 16–07	99	10	2	38.0625	767
Exp 19–08	96	10	2	36.7458	779

$$L = -29.7A + 30.7B - 108O + 3598 \quad (14)$$

Machines availability, size of buffer as well as number of operators have positive influence on value of throughput. Size of buffer has also positive influence on value of lifespan, while machines availability and number of operators have negative influence on value of lifespan.

6 Conclusions and Further Researches

In the paper, the results of the simulation experiments conducted on the model of a series parallel production line, is presented. The impact of intermediate buffer capacity, the availability of resources and the number of maintenance workers on the output and average lifespan of a product, within a manufacturing system, was analysed. The manufacturing system model was created using Tecnomatix Plant Simulation software. To analyse the system's behaviour, two series of 26 simulation experiments were performed for 1 maintenance worker and for 2 maintenance workers. The results of the research will be used for productions planning decision support system [13, 14]. For the input values of the simulation research, different combinations of buffer capacities and availabilities of resources were prepared. The following final conclusions can be formulated:

1. Buffer capacity has a significant impact on the throughput and average lifespan of products of a series parallel production line.
2. For different combinations of the availability of resources and buffer capacities, similar throughput values can be obtained.
3. The average lifespan of products depends on intermediate buffer capacity and on the allocation of the availability of resources.
4. However, the actual number of maintenance workers which guarantees the greatest throughput value, with regard to the allocation of buffer capacity and the availability of resources, in a series parallel production line, is critical.

The results presented are only a small part of the simulation research into manufacturing systems where the buffer allocation problem is taken into account. In further research, more complex systems will be analysed because, at that time, the input variable for the MTTR simulation experiments, that is, Mean Time To Repair, will be taken into consideration.

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Planning and Assessment of Manufacturing Processes Flow Variants Based on a Simulation Experiment

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Abstract. The article presents issues relating to planning, improvement and assessment of manufacturing processes flow variants based on a simulation experiment. A computer simulation model has been created, on which simulation experiments were planned and carried out for several scenarios of events. To carry out the research, a simulation model of a line in universal Arena software for modelling and simulation of manufacturing systems by Rockwell Software Inc. was created. An analysis of work intensity was carried out and the costs were divided in order to identify operations with no value added, particularly at individual manufacturing departments. Also an analysis of ergonomics at work stations was carried. The results of the simulation experiment were subject to a multi-criteria evaluation in order to select an efficient process flow variant. A developed system for supporting making up manufacturing decisions was presented on the example of manufacturing processes of sports equipment. The summary of the obtained results reflects benefits from implementation of the proposed solutions.

Keywords: Modelling · Simulation and design · Production planning

1 Introduction

Modelling and simulation techniques of manufacturing processes are increasingly used to solve problems at the production set-up stage as well as the production stage itself. Modelling and simulation is a technique that allows to quickly analyse different scenarios of events on a computer model of a system. The essence of modelling is not a mathematical description of physical phenomena occurring in a given system but on a description of functional links among the components of a studied system and external factors. Modelling of manufacturing systems comes down to determining characteristics and action of individual elements of the system as well as relationship among them. The manufacturing process may be presented a set of dynamic systems consisting of a series of unrelated or related processes, in which each process is defined as a string of specific actions [1, 2, 8, 10, 14].

In case of production control, simulation allows to plan the most effective control method for a controlled material stream.

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In order to facilitate and accelerate development of input data for a simulation experiment, a simulation package should be integrated with the company's databases (Fig. 1).

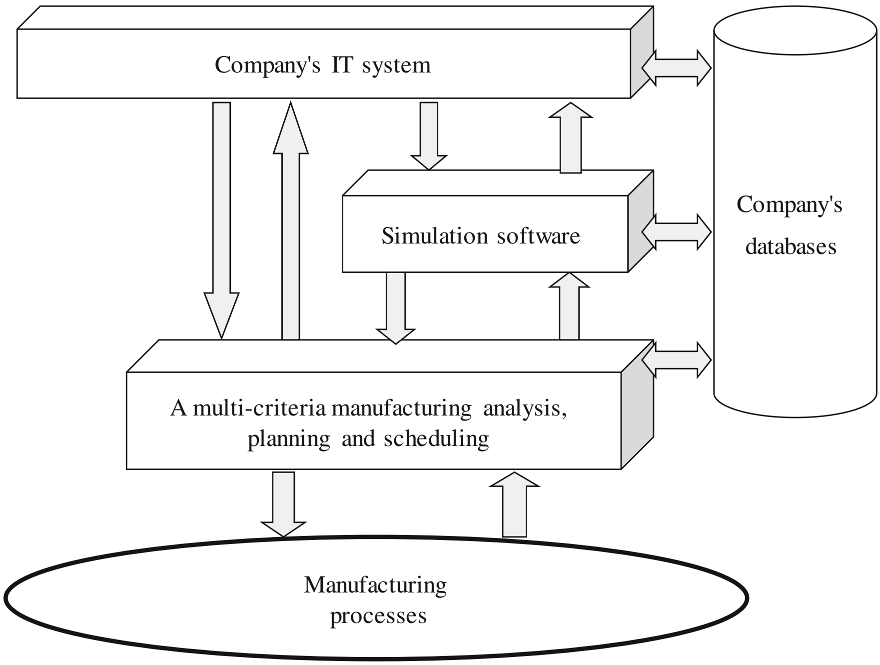


Fig. 1. A company's information system as a source of data for modelling and simulation

The system for modelling and simulation should be integrated also with the company's IT system. Thanks to such an integration, it will be possible to create a tool for facilitating making up manufacturing decisions, enabling to automatically import and export manufacturing data, and to improve flexibility and efficiency of simulation studies [7, 11].

2 Modelling and Simulation of Manufacturing Systems

Figure 2 presents a general concept of the course of a simulation project. The first step of the project is to define a problem. Then, the concept of a model should be specified. In this phase of the simulation project a problem is defined and analysed, usefulness of records is assessed, initial assumptions are made, logical bases of a model are set and input parameters are specified and defined. A detailed analysis of the situation and precise defining of project objectives are crucial for proper scope and level of detail of the simulation model, schedule of realization of the project as well as comparison and price of alternative solutions.

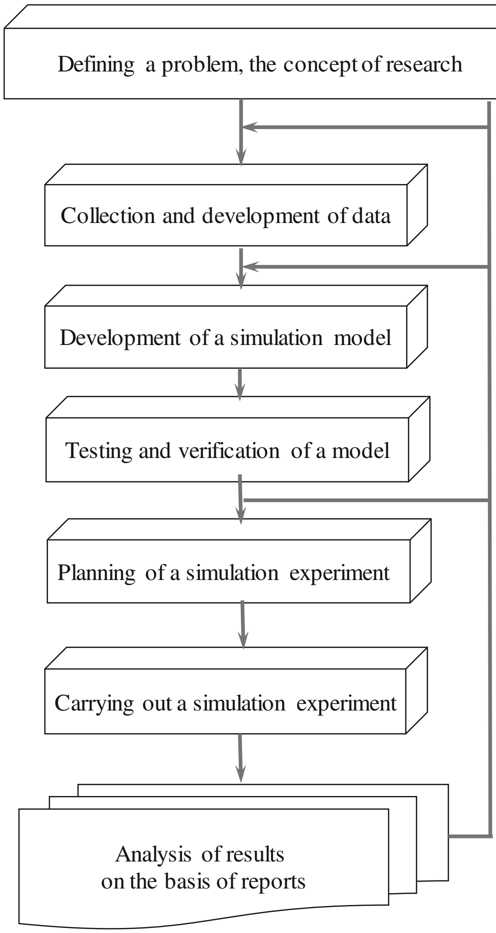


Fig. 2. A course of a simulation project

The next step of the project is to collect and prepare necessary data, such as technical parameters of the equipment, availability of work stations, cycle times, auxiliary times, preparatory and set-up times, material flow diagrams, cost information, scheduling strategies, machines and equipment operation times. Quantity, quality and form of input data have a great importance for a simulation project.

While developing a manufacturing system model, above all, the boundaries of the system, connection of the system with the environment are defined, work stations and their mutual relations with defined material and information flows are modelled.

When the model is developed, it is tested and verified. Before approving the model, it should be thoroughly checked through analysis of the results of the test and observation of a computer animation in order to become convinced about its correctness. The results of a simulation on a model and current data from a real system should be compared.

Upon approval of a model, a simulation experiment should be planned. A computer simulation is not just random experimentation on a model by trial and error. To plan the experiment, large experience and knowledge of methodology of experimental research is necessary. Planning simulation experiments is based on specifying type, number and order of analyses to be carried out, which should be implemented in order to obtain the research objectives. While planning a simulation experiment, a plan that will ensure reliability of characteristics of a real system in the most efficient and an economical way should be selected.

A simulation experiment, which allows for evaluation of the tested system, is carried out upon planning. As a result of simulation experiments carried out on a computer model, a set of reports is obtained. Variants which do not fit to the allowed set of solutions due to certain limits (such as exceeding implementation time or profitability threshold) should be eliminated out of the experiments carried out. Variants from the set of acceptable solutions should be evaluated and the best solution should be selected [3, 5, 7, 9, 11–13].

3 The System for Supporting Making up Manufacturing Decisions Based on a Simulation Experiment and a Multi-criteria Assessment of Variants

The choice of the best solution is difficult if multiple criteria are used for an assessment. To solve the problem, a combination of a simulation experiment and a multi-criteria assessment in accordance with a point-by-point method of assessment according to Yager has been suggested (Fig. 3). The procedure of assessing variants in line with this method was described in the works of [4, 6, 9, 10].

In the framework of the presented example, the criteria of assessment and their significance were determined according to the Saaty's method. The criteria were compared in pairs by assigning them grades in line with the scale provided below: individual b_{ij} values of the matrix being developed were adopted as follows:

- $b_{ij} = 1$ where k_i and k_j are equivalent,
- $b_{ij} = 3$ where k_i is a bit more important than k_j,
- $b_{ij} = 5$ where k_i is a lot more important than k_j,
- $b_{ij} = 7$ where k_i is evidently more important than k_j,
- $b_{ij} = 9$ where k_i is absolutely more important than k_j,
- $b_{ij} = 2, 4, 6, 8$ - intermediate values,
- $b_{ji} = 1/b_{ij}$.

Subsequently, one cumulative matrix of significance of criteria was created and coordinates of a latent root were set, on the basis of which the weights of criteria were specified.

Based on reports from the simulation experiment, individual variants of solutions were assessed according to each criteria separately. The grades of variants were brought to normalised values and cumulative normalised grades were created by averaging of grades indicated for individual experts. On this basis, normalised

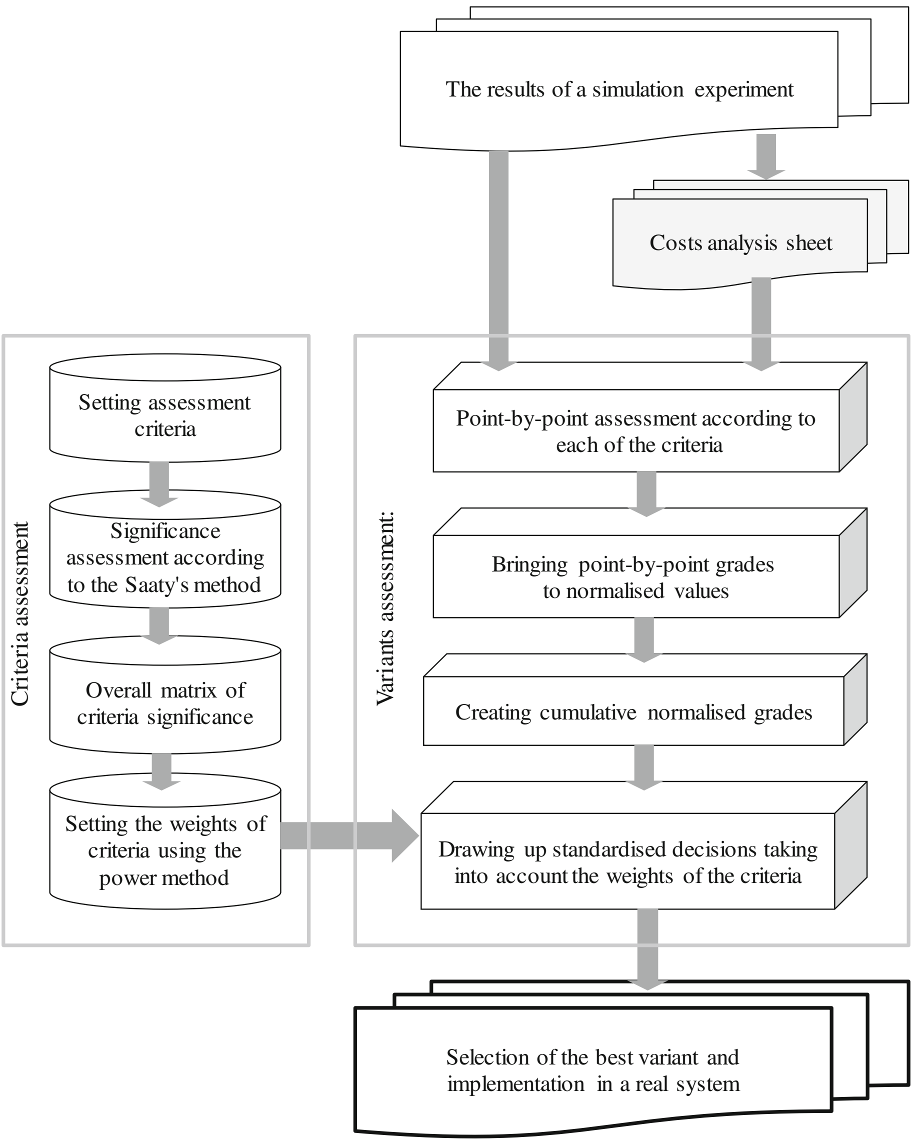


Fig. 3. A system for supporting decisions based on a multi-criteria assessment of variants on the basis of the results of a simulation experiment

decisions were created by raising each component of subsequent normalised grades to a power equal to the appropriate weight of a criteria.

As a consequence, an optimal decision was created, on the basis of which a reasonable course of manufacturing process was selected and implemented in a real system. The best variant of the course of the manufacturing process is a variant to which the highest component in an optimal decision corresponds, i.e. the highest value of a degree of belonging to the set of acceptable solutions.

4 A Description of the Results Obtained

The object of research in the study is a system for manufacturing winter sport equipment.

The purpose of research is to improve organization of material flows in the CNC department and the preparation room by identifying sources of losses using simulation tools. Arena software created by Rockwell Software Inc. was used in the research. This universal software was originally dedicated for business analysts and consultants. At present, it is also used by engineers as a computer tool to aid engineering work. A simulation model was created in this tool for the experiment, the fragment of which was presented in Fig. 4.

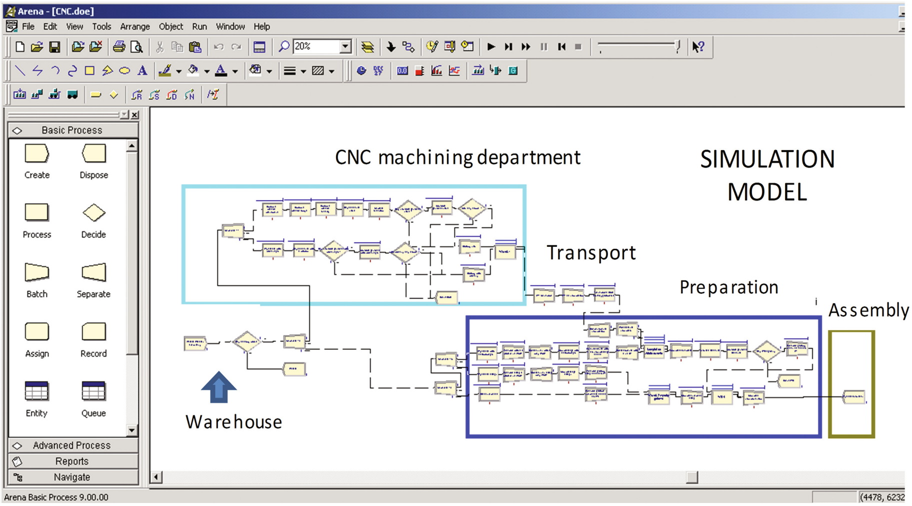


Fig. 4. A fragment of a manufacturing system model in the Arena package

The results obtained by a method of a simulation experiment were assessed in terms of four criteria (Fig. 5):

- Performance,
- Transport costs,
- Average use of work production stations,
- Station costs.

In a developed Excel worksheet the validity of individual criteria was assessed by comparing them in pairs (Fig. 6). On the basis of a cumulative matrix of criteria significance, a latent root was specified with the use of a developed programme, which carried out calculations on the basis of the power method.

The results obtained from the simulation were used to estimate costs. Subsequently, individual variants of solutions were assessed under each of the criteria, a board

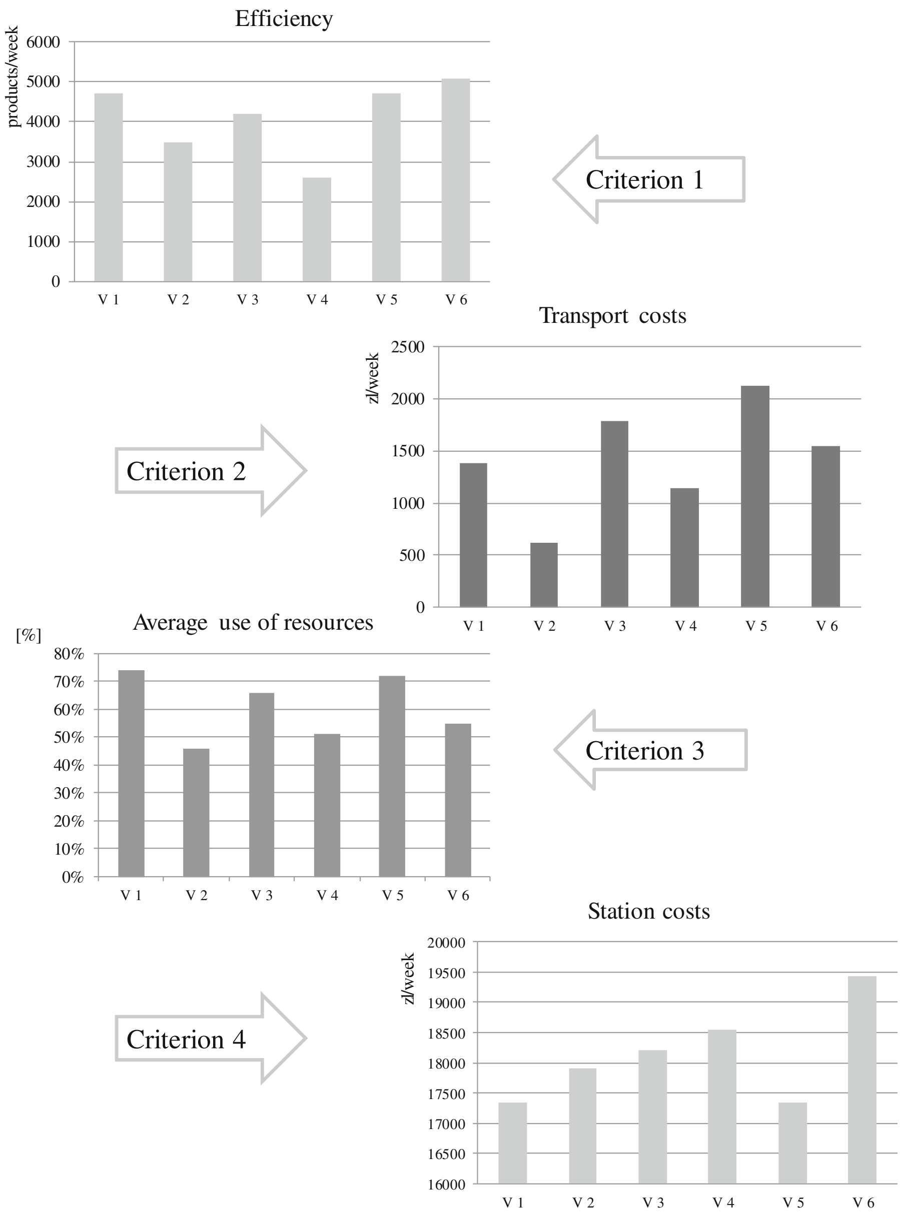


Fig. 5. A graphic presentation of results of the experiment

of cumulative normalised grades were created and aggregation of grades of variants including the weights of criteria was carried out (Fig. 7).

On the basis of so-called optimal decision, the best variant of the manufacturing process flow was set. The best variant appeared to be the solution marked as $V_{5.}$

Expert 1

E1	k_1	k_2	k_3	k_4
k_1	1	4	1	1
k_2	0,25	1	0,5	1
k_3	1	2	1	0,5
k_4	1	1	2	1

Expert 2

E2	k_1	k_2	k_3	k_4
k_1	1	3	2	2
k_2	0,33333	1	0,5	1
k_3	0,5	2	1	1
k_4	0,5	1	1	1

Expert 3

E3	k_1	k_2	k_3	k_4
k_1	1	2	2	1
k_2	0,5	1	0,25	0,5
k_3	0,5	4	1	1
k_4	1	1	1	1

Collective matrix

	k_1	k_2	k_3	k_4
k_1	1	3,000	1,667	1,333
k_2	0,333	1	0,417	0,833
k_3	0,600	2,400	1	0,833
k_4	0,750	1,200	1,200	1

$$\sum_{j=1}^{m} y_j = m$$

Power Method

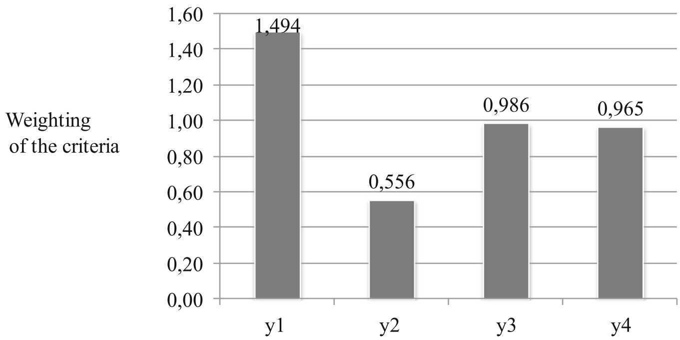
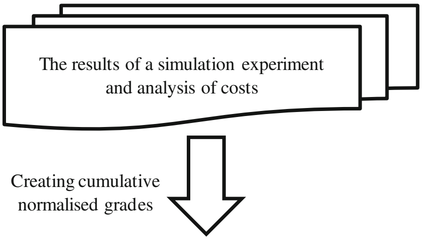
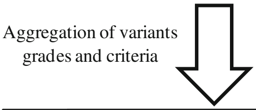


Fig. 6. Significance assessment of criteria according to the Saaty's method



Criteria	Variants					
	V1	V2	V3	V4	V5	V6
k_1	0,1984	0,116	0,167	0,05104	0,21805	0,2495
k_2	0,0768	0,2209	0,1744	0,25597	0,12325	0,1487
k_3	0,2368	0,055	0,1993	0,12675	0,25439	0,1276
k_4	0,2386	0,187	0,1353	0,11778	0,25517	0,0661



Criteria	Variants					
	V_1	V_2	V_3	V_4	V_5	V_6
k_1	0,0893	0,0400	0,0690	0,0118	0,1028	0,1257
k_2	0,2402	0,4321	0,3789	0,4690	0,3125	0,3469
k_3	0,2417	0,0574	0,2040	0,1305	0,2594	0,1314
k_4	0,2509	0,1983	0,1452	0,1270	0,2677	0,0728

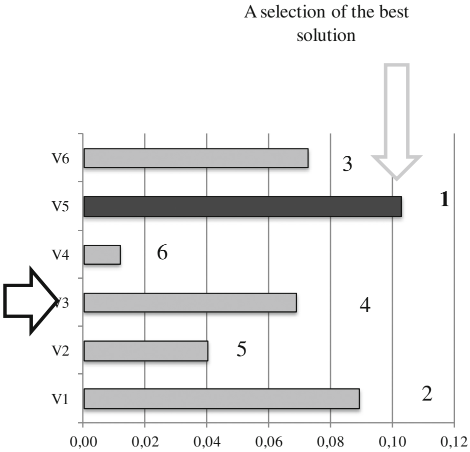


Fig. 7. A multi-criteria assessment of variants and a selection of the best solution

5 Summary and Conclusions

The analysis of the results of the experiment has a great importance for the success of the whole simulation project. Each mistake made during the assessment of the results is able to completely destroy planning and realization of the experiment on a computer model.

At the stage of production planning, a simulation might be used both to specify capacity of selected production stations, lead time of production tasks as well as estimation of costs being paid.

Simulation is a very good tool facilitating a decision-making process at various levels of managing the company. In conjunction with the methods of a multi-criteria assessment, it allows for a more complex approach to difficult and complex problems relating to manufacturing management processes.

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Smart Innovation Engineering (SIE): Experience-Based Product Innovation System for Industry 4.0

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Abstract. This paper presents a semi-automatic system capable of facilitating product innovation process. This system, known as Smart Innovation Engineering (SIE) system, helps in decision-making by using the explicit knowledge of formal decision events. The SIE system carries the promise to support the innovation processes of manufactured products in a quick and efficient way. It stores and reuses the past decisional events or sets of experiences related to innovation issues, which significantly enhances innovation progression.

This system can be potentially used in large enterprises manufacturing a range of similar products or a group of Small and medium-sized enterprises (SMEs). The analysis of basic concepts and implementation method proves that SIE system is an expert system facilitating Cyber Physical Systems (CPS) and it can play a vital role towards Industry 4.0. This system provides flexibility and customization of products, is quick and systematic, and can be further extended and used for lean innovation and sustainable innovation.

Keywords: Smart Innovation Engineering · Product innovation · Industry 4.0 · Set of experience · Decisional DNA

1 Introduction

Due to shear competition among similar manufacturing organizations and high customer expectation for quality products at lower costs, manufacturing units need to implement changes in their products regularly and systematically. They are also facing continuous market changes and need for short product life cycles [1]. Furthermore introduction of new/smart products into the market, technological advancements, development of new materials having enhanced properties/lower costs, improved/cost-effective manufacturing processes, and other similar factors intensify their problems [2]. To overcome this, and for the prosperity and survival of the manufacturing unit in this competitive market, the entrepreneurs and manufacturing organizations have to introduce new features in their products, leading to innovation. They have to repeat the

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product innovation process after a particular time, otherwise their product may become obsolete.

Proper knowledge management therefore plays an important role in product design and innovation for taking effective decisions. In the past, knowledge-based industrial design and manufacturing techniques have been used with considerable success. But they need to be smarter, as they are costly, time-consuming, domain-specific, unreliable in their intelligence and more importantly their inability to take into account the previous experiences [3, 4].

The World is moving forward towards fourth industrial revolution that is known as Industry 4.0. At the Hanover Fair in 2011, an initiative named "Industry 4.0" was promoted by an association of representatives from business, politics, and academia as an approach to strengthening the competitiveness of the German manufacturing industry.

The term Industry 4.0 refers to the fourth industrial revolution and is often understood as the application of the generic concept of Cyber Physical Systems (CPSs). CPSs refer to the next generation of engineered systems that require tight integration of computing, communication, and control technologies to achieve stability, performance, reliability, robustness, and efficiency in dealing with physical systems of many application domains [5].

Knowledge Engineering (KE) and Knowledge Management (KM) are important role players in cyber-physical systems. The concept of Virtual engineering object (VEO) proposed by Shafiq et al. [6, 7] is experience-based knowledge representation of engineering objects can be treated as specific form of CPS and consequently can be utilized in design of Industry 4.0. The concept was extended further by Waris et al. [8–10] into Smart Innovation Engineering (SIE) system. The SIE system uses a collective, team-like knowledge developed by past experiences of the innovation-related formal decisional events. Through this systematic approach, product innovation process can be performed semi-automatically. Smart design and manufacturing systems capable of continuous design/innovation, configuration, monitoring and maintenance of operational capability, quality, and efficiency are, in fact, a requirement for the Industry 4.0 [11]. According to the European commission under the Horizons 2020 program, the self-learning closing feedback loop between production and design should be included in future factories. The goal here is to show how SIE system can be considered as a step forward towards Industry 4.0.

2 Background

To clearly understand the idea, some concepts are described below that will also be helpful in justifying the inter-relationship among each other.

2.1 Product Innovation

The key features for designing and manufacturing a new product are: required features/functions of the product (based on the human aspects so as to make it more valuable for users), technology, resources and materials available, manufacturing processes, and other such factors at that time [8–10]. For the prosperity and survival of the manufacturing unit in this competitive market, the entrepreneurs and manufacturing organizations have to introduce new features in their products, leading to innovation. They have to repeat the product innovation process after a particular time, otherwise their product may become obsolete.

In fact, the process of product innovation is very difficult and complex. Both knowledge and experience are essential attributes of an innovator that are necessary to find the best possible solution for the required changes, leading to achieve innovation. These changes are based on the innovative objectives reapplied to the established, existing product. These innovation objectives can be determined through various techniques. Some of which are lead user analysis [12], beta testing [13], consumer idealized design [14], use of online user toolkits [15] to name a few. Apart from that new technological advancements in materials or processes are required along with the experts' advice for stating the innovation objectives. Product innovation process has to be quick and systematic so that the changes in the product may be implemented at the required time.

In the context of manufactured products, product innovation can be defined as the process of making required changes to the already established product by introducing something new that adds value to users and also providing expertise knowledge that can be stored in the organization [16]. Knowledge and innovation play an important role in regional growth, and it is not a new issue at all. Innovation plays an important role in providing competitive advantage for manufacturing organizations [17].

Thus, innovation-related activities have become a key imperative for many manufacturing organizations. Strategy for implementation of product innovation includes the use of better components, new materials, advanced technologies, and new product features/functions. External factors such as legislation and sustainable development also affect implementation of product innovation. Another factor that is considered during product innovation process is ergonomics. Research suggests that ergonomics is related to product characteristics such as safety, efficiency of use, and comfort aimed at maximizing customer satisfaction [18]. Ergonomic properties are recognized as important because firms are competing on ease of use of the product [19]. Moreover, the establishment of cross-functional, multidisciplinary teams was found to be vital to the success of the innovation project [20].

From the above discussion, it is clear that product innovation is highly complex process that requires vast knowledge and other external factors. Product innovation process can be facilitated by a system that uses a collective, team-like knowledge developed by experiences of the past decisions related to product innovation. This system is called Smart Innovation Engineering (SIE) System.

2.2 Industry 4.0: The Fourth Industrial Revolution

The concept of Industry 4.0 came into existence in 2011, when an association of representatives from academia, business, and politics promoted the idea as an approach for strengthening the competitiveness of the German manufacturing industry [21]. The term “Industry 4.0” is used for the fourth industrial revolution which is about to take place right now. In the history of mankind, the first industrial revolution was the introduction of mechanization of production systems started in the second half of the 18th century and being intensified throughout the entire 19th century. The second industrial revolution started from the 1870s led by electrification, assembly line and the division of labor. The third industrial revolution, also called “the digital revolution”, set in around the 1970s, when advanced electronics and information technology developed further the automation of production processes.

Industry 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industry 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the Internet of Things (IoT), CPS communicate and cooperate with each other and humans in real time. Via Internet of Services (IoS), both internal and cross organizational services are offered and utilized by participants of the value chain [22]. Therefore Industry 4.0 is a concept that will transform current industries into Smart Factories having a well-defined network of intelligent machines, smart products, systems and processes creating real world virtualization into a huge information system. Potential benefits of Industry 4.0 are flexibility, reduced lead times, reduced costs and customization of products.

2.3 Cyber Physical Systems

Cyber Physical Systems has drawn a great deal of attention from academia, industry, and the government due to its potential benefits to society, economy, and the environment. CPSs require tight integration of computing, communication, and control technologies to achieve stability, performance, reliability, robustness, and efficiency in dealing with physical systems of many application domains. Application of CPS in the manufacturing industry leads to Cyber Physical Production System (CPPS) and hence the ability for continuous viewing of product, production equipment and production system under consideration [23].

According to the European Commission under the Horizons 2020 program, the self-learning closing feedback loop between production and design should be included in future factories for optimizing energy expenditure and minimizing waste as a direct relation to the enhancement in control and immediate information processing that a CPS will provide. The Internet of Things will make a new wave of technological changes that will decentralize production control and trigger a paradigm shift in manufacturing. It is highly likely that the world of production will become increasingly networked until everything is interlinked [7].

3 Smart Innovation Engineering (SIE) System

The importance of the aforementioned aspects creates the necessity for systems that collectively work together for Industry 4.0. We propose one of such system known as Smart Innovation Engineering (SIE) system. This system is technically an extension of the work developed by Shafiq et al. [6] known as Virtual Engineering Object (VEO) which permits dual computerized/real-world representation of an engineering artifact. VEO is a specialization of CPS in terms of its extension into knowledge gathering and reuse, whereas CPS is aimed only toward data and information management [6, 7].

The SIE system is a prominent tool to support the innovation processes in a quick and efficient way. It stores the experiential knowledge of the past decisional events related to product innovation in the form of sets of experience and uses such experiential knowledge in decision making. Manufacturing organizations and entrepreneurs can take improved decisions systematically and at an appropriate time by implementing the SIE system in the process of product innovation. The SIE System is based on the Set of Experience Knowledge Structure (SOE) and Decisional DNA (DDNA), which were first presented by Sanin and Szczerbicki [24]. It is a Smart Knowledge Management System (SKMS) capable of storing formal decision events explicitly [25, 26].

The architecture of SIE system is shown in Fig. 1. It consists of three main modules: Systems, Usability and SIE_Experience and is also linked with VEO-DDNA. SIE system extracts the knowledge about the manufacturing scenario of the product from the VEO-DDNA, these are required only for the purpose of selecting relevant manufacturing process and better material for required quality. Other three modules (Systems, Usability, and Experience) are more important for the purpose of innovation process [2]. The Systems, Usability and Experience modules are crucial modules of the SIE system.

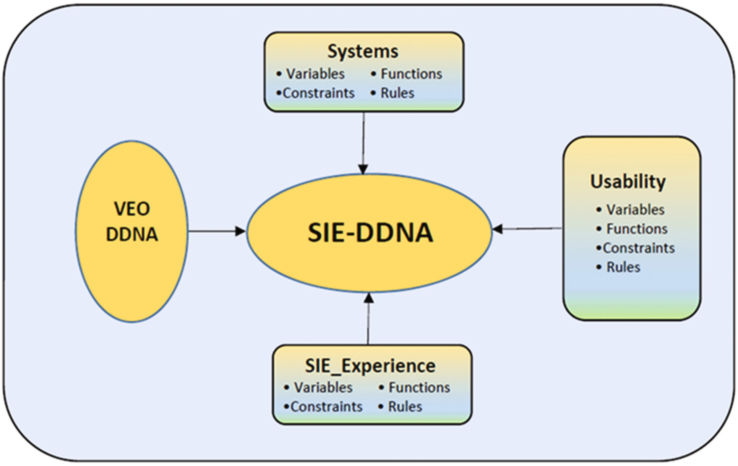

Fig. 1. Architecture of SIE-DDNA.

3.1 Implementation of SIE System

As we have discussed earlier that the structure of the Smart Innovation Engineering System includes three modules (Systems, Usability and SIE_Experience). Sets of experience are created for each module individually that allows the experience-based knowledge to be stored more systematically for a wide range of similar manufactured products. Set of experience is a unique combination of Variables, Functions, Constraints and Rules. Proper implementation of SIE System requires its integration with the Decisional DNA. Sets of experience are generated for each individual modules having specific weightages for the variables of the product. Combination of all the individual Sets of experience are combined under the SIE system that represents complete knowledge and experience necessary for supporting innovation process of manufactured products.

As the decisional DNA is constructed in JAVA and has been successfully applied in various other fields of application like virtual engineering factory, industrial maintenance, diagnosis of Alzheimer's disease by decision support medical system, banking activities involving periodic decision making and storing information, digital control system of the geothermal and renewable energy, e-decisional community, and smart interactive TV to name a few.

The code for SIE system was written in Java programming using Windows 7 operating system. The complete information about manufactured product is stored in each module in Comma Separated Values (CSV) files. This information is in the form of sets of Variable, Functions, Constraints and Rules. Separate CSV files were generated for all modules viz. Characteristics, Functions, Systems, etc. A parser was written in Java programming language to read these files. This parser reads Variables, Functions, Constraints and Rules from CSV files. The CSV files contains data in standard format so that the parser collects information as required.

First the parser looks for the term 'Variables' and goes to the next line. The first line after the term 'Variables' contains the name of the Variables. It stores values written in each cell of the first line as the 'Name' of the Variables. Each line after this contains the Value of the corresponding Variables. The parser assigns the values to the respective Variables. This group of Variables is stored in the system as one 'Set of Variables'. Similarly the parser reads the second set of values from the CSV file and assigns them to the respective Variables that is stored as the second 'Set of Variables'.

The same process continues until the parser finds the term 'Functions', 'Constraints', or 'Rules'. In the same way, the parser reads 'Set of Functions', 'Set of Constraints', and 'Set of Rules' from the CSV file. One 'Set of variables' plus 'Set of Functions', 'Set of Constraints', and 'Set of Rules' are combined together to form one Set of Experience (SOE). Each line containing the values of Variables results in corresponding SOE.

Same procedure is repeated for other CSV files representing data for different modules of SIE System. Each file represents a category of the SIE System. Collection of SOE of the same category forms a Chromosome of the SIE System and collection of different Chromosomes (for each Module) forms what we call as Decisional DNA (DDNA) of the SIE System.

Graphical User Interphase (GUI) for the SIE System is shown in Fig. 2. This GUI will allow the user to interact with SIE System in a user-friendly language. The user can select the set of values from the drop-down menu and the also be able to define the required Constraints and preferences in the form of set of variables with selected values. This set of information (Query) is then converted into SOE and compared with the similar Sets of Experience that were generated by the SIE System from CSV files as

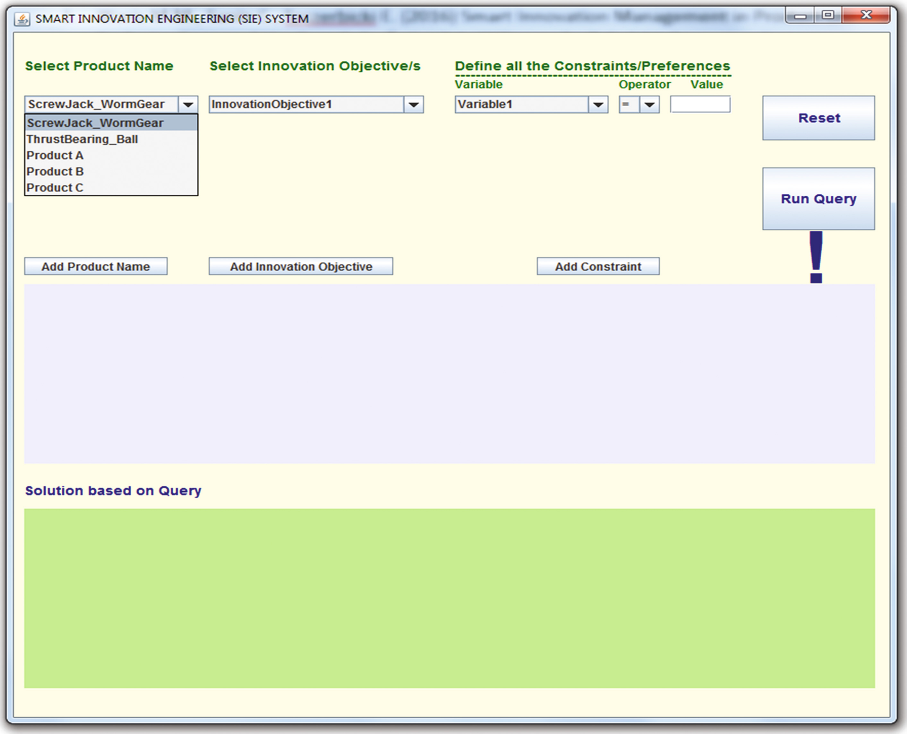

Fig. 2. Graphical User Interphase (GUI) for SIE System

explained above. The SIE System then compares the results of the most similar SOE and stores the changes that were made in those Products. These SOE actually represents the experiential knowledge of the successful changes made in product innovation processes of the group of similar products or products with similar features or objectives. Each past decision (SOE) has its Performance Factor [2] that represents the success of the decision taken in that Product Innovation process. The SIE System looks for the best available option for a change that fits in the current Product (based on the constraints/preference set by the user).

The SIE System provides a list of proposed solutions (say 10) that is displaced in the GUI. At this time, the user/entrepreneur/innovator has the privilege to select the best possible solution from that list. This selected final solution is stored in the SIE System as SOE that can be used in future for similar query. In this way, the SIE System is a semi-automatic system that facilitates the process of Product Innovation. The SIE System gains experience with each decision taken that increases its expertise and behaves as an expert in its domain.

3.2 SIE: A Step Forward Towards Industry 4.0

The importance or contribution of SIE system can be justified from the potential benefits that it offers towards the establishment of Industry 4.0 that itself is a complex system. Some of them are described here:

More Flexibility: SIE system will allow the manufacturing organizations to choose from the list of proposed solutions based on user preferences. Thus allowing the flexibility in product innovation process.

Quick and Systematic: Due to its fast computational capabilities, innovation process is much quicker as compared to the time taken by human group of experts. The process is systematic due to the fact that SIE system behaves as the group of experts that possesses the knowledge required for Product innovation.

Customization: Industry 4.0 allows the incorporation of individual customer-specific criteria concerning design, configuration, ordering, planning, production and operation as well as enabling modifications to be made at short notice. Using SIE system will definitely help in achieving the designing of customized products.

Reduction in Costs: Implementation of SIE system in manufacturing industries will reduce their dependability on experts which will result in significant cost reduction in product innovation process.

Apart from that, the SIE system can be used confidently in the field of lean product development, lean innovation, and sustainable innovation.

4 Conclusion

This paper presented the concept of Smart Innovation Engineering (SIE) that enhances the product innovation process. Implementing this system in manufacturing organizations will allow them to take quick and systematic innovation-related decisions. The analysis of basic concepts and implementation method proves that SIE is an expert system that can facilitate Cyber Physical Systems (CPS) and it can play a vital role towards the establishment of Industry 4.0 and has the potential to be used further for lean innovation and sustainable innovation in future. The SIE system has the potential to be used by large enterprises or group of SMEs, manufacturing similar products sharing data among themselves.

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