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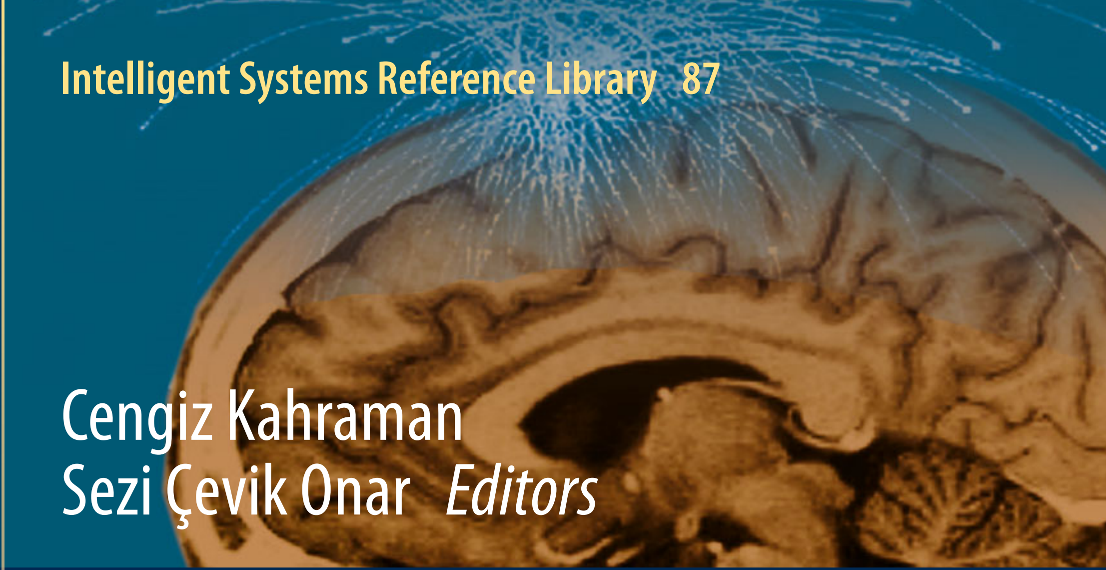

Cengiz Kahraman
Sezi Çevik Onar *Editors*

Intelligent Techniques in Engineering Management

Theory and Applications

Springer

Intelligent Systems Reference Library

Volume 87

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Intelligent Techniques in Engineering Management

Theory and Applications

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I dedicate this book to my elder brother
Hüseyin Kahraman and his sons Ömercan
and Emircan

Prof. Cengiz Kahraman

I dedicate this book to my family;
my lovely son Ege, my love Kerem,
my dear parents Semiha, Ethem and my sister
Sevi and her sweet family

Assist. Prof. Sezi Çevik Onar

Preface

The objective of engineering management is to apply engineering principles to managerial problems. Engineering management handles complex managerial and organizational problems with the engineering problem solving tools and techniques. Both management and engineering knowledge are necessary for successful application of engineering management. Along with engineering characteristics, system thinking, systematic approach, modeling, and human orientation are the main dimensions of the engineering management discipline. Engineering management has a wide range of areas of implementation from quality management to financial management and from human resource management to production management. Engineering management professionals should combine engineering knowledge with problem solving techniques effectively and efficiently.

The contents of this book have been constituted by considering classical engineering management books. The aim of the book is to gather intelligent applications suitable to this content. In recent years, intelligent techniques are widely used in the solution of complex problems that cannot be solved by classical solution techniques. Complex problems in engineering management such as risk management, material management, or quality management have been recently solved using intelligent techniques such as neural networks, genetic algorithms, or fuzzy logic. 27 chapters have been collected from various countries, namely Turkey, Spain, Finland, Romania, South Africa, Germany, Brazil, India, China, Belgium, Netherlands, Iran, Algeria, Serbia, Colombia, and Italy.

Chapter 1 exhibits the relations between engineering management and intelligence and illustrates usage frequencies of intelligent systems in engineering management. It classifies the intelligent techniques. This chapter summarizes the application of intelligent techniques to engineering management areas such as human resources management, quality management, and strategic management.

Chapter 2 focuses on risk situations described by fuzzy numbers. It defines and characterizes possibilistic risk aversion and studies some of its indicators. It also studies two possibilistic models of risk management: a coinsurance problem and an investment portfolio problem. Chapter 3 proposes a novel intelligent technique called evidence-based morphological analysis model based on Dempster–Shafer theory of evidence and morphological analysis methodology to quantify the likelihood of intentional events as threats by identifying them.

Chapter 4 conducts a comprehensive literature review from the years between 2000 and 2014. The motivation for the chapter is to contribute to the literature by presenting an extensive literature review and making a synthesis with regard to intelligent systems in research and development. Chapter 5 concentrates on the conceptual model that reveals the determinants of innovation strategy. It explains the factors and their relations with each other based on the literature survey and experts' opinion. It uses fuzzy cognitive mapping approach which can utilize network models. Chapter 6 adopts a multi-agent system approach-assisted intelligent conceptual design platform for miniature in-pipe inspection robot design synthesizing. The demo case study shows that the proposed MAS-ICD can outperform human designers in many perspectives.

Chapter 7 offers a first exploration of the general potential of Artificial intelligence techniques in human resource management. A brief foundation elaborates on the central functionalities of artificial intelligence techniques and the central requirements of human resource management based on the task technology fit approach. Chapter 8 proposes a fuzzy cognitive map-based model to overcome the modeling difficulty. The factors related to dynamic capabilities, which are collected from an extensive literature review, are defined as concepts and their fuzzy relations are represented as causal links in a graph structure. Chapter 9 uses data envelopment analysis and fuzzy Logic on partners' selection process complying particularly with the risks involved in virtual organizations formation process.

Chapter 10 uses hybrid methods combining more than one algorithm efficiently for maintenance planning. It applies both data-driven and mathematical models but data-driven methods are becoming more practical as computation is increasingly more feasible. Chapter 11 formulates a fuzzy inventory model for deteriorating items with shortages under fully backlogged condition by utilizing uncertain, vague, and imprecise data. Fuzzy set theory is used for handling the uncertainty in the data. Chapter 12 pays attention to economic load dispatch problem (ELDP). The ultimate goal of ELDP is to schedule the output of the committed generating units in a reliable and efficient manner. Artificial bee colony algorithm is employed as an effective approach to optimize the system structure within nonsmooth cost functions due to its simplicity and flexibility than most optimization algorithms in terms of algorithm structure. Chapter 13 is on intelligent technologies and systems of material management. Material management is the engine that drives its supply chain and logistics of manufacturing enterprise or any other organization. Material management is applied to the latest ICT and intelligent technologies or systems, like barcode, RFID, IoT (Internet of Things), GPS/BeiDou navigation satellite system, cloud computing, big data, and parallel control and management, to realize its transformation and upgrade coordinately with its supply chain and logistics.

Chapter 14 shows a new decision support intelligent financial model over SOX compatibility based on artificial intelligent technology together with the theory of argumentation. The main aim of this model is to help and support private companies, auditors, executive boards, and regulatory bodies to take a SOX-compliant decision over a specific process of a typical purchasing financial cycle. Chapter 15 aims at giving a general overview of the existing intelligent systems that can be used to support decision making in a variety of domains. For each category, the ideas behind these systems are explained and the operating principles are summarized. Practical applications and tools used for managerial purposes are also provided.

Chapter 16 implements fuzzy control charts for monitoring and analyzing process, and reducing the variability of process. An intelligent system is also developed to eliminate or reduce uncertainty on data by using a fuzzy approach. Chapter 17 tests a fuzzy process capability index. It also develops the operating characteristic (OC) curves for the fuzzy capability index in testing one-sided and two-sided hypotheses. Chapter 18 gives the main principles of engineering management with system-based intelligent methods.

Chapter 19 proposes a methodology based on computational intelligence techniques for market analysis. In the proposed approach, first customers' comments are collected automatically, then sentiment analysis is applied to each message using artificial neural networks. At the third phase, themes of messages are determined using text mining and clustering techniques. Chapter 20 uses cost-sensitive classification-based models to predict the customer segments. For this aim, classification and regression trees, logistic regression, and chi-squared automatic interaction detector techniques are utilized. In order to compare the performance of the models, new performance measures are promoted, which are hit, capture, and lift rates.

Chapter 21 discusses several applications of intelligent systems in project management practice. First, the relevant literature is reviewed and different applications of intelligent tools are categorized into seven problem types. This categorization provides the basis for analyzing the underlying problem types and prepares the ground for future research via a faster access to the relevant literature.

Chapter 22 proposes a model for evaluation of projects for business process quality improvement. The performances of the treated type of projects are analyzed in the scope of standard ISO 215000:2015 and the results of good practice. Chapter 23 proposes a new simulation approach to develop project progress time-series data, based on the complexity and specifications of the project as well as on the environment in which the project is executed. This simulator is capable of simulating fictitious projects, as well as real projects based on empirical data and helps project managers to monitor the project's execution, despite the lack of historical data.

Chapter 24 presents an application of fuzzy optimization models and methods to a logistic network design problem using linguistic information coming from multiple experts. Chapter 25 intends to provide the reader with an overview of different intelligent tools applicable to the issue of picking optimization. It shows how different types of intelligent algorithms can be used to optimize order picking operations in a warehouse, by decreasing the travel distance (and thus time) of pickers. Chapter 26 discusses several intelligent techniques to solve warehouse problems in uncertain environment. Analogous to chance constraints, real-life necessary and possibility constraints in the context of two warehouses multi-item dynamic production inventory control system with imprecise holding and production costs are defined and defuzzified following fuzzy relations. Chapter 27 reviews supplier selection models based on individual and hybrid MCDM methodologies. A case study of an automobile company is presented to illustrate and propose three alternative supplier selection models based on analytic hierarchy process as an individual MCDM methodology and data envelopment analytic hierarchy process and fuzzy analytic hierarchy process as hybrid MCDM methodologies.

We hope that this book will provide a useful resource of ideas, techniques, and methods for research on the *Theory and Applications of Intelligent Techniques in Engineering Management*. Finally, we thank all the authors. This book would not have been possible without their contributions and efforts. We are grateful to the referees whose valuable and highly appreciated works contributed to select the high quality of chapters published in this book.

Cengiz Kahraman
Sezi Çevik Onar

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Chapter 1
Engineering Management and Intelligent Systems

Cengiz Kahraman and Sezi Çevik Onar

Abstract In this chapter we try to exhibit the relations between engineering management and intelligence and to illustrate usage frequencies of intelligent systems in engineering management. We classify the intelligent techniques since intelligent systems are the systems using these intelligence techniques. Engineering management areas such as human resources management, quality management, and strategic management have many application examples of intelligent techniques. This chapter summarizes these works briefly.

Keywords Engineering management · Intelligence · Intelligent techniques · Metaheuristics

1.1 Introduction

Engineering Management is concerned with the design, development, and implementation of integrated systems of human, machine, information, energy and material. These integrated systems are analyzed and designed with specialized engineering knowledge and skills along with other disciplines such as mathematics, physics and social sciences. The interaction of management functions namely, planning, organizing and controlling and the human factor in organizational functions such as manufacturing, finance and marketing are considered in the design, development and implementation of organizational systems. Engineering management has a wide range of areas of implementation. Some example of these areas are production, technology management, human resource management,

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finance, quality management, and service systems. Engineering management professionals should combine engineering knowledge of effectively and efficiently problem solving with business knowledge. The globalization and the rapid change in the technology increase the need of integrating managerial and engineering knowledge and skills (Damoran et al. 2014).

The engineering management problems can be simply classified as follows:

Technical Problems: problems of an engineering nature that require specialized training in personnel. Generally it is obvious when a problem falls into this category.

Personnel Problems: problems requiring decisions affecting assignment of technical responsibility and authority, organization charts, supervision assignment, and other similar matters. Later discussion will indicate the boundary of this group.

Group Problems: problems concerning sales, costs, expenditures, morale, advertising, prestige, engineering group rewards, incentive plans, etc.

These kinds of problems are tried to be solved by a wide variety of techniques from optimization techniques to engineering economic techniques or from forecasting techniques to production techniques. However, these classical techniques can be used for the solutions of neither Non-deterministic Polynomial-time hard (NP-hard) problems nor the problems with incomplete, vague and/or linguistic data. Intelligent techniques have been developed for the solution of these kinds of problems. Heuristics including intelligent search techniques are the techniques designed for solving these kinds of problems when classical methods fail for finding any exact solution. Heuristics can find exact or approximate solutions in a reasonable time frame that is good enough for solving the problem at hand.

An intelligent system is a formal or informal system to manage gathering data, processing the data, interpreting the data, and providing reasoned judgments to decision makers as a basis for action. Intelligent systems have the ability to solve complex problems, which are hard to solve by classical approaches, and they give optimum or near to optimum solutions within a reasonable time. Engineering management problems are generally complex and hard to solve by traditional methods. Biologically inspired techniques have been recently developed and used in the solutions of these kinds of problems. Metaheuristics such as ant colony optimization, genetic algorithms, artificial bee colony, etc. are intelligent techniques that we can utilize for solving engineering management problems such as maintenance management, project management, quality management, etc. Figure 1.1 represents the relationship of engineering management and intelligent techniques. Any system involving an intelligent solution technique is called an intelligent system.

The aim of this chapter is to present the place of intelligent systems in engineering management area. The rest of the chapter is organized as follows. The engineering management concept is explained in Sect. 1.2. A literature review and classification of works using intelligent systems related to engineering management are given in Sect. 1.3. Trends and future directions for intelligent engineering management are included in Sect. 1.4. The last section concludes the chapter.

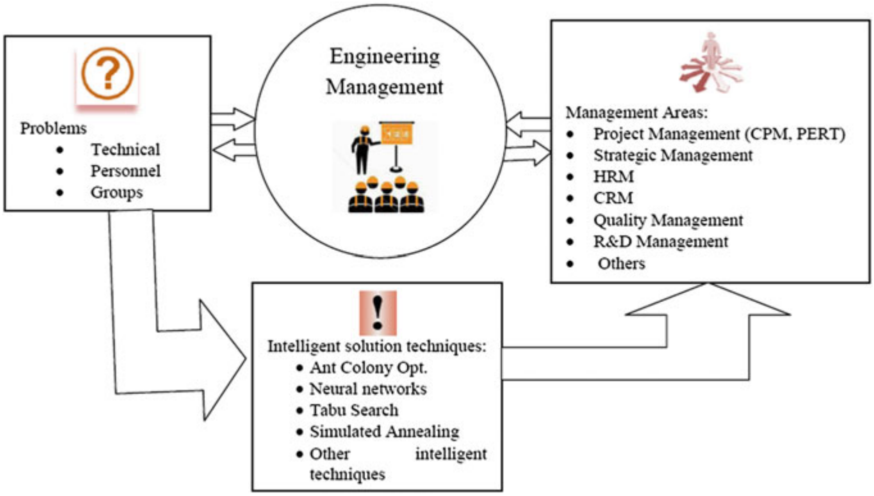


Fig. 1.1 Engineering management problems and intelligent techniques

1.2 Engineering Management

The engineering management discipline does not have a unique definition, since it is a rather new, developing discipline (Xu and Li 2012). It can be defined as the combination of necessary knowledge and skills that an engineer should have in order to be successful in a managerial position (Lannes 2001). According to some researchers, the main purpose of engineering management discipline is to develop products and services which have certain requirements, budget, schedule and risk by using system engineering (Shaw 2002). Engineering Management is also defined as the discipline that focuses on the decision making process for the current and new technologies and impact on interrelated systems (Kocaoglu 2002). Although there are different definitions of Engineering Management, the objective of engineering management discipline can be defined as to apply engineering principles to the business practices. This discipline handles complex managerial and organizational problems with engineering problem solving tools and techniques. These managerial problems involving both people and technology are handled with engineering analysis, design and control processes. Engineering management discipline necessitates both management knowledge and engineering knowledge. Measurement, result orientation, application and technology usage are the main characteristics of engineering discipline. Along with these engineering characteristics, system thinking, systematic approach, modeling and human orientation are the main dimensions of engineering management discipline.

The engineering management discipline has a variety of study areas. Risk management, knowledge management, management and organization, production management, economic and financial management, quality management, marketing and

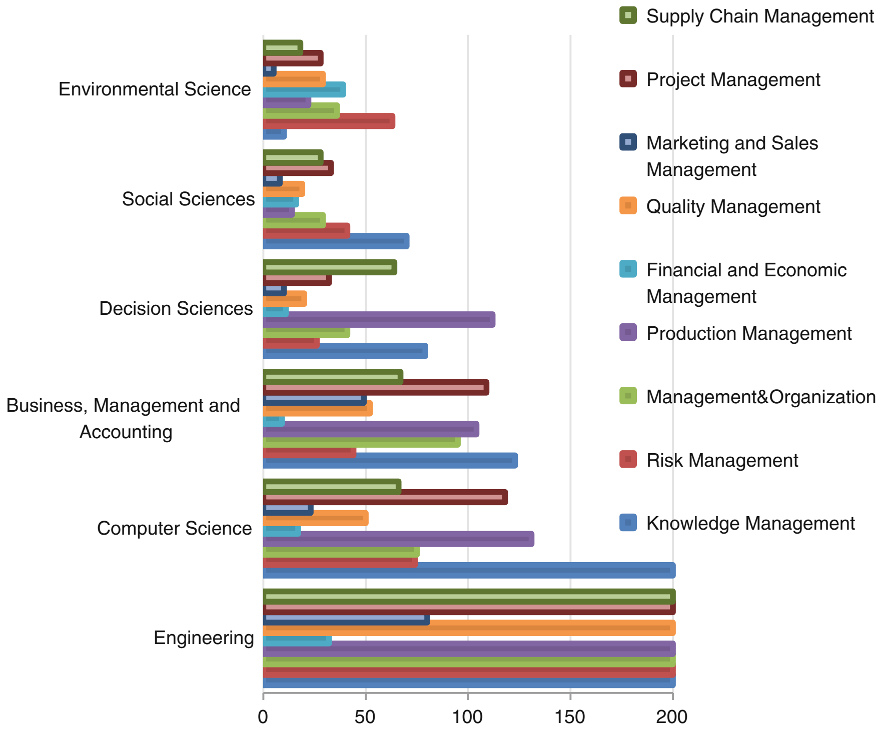


Fig. 1.2 Engineering management study areas and their application fields

sales management, project management, and supply chain management are the main areas that can be analyzed with engineering management perspective. Figure 1.2 shows the results of literature survey using SCOPUS, it illustrates main engineering management study areas and their most commonly applied problem fields.

Knowledge management is the process of effectively managing organizational knowledge. The problems such as strategic software design, innovation strategy selection, and research and development strategy definition are the examples of knowledge management problems that can be solved with engineering management perspective. A literature review for knowledge management with engineering management perspective using SCOPUS gives 495 published papers. Knowledge management with engineering management perspective has been used in different areas such as computer science, engineering, mathematics, business management and accounting, decision sciences, environmental science and social sciences. Knowledge management with engineering management perspective is mostly used for solving engineering and computer science related problems (Fig. 1.2).

Risk management is the process of identifying, evaluating and taking necessary cautions for unwanted events. A literature review for risk management with engineering management perspective using SCOPUS gives 412 published papers and this approach has been used in various areas. The risk management problems in engineering, computer science and environmental science are largely handled with engineering management perspective (Fig. 1.2).

Organizing, leading, planning and controlling are the main functions of management. Engineering approaches can be applied for solving managerial and organizational problems. A literature review for management and organization with engineering management perspective using SCOPUS gives 476 published papers. The strategic management problems, human resource problems and organizational design problems can be solved with engineering management perspective.

Production management focuses on efficiently and effectively converting raw materials into finished goods or products. Facility location and plant layout, maintenance planning and management and materials management are the examples of production management problems that can be solved with engineering management perspective. A literature review for production management with engineering management perspective using SCOPUS gives 597 published papers. Production management with engineering management perspective is mostly used for solving engineering, decision science and computer science related problems (Fig. 1.2).

Financial management and managerial economics try to plan, organize, lead and control financial and economic activities. The engineering perspective improves the problem solving capability of these discipline. A literature review for financial management and managerial economics with engineering management perspective using SCOPUS gives 104 published papers. Financial management and managerial economics with engineering management perspective are mostly used for solving environmental science, engineering, and computer science related problems (Fig. 1.2).

Quality management focuses on maintaining the consistency of the business products, services and the processes. Both the quality services such as developing quality plans, quality control and quality improvement and the approaches such as total quality management have strong ties with engineering management discipline. A literature review for quality management with engineering management perspective using SCOPUS gives 325 published papers. Quality management with engineering management perspective is mostly used for solving engineering, business and computer science related problems (Fig. 1.2).

Marketing and sales management try to plan, organize, lead and control marketing and sales activities of an organization. The marketing and sales resources are managed with the marketing methods and techniques. Engineering management discipline improves these techniques. A literature review for marketing and sales management with engineering management perspective using SCOPUS gives 153 published papers. Marketing and sales management with engineering management perspective are mostly used for solving engineering and business related problems (Fig. 1.2).

A project is a non-routine, one time effort with specific requirements and has budget, time and resource constraints. Project management focuses on planning, organizing, leading and controlling the project related activities. Project planning and project performance evaluation are the examples of the problems in project management that can be improves with engineering management approach. A literature review for project management with engineering management perspective using SCOPUS gives 533 published papers. Project management with engineering management perspective is mostly used for solving engineering, business and computer science related problems (Fig. 1.2).

Supply chain management is the process of managing material and information flow from supplier to the end customer. Logistics management, vehicle routing and warehouse management are some supply chain management problems that can be improved with engineering management. A literature review for supply chain management with engineering management perspective using SCOPUS gives 302 published papers. Supply chain management with engineering management perspective is mostly used for solving engineering, business, computer science and decision science related problems (Fig. 1.2).

1.3 Intelligent Systems

Intelligent systems (IS) are able to handle more complex situations and make more complex decisions. IS includes a range of techniques that provide flexible data/information processing capabilities for handling real life situations. IS can exploit the tolerance for imprecision, uncertainty/ambiguities, approximate reasoning and partial truth in order to achieve tractability, robustness, and low cost solutions. IS techniques are in general based on biologically inspired strategies for solving problems (Hines et al. 2008). IS techniques include neural networks, fuzzy systems, evolutionary algorithms, genetic programming, support vector machines, particle swarm optimization, memetic algorithms, and ant colony optimization.

1.3.1 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking. PSO applies the concept of social interaction to problem solving. PSO is a simple but powerful search technique. It has been applied successfully to a wide variety of search and optimization problems.

1.3.2 Genetic Algorithms (GA)

Genetic algorithm (GA) search methods are rooted in the mechanisms of evolution and natural genetics. GAs are part of the adaptive stochastic optimization algorithms involving search and optimization. GAs provide an alternative to traditional optimization techniques by using directed random searches to locate optimal solutions in complex landscapes. Genetic Algorithms are a family of computational models inspired by evolution. These algorithms encode a potential solution to a specific problem on a simple chromosome like data structure and apply recombination operators to these structures so as to preserve critical information.

1.3.3 Fuzzy Sets (FS)

Fuzzy sets are the basic concept supporting the fuzzy set theory. The main research fields in the fuzzy set theory are fuzzy sets, fuzzy logic, and fuzzy measure. Fuzzy reasoning or approximate reasoning is an application of fuzzy logic to knowledge processing. Fuzzy control is an application of fuzzy reasoning to control devices. One feature of FSs is the ability to realize a complex nonlinear input–output relation as a synthesis of multiple simple input–output relations. The fuzzy set theory has been used in several intelligent technologies by today ranging from control, automation technology, robotics, image processing, pattern recognition, medical diagnosis etc. Fuzzy logic and fuzzy set theory have been successfully applied to handle imperfect, vague, and imprecise information. Different generalizations and extensions of fuzzy sets have recently been introduced (Rodriguez et al. 2012): Type-2 fuzzy sets, nonstationary fuzzy sets, intuitionistic fuzzy sets, fuzzy multisets, and hesitant fuzzy sets.

1.3.4 Ant Colony Optimization (ACO)

Ant Colony Optimization (ACO) is a metaheuristic approach for solving hard combinatorial optimization problems. The basic idea of ACO is to imitate the cooperative behavior of ant colonies. When searching for food, ants initially explore the area surrounding their nest in a random manner. As soon as an ant finds a food source, it evaluates it and carries some food back to the nest. During the return trip, the ant deposits a pheromone trail on the ground. The pheromone deposited, the amount of which may depend on the quantity and quality of the food, guides other ants to the food source. Quantity of pheromone on the arc is decreased in time due to evaporating. Each ant decides to a path or way according to the quantity of pheromone which has been leaved by other ants. More pheromone trail consists in short path than long path. Because the ants drop pheromones every time they bring food, shorter paths are more likely to be stronger, hence optimizing the solution.

1.3.5 Artificial Bee Colony Optimization (ABCO)

Artificial bee colony (ABC) algorithm is a relatively new member of swarm intelligence. It has received increasing interest because of its simplicity, wide applicability, and outstanding performance. Honey bees use several mechanisms like waggle dance to optimally locate food sources and to search new ones. This makes them a good candidate for developing new intelligent search algorithms. In the ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. A bee waiting on the dance area for making decision to choose a food source is called an onlooker and a bee going to the food source visited by itself previously is named an employed bee. A bee carrying out random search is called a scout. In the ABC algorithm, first half of the colony consists of employed artificial bees and the second half constitutes the onlookers. For every food source, there is only one employed bee. The employed bee whose food source is exhausted by the employed and onlooker bees becomes a scout (Karaboga and Basturk 2007).

1.3.6 Neural Networks (NN)

Neural network (NN) models are inspired by brain processes and structures at almost the lowest level, while symbolic AI models by processes at the highest level. Artificial neural networks (ANN) have been developed as generalizations of mathematical models of biological nervous systems. In other words; ANNs, or simply neural networks, are information processing systems that roughly replicate the behavior of a human brain by emulating the operations and connectivity of biological neurons. ANN models can be used to infer a function from observations. This is particularly useful in applications where the complexity of the data or task makes the design of such a function by hand impractical. ANNs can be trained directly from data. ANNs can be used to extract patterns and detect trends thus it can be applied to data classification and nonlinear functional mapping. Specific application examples include process modeling, control, machine diagnosis, and real-time recognition.

1.3.7 Simulated Annealing (SA)

Simulated annealing (SA) methods are methods proposed for the problem of finding, numerically, a point of the global minimum of a function defined on a subset of a k-dimensional Euclidean space. The motivation of the methods lies in the physical process of annealing, in which a solid is heated to a liquid state and, when cooled sufficiently slowly, takes up the configuration with minimal inner energy. SA algorithm is a technique to find a good solution of an optimization problem using a random variation of the current solution. A worse variation is accepted as the new solution with a probability that decreases as the computation proceeds. The slower the cooling schedule, or rate of decrease, the more likely the algorithm is to find an optimal or near-optimal solution (Xinchao 2011).

1.3.8 Tabu Search (TS)

The word tabu (or taboo) comes from Tongan, a language of Polynesia, where it was used by theaborigines of Tonga island to indicate things that cannot be touched because they are sacred. According to Webster's Dictionary, the word now also means "a prohibition imposed by social custom as a protective measure" or of something "banned as constituting a risk." Tabu search (TS) is a higher level heuristic algorithm for solving combinatorial optimization problems. It is an iterative improvement procedure that starts form an initial solution and attempts to determine a better solution.

1.3.9 Swarm Intelligence (SI)

Social insects work without supervision. In fact, their teamwork is largely self-organized, and coordination arises from the different interactions among individuals in the colony. Although these interactions might be primitive, taken together they result in efficient solutions to difficult problems. SI indicates a recent computational and behavioral metaphor for solving distributed problems that originally took its inspiration from the biological examples provided by social insects (ants, termites, bees, wasps) and by swarming, flocking, herding behaviors in vertebrates.

1.3.10 Differential Evolution (DE)

DE is known as population-based optimization algorithm similar to GAs using similar operators; crossover, mutation and selection. DE algorithm uses mutation operation as a search mechanism and selection operation to direct the search toward the prospective regions in the search space. In addition to this, the DE algorithm uses a non-uniform crossover which can take child vector parameters from one parent more often than it does from others. By using the components of the existing population members to construct trial vectors, the recombination (crossover) operator efficiently shuffles information about successful combinations, enabling the search for a better solution space.

1.3.11 Evolutionary Algorithms (EA)

Evolutionary algorithms (EA) are search methods that take their inspiration from natural selection and survival of the fittest in the biological world. EAs differ from more traditional optimization techniques in that they involve a search from a "population" of solutions, not from a single point. Each iteration of EA involves a competitive selection that weeds out poor solutions. The solutions with high "fitness" are "recombined" with other solutions by swaping parts of a solution with another. Solutions are also "mutated" by making a small change to a single element of the solution. Recombination and mutation are used to generate new solutions that are biased towards regions of the space for which good solutions have already been seen (Hines et al. 2008).

Intelligent systems have been used in engineering management problems since the end of 1990s. Wang et al. (1998) introduce an intelligent constraint networks management system in concurrent engineering. They present its function frame, and then introduces several main key techniques: visual dynamic simulation, case indexing and retrieval in case-based reasoning system, and hybrid modelling. Prasad (2000) converts computer-integrated manufacturing into an intelligent information system by combining CIM with concurrent engineering and knowledge management. Hu et al. (2002) discuss an intelligent system for the design of demolition blasting, determination of blasting parameters, pretreatment, vibration-control and protection measures and others according to the reasons of accidents occurred in some demolition blasting projects. Johnson (2007) examines "triple helix" collaborations, which are technology development projects that consist of industry, academia, and government partners. He provides engineering managers with a process for engaging in such collaborations. The process offered follows the general stages of a typical project and discusses the challenges that may arise at each stage. The introduction of a fourth party called a "4th Pillar organization" is recommended as a solution to the difficult process of managing triple helix projects. Durakbasa et al. (2012) propose an intelligent design and advanced metrology to support and improve integrated management systems for quality, environment and energy in production engineering. Shao and Fu (2014) propose a framework of intelligent building engineering information management system. Firstly, they illustrate an overview of intelligent building, which include three main parts: (1) Resources, (2) Construction process and (3) Building products. Particularly, the typical services in intelligent buildings construction contain seven types of services, such as Climate controlling, Light control, Safety and security, Traffic condition, Energy consumption control, communication support, and others. Secondly, information processing process of intelligent building engineering information management system is described and framework of the heterogeneous digital system in an intelligent building is proposed. Thirdly, their intelligent building system is organized as the Server/Client structure, and detection module, Engineering information management module, and System maintenance module are included in this system. Mora et al. (2014) propose an intelligent decision-making support systems approach for IT service management and engineering. Trappey et al. (2015) develop an intelligent engineering asset management system for power transformer maintenance. The system performs real-time monitoring of key parameters and uses data mining and fault prediction models to detect transformers' potential failure under various operating conditions. Principal component analysis (PCA) and a back-propagation artificial neural network (BP-ANN) are the algorithms adopted for the prediction model. Historical industrial power transformer data from Taiwan and Australia are used to train and test the failure prediction models and to verify the proposed general methodology as comparative case studies. The PCA algorithm reduces the number of the primary dissolved gasses as the key factor values for BP-ANN prediction modeling inputs. The accuracy rates are much higher when compared to the fault prediction results without using PCA.

1.4 Trends for Intelligent Techniques

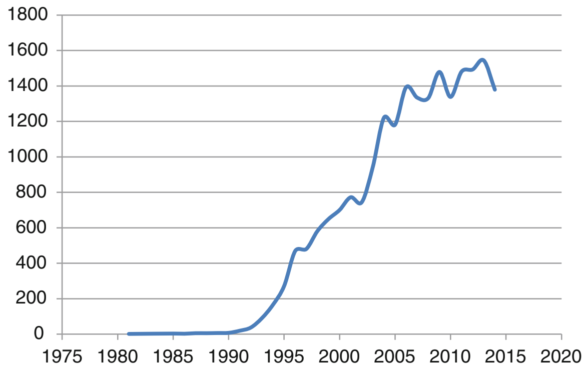
In this subsection we show the usage frequencies of intelligent techniques in the article titles and give the numbers of articles on engineering and management.

Figure 1.3 shows the usage frequencies of GA with respect to publication years. 11,948 over the total 2,1277 GA articles published between 1981 and 2015 are on engineering while 606 of the total are on business, management, and accounting.

Figure 1.4 shows the usage frequencies of PSO with respect to publication years. 3449 over the total 6048 PSO articles published between 1998 and 2015 are on engineering while 90 of the total are on business, management, and accounting.

Figure 1.5 shows the usage frequencies of fuzzy optimization with respect to publication years. 1198 over the total 1975 fuzzy optimization articles published between 1981 and 2015 are on engineering while 48 of the total are on business, management, and accounting.

Fig. 1.3 Usage frequencies of GA with respect to years



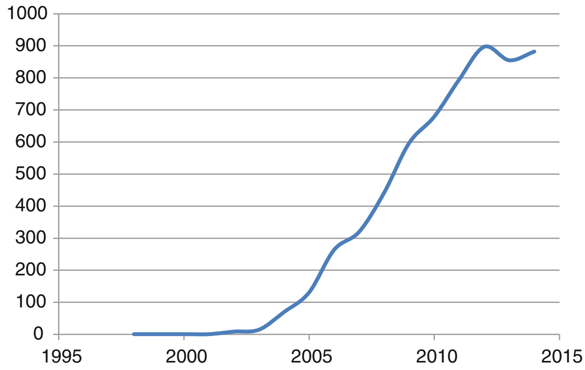


Fig. 1.4 Usage frequencies of PSO with respect to years

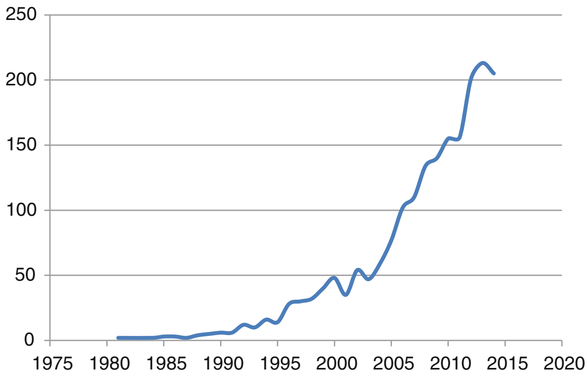


Fig. 1.5 Usage frequencies of fuzzy optimization with respect to years

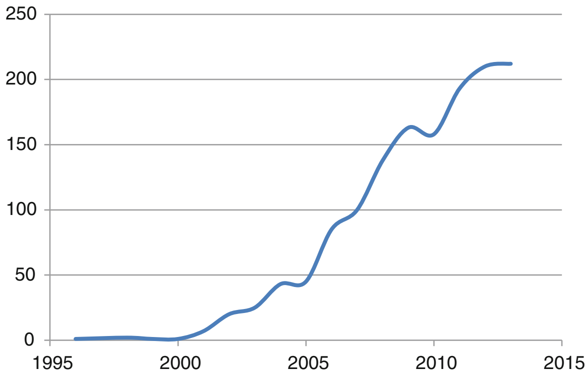


Fig. 1.6 Usage frequencies of ACO with respect to years

Figure 1.6 shows the usage frequencies of ACO with respect to publication years. 864 over the total 1619 ACO articles published between 1996 and 2015 are on engineering while 59 of the total are on business, management, and accounting.

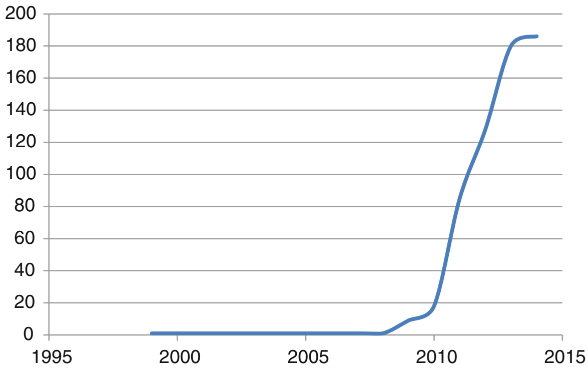


Fig. 1.7 Usage frequencies of ABC with respect to years

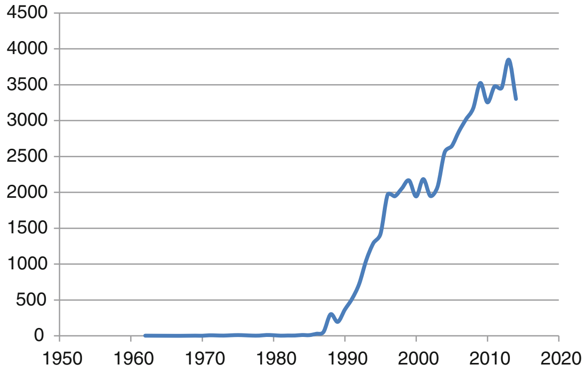


Fig. 1.8 Usage frequencies of NN with respect to years

Figure 1.7 shows the usage frequencies of ABC with respect to publication years. 329 over the total 633 ABC articles published between 1999 and 2015 are on engineering while 12 of the total are on business, management, and accounting.

Figure 1.8 shows the usage frequencies of NN with respect to publication years. 26,345 over the total 26,345 NN articles published between 1962 and 2015 are on engineering while 956 of the total are on business, management, and accounting.

Figure 1.9 shows the usage frequencies of SA with respect to publication years. 1562 over the total 3440 SA articles published between 1967 and 2015 are on engineering while 104 of the total are on business, management, and accounting.

Figure 1.10 shows the usage frequencies of TS with respect to publication years. 646 over the total 1415 TS articles published between 1987 and 2015 are on engineering while 109 of the total are on business, management, and accounting.

Figure 1.11 shows the usage frequencies of SI with respect to publication years. 178 over the total 406 SI articles published between 2001 and 2015 are on engineering while 9 of the total are on business, management, and accounting.

Figure 1.12 shows the usage frequencies of DE with respect to publication years. 1104 over the total 2454 DE articles published between 1934 and 2015 are on engineering while 33 of the total are on business, management, and accounting.

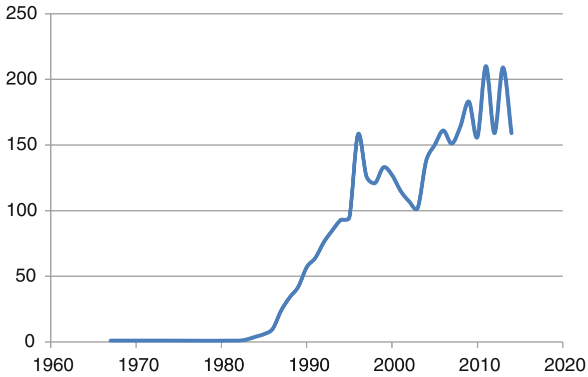


Fig. 1.9 Usage frequencies of SA with respect to years

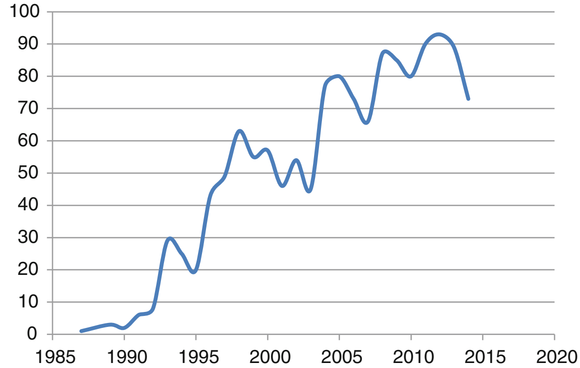


Fig. 1.10 Usage frequencies of Tabu search with respect to years

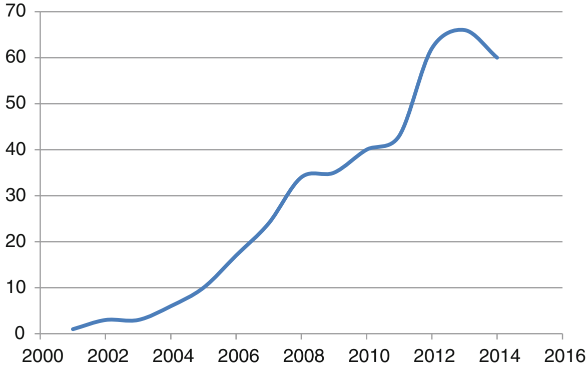


Fig. 1.11 Usage frequencies of SI with respect to years

Figure 1.13 shows the usage frequencies of EA with respect to publication years. 1616 over the total 3348 EA articles published between 1982 and 2015 are on engineering while 72 of the total are on business, management, and accounting.

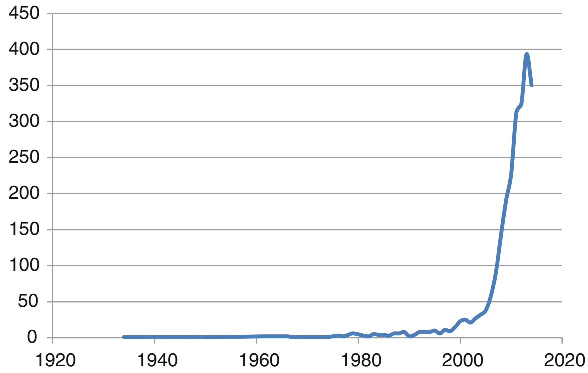


Fig. 1.12 Usage frequencies of DE with respect to years

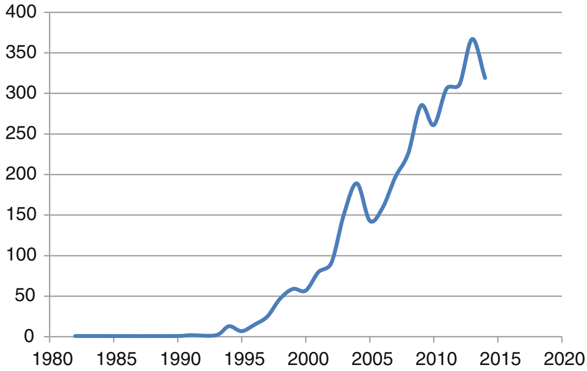


Fig. 1.13 Usage frequencies of EA with respect to years

1.5 Conclusion

Engineering management is a field that concentrates on the application of engineering principles for the effective planning and efficient operations of managing manufacturing or industrial operations. Risk management, customer relationship management, quality management, strategic management, human resources management, marketing and sales management and financial management are all the functions of engineering management field. Intelligent techniques are extensively used in the solutions of engineering management problems since they provide optimum or near to optimum solutions in a reasonable time where the traditional techniques are insufficient for solving these complex problems. Our literature survey showed that the intelligent systems are more and more used for solving complex engineering management problems in recent years. Especially metaheuristics are the tools of intelligent systems used in engineering management.

For further research, we suggest some real application examples of intelligent systems in the various areas of engineering management to be given.

References

Damodaran, P., Vohra, P., Ghrayeb, O.: Glob. J. Eng. Educ. **16**(1), 43–46 (2014)

Hines, E., Leeson, M., Martinez-Ramon, M., Pardo, M., Llobet, E., Lliescu, D., Yang, J. (eds.): Preface in Intelligent Systems: Techniques and Applications, pp. vi–xiv. Shaker Publishing, The Netherlands (2008)

Hu, G., Wang, Z., Yang, J.: Strengthen study of blasting technology and engineering management for ensuring safety of demolition blasting. Process Saf. Sci. Technol. Part B **3**, 1407–1410 (2002)

Johnson, W.H.A.: Managing collaborations of engineering management with academia and government in triple helix technology development projects: a case example of precarn from the intelligent systems sector. EMJ Eng. Manage. J. **19**(2), 12–22 (2007)

Karaboga, D., Basturk, B.: A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm. J. Glob. Optim. **39**(3), 459–471 (2007)

Kocaoglu, D.F.: Research and educational characteristics of the engineering management discipline. IEEE Trans. Eng. Manage. **37**(3), 172–176 (2002)

Lannes III, W.J.: What is engineering management? IEEE Trans. Eng. Manage. **48**(1), 107–115 (2001)

Mora, M., Marx-Gómez, J., Wang, F., Gelman, O.: IT service management and engineering: an intelligent decision-making support systems approach. Intell. Decis. Technol. **8**(2), 65–68 (2014)

Numan Durakbasa, M., Herbert Osanna, P., Bas, G.: Intelligent design and advanced metrology to support and improve integrated management systems for quality, environment and energy in production engineering. Qual. Access Success **13**(SUPPL.5), 17–22 (2012)

Prasad, B.: Converting computer-integrated manufacturing into an intelligent information system by combining CIM with concurrent engineering and knowledge management. Ind. Manage. Data Syst. **100**(7), 301–316 (2000)

Rodriguez, R.M., Martinez, L., Herrera, F.: Hesitant fuzzy linguistic term sets for decision making. IEEE Trans. Fuzzy Syst. **20**(1), 109–119 (2012)

Shao, H., Fu, H.: Design and implementation of intelligent building engineering information management system. In: Proceedings—7th International Conference on Intelligent Computation Technology and Automation, ICICTA 2014, pp. 158–161. Changsha, Hunan, China, 25–26 Oct 2014

Shaw, W.H.: Engineering management in our modern age. In: 2002 IEEE International Engineering Management Conference, 2002. In: IEMC 2002, vol. 2, pp. 504–549 (2002)

Trappey, A.J.C., Trappey, C.V., Ma, L., Chang, J.C.M.: Intelligent engineering asset management system for power transformer maintenance decision supports under various operating conditions. Comput. Indus. Eng. (2015) (Article in press)

Wang, H., Dai, J., Liao, Y., Ma, X.: Intelligent networks management system in concurrent engineering. Gaojishu Tongxin/High Technol. Lett. **8**(6), 29–33 (1998)

Xinchao, Z.: Simulated annealing algorithm with adaptive neighborhood. Appl. Soft Comput. **11** (2), 1827–1836 (2011)

Xu, J., Li, Z.: A review on ecological engineering based engineering management. Omega **40** (2012), 368–378 (2012)

Part II
Risk Management

Chapter 2
Possibilistic Models of Risk Management

Irina Georgescu, Jani Kinnunen and Ana Maria Lucia-Casademunt

Abstract In the traditional treatment, risk situations are modeled by random variables. This chapter focuses on risk situations described by fuzzy numbers. The first goal of the chapter is to define and characterize possibilistic risk aversion and study some of its indicators. The second goal is the study of two possibilistic models of risk management: a coinsurance problem and an investment portfolio problem.

Keywords Risk management · Fuzzy sets · Possibility · Static portfolio · Coinsurance

2.1 Introduction

Risk aversion is an important topic in decision making under uncertainty. The first crucial contributions on this topic were brought by Arrow (1965, 1970) and Pratt (1964). They defined the risk aversion of an agent, they showed how it could be

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evaluated and how two agents' risk aversions could be compared. Then the literature dedicated to risk aversion considerably increased (see e.g. Eeckhoudt et al. (2005), Laffont (1993), Mas-Colell et al. (1995), Ross (1981)), which led to several applications in risk management. The monograph (Eeckhoudt et al. 2005) presents such applications in insurance decision, static and dynamic portfolio choices, consumption and saving, optimal prevention, etc.

The whole risk theory was based on probability theory. The notions and theorems on risk are formulated in terms of probabilistic indicators (expected value, variance, covariance, etc.). However the probability theory cannot model all risk situations related to economic and social phenomena. Zadeh's possibility theory (Zadeh 1978) offers another way of treating mathematically uncertainty (see also Carlsson and Fullér (2011), Dubois and Prade (1988), (1987)). In Georgescu (2009), (2010), (2012), Georgescu and Kinnunen (2012) a few possibilistic models of risk aversion based on a notion of possibilistic expected utility are studied. In the possibilistic approach, the risk is modeled by fuzzy numbers and possibilistic indicators of fuzzy numbers (expected value, variance, covariance, etc.) are used in order to formulate the definitions and the theorems of possibilistic theory.

This chapter continues the investigations of Georgescu (2009), (2010). It has two main goals:

- to develop some new aspects of possibilistic risk aversion
- to apply this theory to two models of risk management: the coinsurance problem and an investment portfolio problem.

The chapter is organized as follows.

In Sect. 2.2 fuzzy numbers and their indicators are presented. Due to their remarkable properties, the fuzzy numbers constitute the most important class of possibilistic distributions (Carlsson and Fullér 2011; Dubois and Prade 1988; Georgescu 2012). They allow us to define some possibilistic indicators analogues with the well-known indicators of random variables. The possibilistic expected value $E_f(A)$ from Carlsson and Fullér (2001), (2011), two notions of possibilistic variance $Var_f(A)$ from Carlsson and Fullér (2001), Fullér and Majlender (2003), (2004) and $Var_f^*(A)$ from Georgescu (2009) are recalled. $Var_f^*(A)$ is more useful than $Var_f(A)$ in the evaluation of possibilistic risk aversion (see Georgescu (2009), (2010), (2012), Georgescu and Kinnunen (2012)). For example, in Georgescu (2009), (2012) the possibilistic risk premium is expressed in terms of $E_f(A)$ and $Var_f(A)$.

Section 2.3 is dedicated to a notion of possibilistic expected utility (associated with a fuzzy number, a utility function and a weighting function) and some of their properties (Georgescu 2009). Among the results of this section we mention an approximation formula of possibilistic expected utility.

In Georgescu (2009), (2012), Georgescu (2010), Georgescu and Kinnunen (2012) we studied the risk aversion of an agent faced to a risk situation described by a fuzzy number. We defined the possibilistic risk premium as a measure for risk aversion and we proved some basic properties of this indicator. However in these papers there exists no definition of what we mean that an agent is risk–averse. In Sect. 2.4 we define a possibilistic risk–averse, a possibilistic risk–lover and a possibilistic risk–neutral agent (represented by a utility function u). These three concepts are characterized by the concavity, convexity and linearity of the utility function u. Some surprising conclusions are reached: an agent is possibilistic risk–averse iff it is probabilistic risk–averse, etc. (in the sense of Eeckhoudt et al. (2005), p. 8).

In Sect. 2.5 two new notions of possibilistic risk premium are defined and they are connected with the one from Georgescu (2009). The section also contains an approximate calculation formula for these indicators of risk aversion and a more complete form of possibilistic Pratt theorem of Georgescu (2010). Finally a characterization theorem of those utility functions for which the possibilistic risk premium is decreasing in wealth is proved.

Section 2.6 tackles the coinsurance problem in the context of possibilistic risk. Insurance contracts for which the loss is modeled by a fuzzy number are studied. Then the mean sum retrieved by the policyholder is a possibilistic expected utility and on its basis the possibilistic premium for insurance indemnity is defined. The optimal coinsurance rate is determined as a solution of a decision problem for which the objective function is expressed as a possibilistic expected utility. Properties of optimal coinsurance rate, its calculation and the way it changes with the variation of the initial wealth are studied.

Section 2.7 deals with a possibilistic model of an investment portfolio problem. The case of a risk–averse agent who invests in a risk–free asset and a risky asset is studied. Our model is based on the hypothesis that the return of the risky asset is described by a fuzzy number. To determine an investment with a maximum payoff a decision problem should be solved whose objective function is a possibilistic expected utility. Several properties of the optimal solution are studied and an approximate calculation formula is proved.

2.2 Fuzzy Numbers and Their Indicators

In this section we recall the definition of fuzzy numbers, their operations and two of their indicators (expected value and variance) (see Carlsson and Fullér (2011), Dubois and Prade (1980), (1988), Majlender (2004)).

Let X be a non–empty set. Following Zadeh (1965), a *fuzzy subset* of X is a function $A : X \rightarrow [0, 1]$. A fuzzy subset A of X is *normal* if there exists $x \in X$ such that $A(x) = 1$. The *support* of a fuzzy set A is $\sup p(A) = \{x \in X | A(x) > 0\}$.

Throughout this chapter,we shall consider that $X = R$. For $\gamma \in [0, 1]$, let the γ-level set $[A]^\gamma$ of a fuzzy subset A of R (see Carlsson and Fullér (2011), Dubois and Prade (1980)). The fuzzy set A is called *fuzzy convex* if $[A]^\gamma$ is a convex subset in R for any $\gamma \in [0, 1]$.

Definition 2.1 A fuzzy subset A of R is called fuzzy number if A is normal, fuzzy convex, upper semicontinuous and with bounded support.

If A, B are two fuzzy numbers and $\lambda \in R$, the fuzzy numbers $A + B$ and λA are defined by

$$(A + B)(x) = \sup_{y+z=x} \min(A(y), B(z));$$
$$(\lambda A)(x) = \sup_{\lambda y=x} A(y).$$

If $A_1, \ldots, A_n$ are fuzzy numbers and $\lambda_1, \ldots, \lambda_n \in R$, then one can consider the fuzzy number $\sum_{i=1}^{n} \lambda_i A_i$.

A non–negative and monotone increasing function $f : [0, 1] \to R$ is a *weighting function* if it satisfies the normality condition $\int_0^1 f(\gamma)d\gamma = 1$.

We fix a fuzzy number A and a weighting function f such that $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for all $\gamma \in [0, 1]$.

Definition 2.2 (Fullér and Majlender 2003) The f-weighted possibilistic expected value of A is defined by $E_f(A) = {}^1\!/_2 \int_0^1 (a_1(\gamma) + a_2(\gamma))f(\gamma)d\gamma$.

Remark 2.3 (Carlsson and Fullér 2011) If $A_1, \ldots, A_n$ are fuzzy numbers and $\lambda_1, \ldots, \lambda_n \in R$ then $E_f(\sum_{i=1}^{n} \lambda_i A_i) = \sum_{i=1}^{n} \lambda_i E_f(A_i)$.

Definition 2.4 (Fullér and Majlender 2003) The f-weighted possibilistic variance of A is defined by $Var_f(A) = {}^1\!/_2 \int_0^1 (a_1(\gamma) - a_2(\gamma))^2 f(\gamma)d\gamma$.

These two possibilistic indicators have important mathematical properties and they have been used in the construction of models with applications to strategic investment planning, fuzzy real options for strategic decisions, portfolio selection with imprecise data, risk assessment in grid computing, etc. (see Carlsson and Fullér (2011), Majlender (2004), Mezei (2011)).

In Georgescu (2009) another notion of possibilistic variance $Var_f^*(A)$ was defined, necessary to the possibilistic risk aversion model from that paper.

Definition 2.5 (Georgescu 2009)
$Var_f^*(A) = \int_0^1 [\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} (x - E_f(A))^2 dx] f(\gamma)d\gamma$.

The next proposition contains a computation formula for $Var_f^*(A)$.

Proposition 2.6 (Georgescu 2009)
$Var_f^*(A) = {}^1\!/_3 \int_0^1 [a_1^2(\gamma) + a_2^2(\gamma) + a_1(\gamma)a_2(\gamma)] f(\gamma)d\gamma - E_f^2(A)$.

2.3 Possibilistic Expected Utility

As far as we know from Eeckhoudt et al. (2005), Georgescu and Kinnunen (in press), Mas-Colell et al. (1995), Quiggin (1993), the probabilistic risk theory is developed in the framework of expected utility theory. A notion of possibilistic expected utility was introduced in Fullér and Majlender (2003), Georgescu (2009), then it was used in the construction of some possibilistic models (Carlsson and Fullér 2011; Georgescu 2009, 2012; Georgescu 2010; Georgescu and Kinnunen 2012; Majlender 2004; Mezei 2011).

In this section we recall this notion of possibilistic expected utility and some of its main properties.

We fix a weighting function $f : [0, 1] \to R$ and a fuzzy number A such that $[A]^{\gamma} = [a_1(\gamma), a_2(\gamma)]$ for any $\gamma \in [0, 1]$.

We consider a utility function u of class C^2. Sometimes the domain of the utility function will be $[0, \infty)$ or a real interval $[m, M]$.

Definition 3.1 (Fullér and Majlender 2003) The possibilistic expected utility $E_f(u(A))$ associated with *f*, *A* and *u* is $E_f(u(A)) = \int_0^1 [\frac{1}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u(x)dx]f(\gamma)d\gamma$.

Each time we use the right hand side integral above we will assume that this integral is finite.

Remark 3.2 (i) If u is the identity function then $E_f(u(A)) = E_f(A)$; (ii) If $u(x) = (x - E_f(A))^2$ for all $x \in R$, then $E_f(u(A)) = Var_f^*(A)$; (iii) If $\lambda \in R$ and $A(x) = \lambda$ for all $x \in R$, then $E_f(u(A)) = \lambda$.

Proposition 3.3 (Georgescu 2009) *Let $g : R \to R$ and $h : R \to R$ be two utility functions and $a, b \in R$. We consider the utility function $u = ag + bh$. Then $E_f(u(A)) = aE_f(g(A)) + bE_f(h(A))$.*

Proposition 3.4 (Georgescu 2009) *Let $g : R \to R$ and $h : R \to R$ be two utility functions such that $g(x) \leq h(x)$ for all $x \in R$. Then $E_f(g(A)) \leq E_f(h(A))$.*

Corollary 3.5 *Let $g : R \to R$ be a utility function.*
(i) If $g(x) \geq 0$ for all $x \in R$, then $E_f(u(A)) \geq 0$.
(ii) If $g(x) \leq 0$ for all $x \in R$, then $E_f(u(A)) \leq 0$.

Corollary 3.6 *Let $g : R \to R$ be a utility function and $a \leq b$ be two real numbers. If $a \leq g(x) \leq b$ for any $x \in R$, then $a \leq E_f(g(A)) \leq b$.*

Proposition 3.7 *Let A be a fuzzy number and $\lambda \in R$. Then $Var_f^*(\lambda + A) = Var_f^*(A)$.*

The following result establishes an approximation formula of the possibilistic expected utility $E_f(u(A))$.

Proposition 3.8 *If the utility function u is of class C_2 then*

$$E_f(u(A)) \approx u(E_f(A)) + \frac{1}{2}u''(E_f(A))Var_f(A)$$

Proof According to the Taylor approximation formula of order II:

$$u(x) \approx u(E_f(A)) + u'(E_f(A))(x - E_f(A)) + \frac{1}{2}u''(E_f(A))(x - E_f(A))^2$$

Let us consider the following functions:

$$\begin{aligned} g(x) &= x - E_f(A), \quad x \in R \\ h(x) &= (x - E_f(A))^2, \quad x \in R \end{aligned}$$

We remark then g = 1_A − $E_f(A)$. Let us denote $a = u(E_f(A))$, $b = u'(E_f(A))$, $c = \frac{1}{2}u''(E_f(A))$. It follows that $u \approx a + bg + ch$.

By Proposition 3.3 one gets

$$E_f(u(A)) \approx E_f((a + bg + ch)(A)) = a + bE_f(g(A)) + cE_f(h(A))$$

Since g = 1_A − $E_f(A)$) it follows that

$$E_f(g(A)) = E_f(x - E_f(A))(A)) = E_f(A) - E_f(A) = 0.$$

According to Remark 3.2(ii), $E_f(h(A)) = Var_f(A)$ therefore

$$E_f(u(A)) \approx u(E_f(A)) + \frac{1}{2}u''(E_f(A))Var_f(A).$$

□

Remark 3.9 If the integral of Definition 3.1 is not finite then one can define the value of possibilistic utility $E_f(u(A))$ by the right member of the equality of Proposition 3.8.

Example 3.10 Let us consider the triangular fuzzy number A = (a, α, β) defined by

$$A(t) = \begin{cases} 1 - \frac{a-t}{\alpha}, & if\ a - \alpha \le t \le a \\ 1 - \frac{t-a}{\beta}, & if\ a \le t \le a + \beta \\ 0, & otherwise \end{cases}$$

(a ∈ **R** and α, β > 0)

We assume that the weighting function f has the form $f(\gamma) = 2\gamma$, for any $\gamma \in [0, 1]$.

According to Georgescu (2012, p. 11), the level sets of the triangular fuzzy number A = (a, α, β) have the form $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$, where $a_1(\gamma) = a - (1 - \gamma)\alpha$ and $a_2(\gamma) = a + (1 - \gamma)\beta$.

By Georgescu (2012, p. 25, 29), the possibilistic expected value $E_f(A)$ and the possibilistic variance $Var_f^*(A)$ have the following expressions:

$$E_f(A) = a + \frac{\beta - \alpha}{6}, Var_f^*(A) = \frac{\alpha^2 + \beta^2}{36}$$

Applying Proposition 3.8, we find the following approximate value of $E_f(u(A))$:

$$E_f(u(A)) \approx u(a + \frac{\beta - \alpha}{6}) + \frac{\alpha^2 + \beta^2}{72} u''(a + \frac{\beta - \alpha}{6})$$

As regards to the form of the utility function u and the numerical values of a, α, β, we will be able to compute the approximate value of $E_f(u(A))$.

For example, if $u(x) = \ln x$ and A = (4, 2, 1) then $E_f(u(A)) \approx 1.331$.

2.4 Possibilistic Risk Aversion

In this section we will consider an agent faced with a risk situation. The agent is represented by a utility function and the risk is described by a fuzzy number. Using the possibilistic expected utility we will define a risk–averse, a risk-lover and a risk–neutral agent. We will prove that these notions are characterized by the concavity, convexity or linearity of the utility function. We identify an agent with its utility function.

We fix a weighting function and a utility function u of class C^2.

Definition 4.1 The agent u is possibilistic risk–averse if for any wealth level w and for any fuzzy number A the following inequality holds:
(1) $E_f(u(w + A)) \leq u(w + E_f(A))$.

When the opposite inequality holds, the agent u is possibilistic risk–lover, and if (1) becomes equality the agent u is possibilistic risk–neutral.

Lemma 4.2 *The following assertions are equivalent:*
(a) The agent u is risk–averse.
(b) For any wealth level w and any fuzzy number B with $E_f(B) = 0$*, the following inequality holds:*
(2) $E_f(u(w + B)) \leq u(w)$.

Proof $(a) \Rightarrow (b)$ is obvious; $(b) \Rightarrow (a)$: Denoting $B = A - E_f(A)$, we have $E_f(B) = 0$. Applying (2) for this B and for $w + E_f(A)$ instead of w it follows that $E_f(u(w + A)) = E_f(u(w + E_f(A) + B)) \leq u(w + E_f(A))$. □

Proposition 4.3 *The following assertions are equivalent:*
(i) The function u is concave.
(ii) The agent u is risk–averse.

Proof $(i) \Rightarrow (ii)$: Let A be an arbitrary fuzzy number and $m = E_f(A)$. The second order Taylor approximation of $u(w+x)$ around $w+m$ gives us
(3) $u(w+x) = u(w+m) + u'(w+m)(x-m) + {}^1\!/_2 u''(\xi(x))(x-m)^2$, where $\xi(x)$ is a real number between x and m.

By Proposition 3.3,

$$E_f(u(w+A)) = u(w+m) + u'(w+m)E_f(A-m) + {}^1\!/_2 E_f(u''(\xi(A))(A-m)^2)$$

Since $E_f(A-m) = E_f(A) - m = 0$, we obtain
(4) $E_f(u(w+A)) = u(w+m) + {}^1\!/_2 E_f(u''(\xi(A))(A-m)^2)$.

Let $g(x) = u''(\xi(x))(x-m)^2$ for $x \in R$. Since u is concave, we have $u''(\xi(x)) \le 0$, therefore $g(x) \le 0$ for any $x \in R$. Applying Corollary 3.5(ii) it follows that $E_f(u''(\xi(A))(A-m)^2) = E_f(g(A)) \le 0$.

Then, by (4), $E_f(u(w+A)) \le u(w+A)$ for any w. Thus the agent u is possibilistic risk–averse.

$(ii) \Rightarrow (i)$: Assume that the function u is not concave. Then there exists $w \in R$ and an interval $I = [w-\delta, w+\delta]$ such that $u'(x) > 0$ for any $x \in I$.

We choose a fuzzy number A such that $supp(A) \subseteq I$. If $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for $\gamma \in [0,1]$, then $[a_1(0), a_2(0)] = supp(A) \subseteq I$. For any $\gamma \in [0,1]$, $[a_1(\gamma), a_2(\gamma)] \subseteq [a_1(0), a_2(0)] \subseteq I$.

We consider the function $g(x) = u''(\xi(x))(x-m)^2$ for any $x \in R$ (associated with the Taylor expansion (3)). Then
(5) $E_f(g(A)) = \int_0^1 [\frac{1}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u''(\xi(x))(x-m)^2 dx] f(\gamma) d\gamma$.

One notices that $a_1(0) \le E_f(A) \le a_2(0)$. Thus $m = E_f(A) \in I$. Accordingly, $u''(\xi(x)) < 0$. Thus $u''(\xi(x))(x-m)^2 < 0$ for any $x \in [a_1(\gamma), a_2(\gamma)] - \{m\}$. It follows that $\int_{a_1(\gamma)}^{a_2(\gamma)} u''(\xi(x))(x-m)^2 dx > 0$ for any $\gamma \in [0,1]$. Since $a_2(\gamma) - a_1(\gamma) > 0$ for any $\gamma \in [0,1]$, it follows that $\frac{1}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u''(\xi(x))(x-m)^2 dx > 0$.

Using this inequality and the properties of f from (5) it follows that $E_f(g(A)) > 0$. Now (4) can be written

$E_f(u(w+A)) = u(w+m) + \frac{1}{2} E_f(g(A))$,

thus $E_f(u(w+A)) > u(w+m) + {}^1\!/_2 E_f(g(A))$. Thus $E_f(u(w+A)) > u(w+m)$. Then the agent u is not risk–averse. □

Corollary 4.4 *The following assertions are equivalent:*
(i) The function u is convex.
(ii) The agent u is risk–lover.

Proof It follows from Proposition 4.3 and from the fact that u is convex iff –u is concave. □

Corollary 4.5 *The following assertions are equivalent:*
(i) The function u is linear.
(ii) The agent u is risk–neutral.

Proof From real analysis it is known that u is linear iff u is simultaneously convex and concave. Proposition 4.3 and Corollary 4.4 are applied then. □

By Proposition 1.2 from Eeckhoudt et al. (2005), an agent u is possibilistic risk–averse iff u is concave. Combining this result with Proposition 4.3 it follows:

Proposition 4.6 *Given a utility function u the following assertions are equivalent:*
(i) The agent u is probabilistic risk–averse.
(ii) The agent u is possibilistic risk–averse.

Due to Proposition 4.6, we will use the term risk–averse agent instead of probabilistic or possibilistic risk–averse agent.

2.5 Possibilistic Risk Aversion Indicators

In papers Georgescu (2009) and Georgescu (2010) the study of possibilistic risk aversion started. In Georgescu (2009) a notion of possibilistic risk premium was defined, and in Georgescu (2010) a possibilistic version of Pratt theorem was proved (Pratt 1964).

In this section two more notions of possibilistic risk premium are introduced and they are compared with the one from Georgescu (2009). Approximation formulas are obtained and the Pratt-type theorem from Georgescu (2010) is strengthened. A necessary and sufficient condition for the possibilistic risk aversion to be decreasing in wealth is found.

We fix a weighting function f and an injective utility function u.

Definition 5.1 (Georgescu 2009) Let A be a fuzzy number. We define the possibilistic risk premium $\rho(A, u)$ associated with A and u as the unique solution of the equation

$$E_f(u(A)) = u(E_f(A) - \rho(A, u)) \tag{2.1}$$

Proposition 5.2 (Georgescu 2009) *Assume that u has the class* C^2 *and* $u' > 0$. *Then an approximate solution of* Eq. (2.1) *is*

$$\rho(A, u) \approx -{}^1\!/_2 \frac{u''(E_f(A))}{u'(E_f(A))} Var_f^*(A) \tag{2.2}$$

We recall from Arrow (1965) and Pratt (1964) the definition of the Arrow–Pratt index of the utility function u:

$$r_u(x) = -\frac{u''(x)}{u'(x)} \text{ for } x \in R \tag{2.3}$$

Then (2.2) can be written as:

$$\rho(A, u) \approx {}^1\!/_2 Var_f^*(A) r_u(E_f(A)) \tag{2.4}$$

We define now two more notions of possibilistic risk premium.

Definition 5.3 Let A be a fuzzy number and $x \in R$. We define $\pi(x, A, u)$ as the unique solution of the equation

$$E_f(u(x + A)) = u(x + E_f(A) - \pi(x, A, u)) \tag{2.5}$$

Definition 5.4 Let $y \in R$ and B a fuzzy number such that $E_f(B) = 0$. We define $\pi_1(y, B, u)$ as the unique solution of the equation

$$E_f(u(y + B)) = u(y - \pi_1(y, B, u)) \tag{2.6}$$

$\pi(x, A, u)$ is the possibilistic analogue of the probabilistic risk premium from Pratt (1964), and $\pi_1(y, B, u)$ is the possibilistic analogue of the probabilistic risk premium from Ross (1981).

Next we study the relationship between the three notions of possibilistic risk premium $\pi(x, A, u)$, $\pi_1(y, B, u)$ and $\rho(A, u)$.

Lemma 5.5 *For any* $\mu \in R$ *we have*

$$\pi(x, A, u) = \pi(x + \mu, A - \mu, u) \tag{2.7}$$

Proof One notices that $E_f(A - \mu) = E_f(A) - \mu$. Therefore applying twice (2.5) one obtains
$u(x + E_f(A) - \pi(x + \mu, A - \mu, u)) = u(x + \mu + E_f(A - \mu) - \pi(x + \mu, A - \mu, u)$-
$= E_f(u(x + A)) = u(x + E_f(A) - \pi(x, A, u))$.

Then (2.7) results from u's injectivity. □

Proposition 5.6 *(i) If* $y \in R$ *and* B *is a fuzzy number with* $E_f(B) = 0$*, then* $\pi(y, B, u) = \pi_1(y, B, u)$*; (ii) If* $x \in R$ *and* A *is an arbitrary fuzzy number, then* $\pi(x, A, u) = \pi_1(x + E_f(A), A - E_f(A), u)$.

Proof (i) Since $E_f(B) = 0$ from (2.5) and (2.6) it follows that $u(y - \pi(y, B, u)) = E_f(u(y + B)) = u(y - \pi_1(y, B, u))$ from where, due to u's injectivity, one obtains

$\pi(y, B, u) = \pi_1(y, B, u)$; (ii) One notices that $E_f(A - E_f(A)) = 0$. Thus, by Lemma 5.5 and (i), it follows that
$\pi(x, A, u) = \pi(x + E_f(A), A - E_f(A), u) + \pi_1(x + E_f(A), A - E_f(A), u)$. □

By Proposition 5.6 we will always write $\pi(y, B, u)$ instead of $\pi_1(y, B, u)$.

Proposition 5.7 *Let $x \in R$ and A an arbitrary fuzzy number. Then*
(i) $\rho(A, u) = \pi(0, A, u)$;
(ii) $\pi(x, A, u) = \rho(x + A, u)$.

Proof (i) By applying (2.5) for $x = 0$ and then (2.1) it follows that $u(E_f(A) - \pi(0, A, u)) = E_f(u(A)) = u(E_f(A) - \rho(A, u))$ from where $\rho(A, u) = \pi(0, A, u)$.
(ii) We apply (2.1) and (2.5):
$u(E_f(x + A) - \rho(x + A, u)) = E_f(u(x + A))$
$= u(x + E_f(A) - \pi(x, A, u)) = u(E_f(x + A) - \pi(x, A, u))$ from where $\pi(x, A, u) = \rho(x + A, u)$ follows. □

The relationship between the indicators π, π_1 and ρ established by Propositions 5.6 and 5.7 allows a result obtained for one of them to be able to be transferred to the others. We will exemplify next this idea.

Proposition 5.8 *Let $x \in R$, A a fuzzy number and u a utility function of class C^2 such that $u' > 0$. Then*

$$\pi(x, A, u) \approx {}^1\!/_2 r_u(x + E_f(A)) Var_f^*(A) \tag{2.8}$$

Proof By Proposition 5.7, $Var_f^*(x + A) = Var_f^*(A)$. Then, applying Propositions 5.2 and 5.7 it follows that $\pi(x, A, u) = \rho(x + A, u) \approx {}^1\!/_2 Var_f^*(x + A) r_u (E_f(x + A)) = {}^1\!/_2 Var_f^*(A) r_u(x + E_f(A))$. □

Remark 5.9 If $E_f(A) = 0$, then (2.8) becomes:

$$\pi(x, A, u) \approx {}^1\!/_2 Var_f^*(A) r_u(x) \tag{2.9}$$

Applying in this case Proposition 2.6, $Var_f^*(A) = {}^1\!/_3 \int_0^1 [a_1^2(\gamma) + a_2^2(\gamma) + a_1(\gamma) a_2(\gamma)] f(\gamma) d\gamma$, thus (2.9) can be written as:

$$\pi(x, A, u) \approx {}^1\!/_6 r_u(x) \int_0^1 [a_1^2(\gamma) + a_2^2(\gamma) + a_1(\gamma) a_2(\gamma)] f(\gamma) d\gamma \tag{2.10}$$

Example 5.10 Let A be the triangular fuzzy number (a, α, β). According to Example 3.10 *and* (2.4), (2.10) *the following approximation formulas are obtained:*

$$\rho(A,u) \approx \frac{\alpha^2+\beta^2}{72} r_u\left(a+\frac{\beta-\alpha}{6}\right)$$
$$\pi(x,A,u) \approx \frac{\alpha^2+\beta^2}{72} r_u\left(x+a+\frac{\beta-\alpha}{6}\right).$$

Let u_1 and u_2 be two utility functions of class C^2 such that $u_1' > 0$, $u_2' > 0$, $u_1'' < 0$, $u_2'' < 0$. We denote by $r_1(x) = r_{u1}(x)$ and $r_2(x) = r_{u2}(x)$ the Arrow–Pratt indexes of u_1 and u_2.

The following result is a possibilistic version of Pratt theorem (Pratt 1964).

Proposition 5.11 *The following assertions are equivalent:*
(a) For any $x \in R$ and for any fuzzy number A, we have $\pi(x,A,u_1) \geq \pi(x,A,u_2)$.
(b) For any $y \in R$ and for any fuzzy number B with $E_f(B) = 0$, we have $\pi(x,B,u_1) \geq \pi(x,B,u_2)$.
(c) For any fuzzy number A, we have $\rho(A,u_1) \geq \rho(A,u_2)$.
(d) $r_1(x) \geq r_2(x)$ for any $x \in R$.
(e) u_1 is more concave than u_2: there exists a function $\phi : R \to R$ with $\phi' > 0$ and $\phi'' \leq 0$ such that $u_2(x) = \phi(u_1(x))$ for any $x \in R$.

Proof The equivalences $(c) \Leftrightarrow (d) \Leftrightarrow (e)$ were proved in Georgescu (2009) (see also Georgescu (2012), Proposition 4.3.7); $(a) \Leftrightarrow (b)$ follows from Proposition 5.6; and $(a) \Leftrightarrow (c)$ follows from Proposition 5.7. □

Definition 5.12 Consider two agents with the utility functions u_1 and u_2. If the equivalent conditions of Proposition 5.11 are fulfilled, then we say that the agent u_1 is possibilistic more risk–averse than u_2.

Remark 5.13 One notices that the equivalent conditions (d) and (e) from Proposition 5.11 also appear in Pratt theorem from probabilistic risk aversion (see Pratt (1964) or Eeckhoudt et al. (2005), Proposition 1.5, p. 14). Then, by combining Pratt theorem with Proposition 5.11, it follows that u_1 is probabilistic more risk–averse than u_2 iff u_1 is possibilistic more risk–averse than u_2. In this case we say that u_1 is more risk averse than u_2.

Let u be a utility function of class C^2 with $u' > 0$, $u'' < 0$, $u''' > 0$. Then the function $v = -u'$ has the class C^2 and the properties $v' > 0$, $v'' < 0$. Thus u and v are utility functions verifying the hypotheses in which Proposition 5.11 can be applied.

The following result establishes a necessary and sufficient condition for the possibilistic risk premium $\pi(x,A,u)$ to be decreasing in wealth.

Proposition 5.14 *The following assertions are equivalent:*
(i) For any fuzzy number A, the possibilistic risk premium $\pi(x,A,u)$ is decreasing in wealth; $x_1 \leq x_2$ implies that $\pi(x_2,A,u) \leq \pi(x_1,A,u)$.

(ii) For any fuzzy number A with $E_f(A) = 0$, *the possibilistic risk premium* $\pi(x, A, u)$ *is decreasing in wealth.*
(iii) v is more concave than u.

Proof $(i) \Leftrightarrow (ii)$: by Proposition 5.6; $(ii) \Leftrightarrow (iii)$: Let A be a fuzzy number with $E_f(A) = 0$. Assume that $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for all $\gamma \in [0, 1]$. By (2.6) we have

$$\begin{aligned} u(x - \pi(x, A, u)) &= E_f(u(x + A)) \\ &= \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u(x + t)dt \right] f(\gamma)d\gamma. \end{aligned}$$

Deriving with respect to x and taking into account (2.6) applied to v it follows that

$$\begin{aligned} (1 - \pi'(x, A, u))u'(x - \pi(x, A, u)) &= \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u'(x + t)dt \right] f(\gamma)d\gamma \\ &= -\int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} v(x + t)dt \right] f(\gamma)d\gamma \\ &= -E_f(v(x + A)) = -v(x - \pi(x, A, v)) \end{aligned}$$

From the above equalities it follows that $\pi'(x, A, u)$
$= \frac{u'(x - \pi(x, A, u)) + v(x - \pi(x, A, v)}{u'(x - \pi(x, A, u))} = \frac{v(x - \pi(x, A, v)) - v(x - \pi(x, A, u)}{u'(x - \pi(x, A, u))}$.
But $u'(x - \pi(x, A, u)) > 0$ and v and is strictly increasing. Thus the following assertions are equivalent:

- $\pi(x, A, u)$ is decreasing in x;
- For all x, $\pi'(x, A, u) \leq 0$;
- For all x, $v(x - \pi(x, A, v)) \leq v(x - \pi(x, A, u))$;
- For all x, $\pi(x, A, v) \geq \pi(x, A, u)$.

Then (ii) is equivalent with condition (b) of Proposition 5.11 stated for the utility functions u and v. According to the equivalence $(b) \Leftrightarrow (c)$ from Proposition 5.11, it follows that $(ii) \Leftrightarrow (iii)$. □

Definition 5.15 (Eeckhoudt et al. 2005) The Arrow–Pratt index of the utility function $v = -u'$:

$$P_u(x) = r_v(x) = -\frac{u'''(x)}{u''(x)} \tag{2.11}$$

is called the degree of absolute prudence of the agent u.

Remark 5.16 According to the equivalence $(d) \Leftrightarrow (c)$ of Proposition 5.11, the three conditions of Proposition 5.14 are equivalent with the following property:

$$\text{For all} \quad x \in R, P_u(x) \geq r_u(x) \tag{2.12}$$

(i.e., prudence is larger than absolute risk aversion).

2.6 Possibilistic Coinsurance Problem

We consider a risk–averse agent with a utility function u and an initial wealth w_0. The agent faces a risk situation where it can lose a part of w_0. We will assume that the loss is described mathematically by the fuzzy number A.

To retrieve a part of the loss the agent will close an insurance contract. By Eeckhoudt et al. (2005, p. 46), an insurance contract consists of a premium P to be paid by the policyholder and an indemnity schedule $I(x)$ representing the amount to be paid by the insurer for a loss of size x.

$I(x)$ will be considered a utility function. The form of the premium P depends on the mathematical modeling of the loss: a random variable in the probabilistic approach (Eeckhoudt et al. 2005) and a fuzzy number in the possibilistic approach. If the loss is a random variable $X \geq 0$, then the mean sum retrieved by the agent will be the probabilistic expected utility $M(I(X))$ and P will be defined with respect to this indicator (Eeckhoudt et al. 2005, p. 49).

In this section we will assume that the loss is a fuzzy number A whose level sets are $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for $\gamma \in [0, 1]$. We will assume that A is not a fuzzy point and $supp(A) \subseteq R_+$, thus $[A]^\gamma \subseteq R_+$ for any $\gamma \in [0, 1]$. We will fix a weighting function $f : [0, 1] \to R$.

We will consider the possibilistic expected utility associated with f, A and I:

$$E_f(I(A)) = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} I(x)dx \right] f(\gamma)d\gamma \tag{2.13}$$

In our possibilistic model, $E_f(I(A))$ is the mean sum retrieved by the agent through the insurance contract.

The *possibilistic premium for insurance indemnity* will be

$$P = (1 + \lambda)E_f(I(A)) \tag{2.14}$$

where λ is a loading factor.

Equation (2.14) is inspired from the form of probabilistic premium for insurance indemnity from Eeckhoudt et al. (2005, pp. 49–50), $E_f(I(A))$ replaces the probabilistic actuarial value from Eeckhoudt et al. (2005).

The function I may have various forms. We will assume that $I(x) = \beta x$ for all x. The constant β is called *coinsurance rate* and $1 - \beta$ is called *retention rate* (see Eeckhoudt et al. (2005), p. 49),

For the function $I(x) = \beta x$ one gets the form:

$$E_f(I(A)) = \beta E_f(A) \tag{2.15}$$

Then by (2.13) and (2.15) the possibilistic premium for insurance indemnity will depend on the parameter β and will have the form

$$P(\beta) = (1 - \beta)E_f(I(A)) = \beta(1 - \beta)E_f(A) \tag{2.16}$$

By denoting $P_0 = (1 + \lambda)E_f(A)$ (= the full possibilistic insurance premium), (2.16) becomes

$$P(\beta) = \beta P_0 \tag{2.17}$$

The coinsurance rate β represents the fraction of loss which returns to the policyholder and is a priori fixed by it. Next we study an optimization problem to choose β.

We consider the function g defined as

$$g(x, \beta) = w_0 - \beta P_0 - (1 - \beta)x \tag{2.18}$$

$g(x, \beta)$ represents the sum from w_0 that remains to the agent if the loss is x and if it closed an insurance contract with the premium P and the coinsurance rate β. Since x is one of the values which the fuzzy number A can take, representing the loss, the *final wealth* of the policyholder with loss A and the coinsurance rate β will be the fuzzy number

$$g(A, \beta) = w_0 - \beta P_0 - (1 - \beta)A \tag{2.19}$$

We recall that the utility function u has the class C^2. The agent being risk–averse, by Proposition 4.3 the function u will be concave.

We consider the function

$$h(x, \beta) = u(g(x, \beta)) = u(w_0 - \beta P_0 - (1 - \beta)x) \tag{2.20}$$

and the possibilistic expected utility associated with f, A and h:

$$H(\beta) = E_f(h(A, \beta)) = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} h(x, \beta)dx \right] f(\gamma)d\gamma \tag{2.21}$$

Remark 6.1 By Proposition 3.8, we have the following approximation formula of $H(\beta)$:

$$H(\beta) \approx h(E_f(A), \beta) + \frac{1}{2}h''(E_f(a), \beta)Var_f^*(A)$$

In our model, $H(\beta)$ is the *possibilistic expected final wealth* of the policyholder with loss A and coinsurance rate β. The choice of β by the policyholder will maximize $H(\beta)$. This way we reach the following optimization problem:

$$H(\beta^*) = \max_{\beta} H(\beta) \tag{2.22}$$

whose solution β^* is called *optimal coinsurance rate*.

Next we deal with the calculation and the properties of β^*. By (2.20), $H(\beta)$ is written as

$$H(\beta) = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u(g(x, \beta))dx\right] f(\gamma)d\gamma \tag{2.23}$$

Proposition 6.2 *(i) The function H is concave.*
(ii) The necessary and sufficient condition for the real number β^* to be the optimal solution of problem (2.22) *is $H'(\beta^*) = 0$.*

Proof (i) We compute the first derivative of H:
$H'(\beta) = \int_0^1 [\frac{1}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u'(g(x, \beta)) \frac{\partial g(x,\beta)}{\partial \beta} dx] f(\gamma)d\gamma.$
By (2.19), $\frac{\partial g(x,\beta)}{\partial \beta} = x - P_0$. Thus,

$$H'(\beta) = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u'(g(x, \beta))(x - P_0)dx\right] f(\gamma)d\gamma \tag{2.24}$$

Similarly we obtain the second derivative of H:

$$H''(\beta) = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u''(g(x, \beta))(x - P_0)^2 dx\right] f(\gamma)d\gamma \tag{2.25}$$

Since u is concave, $u''(g(x, \beta)) \le 0$ for all x and β. Thus for any $\gamma \in [0, 1]$ we have $H''(\beta) = \int_{a_1(\gamma)}^{a_2(\gamma)} u''(g(x, \beta))(x - P_0)^2 dx \le 0$. Since $a_2(\gamma) - a_1(\gamma) \ge 0$ for any $\lambda_1, \ldots, \lambda_n \in R$, from (2.5) it follows $H''(\beta) \le 0$ for all β. Thus, H is concave.
(ii) follows from (i). □

The following result is the possibilistic version of a theorem of Mossin (see Mossin (1968) or Proposition 3.1 of Eeckhoudt et al. (2005, p. 51)).

Proposition 6.3 *Assume that $u' > 0$ and $u'' \le 0$.*

(i) If $\lambda = 0$*, then* $\beta^* = 1$*;*
(ii) If $\lambda > 0$*, then* $\beta^* < 1$*.*

Proof (i) If $\beta = 1$, then by (2.6) $g(x, 1) = w_0 - P_0$ for all x. By applying (2.25) to this particular case:

$$H'(1) = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u'(g(x,\beta))(x - P_0)dx\right] f(\gamma)d\gamma$$
$$= u'(w_0 - P_0) \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} (x - P_0)dx\right] f(\gamma)d\gamma$$
$$= u'(w_0 - P_0) \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} xdx - P_0\right] f(\gamma)d\gamma$$
$$= u'(w_0 - P_0)(E_f(A) - P_0).$$

But $E_f(A) - P_0 = E_f(A) - (1 + \lambda)E_f(A) = -\lambda E_f(A)$. Thus:

$$H'(1) = -\lambda u'(w_0 - P_0)E_f(A) \tag{2.26}$$

For $\lambda = 0$, we obtain $H'(1) = 0$. Thus, by Proposition 6.2(ii), $\beta^* = 1$ is the optimal solution of the problem (2.22).
(ii) One knows that $a_1(0) \leq E_f(A) \leq a_2(0)$. By the hypothesis that A is not a fuzzy point and $supp(A) = [a_1(0), a_2(0)] \in R_+$, thus, $E_f(A) > 0$ follows. Since $u'(w_0 - P_0) > 0$ and $\lambda > 0$, by (2.26) we have $H'(1) = -\lambda u'(w_0 - P_0)E_f(A) < 0$. Assume that the optimal solution β^* of the problem (2.10) verifies that $\beta^* \geq 1$. By Proposition 6.2(i), H is concave. Thus, its derivative H' is decreasing. It follows that $H'(\beta^*) \leq H'(1) < 0$, which contradicts $H'(\beta^*) = 0$. Accordingly, $\beta^* < 1$. □

Proposition 6.4 *If* $\lambda = 0$*, then the possibilistic expected final wealth* $E_f(g(A, \beta))$ *is constant.*

Proof If $\lambda = 0$, then $P_0 = E_f(A)$. Thus, $g(x, \beta) = w_0 - \beta E_f(A) - (1 - \beta)x$ for all x and β. We compute $E_f(g(A, \beta))$ by the formula

$E_f(g(A, \beta)) = \int_0^1 [\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} g(x, \beta))dx] f(\gamma)d\gamma.$

A simple calculation shows that

$\int_{a_1(\gamma)}^{a_2(\gamma)} g(x, \beta))dx = \int_{a_1(\gamma)}^{a_2(\gamma)} (w_0 - \beta E_f(A) - (1 - \beta)x)dx = (w_0 - \beta E_f(A))(a_2(\gamma) - a_1(\gamma)) - \frac{1-\beta}{2}(a_2(\gamma) - a_1(\gamma)).$

Replacing in the expression of $E_f(g(A, \beta))$ one obtains:

$$E_f(g(A,\beta)) = \int_0^1 \left[w_0 - \beta E_f(A) - \frac{1-\beta}{2}(a_1(\gamma)+a_2(\gamma))\right] f(\gamma)d\gamma$$
$$= (w_0 - \beta E_f(A)) \int_0^1 f(\gamma)d\gamma - (1-\beta)\int_0^1 \frac{a_1(\gamma)+a_2(\gamma)}{2} f(\gamma)d\gamma$$
$$= w_0 - \beta E_f(A) - (1-\beta)E_f(A) = w_0 - E_f(A).$$

□

For the rest of the section we assume that $f(\gamma) = 2\gamma$ for any $\gamma \in [0,1]$.

Proposition 6.5 *If* $u''(x) < 0$ *for all x, then* $H''(\beta) < 0$ *for all* β.

Proof By (2.25) we have

$$H''(\beta) = 2\int_0^1 \left[\frac{1}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u''(g(x,\beta))(x-P_0)^2 dx\right] f(\gamma)d\gamma \tag{2.27}$$

A is not a fuzzy point. Thus, $a_2(\gamma) - a_1(\gamma) > 0$ for any $\gamma \in [0,1]$. Also $u''(g(x,\beta)) < 0$ and $(x-P_0)^2 > 0$ for any $x \in [a_1(\gamma), a_2(\gamma)] - \{P_0\}$. Therefore, $\int_{a_1(\gamma)}^{a_2(\gamma)} u''(g(x,\beta))(x-P_0)^2 dx < 0$ for any $\gamma \in [0,1]$. Thus, for any $\gamma \in [0,1]$, $\frac{\gamma}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u''(g(x,\beta))(x-P_0)^2 dx < 0$.

It follows that $H''(\beta) < 0$ for any β. □

We consider two agents with the utility functions u_1 and u_2 such that $u_1' > 0$, $u_2' > 0$, $u_1'' < 0$, $u_2'' < 0$. Let β_1^* and β_2^* be the optimal coinsurance rates associated with u_1 and u_2 (in the sense of problem (2.22)).

Proposition 6.6 *If* u_1 *is more risk–averse than* u_2 *then* $\beta_1^* \geq \beta_2^*$.

Proof We consider the possibilistic expected final wealths $H_1(\beta)$ and $H_2(\beta)$ associated with u_1 and u_2:

$$H_1(\beta) = 2\int_0^1 \left[\frac{\gamma}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u_1(g(x,\beta))dx\right] d\gamma;$$
$$H_2(\beta) = 2\int_0^1 \left[\frac{\gamma}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u_2(g(x,\beta))dx\right] d\gamma.$$

Then $H_1'(\beta_1^*) = 0$ and $H_2'(\beta_2^*) = 0$.

If $\lambda = 0$, then, by Proposition 6.3(i), $\beta_1^* = \beta_2^* = 1$ and the assertion is verified.

Assume $\lambda > 0$. Using condition (c) of Proposition 5.11 and judging the same way as in the proof of Proposition 3.2 of Eeckhoudt et al. (2005) one proves that for any x:

$(x-P_0)u_2'(w_0 - (1-\beta_1^*)x - \beta_1^* P_0) \leq (x-P_0)u_1'(w_0 - (1-\beta_1^*)x - \beta_1^* P_0)$, which by (2.18) can be written as $(x-P_0)u_2'(g(x,\beta_1^*)) \leq (x-P_0)u_1'(g(x,\beta_1^*))$.

Then for any $\gamma \in [0,1]$:
$\int_{a_1(\gamma)}^{a_2(\gamma)} (x - P_0)u_2'(g(x, \beta_1^*))dx \le \int_{a_1(\gamma)}^{a_2(\gamma)} (x - P_0)u_1'(g(x, \beta_1^*))dx$.

Taking into account that $a_2(\gamma) - a_1(\gamma) > 0$ for any $\gamma \in [0,1]$, it follows, by (2.24), that

$H_2'(\beta_1^*) = 2\int_0^1 [\frac{\gamma}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} (x - P_0)u_2'(g(x, \beta_1^*))dx]d\gamma \le 2\int_0^1 [\frac{\gamma}{a_2(\gamma)-a_1(\gamma)}$
$\int_{a_1(\gamma)}^{a_2(\gamma)} (x - P_0)u_1'(g(x, \beta_1^*))dx]d\gamma = H_1'(\beta_1^*) = 0$.

By hypothesis $u_2'' < 0$, thus by Proposition 6.5, $H_2''(\beta) < 0$ for all β. Therefore, H_2' is strictly decreasing. Thus, from $H_2'(\beta_1^*) \le 0 = H_2'(\beta_2^*)$, $\beta_2^* \le \beta_1^*$ follows. □

2.7 Static Portfolio Choices: A Possibilistic Model

By Eeckhoudt et al. (2005, p. 65), we consider an agent with a wealth w_0, which it invests in a risk–free asset and in a risky asset. In the probabilistic approach of Eeckhoudt et al. (2005), the return of the risky asset is a random variable. In this section we will study a model in which the return of the risky asset is a fuzzy number.

Let r be the risk–free return of the first asset and x the value of the return of the risky asset. The agent invests the sum α in the risky asset and $w_0 - \alpha$ in the risk–free asset. Then the value of the portfolio $(w_0 - \alpha,\ \alpha)$ at the end of the considered period is by Eeckhoudt et al. (2005, p. 66): $(w_0 - \alpha)(1 + r) + \alpha(1 + x) = w_0(1 + r) + \alpha(x - r) = w + \alpha(x - r)$, where $w = w_0(1 + r)$ is the future wealth obtained with risk–free strategy.

In the probabilistic model of Eeckhoudt et al. (2005), x is the value of a random variable. In the possibilistic model, which we will develop, x will be the value of a fuzzy number A.

We consider the function

$$g(\alpha, w, x) = w + \alpha(x - r) \tag{2.28}$$

If the fuzzy number A is the return of the risky asset, then the fuzzy number $g(\alpha, w, A) = w + \alpha(A - r)$ is the value of the portfolio at the end of the period.

We fix a weighting function $f : [0,1] \to R$. Assume that the agent has an increasing and concave utility function u of class C^2. Also, we assume that $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for $\gamma \in [0,1]$. We consider the function

$$h(\alpha, w, x) = u(g(\alpha, w, x)) \tag{2.29}$$

and the possibilistic expected utility associated with f, A and h: $K(\alpha, w) = E_f(h(\alpha, w, A)) = \int_0^1 \frac{1}{a_2(\gamma)-a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} h(\alpha, w, x)dx]f(\gamma)d\gamma$.

By (2.2) we have

$$K(\alpha, w) = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u(g(\alpha, w, x))dx\right] f(\gamma)d\gamma \tag{2.30}$$

Remark 7.1 By Proposition 3.9, we have the following approximation formula for $K(\alpha, w)$:

$$K(\alpha, w) \approx h(\alpha, w, E_f(A)) + \frac{1}{2}\frac{\partial^2 h(\alpha, w, E_f(A))}{\partial^2 x} \cdot Var_f^*(A)$$

The investor's problem is to choose a value α^* such that

$$K(\alpha^*, w) = \max_{\alpha} K(\alpha, w) \tag{2.31}$$

We prove next some properties of K and the optimal solution α^*.

Proposition 7.2 *(i) The function $K(\alpha, w)$ is concave in α;*

(ii) The necessary and sufficient condition for the real number α^* to be the optimal solution of (2.31) *is* $\frac{\partial K(\alpha^*, w)}{\partial \alpha} = 0$.

Proof (i) From (2.30) it follows that
$\frac{\partial K(\alpha., w)}{\partial \alpha} = \int_0^1 [\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u'(g(\alpha, w, x)) \frac{\partial g(\alpha, w, x)}{\partial \alpha} dx] f(\gamma)d\gamma.$
But $\frac{\partial g(\alpha, w, x)}{\partial \alpha} = x - r$. Thus,

$$\frac{\partial K(\alpha, w)}{\partial \alpha} = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u'(g(\alpha, w, x))(x - r)dx\right] f(\gamma)d\gamma \tag{2.32}$$

From (2.5) one obtains

$$\frac{\partial^2 K(\alpha, w)}{\partial \alpha^2} \tag{2.33}$$

$$= \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} u''(g(\alpha, w, x))(x - r)^2 dx\right] f(\gamma)d\gamma$$

u is concave and $u''(g(\alpha, w, x)) \leq 0$. Thus, for any $\gamma \in [0, 1]$, we have $\int_{a_1(\gamma)}^{a_2(\gamma)} u''(g(\alpha, w, x))(x - r)^2 dx \leq 0$.

Then from (2.33) it follows that $\frac{\partial^2 K(\alpha, w)}{\partial \alpha^2} \leq 0$ for any α. Thus, $K(\alpha, w)$ is concave in α.
(ii) follows from (i). □

Proposition 7.3 *Assume that $u' > 0$ and $u'' < 0$.*

(i) If $E_f(A) = r$*, then* $\alpha^* = 0$;
(ii) If $E_f(A) > r$*, then* $\alpha^* > 0$.

Proof We notice that $g(0, w, x) = w$, thus making $\alpha = 0$ in (2.32) it follows that

$$\frac{\partial K(\alpha, w)}{\partial \alpha} \approx u'(w) \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} (x - r) dx \right] f(\gamma) d\gamma$$
$$= u'(w) \left[\int_0^1 \frac{a_1(\gamma) + a_2(\gamma)}{2} f(\gamma) d\gamma - r \right] = u'(w)[E_f(A) - r].$$

If $E_f(A) = r$, then $\frac{\partial K(0,w)}{\partial \alpha} = 0$. Thus, by Proposition 7.2(ii), $\alpha^* = 0$ is the optimal solution of (2.31).

(ii) Assume by absurdum that $\alpha^* \leq 0$. If $r < E_f(A)$, then $\frac{\partial K(0,w)}{\partial \alpha} = u'(w)(E_f(A) - r) > 0$, since $u'(w) > 0$. Then from $\alpha^* \leq 0$ it follows that $0 = \frac{\partial K(\alpha^*,w)}{\partial \alpha} > \frac{\partial K(0,w)}{\partial \alpha} > 0$.

The obtained contradiction shows that $\alpha^* = 0$. □

Proposition 7.4 *An approximate value of the optimal solution of* (2.31) *is*

$$\alpha^* \approx -\frac{u'(w)}{u''(w)} \frac{E_f(A) - r}{Var_f^*(A) + (E_f(A) - r)^2} \tag{2.34}$$

Proof We use the first–order Taylor approximation of $u'(w + \alpha(x - r))$ around w:

$$u'(g(\alpha, w, x)) = u'(w + \alpha(x - r)) \approx u'(w) + \alpha(x - r)u''(w) \tag{2.35}$$

Replacing $u'(g(\alpha, w, x))$ in (2.32) with the approximate value from (2.35) it follows that
$\frac{\partial K(\alpha,w)}{\partial \alpha} \approx \int_0^1 [\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} (u'(w) + \alpha(x - r)u''(w)(x - r))(x - r)dx] f(\gamma)d\gamma$.

We write this relation under the form:

$$\frac{\partial K(\alpha, w)}{\partial \alpha} \approx u'(w) I_1 + \alpha u''(w) I_2, \tag{2.36}$$

where

$$I_1 = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} (x - r) dx \right] f(\gamma) d\gamma; \quad \textit{and}$$
$$I_2 = \int_0^1 \left[\frac{1}{a_2(\gamma) - a_1(\gamma)} \int_{a_1(\gamma)}^{a_2(\gamma)} (x - r)^2 dx \right] f(\gamma) d\gamma$$

We compute I_1:

$I_1 = {}^1\!/_2 \int_0^1 [a_1(\gamma) + a_2(\gamma) - 2r] f(\gamma) d\gamma = \int_0^1 \frac{a_1(\gamma)+a_2(\gamma)}{2} f(\gamma) d\gamma - r = E_f(A) - r.$

We compute I_2:

$I_2 = {}^1\!/_3 \int_0^1 [(a_1(\gamma) - r)^2 + (a_2(\gamma) - r)^2 + (a_1(\gamma) - r)(a_2(\gamma) - r)] f(\gamma) d\gamma.$

We notice that $(a_1(\gamma) - r)^2 + (a_2(\gamma) - r)^2 + (a_1(\gamma) - r)(a_2(\gamma) - r) = a_1^2(\gamma) + a_2^2(\gamma) + a_1(\gamma)a_2(\gamma) - 3r(a_1(\gamma) + a_2(\gamma)) + 3r^2$. Thus,

$I_2 = {}^1\!/_3 \int_0^1 [a_1^2(\gamma) + a_2^2(\gamma) + a_1(\gamma)a_2(\gamma)] f(\gamma) dv - 2r \int_0^1 \frac{a_1(\gamma)+a_2(\gamma)}{2} f(\gamma) d\gamma + r^2$ and by Proposition 2.6:

$I_2 = Var_f^*(A) + E_f^2(A) - 2rE_f(A) + r^2 = Var_f^*(A) + (E_f(A) - r)^2.$

Introducing the above values of I_1 and I_2 in (2.36), we find that $\frac{\partial K(\alpha, w)}{\partial \alpha} \approx u'(w)(E_f(A) - r) + \alpha u''(w)[Var_f^*(A) + (E_f(A) - r)^2].$

An approximate value of the equation $\frac{\partial K(\alpha^*, w)}{\partial \alpha} = 0$ will be obtained by equaling with 0 the right hand side member of the previous equation. It follows that $\alpha^* \approx -\frac{u'(w)}{u''(w)} \frac{E_f(A) - r}{Var_f^*(A) + (E_f(A) - r)^2}.$ □

Example 7.5 Let us assume that the return of the risky asset is the triangular fuzzy number A = (a, α, β) and the weighting function f has the form $f(\gamma) = 2\gamma$, for $\gamma \in [0, 1]$.

Therefore $E_f(A) = a + \frac{\beta - \alpha}{6}$ and $Var_f^*(A) = \frac{\alpha^2 + \beta^2}{36}$, hence by Proposition 7.4, the agent will invest in the risky asset the amount

$$\alpha^* \approx -\frac{u'(w)}{u''(w)} \cdot \frac{a + \frac{\beta - \alpha}{6} - r}{\frac{\alpha^2 + \beta^2}{36} + \left(a + \frac{\beta - \alpha}{6} - r\right)^2}$$

If a is exactly the risk-free return r (a = r) we obtain :

$\alpha^* \approx -3 \frac{u'(w)}{u''(w)} \cdot \frac{\beta - \alpha}{\alpha^2 + \beta^2 + \alpha\beta}.$

2.8 Conclusions

This work fits in a recent research direction in which risk is treated by the possibility theory (Carlsson and Fullér 2011; Georgescu 2009, 2012; Georgescu 2010; Georgescu and Kinnunen 2012).

First the theme of possibilistic risk aversion, whose study began in Georgescu (2009), (2010), (2012), Georgescu and Kinnunen (2012) is deepened. This will provide a framework for the two risk management models of the chapter. Both models are about a risk–averse agent in front of a situation of uncertainty.

In the first case we deal with an insurance contract the agent closes to recover a part of the loss due to the risk situation. In the second case we develop a two-agent investment model in which the risk has a possibilistic representation.

Both models lead to optimization problems: in the first one the optimal coinsurance rate (in the possibilistic sense) should be achieved, and in the second one the optimal investment problem should be found. The main results of the chapter focus on the optimal solutions of the problems: existence, properties, calculation, behaviour towards risk aversion.

We present now some directions for further research.

1. A rich literature was dedicated to probabilistic models of multidimensional risk (see the paper Jouini et al. (2013) for a survey of such models). In Georgescu (2012) a possibilistic model for the situations with many risk parameters was proposed. This model studies the risk aversion of an agent in the face of a multidimensional possibilistic risk where the components are fuzzy numbers. An open problem is to extend the models of Sects. 2.6 and 2.7 (coinsurance problem and investment portfolio problem) to multidimensional possibilistic risk.

2. Credibility theory invented by Liu and Liu in (2002) is another way to describe phenomena with incomplete information. A complete expose of this field can be found in the monograph (Liu 2007). The paper Georgescu and Kinnunen (in press) proposes a risk aversion approach by credibility theory. In particular, a risk-prudent agent in credibilistic sense is defined and a credibilistic Pratt-type theorem is proved. The treatment of coinsurance problem and investment portfolio problem in the framework of such credibilistic models may be a topic for further research.

3. In paper Wu et al. (2014) various Principal—Agent Problems are studied by credibility theory. Among others, necessary and sufficient conditions are established for the optimal solution when the principal is risk-averse or risk-neutral (in a credibilistic sense). To our knowledge, an approach of the Principal—Agent Problem by possibility theory has not been discussed yet. In case of such approach the results of the chapter would be certainly useful.

4. In Georgescu and Kinnunen (2011) and Georgescu (2012) a risk aversion model for mixed parameter situations was considered: some parameters are modeled by random variables and others by fuzzy numbers. An open problem is to define a risk-averse, risk-lover or risk-neutral agent in the context of such mixed models. It would be interesting coinsurance problem and investment portfolio problem to be tackled for mixed parameter problems.

5. The mixed parameter risk models from Georgescu and Kinnunen (2011), Georgescu (2012) combine probabilistic and possibilistic risk modeling. We can figure out situations with three types of risk parameters: some probabilistically modeled by random variables, some by fuzzy numbers and others by credibilistic distributions. Can the concepts and results of this chapter be generalized to this tridimensional context? Can concrete risk situations be found for which such hybrid models offer an appropriate modeling?

References

Arrow, K.J.: Aspects of the Theory of Risk Bearing. Yrjö Johanssonin Säätiö, Helsinki (1965)
Arrow, K.J.: Essays in the Theory of Risk Bearing. North-Holland, Amsterdam (1970)

Carlsson, C., Fullér, R.: On possibilistic mean value and variance of fuzzy numbers. Fuzzy Sets Syst. **122**, 315–326 (2001)
Carlsson, C., Fullér, R.: Possibility for Decision. Springer, New York (2011)
Dubois, D., Prade, H.: Fuzzy Sets and Systems: Theory and Applications. Academic Press, New York (1980)
Dubois, D., Prade, H.: The mean value of a fuzzy number. Fuzzy Sets Syst. **24**, 279–300 (1987)
Dubois, D., Prade, H.: Possibility Theory. Plenum Press, New York (1988)
Eeckhoudt, L., Gollier, C., Schlesinger, H.: Economic and Financial Decision Under Risk. Princeton University Press, Princeton (2005)
Fullér, R., Majlender, P.: On weighted possibilistic mean and variance of fuzzy numbers. Fuzzy Sets Syst. **136**, 363–374 (2003)
Fullér, R., Majlender, P.: On interactive fuzzy numbers. Fuzzy Sets Syst. **143**, 355–369 (2004)
Georgescu, I.: Possibilistic risk aversion. Fuzzy Sets Syst. **60**, 2608–2619 (2009)
Georgescu, I.: Possibilistic Pratt theorem. In: 8th IEEE International Symposium on Intelligent Systems and Informatics, pp. 193–196. Subotica, Serbia, 10–11 Sept 2010
Georgescu, I.: Possibility Theory and the Risk. Springer, New York (2012)
Georgescu, I., Kinnunen, J.: Credibilistic risk aversion and prudence, Int. J. Bus. Innov. Res. (in press)
Georgescu, I., Kinnunen, J.: Multidimensional risk aversion with mixed parameters. In: Proceedings of the 6th IEEE International Symposium on Applied Computational Intelligence and Informatics SACI 2011, pp. 63–68. Romania (2011)
Georgescu, I., Kinnunen, J.: Possibilistic risk aversion and its indicators. In: Proceedings of the 11th WSEAS International Conference on Applied Computer and Applied Computational Science (ACASOS 2012), pp. 178–183. Rovaniemi, Finland, 18–20 April (2012)
Jouini, E., Napp, C., Nocetti, D.: On multivariate prudence. J. Econ. Theory **148**(3), 1255–1267 (2013)
Laffont, J.J.: The economics of uncertainty and information. MIT Press, Cambridge (1993)
Liu, B.: Uncertainty theory. Springer, Heidelberg (2007)
Liu, B., Liu, Y.K.: Expected value of fuzzy variable and fuzzy expected models. IEEE Trans. Fuzzy Syst. **10**, 445–450 (2002)
Majlender, P.: A normative approach to possibility theory and decision support. Ph.D. Thesis, Turku Centre for Computer Science (2004)
Mas-Colell, A., Whinston, M.D., Green, J.R.: Microeconomic theory. Oxford University Press, USA (1995)
Mezei, J.: A quantitative view on fuzzy numbers. Turku Centre for Computer Science, Ph.D. Dissertations, No. 142, 2011
Mossin, J.: Aspects of rational insurance purchasing. J. Political Economy **76**, 533–568 (1968)
Pratt, J.: Risk aversion in the small and in the large. Econometrica **32**, 122–130 (1964)
Quiggin, J.: Generalized Expected Utility Theory. Kluwer-Nijhoff, Amsterdam (1993)
Ross, S.: Some stronger measures of risk aversion in the small and in the large with applications. Econometrica **40**, 621–638 (1981)
Wu, X., Zhao, R., Tang, W.: Principal-agent problem based on credibility measure. IEEE Trans. Fuzzy Syst. 1230–1237 (2014). doi: 10.1109/TFUZZ.2014.2333773
Zadeh, L.A.: Fuzzy sets. Inf. Control **8**, 228–253 (1965)
Zadeh, L.A.: Fuzzy sets as a basis for a theory of possibility. Fuzzy Sets Syst. **1**, 3–28 (1978)

Chapter 3
Likelihood Estimation of Intentional Events in Risk Management: Evidence Based Intelligent Morphological Analysis Approach

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Abstract Risk management as a special Engineering Management field involves understanding the risks called risk assessment. Risk assessment is a highly complex strategic activity and requires a structured quantified methodology for identifying undesired events and estimating their likelihoods. However, undesired events like human caused intentional events are deliberate, innovative, and unpredictable acts unlike accidental failures and different from random events. Although there is a significant increase in the number of intentional events such as homeland and cyber security events in recent years, current risk assessment methods are not suitable for risk assessment of intentional events. In this study, a novel intelligent technique called evidence based Morphological Analysis (EMA) model based on Dempster-Shafer theory of evidence (DST) and Morphological Analysis (MA) methodology is proposed to quantify the likelihood of intentional events as threats by identifying them. It is based on the appropriate uncertainty model and supplementary methods for a risk management of a critical facility protection considering both information at hand and information requirements of decision makers. The proposed approach is presented step by step and applied to a simple case study on an airport. The two common DST combination rules are also analysed by considering decision maker's attitude either risk averse or risk seeking. The results show that EMA analyses a wide range of plausible threat scenarios more easily than hierarchical techniques as tree structures with modest computational effort. Therefore, EMA can be used to reason about risk assessment by providing required output data precision for comparing and ranking of scenarios systematically.

Keywords Risk management · Morphological analysis · Likelihood estimation · Intelligent systems

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3.1 Introduction

All kinds of businesses and organizations face risk. Risk traditionally has a negative meaning and can be defined both qualitatively and quantitatively. According to the qualitative definition of risk, which is the dictionary definition, risk is “the effect of uncertainty on your objectives” (ISO 2009). The quantitative definition of risk is commonly defined as a measure of expected loss which is the product of likelihood and severity of loss based on the probability theory in the literature.

Risk management is an important management practice in all kind of businesses and organizations. It can be considered as a special engineering management field which applies engineering design and analysis principles to management practices. To manage risk in an efficient way, risk assessment (RA) is required. RA is a systematic decision analysis methodology for identifying the expected loss incurred by a system or process as a result of undesired event.

Typical RA is generally related to expected losses from failures, accidents, and natural disasters and is a kind of safety analysis. There are different sources of risk and Renn (1992) identifies five major types of RA: technical RA, economic RA, psychological RA, sociological RA and cultural RA (Renn 1992). The first two types of RA are quantitative and the last three are qualitative. Each of RA has different assumptions about the underlying reality under consideration depending on the concerned risk type. For example, in economic RA, risk is associated with the unexpected variability or volatility of returns. However, risk of random events is different from risk of intentional events. The risk arising from intentional acts is called security risk. The security risk includes intelligent, deliberate, and unpredictable acts which are intended to create fear, are committed for an ideological goal, and deliberately target or disregard the safety of civilians (Garrick et al. 2004). The security risk differs in kind from other type of risks because of these special characteristics.

In the security field, a threat is an intentional event that is defined as any human caused act, entity, event or phenomenon with the potential to cause harm or damage to a critical facility by adversely changing its state. In other words, a threat is a human caused intentional event of undesired consequence. The developed societies become more vulnerable to security risks caused by threats as they get more dependent on critical facilities like airports, nuclear power plants, oil plants, dams, harbours, governmental facilities which are attractive targets subject to threats. The prediction of threats are difficult because adversaries will continue to improve tactics and enhance their capabilities according to changing conditions. Before the security risk is assessed, threats and their likelihoods must be identified and quantified. Therefore, threat assessment which is the task of identifying threats and estimating their likelihoods, involves two sub-phases: threat identification and threat likelihood estimation.

Threat identification sub-phase identifies threats that a critical facility may suffer by developing an exhaustive set of plausible threat scenarios based on the susceptibilities of its possible targets to possible attack profiles considering information on the intentions and capabilities of the attackers, targets and weapon delivery systems. The threat identification is the basis for identification, filtering and prioritizing of threat scenarios on which concentration is needed. For developing plausible threat scenarios, extensive involvement of security experts is required. The aim is to develop a complete set of plausible threat scenarios which are bounded in terms of the intentions and capabilities of the attackers. The development of threat scenarios is different because of the intelligent attacker. An examination of historical data is useful when identifying possible threat scenarios, but it is also required to identify possible threat scenarios that have never been happened in the past.

Since the development of scenarios is critical for threat identification, a method for developing threat scenarios is required. In the literature, a variety of tree structures are often used to develop scenarios. Tree structures are important tools for exploring the scenario space, analyzing uncertain events and defining scenarios (Harris 2004). Tree structures can be categorized in two types: event trees or fault trees that display functional and logical relationships among events. An event tree is a cause-and-effect representation of logic and each path through this tree represents a scenario and ends up at an end state started by an initiating event (Andrews and Dunnett 2000). A fault trees are effect-and-cause representations of logic and a fault tree starts with the end-state and attempts to determine all of the contributing system states (Ericson 1999). Therefore, an event tree is developed by inductive reasoning while a fault tree is based on deductive reasoning. In the literature, event trees and fault trees have been used to identify threat scenarios in several studies (Ezell et al. 2001; Rosoff and von Winterfeldt 2007). But, tree structures as a hierarchical technique quickly become difficult to handle because of the wide variety of possible scenarios. Proposed technique must be fast enough to quickly analyse a wide range of plausible scenarios with modest computational effort. Therefore, MA is used for threat identification in this study. The fundamentals of MA and reasons for using MA are described in the following sections.

As threat scenarios are about what will happen, threat likelihood is about how likely it is to happen. At the threat likelihood estimation sub-phase, threat scenario likelihoods are determined. The critical research question is “Which interpretation of likelihood is the most informative and is the preferred way of capturing and quantifying the state of knowledge about the likelihood of a defined threat scenario for a critical facility?” Quantification of likelihood means that the threat likelihood is represented by a mathematical parameter that embodies enough information supported by the evidence for estimating the future occurrences of intentional attacks. To quantify the threat likelihood, it is first necessary to choose the appropriate uncertainty model and define the concept of likelihood. Since the appropriate uncertainty model used to describe studied situation should obviously be compatible with the features of this situation, by the type of required input information, by the quality of required output information and by the axiomatic assumptions about the cause of uncertainty, modelling uncertainty is one of the most critical modelling decisions (Zimmermann 2007).

In this study, DST is used for uncertainty modelling and the input data for threat likelihood are represented by DST variables. The fundamentals of DST, reasons for modelling uncertainty by DST, and how DST is applied for threat likelihood estimation within MA is described in the following sections.

After reviewing the existing approaches and the factors that influence the threat identification and likelihood estimation, the remainder of this study is organized as follows based on the second chapter of my Ph.D. dissertation titled "Security Risk Assessment for Critical Facility Protection": In Sect. 3.2, theoretical background information for the proposed approach is represented. The proposed EMA model and its process flow are introduced in Sect. 3.3. The illustrative application of the proposed approach is performed over an airport case study in Sect. 3.4. This section also examines the utility of findings and discusses the analysis results. Conclusions and further issues are addressed respectively in the final section.

3.2 Theoretical Background

In this section, theoretical background information on Morphological Analysis (MA), uncertainty modelling and fundamentals of Dempster-Shafer theory of evidence (DST) are presented, respectively.

3.2.1 Morphological Analysis

MA, developed by Fritz Zwicky in 1969, is a qualitative modelling method for structuring parameter space of the multidimensional non-quantifiable problems by defining relationships between the parameters on the basis of internal consistency (Zwicky 1969). As a qualitative problem structuring method, MA has been applied to complex social, organizational and technical problem fields for the scenario planning, strategy formulation, policy development, etc. (Sharif and Irani 2006; Ritchey 2009, 2011).

MA begins by forming a morphological field and corresponding cross-consistency assessment (CCA) matrix in MA's terms. A morphological field, matrix of the state of all conditions in the system, is constructed by identifying and defining the parameters of the problem and assigning each parameter a range of relevant values in a multidimensional matrix. A configuration contains one value from each of the parameters and represents a particular state, solution or scenario in the problem. The next step in the MA is to examine the internal relationships between the parameters and reduce the morphological field by eliminating all mutually contradictory conditions. This is achieved by a process of cross-consistency assessment in the CCA matrix where all of the parameter values in the morphological field are evaluated pair wise with the other parameter values by defining pairs that cannot coexist and removing the configurations that contain a single illogical pair. The exponential growth to unmanageable numbers of permutations is decreased by discarding illogical pairs through a process of cross-consistency assessment in the CCA matrix. By doing this, solution space of the problem is determined. The solution space consists of the subsets of configurations that satisfy the condition of internal consistency.

In MA different from event trees and failure trees, structuring of a configuration is done by using logical relationships instead of casual relationships. The important feature of MA is to reduce the solution space. The total number of configurations (possible or not) is the product of the number of values under each parameter. The total number of configurations grows exponentially with each new parameter but the number of pair wise relationships between parameters grows only as a quadratic polynomial that is proportional to the triangular number series (Ritchey 2009, 2011). Therefore, even a morphological field involves many configurations, fewer number of pair wise evaluations is always required than the total number of configurations in order to create solution space. Advantages of MA are as follows:

- The solution space of any given problem can be derived systematically,
- New configurations or relations that is not so evident can be discovered more easily,
- Impossible configurations can be screened rapidly,
- Multi-dimensions in columns can easily be represented by morphological field and MA matrix structure helps to keep the solution space organized, accessible and traceable even at large sizes,
- New parameters and new parameter values can easily be added, and new relations can easily be updated.

But, there is no mechanism to address the issue of how to deal with incomplete, imprecise and ignorance in MA, which is essentially inherent and inevitable in expert judgements. Pair wise evaluations can take different forms instead of binary decision to determine the strength of the logical relations between the parameter values as proposed in this study.

In this study, MA is used for the purpose of the threat identification because MA is fast enough to quickly analyse a wide range of plausible threat scenarios with modest computational effort.

3.2.2 Uncertainty Modelling

Uncertainty models transform input information to output information. Underestimation and wrong interpretation of uncertainty is an important mistake. Therefore, the choice of appropriate uncertainty model for threat likelihood estimation is crucial. There are two main types of uncertainty: aleatory uncertainty and epistemic uncertainty. Epistemic uncertainty is referred to as reducible, subjective and state-of-knowledge uncertainty and aleatory uncertainty is referred to as random, irreducible and stochastic uncertainty (Helton 1997; Oberkampf et al. 2004).

There exist a considerable number of theories, methods or paradigms to model uncertainty such as probability theory, fuzzy set theory, possibility theory, and Dempster-Shafer theory of evidence (Laplace 1812; Kolmogorov 1950; Zadeh 1965, 1978; Dubois and Prade 1988; Dempster 1967; Shafer 1976). Each of these theories makes assumptions about available information and contains a calculus by which this information is processed with certain measures of uncertainty. A specific uncertainty model should not be used if its mathematical operations require a higher level of information than the available information. This is very important when applying those theories.

It is difficult to obtain precise relation between events and their likelihoods. In probabilistic risk assessment (PRA), quantitative interpretations of likelihood are frequency, probability, and probability of frequency (Ezell et al. 2010; Kirchsteiger 1999). If the event happens repeatedly, its likelihood can be expressed as frequency like in occurrences per day, per year, per trial, etc. If the event happens either once or not, its likelihood can be quantified in terms of probability. If the event happens repeatedly and has a frequency, but the numerical value of that frequency is not fully known, its likelihood can be expressed as a probability of frequency. The PRA requires having all the information on the probability of all events. When such information is not available, the uniform distribution function, which states that all events in a given sample space are equally likely, is used. Because of the axiom of additivity (where all probabilities that satisfy specific properties must sum to 1) in the probability theory, if it is believed that a likelihood of an event A is 0.25, it is necessarily believed that likelihood of not event A (complement of A) is 0.75. This is a strict assumption for threat likelihood. Even if there is a historical data and predetermined probability function fits the limited historical data well, the threat likelihood estimation results may not be good in practice because of the human factor in deliberate and adaptive events of security risk. In case of partial ignorance, the use of a single probability measure introduces information that is in fact not available. This may seriously bias the outcome of a threat assessment in a non-conservative manner. Probability theory is an appropriate uncertainty theory for analysis of random events when the given information is perfect and complete. But, is randomness one of threat likelihood nature? Although some threat has never happened, it will be possible in the future. Threat likelihood estimation involves uncertainty associated with predicting an event in the future. Zadeh's possibility-probability consistency principle illustrated the difference between probability and possibility simply by stating that a high degree of possibility does not imply a high degree of probability, nor does a low degree of probability implies a low degree of possibility, but a high degree of probability implies a high degree of possibility and low degree of possibility implies low probability (Zadeh 1978). Threats are also a class of events that may have a probability of zero but may not be impossible. Although something has never happened, it will be possible in the future. Fuzzy logic based approaches have been extensively used to model vagueness and ambiguity, but it cannot deal with such uncertainties as incomplete, imprecise and missing information (ignorance). Vagueness is uncertainty about the classification of a known event. For example, Mehmet is 22 years old, but it is said that Mehmet is young without the precise definition of young. At this example, the word young is vague and can be addressed by using fuzzy set theory.

The threat is chosen and executed for a reason by the attacker. A threat, intentional event against a critical facility, is neither random event nor vague event and uncertainty associated with such intentional event involves epistemic uncertainty rather than aleatory uncertainty. In this study, DST is used for uncertainty modelling and the input data for threat likelihood are represented by DST variables due to epistemic uncertainty.

3.2.3 Dempster-Shafer Theory of Evidence

The Dempster-Shafer theory of evidence (DST) is an alternative theory for the mathematical representation of uncertainty in intelligent systems (Dempster 1967; Shafer 1976; Kohlas and Monney 2013). There are many practical applications of DST in the literature such as artificial intelligence, expert systems, pattern recognition, data fusion, decision making, failure modes and effect analysis, etc. (Kohlas and Monney 2013; Awasthi and Chauhan 2011; Shoyaib et al. 2012; Yang et al. 2011; Dempster et al. 2008). Applications of DST in typical risk assessment have been very limited because probabilistic methods are successful where a lot of experimental data and expert knowledge are available (Demotier et al. 2006).

The theory begins by defining the frame of discernment (FD), denoted by $\Theta = \{H_1, \ldots, H_N\}$, which is a collectively exhaustive and mutually exclusive set of propositions or hypotheses. The power set, 2^{Θ}, is constructed from Θ which consists all subsets of Θ, including the empty set (Ø) and Θ itself i.e. $2^{\Theta} = \{\varnothing, \{H_1\}, \ldots, \{H_N\}, \{H_1, H_2\}, \ldots, \{H_1, H_N\}, \ldots, \Theta\}$.

DST uses three basic parameters, i.e., basic probability assignment (bpa), belief measure (Bel), and plausibility measure (Pls) to characterize the uncertainty in a belief structure. The bpa (m) which is a function $m : 2^{\Theta} \rightarrow [0, 1]$ satisfying following axioms:

$$m(\varnothing) = 0 \quad \text{and} \quad \sum_{A \subseteq \Theta} m(A) = 1 \tag{3.1}$$

where A is any subset of Θ ($A \in 2^{\Theta}$). The bpa for a given set A, m(A), measures the belief exactly assigned to A and represents how strongly the evidence supports A. The bpa's of all the subsets of Θ sum to unity and the bpa of Ø is 0. The bpa of Θ, $m(\Theta)$, is called the degree of ignorance. Each subset A with $m(A) > 0$ is called a focal element and all the focal elements are called the body of evidence.

The belief measure (Bel) and the plausibility measure (Pls) are the functions associated with each bpa and defined by the following equations:

$$\mathrm{Bel(A)} = \sum_{B \subseteq A} m(B) \tag{3.2}$$

$$Pls(A) = \sum_{A \cap B \neq \emptyset} m(B) \tag{3.3}$$

where A and B are subsets of Θ. Bel(A) represents the exact support to A. Pls(A) represents the possible support to A. The two functions are connected by the equation:

$$\mathrm{Pls(A)} = 1 - \mathrm{Bel}(\bar{\mathrm{A}}) \tag{3.4}$$

where $\bar{\mathrm{A}}$ denotes the complement of A. The difference between the Bel(A) and Pls (A) describes the ignorance of the assessment for the set A (Fig. 3.1).

[Bel(A), Pls(A)] constitutes the interval of support to A and can be interpreted as the lower and upper bounds of the probability to which A is supported due to lack of information. The precise probability of an event lies within the lower and upper bounds of Bel and Pls, respectively (Bel(A) ≤ P(A) ≤ Pls(A)). The wider the interval, the less informative it is. The measurements Bel, Pls, and probability will converge to a single probability when the information increased sufficiently (Bel (A) = P(A) = Pls(A)). The sum of all the Bel and the sum of all the Pls are not required to be 1 and therefore, both Bel and Pls are non-additive.

The other important aspect of DST is the combination rules that are the special types of aggregation methods for data obtained from multiple independent information sources. Detailed discussions on these rules can be found in the literature (Sentz and Ferson 2002; Smets 2007). These rules can be either conjunctive rules (AND-based on set intersection) or disjunctive rules (OR-based on set union) from a set theoretic standpoint. Two most common combination rules, both one conjunction based rule and one disconjunction based rule, are used and compared in this study: the Yager's modified Dempster's rule (Yager's rule) and the Dubois and Prade's disjunctive consensus rule (DP's rule) (Dempster 1967; Yager 1987a, b; Dubois and Prade 1992).

$$m_1 \oplus_{DP} \cdots \oplus_{DP} m_i \oplus_{DP} \cdots \oplus_{DP} m_n(A) = \begin{cases} \sum_{\cup_{i=1}^{n} A_i = A} m_1(A_1)^* \ldots {}^* m_i(A_i)^* \ldots {}^* m_n(A_n), & A \neq \emptyset \\ 0, & A = \emptyset \end{cases} \tag{3.5}$$

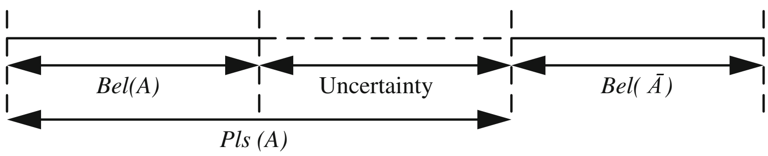

Fig. 3.1 Belief and plausibility

$$
\begin{aligned}
& m_1 \oplus_Y \cdots \oplus_Y m_i \oplus_Y \cdots \oplus_Y m_n(A) \\
& = \begin{cases} \sum\limits_{\cap_{i=1}^n A_i = A} m_1(A_1)^* \ldots {}^* m_i(A_i)^* \ldots {}^* m_n(A_n), & A \neq \Theta \\ \sum\limits_{\cap_{i=1}^n A_i = A} m_1(A_1) * \ldots * m_i(A_i) * \ldots * m_n(A_n) + K, & A = \Theta \\ 0, & A = \varnothing \end{cases}
\end{aligned} \tag{3.6}
$$

$$
K = \sum_{\cap_{i=1}^n A_i = \Phi} m_1(A_1) * \ldots * m_i(A_i) * \ldots * m_n(A_n) \tag{3.7}
$$

where A_i's are propositions from different information sources, $m_i(A_i)$s are corresponding bpas, K represents bpa associated with conflict, and the symbol $\oplus$ represents operator of combination. The symbol $\oplus_{DP}$ represents DP's rule and the symbol $\oplus_Y$ represents Yager's rule.

In the case of multiple information sources, two algebraic properties enable evidence to be combined in any order: commutativity and associativity. Therefore, commutativity and associativity of the combination rules are required for multiple information combinations. These algebraic properties are satisfied by each of the applied rules: the Yager's rule is both commutative and quasi-associative, and the DP's rule is both commutative and associative. These properties can be seen in Sentz and Ferson (2002).

Major difficulty in applying the DST is the computational complexity. There is no explicit function of the given imprecise information in DST like the probability density function. The significant difference of DST is that bpas are assigned to sets and subsets of sample space rather than mutually exclusive singletons as in probability theory. This implies an exponential increase in computational complexity. The subsets to which the bpas are assigned can be consonant (nested) or non consonant and continuous or discrete. Under the restriction that all the focal subsets are nested, Pls is referred to as possibility and Bel is referred to as necessity in possibility theory (Dubois and Prade 1988).

DST is selected for the likelihood estimation because both epistemic uncertainty and aleatory uncertainty can be handled by the help of the flexibility of DST basic axioms. DST is also well suited for handling incomplete information without any additional assumptions as additivity. Lastly, DST combination rules allow aggregating different types of evidence obtained from multiple sources easily. Details of the application of DST within MA to likelihood estimation are described in the next section.

3.3 Evidence Based Morphological Analysis Model

Likelihood estimation of complex events like intentional attacks in threat assessment is difficult to assess directly because it is not possible to obtain a precise measurement from experiments. Therefore, EMA model decomposes these events into simple relations and determine the overall event likelihood by assembling the relations' likelihoods using DST combination rules. EMA model provides an efficient approach for breaking/making a large and complex assessment into a sequence of smaller and simpler relations that can be more easily addressed in a structured way.

The proposed EMA model incorporates DST with MA in this study. Different from typical MA applications, the strength of logical relations between the parameter values are not limited to binary (Yes or No) decisions since experts may express likelihood of existence of relation which is characterized by the linguistic evaluation grades that represent the qualitative expert assessments. Typical qualitative analysis of MA identifies all the plausible scenarios, whereas proposed EMA both identifies all the plausible scenarios and estimates the likelihood of plausible scenarios based on DST. The proposed model allows to express qualitative judgements using belief structures developed on the basis of DST and make full use of available information without information loss and exaggeration. A relation in MA may change when more information is get by time. Thus, the notion of time, t, is also introduced into the problem formulation.

The proposed model first identifies the parameters of the scenarios and defines a range of values for each parameter. Original FD is determined for evaluation of CCA matrix relations and bpas for evaluation of CCA matrix relations are assigned. Relations within MA are combined using belief structures that are aggregated to form the scenarios by two well-known DST combination rules: DP's rule and Yager's rule. Then, the belief intervals of all scenario likelihoods are calculated. The likelihoods of identified scenarios are ranked based on their belief intervals according to defined preference relation using bubble sort algorithm. The proposed approach consists of the following steps shown in Fig. 3.2.

Step 1: Identify the parameters and define a range of values for each parameter

In this step, the scenario parameters are identified and a range of values for each scenario parameters are defined. Suppose in a morphological field there are L basic parameters and let be a set of parameters $A = \{A_1, \ldots, A_i, \ldots A_L\}$. A set of basic values for parameter A_i is defined as $A_i = \{a_1^i, \ldots, a_k^i, \ldots, a_{L(A_i)}^i\}$ where a_k^i is the kth value of the parameter A_i and $L(A_i)$ is the total number of the values of parameter A_i.

Step 2: Form Morphological Field

Morphological field is formed as shown in Table 3.1.

Step 3: Construct Cross-Consistency Assessment (CCA) Matrix

At this step, definition and representation of CCA matrix is done based on DST.

Sub-step 3.1: Determine the Frame of Discernment for evaluation of CCA Matrix relations

Determination of the FD is context dependent and very important. Since bpas are assigned to subsets of the FD in DST, this implies an exponential increase in computational complexity (Liu et al. 2007). The other point is that FD affects the way information captured. Therefore, FD is determined considering both information at hand and computational complexity in this study.

Fig. 3.2 The steps of EMA model

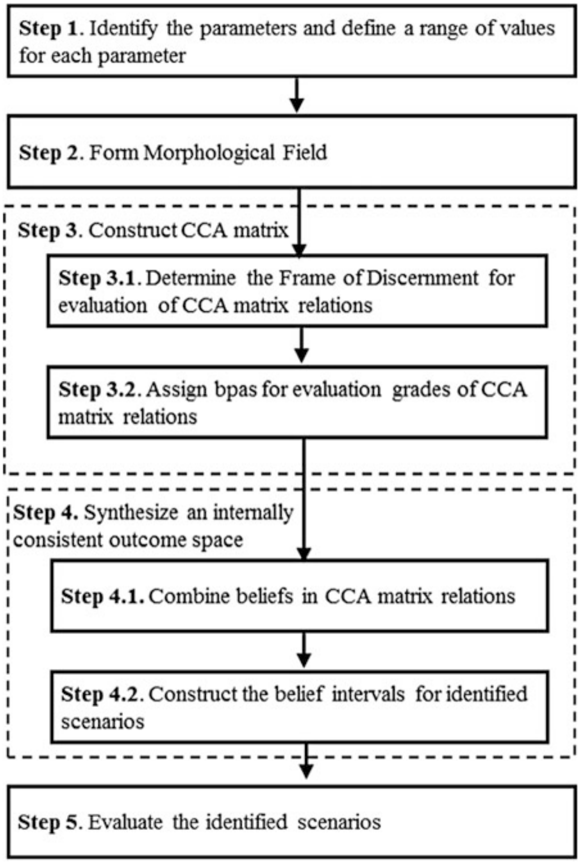

Table 3.1 Sample morphological field

Parameter A_1	…	Parameter A_L
a_1^1	…	a_1^L
…	…	…
…	…	$a_{L(A_L)}^L$
$a_{L(A_1)}^1$	…	

For threat likelihood estimation, it is not possible to obtain a measurement from experiments and the input information is commonly obtained from expert elicitation. Qualitative judgement information given by security experts is essential to quantify likelihood. Security experts as in many fields tend to think in linguistic terms and usually give their subjective judgements linguistically by means of a set of evaluation grades. There is a significant body of knowledge in qualitative or linguistic form for determining threat likelihood and this knowledge has to be captured. Different types of assessment information, such as complete and incomplete, precise and imprecise assessments, may be expressed as follows (Yang and Singh 1994):

- *Assessment 1:* Absolutely (100 %) believe that explosive attack to target 1 is "Likely" expressed by DST format as {(Likely, 1)};
- *Assessment 2:* 70 % believe that explosive attack to target 2 is "Likely" and 30 % believe that it is "Highly Likely" expressed by DST format as {(Likely, 0.7), (Highly Likely, 0.3)};
- *Assessment 3:* 80 % believe that explosive attack to target 3 is "Likely" expressed by DST format as {(Likely, 0.8)};
- *Assessment 4:* 90 % believe that explosive attack to target 4 is between "Likely" to "Highly Likely" and 10 % believe that "Extremely Likely" expressed by DST format as {(Likely-Highly Likely, 0.9), (Extremely Likely, 0.1)};
- *Assessment 5:* No judgement, which means experts can not provide an assessment for likelihood of relation under consideration, is expressed by DST format as {(Θ, 1)}.

In the above statements, the input is given as a distribution using linguistic terms with the belief degrees (30, 70 %, etc.) based on subjective judgments. Each belief degree is the individual bpa of the input to the evaluation grade. When all the belief degrees are summed to one in an assessment, the assessment is said to be complete; otherwise, it is said to be incomplete. Assessment 1, 2 and 4 are complete while assessment 3 is incomplete. No judgement is referred to as total ignorance as in assessment 5. Total ignorance corresponds to whole domain of likelihood being possible. The decision maker may not always be 100 % sure that the state of a relation is exactly confirmed to one of the evaluation grades since FD, Θ, consists all evaluation grades. Incomplete assessments may result from lack of data, unavailable data, partially known data or the inability of experts to provide valid and accurate information. For handling incomplete information, the Θ is taken as a focal element by assuming that the unknown evidence may let all evaluation grades have equal evaluation. For example, in assessment 3 the missing 0.2 represents the degree of ignorance and is assigned to Θ. The decision maker also may not always be confident enough to provide subjective assessments to individual grades and may assess beliefs to subsets of adjacent grades, intervals, like in assessment 4. In assessment 4, the individual grades are extended to include interval grades such as "Likely-Highly Likely".

In order to reduce the computational complexity, all of the CCA matrix relation likelihoods between each scenario parameter are assessed on the basis of $H_{pq}(p, q = 1, \ldots, N)$ evaluation grades where H_{pp} is an individual evaluation grade, and H_{pq} for p = 1 to N and q = p + 1 to N − 1 is the interval evaluation grade between H_{pp} and $H_{qq}(p < q,\ q = 2, \ldots, N)$. $H_{pp}(p = 1, \ldots, N)$ are required to be mutually exclusive. Therefore, a set of evaluation grades for relation likelihood, FD, is denoted by

$$\Theta = \{H_{pq}, \mathrm{p} = \mathrm{q}, \mathrm{p} = 1, \ldots, \mathrm{N}\} \quad (3.8)$$

Θ constitutes a FD and interval evaluation grades are special subsets of mutually exclusive individual evaluation grades in the terminology of DST. H_{11} and H_{NN} are set to be the worst and the best grades, respectively, and $H_{\mathrm{p+1p+1}}$ is to be preferred to H_{pp} among evaluation grades.

In this study, uncertain subjective judgments, such as complete and incomplete, precise and imprecise assessments, for evaluation of CCA matrix relation likelihoods are acquired using statements similar to statements 1–5 where H_{pq} represents an evaluation grade to which relations between each scenario parameter in MA may be assessed and (H_{pq}, $m(H_{\mathrm{pq}})$) represents the input information.

Sub-step 3.2: Assign bpas for evaluation grades of CCA matrix relations

In the proposed EMA model, the relations among scenario parameters in CCA matrix are evaluated by assigning bpa to each linguistic evaluation grade and/or linguistic interval evaluation grades. Likelihood bpa assignments are based on subjective judgements because of the limited numeric data, and human judgement is needed to weigh alternative interpretations of whatever data available. It is assumed that group of experts provide consensus evaluation for each relation. Group decision making techniques can be applied but beyond the scope of this study.

The Cartesian product of any two parameters in CCA matrix, $\mathrm{A_i}$ and $\mathrm{A_j}$ is determined as:

$$\mathrm{A_i} \ \mathrm{X} \ \ \mathrm{A_j} = \{(\mathrm{a}_k^i, \mathrm{a}_l^j) | \mathrm{a}_k^i \in \mathrm{A_i}, \ \mathrm{a}_l^j \in \mathrm{A_j}\} \quad (3.9)$$

which forms ordered pair of every $\mathrm{a}_k^i \in \mathrm{A_i}$ with every $\mathrm{a}_l^j \in \mathrm{A_j}$. The strength of relationship between ordered pairs of elements in typical MA is measured by the characteristic function, denoted χ, where a value of unity is associated with complete relationship and a value of zero is associated with no relationship as follows:

$$\chi_{\mathrm{A_i X A_j}}(\mathrm{a}_k^i, \mathrm{a}_l^j) = \begin{cases} 1, & (\mathrm{a}_k^i, \mathrm{a}_l^j) \in \mathrm{A_i} \ \mathrm{X} \ \ \mathrm{A_j} \\ 0, & \textit{otherwise} \end{cases} \quad (3.10)$$

However, in proposed approach the strength of relationship between ordered pairs of elements is measured by the following DST characteristic function as:

$$\chi_{\mathrm{A_i X A_j}}(\mathrm{a}_k^i, \mathrm{a}_l^j) = \begin{cases} m_t(H_{pq}/R_{ij}(\mathrm{a}_k^i, \mathrm{a}_l^j)), & (\mathrm{a}_k^i, \mathrm{a}_l^j) \in \mathrm{A_i} \ \mathrm{X} \ \ \mathrm{A_j}, H_{pq} \in 2^{\Theta} \\ 0, & \textit{otherwise} \end{cases} \quad (3.11)$$

where $m_t(H_{pq}/R_{ij}(\mathrm{a}_k^i, \mathrm{a}_l^j))$ expresses a bpa assigned to pair $(\mathrm{a}_k^i, \mathrm{a}_l^j)$ from kth value of $\mathrm{A_i}$ and lth value of $\mathrm{A_j}$ confirmed to H_{pq} at time t. Therefore, each relation in proposed MA at time t is defined by the following expression:

$$\mathrm{R}_{ij}^{t}(A_i, A_j) = \{(\mathrm{a}_k^i, \mathrm{a}_l^j) | m_t(H_{pq}/R_{ij}(\mathrm{a}_k^i, \mathrm{a}_l^j)) > 0,\ \mathrm{a}_k^i \in \mathrm{A_i},\ \mathrm{a}_l^j \in \mathrm{A_j}, H_{pq} \in 2^{\Theta}\},$$
$$i \neq j, \quad i,j = 1,..,L \tag{3.12}$$

The belief structure of each relation $(\mathrm{a}_k^i, \mathrm{a}_l^j) \in \mathrm{R}_{ij}^t(A_i, A_j)$ at time t can be defined as follows:

$$\mathrm{S}_t(\mathrm{a}_k^i, \mathrm{a}_l^j) = \{(H_{pq}, m_t(H_{pq}/R_{ij}(\mathrm{a}_k^i, \mathrm{a}_l^j)))\},\ (\mathrm{a}_k^i, \mathrm{a}_l^j) \in \mathrm{R}_{ij}^t(A_i, A_j), H_{pq} \in 2^{\Theta} \tag{3.13}$$

For example, in Table 3.2 belief structure for $(\mathrm{a}_1^1, \mathrm{a}_1^L) \in \mathrm{R}_{1L}^t(A_1, A_L)$ at time t is $\mathrm{S}_t(\mathrm{a}_1^1, \mathrm{a}_1^L) = \{(H_{24}, 0.5), (H_{11}, 0.5)\}$.

Step 4: Synthesize an internally consistent outcome space

Sub-step 4.1: Combine beliefs in CCA matrix relations

If a morphological field is defined by L basic parameters, there will be C_2^L relations in CCA matrix and each scenario is defined as a unique combination of relations in CCA matrix. Therefore, each relation considered as different information source and fused by using DST combination rules in order to produce an aggregated likelihood estimation of the scenarios. The relations, as different information sources, provide different assessments for the same FD and the aggregation among the relations produces the scenarios. The beliefs of relations in CCA matrix is aggregated using the DP's rule (Eq. 3.5) and the Yager's rule (Eq. 3.6) as follows:

$$m_t(H_{pq}/T(\mathrm{a}_{.}^1, \ldots, \mathrm{a}_{.}^L)) = \sum_{\substack{ij \in C_2^L \\ k,l \in \{\mathrm{a}_{.}^1, \ldots, \mathrm{a}_{.}^M\}, k \neq l}} \oplus_{DP/Y} m_t(H_{pq}/R_{ij}(\mathrm{a}_k^i, \mathrm{a}_l^j)),\ \forall H_{pq} \tag{3.14}$$

Therefore, each scenario in proposed MA at time t is defined by the following expression:

Table 3.2 CCA matrix

		Parameter A_1			Parameter …			Parameter A_L		
		a_1^1	…	$a_{L(A_1)}^1$	…	…	…	a_1^L	…	$a_{L(A_L)}^L$
Parameter …	…									
	…									
	…									
Parameter A_L	a_1^L	{(H_{24}, 0.5), (H_{11}, 0.5)}								
	…									
	$a_{L(A_L)}^L$									

$$\mathrm{T}_t(A_1,\ldots,A_L) = \{(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})|m_t(H_{pq}/T(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})) > 0,\ \mathrm{a}_{\cdot}^{1} \in \mathrm{A}_1,\ldots,\ \mathrm{a}_{\cdot}^{L} \in \mathrm{A}_L, H_{pq} \in 2^{\Theta}\} \tag{3.15}$$

The belief structure of each scenario $(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}) \in \mathrm{T}_t(A_1,\ldots,A_L)$ at time t can be defined as follows:

$$\mathrm{S}_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}) = \{(H_{pq}, m_t(H_{pq}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})))\}, \forall(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}) \in T_t(A_1,\ldots,A_L), H_{pq} \in 2^{\Theta} \tag{3.16}$$

Sub-step 4.2: Construct the belief intervals for identified scenarios
After identifying scenarios by combining beliefs in CCA matrix relations, Bel, Pls and the belief intervals of evaluation grades for identified scenarios are determined by applying Eqs. 3.2 and 3.3 as:

$$\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})) = \sum_{H_{pq}\subseteq H_{pp}} m(H_{pq}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})), \quad p,q = 1,\ldots,N \tag{3.17}$$

$$\mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})) = \sum_{H_{pq}\cap H_{pp}\neq\varnothing} m(H_{pq}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})), \quad p,q = 1,\ldots,N \tag{3.18}$$

$$\mathrm{S}_t^{'}(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}) = \{(H_{pp}, [\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})), \mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}))]), \ p = 1,\ldots,N\} \tag{3.19}$$

The result is used as a belief interval indicating how strongly the evidence support each scenario. The end points of the belief interval $[\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})), \mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}))]$ can be viewed as the lower and upper bounds of the probability to which H_{pp} is supported under the current evidence for scenario $(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})$. Figure 3.1 illustrates the interpretation of the belief interval. For example;

- If $[\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})), \mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}))] = [0, 0]$, then there is no evidence to support H_{pp} for scenario $(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})$,
- If $[\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})), \mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}))] = [0, 1]$, then there is no evidence available either to support or not to support H_{pp} for scenario $(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})$,
- If $[\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})), \mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L}))] = [1, 1]$, H_{pp} for scenario $(\mathrm{a}_{\cdot}^{1},\ldots,\mathrm{a}_{\cdot}^{L})$ has been completely confirmed,

- If $[\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}_\cdot^1,\ldots,\mathrm{a}_\cdot^L)),\ \mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}_\cdot^1,\ldots,\mathrm{a}_\cdot^L))] = [0.6,\ 0.9]$, then the probability of exact support to $\mathrm{H_{pp}}$ for scenario $(\mathrm{a}_\cdot^1,\ldots,\mathrm{a}_\cdot^L)$ is 0.6, and the maximal probability of possible support to $\mathrm{H_{pp}}$ for scenario $(\mathrm{a}_\cdot^1,\ldots,\mathrm{a}_\cdot^L)$ is 0.9, i.e., there is a probability of 0.1 to refuse $\mathrm{H_{pp}}$ for scenario $(\mathrm{a}_\cdot^1,\ldots,\mathrm{a}_\cdot^L)$.

Step 5: Evaluate the identified scenarios

In order to evaluate the identified scenarios, the likelihood of identified scenarios is needed to be ranked and compared based on their belief intervals. Therefore, ranking of identified scenarios based on their belief intervals is required.

For this purpose, preference function proposed by Wang is adopted (Wang et al. 2005; Knuth 1997). In Wang's method each alternative, here called scenario, has one belief interval. But, because of the different determination of the FD in this study, any scenario could have more than one belief interval; one belief interval for any evaluation grade, $\mathrm{H_{pp}}(\mathrm{p}=1,\ldots,\mathrm{N})$. Therefore, the degree of preference of scenario A over scenario B for $\mathrm{H_{pp}}(\mathrm{p}=1,\ldots,\mathrm{N})$ at time t, denoted by $\mathrm{P(A > B, H_{pp})_t} \in [0, 1]$, is defined as follows:

$$P(A > B, H_{pp})_t = \frac{\max[0, Pls_t(H_{pp}/A) - Bel_t(H_{pp}/B)] - \max[0, Bel_t(H_{pp}/A) - Pls_t(H_{pp}/B)]}{[Pls_t(H_{pp}/A) - Bel_t(H_{pp}/A)] + [Pls_t(H_{pp}/B) - Bel_t(H_{pp}/B)]} \tag{3.20}$$

According to definition, it is obvious that

- $P(A > B, H_{pp})_t = 1 \quad \text{iff} \quad Bel_t(H_{pp}/A) \geq Pls_t(H_{pp}/B)$,
- $P(A > B, H_{pp})_t = 0 \quad \text{iff} \quad Pls_t(H_{pp}/A) \leq Bel_t(H_{pp}/B)$,
- $P(A > B, H_{pp})_t = 0.5 \quad \text{iff} \quad Bel_t(H_{pp}/A) + Pls_t(H_{pp}/A) = Bel_t(H_{pp}/B) + Pls_t(H_{pp}/A)$,
- $P(A > B,\ H_{pp})_t > 0.5$ if
  - $Bel_t(H_{pp}/A) > Bel_t(H_{pp}/B)$ and $Pls_t(H_{pp}/A) > Pls_t(H_{pp}/B)$,
  - $Bel_t(H_{pp}/A) < Bel_t(H_{pp}/B)$, $Pls_t(H_{pp}/A) > Pls_t(H_{pp}/B)$ and $\dfrac{Bel_t(H_{pp}/A) + Bel_t(H_{pp}/B)}{2} > \dfrac{Pls_t(H_{pp}/A) + Pls_t(H_{pp}/B)}{2}$.

Therefore, based on above mentioned properties for any evaluation grade, $\mathrm{H_{pp}}$, A is superior to B if $P(A > B,\ H_{pp})_t > 0.5$, A is indifferent to B if $P(A > B,\ H_{pp})_t = 0.5$, and A is inferior to B if $P(A > B,\ H_{pp})_t < 0.5$. The preference function between scenarios has transitivity, i.e., if scenario A is superior to B, and scenario B is superior to C, then scenario A is superior to C. By applying Eq. 3.20, preference relations among all scenarios can be determined for any evaluation grade, $\mathrm{H_{pp}}$.

In this study, for ranking of scenarios having more than one belief interval, one belief interval for several evaluation grades, new ranking algorithm based on bubble sort is developed. Identified scenarios are sorted from highest likelihood to lowest likelihood according to preference function using bubble sort (Knuth 1997). Bubble sort is used in this study because bubble sort is one of the simplest sorting algorithms to understand and to implement. At the sorting process, there are two alternatives of DM's attitude toward the decision environment: pessimistic or optimistic, in other words risk averse or risk seeking. For the DM's pessimistic attitude, the proposed ranking algorithm is used to identify the worst evaluation grade of any scenario and pick a scenario that has the best of the worst evaluation grade interval based on the preference function mentioned above. For the DM's optimistic attitude, the proposed ranking algorithm is used to select scenario with the best of the best intervals. If one scenario has a higher (or more preferable) evaluation grade value than any of the other scenarios, that scenario is chosen and the sorting process ends. However, if some scenarios are tied on the most important evaluation grade, the subset of tied scenarios is then compared on the next most important evaluation grade. The process continues sequentially until all the alternatives are sorted. Pseudo code implementation of the two proposed ranking algorithm called *BubbleSortByMinLikelihood* and *BubbleSortByMaxLikelihood* can be expressed as:

```
procedure BubbleSortByMinLikelihood
( T : list of scenarios )
  do
    swapped = false
    for i = 1 to length(T)-1
      if is_superior (T[i-1],T[i]) then
        swap( T[i-1], T[i] )
        swapped = true
      end if
    end for
  while swapped
end procedure

function is_superior( A,B : scenario )
  for p=1 to N
    if P(A,B,p)> 0.5 then
      return is_superior = false
    end if
  end for
  return is_superior = true
end function
```

```
procedure BubbleSortByMaxLikelihood
( T : list of scenarios )
  do
    swapped = false
    for i = 1 to length(T)-1
      if is_superior (T[i-1],T[i]) then
        swap( T[i-1], T[i] )
        swapped = true
      end if
    end for
  while swapped
end procedure

function is_superior( A,B : scenario )
  for p=N down to 1
    if P(A,B,p)> 0.5 then
      return is_superior = true
    end if
  end for
  return is_superior = false
end function
```

The detailed descriptions of each step are elaborated in the following illustrative case study section.

3.4 An Illustrative Example

In this section, the proposed EMA model as described in Sect. 3.3 is applied to a hypothetical Airport X to identify the threat scenarios and evaluate their likelihoods. Modern airports with their runways, taxiways, aprons, passenger terminals, ground handling and flight navigation equipment are very complex facilities (Ashford et al. 1997; Akgun et al. 2010). Simply, the mission of an airport is to land, to unload payload, to load payload and to take off aircrafts. When the security requirements are considered against the possible intentional attacks, the challenge of threat assessment for an airport becomes very complicated. Therefore, it is thought that an airport case can be an interesting example. Note that for security reasons, all the data used throughout this example are purely generic and notional. Even though this case study is very simple, the resulting qualitative relationships and insights drawn from this example validate the proposed approach.

Assume that at time t officials issued an intelligence bulletin to warn security departments of critical facilities that says "terrorists could target large crowds at holiday gatherings and they might have entered the city with explosive loaded car" and as a security manager of Airport X "what should I do to accomplish a realistic threat assessment?" A step-by-step algorithm for this example is as follows:

Step 1: Identify the parameters and define a range of values for each parameter
In this step, the parameters of the threat scenario are identified and range of values for each parameter is defined for critical facility, Airport X. History of attacks against similar assets and possible methods of attacks are examined. Many of these attacks to date are one-time strike and run-away events. As the attack strategy, attacking a single target is considered, attacking multiple targets is not considered. After data of attacks were collected and compiled for this research from unclassified resources, four critical most common parameters of possible threat scenarios are determined as:

A = {Target (A_1), Weapon type (A_2), Part of target attacked (A_3), Magnitude (A_4)}

Originally more parameters could be defined but this study considers four parameters for possible threat scenarios against critical facility assets. Based on available data and expert knowledge, the detailed descriptions of these parameters and their values are listed below:

- Target (A_1): Targets are specific high value assets at the critical facility, Airport X. After investigating Airport X, 20 possible targets are determined (Ashford et al. 1997; Akgun et al. 2010).
  A_1 = {"Airfield Maintenance Building" (a_1^1), "Fuel Complex Building" (a_2^1), "Passenger Terminal" (a_3^1), "Parking Facility" (a_4^1), "Bus Station" (a_5^1), "Custom Building" (a_6^1), "Cargo Terminal" (a_7^1), "Air Traffic Control Tower" (a_8^1), "Apron" (a_9^1), "Runway and Taxiway" (a_{10}^1), "Main Entrance and Security Control Building" (a_{11}^1), "Security Building" (a_{12}^1), "Aircraft Rescue and Fire Fighting Building" (a_{13}^1), "Police Station Building" (a_{14}^1), "Fuel Complex Guard Building" (a_{15}^1), "Guard Tower" (a_{16}^1), "Fencing" (a_{17}^1), "Heating Centre Building" (a_{18}^1), "Power Centre Building" (a_{19}^1), "Water Storage Building" (a_{20}^1)}
- Weapon type (A_2): Possible types of the weapon or equipment used for the attacks are determined. Explosive attacks are most common in historical analysis of past attacks (LaTourrette et al. 2006). In this study, chemical, biological,

radiological and nuclear threats are not considered. following weapon types used in disruptive attacks are interested:

A_2 = {"Explosives" (a_1^2), "Truck/Car bomb" (a_2^2), "Fire/fire bomb" (a_3^2), "Firearms" (a_4^2)}

- Part of target attacked (A_3): Different part of the target may be subject to attack. Part of the targets subject to attack is classified as:
  A_3 = {"Perimeter" (a_1^3), "Protected areas" (a_2^3), "Infrastructure Systems" (a_3^3)}
  Perimeter is the peripheral/outside part, protected areas are inside part and infrastructure systems are especially equipment dense part of the targets.
- Magnitude (A_4): Intensity of the attack may vary. Intensity of attacks are categorized as:
  A_4 = {"Low" (a_1^4), "Medium" (a_2^4), "High" (a_3^4)}

Therefore, threat scenario of Airport X is defined as a combination of four parameters: target, weapon type, part of target attacked and magnitude.

Step 2: Form Morphological Field

The morphological field is constructed depending on the information provided by step 1 (Table 3.3). There are totally 20 * 4 * 3 * 3 = 720 threat scenarios either possible or not in the formed morphological field. For example, a threat scenario which describes a low magnitude explosive attack to perimeter of power centre building in the morphological field is developed by the highlighted parameter values in the Table 3.3.

Step 3: Construct Cross-Consistency Assessment (CCA) matrix

Sub-step 3.1: Determine the Frame of Discernment for evaluation of CCA matrix relations

Uncertain subjective judgments for evaluation of CCA matrix relation likelihoods are acquired using statements similar to statements 1–5. It is important to capture fine threat likelihood distinction among threat scenarios with proposed linguistic evaluation grades that represent the input information. In this study, security experts give their subjective judgements linguistically by means of a following mutually exclusive set of evaluation grades: "Likely" (L), "Very Likely" (VL), "Highly Likely" (HL), "Very Highly Likely" (VHL) and "Extremely Likely" (EL). In the terminology of DST, the FD, Θ, is defined as follows:

$$\Theta = \{\text{L, VL, HL, VHL, EL}\} = \{H_{11}, H_{22}, H_{33}, H_{44}, H_{55}\} \quad (3.21)$$

Therefore, all of the relations between each scenario parameter are assessed on the basis of individual evaluation grades $H_{\text{pq}}(\text{p} = \text{q},\ \text{p} = 1, \ldots, 5)$ and the interval evaluation grades between H_{pp} and $H_{\text{qq}}(\text{p} < \text{q},\ \text{q} = 2, \ldots, 5)$ similar to statements 1–5 as:

Table 3.3 Morphological field of the case study

Target (A_1)		Weapon type (A_2)		Part of target attacked (A_3)		Magnitude (A_4)	
a_1^1	Airfield maintenance building	a_1^2	***Explosives***	a_1^3	***Perimeter***	a_1^4	***Low***
a_2^1	Fuel complex building	a_2^2	Truck/car bomb	a_2^3	Protected areas	a_2^4	Medium
a_3^1	Passenger terminal	a_3^2	Fire/fire bomb	a_3^3	Infrastructure systems	a_3^4	High
a_4^1	Parking facility	a_4^2	Firearms				
a_5^1	Bus station						
a_6^1	Custom building						
a_7^1	Cargo terminal						
a_8^1	Air traffic control tower						
a_9^1	Apron						
a_{10}^1	Runway and taxiway						
a_{11}^1	Main entrance and security control building						
a_{12}^1	Security building						
a_{13}^1	Aircraft rescue and fire fighting building						
a_{14}^1	Police station building						
a_{15}^1	Fuel complex guard building						
a_{16}^1	Guard tower						
a_{17}^1	Fencing						
a_{18}^1	Heating centre building						
a_{19}^1	***Power centre building***						
a_{20}^1	Water storage building						

$$\begin{Bmatrix} L & L-VL & L-HL & L-VHL & L-EL \\ & VL & VL-HL & VL-VHL & VL-EL \\ & & HL & HL-VHL & HL-EL \\ & & & VHL & VHL-EL \\ & & & & EL \end{Bmatrix} = \begin{Bmatrix} H_{11} & H_{12} & H_{13} & H_{14} & H_{15} \\ & H_{22} & H_{23} & H_{24} & H_{25} \\ & & H_{33} & H_{34} & H_{35} \\ & & & H_{44} & H_{45} \\ & & & & H_{55} \end{Bmatrix} \tag{3.22}$$

Sub-step 3.2: Assign bpas for evaluation grades of CCA matrix relations
In the model, the relations among threat scenario parameters in CCA are required to be evaluated. All the evidence of a threat will be in the form of intelligence information and analyses of past adversary attacks. Reliable threat data are the most difficult to assess because prediction of adversary intentions are complex and difficult. Although historical data can help to define threat likelihood, it must be interpreted by considering technical capabilities of attacker, the attacker's perception of both the vulnerability and the potential consequences from a successful attack of the target. Attacker will attack the targets with high consequence and high vulnerable in order to maximize expected consequence. The attacker's intelligence/knowledge of the system may vary. The attacker may have perfect intelligence, partial intelligence, bad intelligence or no intelligence. Perception and capabilities of attackers are also not known. Therefore, identifying all of the actions into the future is not possible. The experts and their knowledge base examining the current evidence become the basis for assigning bpas to evaluation grades of CCA matrix relations. The experts typically ask the question, "If I were an attacker, I would …" thinking like an attacker and assign bpas to simple relations in CCA rather than complex relations without getting overloaded considering above mentioned facts. The use of judgment is necessary because of the subjective nature of these assessments and the experts can cast this information into an easy form provided by proposed EMA model.

In this study, the evidence is quantified by representing it as a belief structures that clearly communicates the uncertainty based on the quality of the evidence. The belief structures are easy to use and very flexible way to expert judgements and can help to better evaluate the threat likelihood. In terms of the defined evaluation grades, experts express their opinions using belief structure and providing consensus evaluation for each relation. Each relation is described by evaluation grades and their associated bpas. Explicitly, the assigned bpas represents the degree of expert belief for each evaluation grade, and implicitly, it represents the total evidence to clarify the threat scenario likelihood. By using expert judgement, the belief structure of any relation based on intelligence at time t reporting "possible bomb attack especially focusing on civilians" is given in Table 3.4. For example, in Table 3.4 the belief structure of $(\mathrm{a}_3^1, \mathrm{a}_1^2) \in \mathrm{R}_{12}^t(\mathrm{a}_k^1, \mathrm{a}_l^2)$ at time t is $\mathrm{S}_t(\mathrm{a}_3^1, \mathrm{a}_1^2) = \{(H_{11}, 0.4), (H_{25}, 0.2)\}$.

Step 4: Synthesize an internally consistent outcome space
Sub-step 4.1: Combine beliefs in CCA matrix relations
In this case study, the morphological field is defined by four basic parameters. Therefore, there are six (C_2^4) relations in CCA matrix, and the information collected by experts comes from these six different relations that constructs a threat scenario. These relations are independent pieces of evidence offering information on the experts' knowledge towards the likelihood of the threat scenario. Threat scenarios are constructed depending on evaluation grades of each relation using the DP's rule (Eq. 3.5) and the Yager's rule (Eq. 3.6) as follows:

Table 3.4 CCA matrix at time t

		Weapon type		Part of target attacked		Magnitude	
		a_1^2	a_2^2	a_1^3	a_2^3	a_1^4	a_2^4
Target	a_3^1	$\{(H_{11}, 0.4), (H_{25}, 0.2)\}*$	–	$\{(H_{34}, 0.7), (H_{55}, 0.3)\}$	$\{(H_{12}, 0.6), (H_{34}, 0.2)\}^*$	$\{(H_{34}, 0.5), (H_{55}, 0.5)\}$	$\{(H_{12}, 0.6), (H_{34}, 0.4)\}$
	a_4^1	–	$\{(H_{12}, 0.5), (H_{34}, 0.2)\}^*$	–	$\{(H_{34}, 0.4), (H_{55}, 0.6)\}$	$\{(H_{13}, 0.7), (H_{45}, 0.3)\}$	$\{(H_{34}, 0.8), (H_{55}, 0.2)\}$
	a_5^1	$\{(H_{12}, 0.6), (H_{35}, 0.4)\}$	–	$\{(H_{33}, 0.2), (H_{45}, 0.8)\}$	$\{(H_{13}, 0.5), (H_{44}, 0.5)\}$	$\{(H_{12}, 0.6), (H_{35}, 0.4)\}$	$\{(H_{12}, 0.5), (H_{33}, 0.4)\}^*$
	a_{11}^1	$\{(H_{12}, 0.4), (H_{33}, 0.3)\}^*$	–	$\{(H_{13}, 0.7), (H_{45}, 0.3)\}$	–	$\{(H_{13}, 0.6), (H_{45}, 0.4)\}$	$\{(H_{33}, 0.7), (H_{45}, 0.3)\}$
Weapon Type	a_1^2			$\{(H_{22}, 0.2), (H_{35}, 0.8)\}$	$\{(H_{13}, 0.7), (H_{45}, 0.3)\}$	$\{(H_{33}, 0.6), (H_{45}, 0.3)\}^*$	$\{(H_{22}, 0.5)\}^*$
	a_2^2			$\{(H_{33}, 0.3), (H_{45}, 0.7)\}$	$\{(H_{22}, 0.4), (H_{35}, 0.5)\}^*$	$\{(H_{12}, 0.4), (H_{34}, 0.6)\}$	$\{(H_{12}, 0.5), (H_{34}, 0.5)\}$
Part of target attacked	a_1^3					$\{(H_{12}, 0.6), (H_{35}, 0.4)\}$	$\{(H_{13}, 0.7), (H_{45}, 0.3)\}$
	a_2^3					$\{(H_{12}, 0.7), (H_{33}, 0.3)\}$	$\{(H_{11}, 0.8), (H_{23}, 0.2)\}$

note "*" refers to incomplete information

$$m_t(H_{pq}/T(a^1_., a^2_., a^3_., a^4_.)) = \sum m_t(H_{pq}/R_{12}(a^1_., a^2_.)) \oplus m_t(H_{pq}/R_{13}(a^1_., a^3_.)) \oplus m_t(H_{pq}/R_{14}(a^1_., a^4_.)) \oplus m_t(H_{pq}/R_{23}(a^2_., a^3_.)) \oplus m_t(H_{pq}/R_{24}(a^2_., a^4_.)) \oplus m_t(H_{pq}/R_{34}(a^3_., a^4_.)) \tag{3.23}$$

Sample combination of two relations by using both rules is shown in Tables 3.5 and 3.6.

Note that if there is an intersection, the union of two intervals in Table 3.5 is defined by the set consisting minimum of the two lower bounds and the maximum of the two upper bounds corresponding to an intersection. If there is no intersection, the union of two intervals in Table 3.5 is defined by the set consisting of two intervals separately.

Note that the intersection of two intervals in Table 3.6 is defined by the maximum of the two lower bounds and the minimum of the two upper bounds corresponding to an intersection. For K, there are two cells that contribute to conflict

Table 3.5 Combination of $R^t_{12}(a^1_3, a^2_1)$ and $R^t_{13}(a^1_3, a^3_1)$ by DP's rule

$R^t_{12}(a^1_3, a^2_1) \oplus R^t_{13}(a^1_3, a^3_1)$			$R^t_{13}(a^1_3, a^3_1)$			
			Interval	m_t	Interval	m_t
			H_{34}	0.7	H_{55}	0.3
$R^t_{12}(a^1_3, a^2_1)$	Interval	m_t				
	H_{11}	0.4	$[H_{11}, H_{34}]$	0.28	$[H_{11}, H_{55}]$	0.12
	H_{25}	0.2	H_{25}	0.14	H_{25}	0.06
	Θ	0.4	Θ	0.28	Θ	0.12
$\sum_{B_i \cup B_j = A} m_1(B_i)m_2(B_j)$	$\{([H_{11}, H_{34}], 0.28), ([H_{11}, H_{55}], 0.12), (H_{25}, 0.2)\}$					
$m_1 \oplus_{DP} m_2(A)$	$\{([H_{11}, H_{34}], 0.28), ([H_{11}, H_{55}], 0.12), (H_{25}, 0.2), (\Theta, 0.4)\}$					

Table 3.6 Combination of $R^t_{12}(a^1_3, a^2_1)$ and $R^t_{13}(a^1_3, a^3_1)$ by Yager's rule

$R^t_{12}(a^1_3, a^2_1) \oplus R^t_{13}(a^1_3, a^3_1)$			$R^t_{13}(a^1_3, a^3_1)$			
			Interval	m_t	Interval	m_t
			H_{34}	0.7	H_{55}	0.3
$R^t_{12}(a^1_3, a^2_1)$	Interval	m_t				
	H_{11}	0.4	Ø	0.28	Ø	0.12
	H_{25}	0.2	H_{34}	0.14	H_{55}	0.06
	Θ	0.4	H_{34}	0.28	H_{55}	0.12
K	0.4					
$\sum_{B_i \cap B_j = A} m_1(B_i)m_2(B_j)$	$\{(H_{34}, 0.42), (H_{55}, 0.18)\}$					
$m_1 \oplus_Y m_2(A)$	$\{(H_{34}, 0.42), (H_{55}, 0.18), (\Theta, 0.4)\}$					

represented by empty intersections and using Eq. 3.7, K = (0.4 × 0.7) + (0.4 × 0.3) = 0.4.

Belief structures of identified threat scenarios at time t by using both combination rules is shown in Table 3.7.

Sub-step 4.2: Construct the belief intervals for identified scenarios
After identifying threat scenarios by combining beliefs in CCA matrix relations, Bel, Pls and the belief intervals of evaluation grades for identified threat scenarios are determined by applying Eqs. 3.2 and 3.3 as:

$$\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}^1_., \mathrm{a}^2_., \mathrm{a}^3_., \mathrm{a}^4_.)) = \sum_{H_{pq} \subseteq H_{pp}} m(H_{pq}/T_t(\mathrm{a}^1_., \mathrm{a}^2_., \mathrm{a}^3_., \mathrm{a}^4_.)), \quad p, q = 1, \ldots, 5 \tag{3.24}$$

$$\mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}^1_., \mathrm{a}^2_., \mathrm{a}^3_., \mathrm{a}^4_.)) = \sum_{H_{pq} \cap H_{pp} \neq \varnothing} m(H_{pq}/T_t(\mathrm{a}^1_., \mathrm{a}^2_., \mathrm{a}^3_., \mathrm{a}^4_.)), \quad p, q = 1, \ldots, 5 \tag{3.25}$$

$$\mathrm{S}'_t(\mathrm{a}^1_., \mathrm{a}^2_., \mathrm{a}^3_., \mathrm{a}^4_.) = \left\{ \begin{array}{l} (H_{pp}, [\mathrm{Bel}_t(H_{pp}/T_t(\mathrm{a}^1_., \mathrm{a}^2_., \mathrm{a}^3_., \mathrm{a}^4_.)), \\ (\mathrm{Pls}_t(H_{pp}/T_t(\mathrm{a}^1_., \mathrm{a}^2_., \mathrm{a}^3_., \mathrm{a}^4_.))], \qquad p = 1, \ldots, 5 \end{array} \right. \tag{3.26}$$

The belief intervals calculated for the identified threat scenarios by using both combination rules are provided in Table 3.8 and plotted in Figs. 3.3 and 3.4.

When the two rules are compared, the Yager's rule transfers the conflict into the total ignorance by adding K to joint evidence of Θ but the DP's rule does not generate any conflict. In other words, the Yager's rule as conjunctive rule (AND-based on set intersection) discards the conflict information and increases the total ignorance but the DP's rule as a disjunctive rule (OR-based on set union) does not reject any information asserted by the sources. It is seen that the DP's rule provides larger belief intervals to more evaluation grades for the same threat scenarios than the Yager's rule. Therefore, when the conflict is higher (for a higher K value), the total ignorance will increase significantly and the Yager's rule gives more stable and robust results than the DP's rule. The drawback of DP's rule is that it yields more imprecise result than desirable when there is a strong conflict among relations.

Step 5: Evaluate the identified scenarios
At this step, the likelihood of identified scenarios are ranked and compared based on their belief intervals by the developed sorting algorithm. The results are interpreted to guide threat assessment. The ranking of 12 identified threat scenarios based on their likelihoods is calculated and presented in Table 3.9. Since there are two DST combination rules and two sorting algorithms, four ranking alternatives are presented in Table 3.9. Rankings enable the DMs to identify the higher likelihood scenarios from the lower likelihood ones.

Risk bearer's attitude, either risk seeking or risk averse, is important when choosing the appropriate ranking among four different ranking alternatives. For risk

Table 3.7 Belief structures of identified threat scenarios

Rule	No.	$S_t(.)$	Belief Structure
DP	1	$S_t(a_3^1, a_1^2, a_1^3, a_1^4)$	$\{(H_{14}, 0.0101), (H_{25}, 0.0720), (\Theta, 0.9179)\}$
	2	$S_t(a_3^1, a_1^2, a_2^3, a_1^4)$	$\{(H_{14}, 0.0672), (H_{25}, 0.0032), (\Theta, 0.9296)\}$
	3	$S_t(a_3^1, a_1^2, a_1^3, a_2^4)$	$\{(H_{14}, 0.0196), (H_{25}, 0.0120), (\Theta, 0.9684)\}$
	4	$S_t(a_3^1, a_1^2, a_2^3, a_2^4)$	$\{(H_{12}, 0.0230), (H_{13}, 0.0058), (H_{14}, 0.0992), (H_{25}, 0.0014), (\Theta, 0.8706)\}$
	5	$S_t(a_4^1, a_2^2, a_2^3, a_1^4)$	$\{(H_{14}, 0.0784), (H_{25}, 0.0043), (H_{35}, 0.0054), (\Theta, 0.9119)\}$
	6	$S_t(a_4^1, a_2^2, a_2^3, a_2^4)$	$\{(H_{14}, 0.0870), (H_{24}, 0.0026), (H_{25}, 0.0154), (\Theta, 0.8950)\}$
	7	$S_t(a_5^1, a_1^2, a_1^3, a_1^4)$	$\{(H_{13}, 0.0052), (H_{25}, 0.0115), (H_{35}, 0.0461), (\Theta, 0.9372)\}$
	8	$S_t(a_5^1, a_1^2, a_2^3, a_1^4)$	$\{(H_{13}, 0.0756), (H_{14}, 0.0756), (H_{35}, 0.0065), (\Theta, 0.8423)\}$
	9	$S_t(a_5^1, a_1^2, a_1^3, a_2^4)$	$\{(H_{13}, 0.0076), (H_{25}, 0.0240), (\Theta, 0.9684)\}$
	10	$S_t(a_5^1, a_1^2, a_2^3, a_2^4)$	$\{(H_{13}, 0.0945), (H_{14}, 0.0945), (H_{25}, 0.0024), (\Theta, 0.8086)\}$
	11	$S_t(a_{11}^1, a_1^2, a_1^3, a_1^4)$	$\{(H_{13}, 0.0212), (H_{25}, 0.0026), (H_{35}, 0.0104), (\Theta, 0.9659)\}$
	12	$S_t(a_{11}^1, a_1^2, a_1^3, a_2^4)$	$\{(H_{13}, 0.0240), (H_{25}, 0.0135), (\Theta, 0.9625)\}$
Yager	1	$S_t(a_3^1, a_1^2, a_1^3, a_1^4)$	$\{(H_{33}, 0.0269), (H_{34}, 0.0022), (H_{44}, 0.0134), (H_{55}, 0.0131), (\Theta, 0.9444)\}$
	2	$S_t(a_3^1, a_1^2, a_2^3, a_1^4)$	$\{(H_{33}, 0.0149), (\Theta, 0.9851)\}$
	3	$S_t(a_3^1, a_1^2, a_1^3, a_2^4)$	$\{(H_{33}, 0.0470), (H_{44}, 0.0202), (\Theta, 0.9328)\}$
	4	$S_t(a_3^1, a_1^2, a_2^3, a_2^4)$	$\{(H_{11}, 0.0077), (H_{22}, 0.0137), (H_{33}, 0.0058), (\Theta, 0.9729)\}$
	5	$S_t(a_4^1, a_2^2, a_2^3, a_1^4)$	$\{(H_{33}, 0.0126), (\Theta, 0.9874)\}$
	6	$S_t(a_4^1, a_2^2, a_2^3, a_2^4)$	$\{(H_{33}, 0.0096), (\Theta, 0.9904)\}$
	7	$S_t(a_5^1, a_1^2, a_1^3, a_1^4)$	$\{(H_{33}, 0.0061), (H_{45}, 0.0123), (\Theta, 0.9816)\}$
	8	$S_t(a_5^1, a_1^2, a_2^3, a_1^4)$	$\{(H_{12}, 0.0088), (H_{33}, 0.0118), (\Theta, 0.9764)\}$
	9	$S_t(a_5^1, a_1^2, a_1^3, a_2^4)$	$\{(H_{33}, 0.0090), (H_{45}, 0.0038), (\Theta, 0.9872)\}$
	10	$S_t(a_5^1, a_1^2, a_2^3, a_2^4)$	$\{(H_{11}, 0.0504), (H_{22}, 0.0273), (H_{33}, 0.0070), (\Theta, 0.9153)\}$
	11	$S_t(a_{11}^1, a_1^2, a_1^3, a_1^4)$	$\{(H_{22}, 0.0035), (H_{33}, 0.0564), (H_{45}, 0.0046), (\Theta, 0.9354)\}$
	12	$S_t(a_{11}^1, a_1^2, a_1^3, a_2^4)$	$\{(H_{33}, 0.0412), (H_{45}, 0.0032), (\Theta, 0.9556)\}$

Table 3.8 Belief intervals for threat scenarios

R	No	Threat scenario	H_{11}		H_{22}		H_{33}		H_{44}		H_{55}	
			Bel	Pls	Bel	Pls	Bel	Pls	Bel	Pls	Bel	Pls
DP	1	$S'_t(a_3^1, a_1^2, a_1^3, a_1^4)$	0	0.9280	0	1	0	1	0	1	0	0.9899
	2	$S'_t(a_3^1, a_1^2, a_1^3, a_1^4)$	0	0.9968	0	1	0	1	0	1	0	0.9328
	3	$S'_t(a_3^1, a_1^2, a_1^3, a_2^4)$	0	0.9880	0	1	0	1	0	1	0	0.9804
	4	$S'_t(a_3^1, a_1^2, a_2^3, a_1^4)$	0	0.9986	0	1	0	0.9770	0	0.9712	0	0.8720
	5	$S'_t(a_4^1, a_2^2, a_2^3, a_1^4)$	0	0.9903	0	0.9946	0	1	0	1	0	0.9216
	6	$S'_t(a_4^1, a_2^2, a_2^3, a_2^4)$	0	0.9820	0	1	0	1	0	1	0	0.9104
	7	$S'_t(a_5^1, a_1^2, a_1^3, a_1^4)$	0	0.9424	0	0.9539	0	1	0	0.9948	0	0.9948
	8	$S'_t(a_5^1, a_1^2, a_2^3, a_1^4)$	0	0.9935	0	0.9935	0	1	0	0.9244	0	0.8488
	9	$S'_t(a_5^1, a_1^2, a_1^3, a_2^4)$	0	0.9760	0	1	0	1	0	0.9924	0	0.9924
	10	$S'_t(a_5^1, a_1^2, a_2^3, a_2^4)$	0	0.9976	0	1	0	1	0	0.9055	0	0.8110
	11	$S'_t(a_{11}^1, a_1^2, a_1^3, a_1^4)$	0	0.9870	0	0.9896	0	1	0	0.9788	0	0.9788
	12	$S'_t(a_{11}^1, a_1^2, a_1^3, a_2^4)$	0	0.9865	0	1	0	1	0	0.9760	0	0.9760
Yager	1	$S'_t(a_3^1, a_1^2, a_1^3, a_1^4)$	–	–	–	–	0.0269	0.9734	0.0134	0.9600	0.0131	0.9574
	2	$S'_t(a_3^1, a_1^2, a_2^3, a_1^4)$	–	–	–	–	0.0149	1	–	–	–	–
	3	$S'_t(a_3^1, a_1^2, a_1^3, a_2^4)$	–	–	–	–	0.0470	0.9798	0.0202	0.9530	–	–
	4	$S'_t(a_3^1, a_1^2, a_2^3, a_2^4)$	0.0077	0.9806	0.0137	0.9866	0.0058	0.9786	–	–	–	–
	5	$S'_t(a_4^1, a_2^2, a_2^3, a_1^4)$	–	–	–	–	0.0126	1	–	–	–	–
	6	$S'_t(a_4^1, a_2^2, a_2^3, a_2^4)$	–	–	–	–	0.0096	1	–	–	–	–
	7	$S'_t(a_5^1, a_1^2, a_1^3, a_1^4)$	–	–	–	–	0.0061	0.9877	0	0.9939	0	0.9939
	8	$S'_t(a_5^1, a_1^2, a_2^3, a_1^4)$	0	0.9882	0	0.9882	0.0118	0.9912	–	–	–	–
	9	$S'_t(a_5^1, a_1^2, a_1^3, a_2^4)$	–	–	–	–	0.0090	0.9962	0	0.9910	0	0.9910
	10	$S'_t(a_5^1, a_1^2, a_2^3, a_2^4)$	0.0504	0.9657	0.0273	0.9426	0.0070	0.9223	–	–	–	–
	11	$S'_t(a_{11}^1, a_1^2, a_1^3, a_1^4)$	–	–	0.0035	0.9389	0.0564	0.9919	0	0.9400	0	0.9400
	12	$S'_t(a_{11}^1, a_1^2, a_1^3, a_2^4)$	–	–	–	–	0.0412	0.9968	0	0.9588	0	0.9588

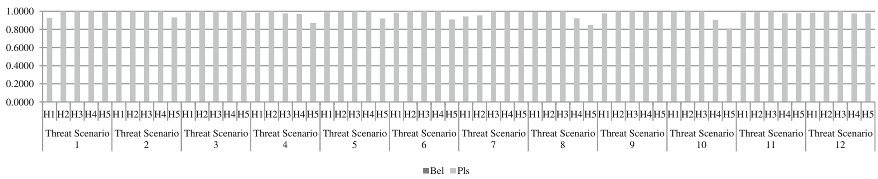

Fig. 3.3 The belief intervals of DP's rule

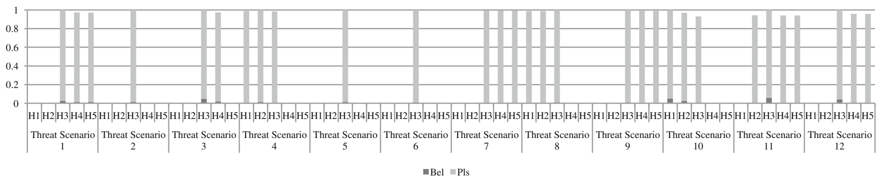

Fig. 3.4 The belief intervals of Yager's rule

Table 3.9 Threat scenario rankings based on belief intervals

No.	Threat scenario	Ranking			
		DP		Yager	
		By min likelihood	By max likelihood	By min likelihood	By max likelihood
1	$(a^1_3, a^2_1, a^3_1, a^4_1)$	**1**	3	2	3
2	$(a^1_3, a^2_1, a^3_2, a^4_1)$	10	7	6	7
3	$(a^1_3, a^2_1, a^3_1, a^4_2)$	7	4	7	6
4	$(a^1_3, a^2_1, a^3_2, a^4_2)$	**12**	10	10	11
5	$(a^1_4, a^2_2, a^3_2, a^4_1)$	8	8	5	8
6	$(a^1_4, a^2_2, a^3_2, a^4_2)$	4	9	4	9
7	$(a^1_5, a^2_1, a^3_1, a^4_1)$	2	**1**	**1**	**1**
8	$(a^1_5, a^2_1, a^3_2, a^4_1)$	9	11	11	10
9	$(a^1_5, a^2_1, a^3_1, a^4_2)$	3	2	3	2
10	$(a^1_5, a^2_1, a^3_2, a^4_2)$	11	**12**	**12**	**12**
11	$(a^1_{11}, a^2_1, a^3_1, a^4_1)$	6	5	9	5
12	$(a^1_{11}, a^2_1, a^3_1, a^4_2)$	5	6	8	4

seeking attitude, ranking based on Yager's rule with sorting algorithm by maximum likelihood is appropriate and for risk averse attitude, ranking based on DP's rule with sorting algorithm by minimum likelihood is appropriate.

After threat assessment has been completed based on the intelligence at time t, depending on the ranking of security risks from highest likelihood to lowest likelihood, security risk management can be accomplished by allocating available security risk management resources to security risk-reducing countermeasures (e.g., for vulnerability reduction or consequence mitigation) from the top of the list down. Fine threat likelihood distinction among threat scenarios can be captured with proposed EMA model that represents the available input information. Therefore, EMA model can be used to reason about threat likelihood and provide adequate precision for threat assessment.

3.5 Conclusions

In risk management, there is a need for understanding the intentional events, in other word threats, involved. Therefore, showing how to deal with different kind of uncertain information, in intelligent systems and engineering management, the main goal of this study is to identify threats for which there is intelligence of an imminent threat and to estimate their likelihoods for critical facility protection. For this purpose, a novel intelligent approach called Evidence based Morphological Analysis (EMA) is proposed by describing reasons for modelling uncertainty by DST, the fundamentals of DST and MA, and how DST is applied for threat likelihood estimation within MA.

Firstly, the appropriate uncertainty model for threat assessment of a critical facility is discussed in detail by considering the type of input information at hand, the quality of required output information, and the axiomatic assumptions about the cause of uncertainty. It is stated that DST is the appropriate uncertainty model for threat likelihood estimation since threat is neither random event nor vague event and uncertainty associated with such intentional event involves epistemic uncertainty.

Secondly, qualitative method MA is integrated with DST. Original FD is determined for evaluation of relations considering computational complexity. Determination of the FD for input data is the most informative and is the efficient way of capturing and quantifying the state of knowledge about the likelihood of a defined threat scenario for a critical facility. The proposed model allows to express qualitative judgements using belief structures developed on the basis of DST and make full use of available information without information loss and exaggeration. EMA also converts limited information to quantifiable threat likelihood parameter for quantitative analysis based on the complete and/or incomplete information which can be both linguistic evaluation grades and interval evaluation grades. The notion of time, t, is also introduced into the problem formulation because a relation in MA may change when more information is get by time.

To summarize, EMA is a quantified MA that integrates MA with DST. The strength of MA provides both identifying and developing the plausible scenarios while DST allows for both the definition and the quantification of relationships between parameters of the scenario in MA. Scenarios are developed by combining simple relations using two most common DST combination rules. The two most common DST combination rules (conjunctive and disconjunctive) are analysed for threat likelihood estimation by considering DM's attitude (risk averse and risk seeking) and new interval sorting algorithm is developed for scenario ranking. EMA analyzes and handles a wide range of plausible scenarios more easily than hierarchical techniques as tree structures with modest computational effort. This screening, shifting and filtering increasing flow of data property of approach is also a required function in intelligent system applications (Shim et al. 2002). By using EMA, alternative threat scenarios can be formulated, developed and evaluated in a structured way. This approach provides required output data precision for comparing and ranking of threat scenarios systematically.

An important feature of EMA is the ability to update easily with less computational burden. The threat is usually assumed to be static but dynamic risk management requires dynamic threat assessment. Intelligent attackers innovate and threat scenarios evolve based on changing conditions as changing defences, technology and social situations in an adaptive way. When new intelligence information about adversary intent and assumed adversary capabilities become available, EMA can be easily updated by recalculating only the affected threat scenario likelihoods or extending the morphological field (adding new parameters or adding new parameter values). Since likelihood estimation is a continuous process, the new information obtained can be easily fed back to proposed model to update evaluation.

As a result, EMA has been successfully used to represent the threat likelihood for critical facility by synthesizing linguistic judgement information of experts. This approach better captures the uncertainty in threat assessment than traditional probabilistic risk approaches that use point estimates. EMA improves threat assessment and is shown to be a useful tool in threat assessment of critical facilities in a simple case study. EMA is not limited to threat assessment and can also be applied to likelihood estimation problems involving epistemic uncertainty and scenario development.

References

Akgun, I., Kandakoglu, A., Ozok, A.F.: Fuzzy integrated vulnerability assessment model for critical facilities in combating the terrorism. Expert Syst. Appl. **37**, 3561–3573 (2010)

Andrews, J.D., Dunnett, S.J.: Event tree analysis using binary decision diagrams. IEEE Trans. Reliab. **49**, 230–238 (2000)

Ashford, N., Stanton, H.P.M., Moore, C.A.: Airport Operations, 2nd edn. McGraw-Hill, London (1997)

Awasthi, A., Chauhan, S.S.: Using AHP and Dempster-Shafer theory for evaluating sustainable transport solutions. Environ. Model Softw. **26**(6), 787–796 (2011)

Demotier, S., Schön, W., Denoeux, T.: Risk assessment based on weak information using belief functions: a case study in water treatment. IEEE Trans. Syst. Man Cybern. Part C Appl. Rev. **36**(3), 382–396 (2006)

Dempster, A.P.: Upper and lower probabilities induced by a multivalued mapping. Ann. Stat. **28**, 325–339 (1967)

Dempster, A.P., Yager, R.R., Liu, L.: The Classic Works on the Dempster-Shafer Theory of Belief Functions. Springer, Berlin (2008)
Dubois, D., Prade, H.: Possibility Theory. Plenum Press, New York (1988)
Dubois, D., Prade, H.: On the combination of evidence in various mathematical frameworks. In: Flamm, J., Luisi, T. (eds.) Reliability Data Collection and Analysis, pp. 213–241. Springer, Berlin (1992)
Ericson, C.: Fault tree analysis: a history. Proceedings of the 17th International System Safety Conference, Orlando, Florida, August 1999
Ezell, B., Haimes, Y., Lambert, J.: Risk of cyber attack to water utility supervisory control and data acquisition systems. Mil. Oper. Res. **6**(2), 30–46 (2001)
Ezell, B.C., Bennett, S.P., Winterfeldt, D., Sokolowski, J., Collins, A.J.: Probabilistic risk analysis and terrorism risk. Risk Anal. **30**(4), 575–589 (2010)
Garrick, B. J., Hall, J.E., Kilger, M., McDonald, J.C., O'Toole, T., Probst, P.S., Rindskopf Parker, E., Rosenthal, R., Trivelpiece, A.W., van Arsdale, L.A., Zebroski, E.L.: Confronting the risks of terrorism: making the right decisions. Reliab. Eng. Syst. Saf. 86(2), 129–176 (2004)
Harris, B.: Mathematical methods in combatting terrorism. Risk Anal. **24**(4), 985–988 (2004)
Helton, J.C.: Uncertainty and sensitivity analysis in the presence of stochastic and subjective uncertainty. J. Stat. Comput. Simul. **57**, 3–76 (1997)
ISO 31000:2009 Risk management—principles and guidelines (2009)
Kirchsteiger, C.: On the use of probabilistic and deterministic methods in risk analysis. J. Loss Prev. Process. Ind. **12**, 399–419 (1999)
Knuth, D.: The art of computer programming. In: Sorting and Searching, vol. 3, 3rd edn. Addison-Wesley, Boston (1997)
Kohlas, J., Monney, P.A.: A mathematical theory of hints: an approach to the Dempster-Shafer theory of evidence. Lecture Notes in Economics and Mathematical Systems, vol. 425. Springer, Berlin (2013)
Kolmogorov, A.N.: Foundations of the Theory of Probability. Chelsea Publishing Co., UK (1950)
Laplace, P.S.: Analytical Theory of Probability. Courier, Paris (1812)
LaTourrette, T., Howell, D.R., Mosher, D.E., MacDonald, J.: Reducing Terrorism Risk at Shopping Centers: An Analysis of Potential Security Options. RAND Corporation, Santa Monica, CA (2006)
Liu, C., Grenier, D., Jousselme, A., Bosse, E.: Reducing algorithm complexity for computing an aggregate uncertainty measure. IEEE Trans. Syst. Man Cybern. Part A Syst. Hum. **37**(5), 669–679 (2007)
Oberkampf, W.L., Helton, J.C., Joslyn, C.A., Wojtkiewicz, S.F., Ferson, S.: Challenge problems: uncertainty in system response given uncertain parameters. Reliab. Eng. Syst. Saf. **85**, 11–19 (2004)
Renn, O.: Concepts of risk: a classification. In: Krimsky, S., Golding, D. (eds.) Social Theories of Risk. Praeger, Westport CT (1992)
Ritchey, T.: Futures studies using morphological analysis. http://www.swemorph.com/pdf/futures.pdf (2009). Accessed 12 Jan 2010
Ritchey, T.: Wicked Problems—Social Messes: Decision support Modelling with Morphological Analysis. Springer, Berlin (2011)
Rosoff, H., von Winterfeldt, D.: A risk and economic analysis of dirty bomb attacks on the ports of Los Angeles and Long Beach. Risk Anal. **27**(3), 533–546 (2007)
Sentz, K., Ferson, S.: Combination of Evidence in Dempster-Shafer Theory, Sandia National Laboratories Report, SAND2002-0835 (2002)
Shafer, G.: A Mathematical Theory of Evidence. Princeton University Press, Princeton (1976)
Sharif, A.M., Irani, Z.: Applying a fuzzy-morphological approach to complexity management decision making. Manage. Decis. **44**(7), 930–961 (2006)
Shim, J.P., Warkentin, M., Courtney, J.F., Power, D.J., Sharda, R., Carlsson, C.: Past, present, and future of decision support technology. Decis. Support Syst. **33**(2), 111–126 (2002)
Shoyaib, M., Wadud, M.A., Chae, O.: A skin detection approach based on the Dempster–Shafer theory of evidence. Int. J. Approx. Reason **53**(4), 636–659 (2012)

Smets, P.: Analyzing the combination of conflicting belief functions. Inf. Fusion. **8**, 387–412 (2007)

Wang, Y.M., Yang, J.B., Xu, D.L.: A preference aggregation method through the estimation of utility intervals. Comput. Oper. Res. **32**(8), 2027–2049 (2005)

Yager, R.: On the dempster-shafer framework and new combination rules. Inf. Sci. **41**, 93–137 (1987a)

Yager, R.: Quasi-associative operations in the combination of evidence. Kybernetes **16**, 37–41 (1987b)

Yang, J.B., Singh, M.G.: An evidential reasoning approach for multiple attribute decision making with uncertainty. IEEE Trans. Syst. Man Cybern. **24**(1), 1–18 (1994)

Yang, J., Huang, H.Z., He, L.P., Zhu, S.P., Wen, D.: Risk evaluation in failure mode and effects analysis of aircraft turbine rotor blades using Dempster-Shafer evidence theory under uncertainty. Eng. Fail. Anal. **18**(8), 2084–2092 (2011)

Zadeh, L.: Fuzzy sets. Inf. Control **8**, 338–358 (1965)

Zadeh, L.: Fuzzy sets as a basis for a theory of possibility. Fuzzy Sets Syst. **1**(1), 3–28 (1978)

Zimmermann, H.J.: An application-oriented view of modeling uncertainty. Eur. J. Oper. Res. **122**, 190–198 (2007)

Zwicky, F.: Discovery, Invention, Research—Through the Morphological Approach. The MacMillian Company, Toronto (1969)

Part III
Knowledge Management

Chapter 4
A Review on Intelligent Systems in Research and Development

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Abstract Research and development (R&D) is one of the topics drawing great concern from researchers and practitioners. R&D is important for many of the areas such as pharmaceutical and medical industry, technology, and manufacturing. On the other hand, the sophisticated nature of the real life problems and its long computational time led researchers to develop intelligent systems. Intelligent systems have been used in many of the R&D areas since they give more reliable and consistent solutions when compared to the traditional solution techniques. In this pursuit, the chapter focuses on analyzing intelligent systems from a broader perspective considering a various research and development areas. For this aim, a comprehensive literature review from the years mainly between 2000 and 2014 is conducted. From the literature, it is observed that there are a large number of studies from 2010 to 2014. The motivation to conduct this chapter is to contribute to the literature by presenting an extensive literature review and making a synthesis with regard to intelligent systems in research and development.

Keywords Research and development · Intelligence · Intelligent systems · Review

4.1 Introduction

Research and Development or as commonly used its abbreviated form, R&D incorporates many activities for creating and using knowledge to develop new goods, services and even products. According to OECD (2002), R&D is a creative work used to increase the stocks of a variety of knowledge containing man, culture as well as society. Innovation is one of the outputs of R&D (Jespersen and Olsen

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2007). According to the researchers, R&D concentrates on engineering and natural sciences as well as social sciences and humanities (Djellal et al. 2003). However, determining the boundaries of R&D is a tough task especially for the service sector since the boundaries can be flurred (Sawatani and Arimoto 2013).

Intelligent systems (IS) have appeared in the literature in the 1980s and have been developed for bringing solutions to the problems having computational complexity, long computational time, and when conventional solution techniques do not provide solutions. Particle swarm optimization algorithm (PSOA), Artificial bee colony (ABC) algorithm, Ant colony algorithm, Genetic algorithms (GA), Artificial intelligence (AI), Simulated annealing (SA), Fuzzy logic and applications and Tabu search (TS) are some of the well-known and frequently used intelligent system tools. According to the researchers, research and development areas of intelligent systems range from engineering and manufacturing to robotics, from medical studies, to defense including security, from learning systems to expert systems (Schalkoff 2011).

This chapter summarizes the whole picture of Intelligent Systems in many of R&D areas, providing insights to researchers, and indicating the gaps and opportunities to work on the topic. For this purpose, in this chapter, a comprehensive literature review is conducted for intelligent systems used in research and development activities. Scopus database is used to search for published articles in the related literature. Primarily, existing publications are searched by entering keywords of *Research and Development* and *Intelligent Systems*, sequentially to find out mostly in which field/s or industry/ies, IS are employed to solve R&D problems. The literature review highlights that intelligent systems have been used in a variety of fields from manufacturing to education, from defense to transportation and mobile robotics. For each of the fields, there are a vast amount of studies employing Intelligent Systems in R&D activities. Hence, in the scope of this chapter only a limited number of studies, specifically recently published ones are mentioned. For each of the research areas, the most researched problem types have been determined and intelligent systems used for the solution of these problems have been presented. Then, by using Scopus database, the statistical analyses of the review results from 1975 to 2014 are presented for each problem type and the number of the publications per year for the years between 2000 and 2014 is graphically illustrated.

The rest of the chapter is organized as follows: In Sects. 4.2 and 4.3, the terminology related to Research and Development and Intelligent Systems are stated. In Sect. 4.4, the institutions/organizations around the world with regard to Intelligent Systems in R&D are represented. In Sect. 4.5, research areas that IS have been applied are generally examined and analyzed by using statistics from Scopus while in Sect. 4.6 some of the popular R&D areas using Intelligent Systems are discussed in detail. Finally, in Sect. 4.7, conclusions and the suggestions for further studies are presented.

4.2 Research and Development (R&D)

Research and Development has been worked by National Experts on Science and Technology Indicators abbreviated as NESTI since 1960. In the beginning, R&D is thought to be related to only natural sciences and engineering. However, Djellal et al. (2003) made a wider definition by incorporating social sciences and humanities. The very well-known definition of R&D was stated by OECD Frascati Manual (2002). Some of the R&D definitions are stated below:

> According to Australia Bureau of Statistics (ABS), R&D is a "systematic investigation or experimentation involving innovation or technical risk, the outcome of which is new knowledge, with or without a specific practical application of new or improved products, processes, materials, devices or services" (ABS 1996).
> In 2002, the definition is revised by OECD as follows: "Research & Experimental Development comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (Frascati Manual OECD 2002).

R&D includes three main activities which are basic research, applied research, and experimental development. Basic research covers experimental and theoretical work while applied research having a specific aim or objective is original investigation aims to gain new knowledge. Experimental development purposes to produce new products/devices and even materials as well as new services and systems by employing a systematic approach. It also aims to improve already produced products or services (Frascati Manual OECD 2002).

4.3 Intelligent Systems (IS)

Intelligent means "capacity for learning, reasoning, understanding, and similar forms of mental activity, aptitude in grasping truths, relationships, facts and meanings" (http://dictionary.reference.com/browse/intelligent?s=t). The term is also defined as "the ability to comprehend; to understand and profit from experience; the ability to acquire and retain knowledge; mental ability; and the ability to respond quickly and successfully to a new situation (Rudas and Fodor 2008).

Intelligent Systems produce consistent and reliable results by employing systematic and standardized approach for bringing solutions to complex problems. Some of the definitions of IS are stated as follows:

> According to Krishnakumar (2003), "An intelligent system is a system that emulates some aspects of intelligence exhibited by nature. These include learning, adaptability, robustness across problem domains, improving efficiency (over time and/or space), information compression (data to knowledge), and extrapolated reasoning."
> "Flexibility, adaptability, memory, learning, temporal dynamics, reasoning, and the ability to manage uncertain and imprecise information (Krishnakumar 2003)" are also important factors to identify IS.

Intelligent systems are also basically defined as “the systems that can simulate some degree of the human-like capabilities such as learning, observation, perception (sense the environment), interpretation, reasoning, planning, decision-making, and controlling actions” (Lu 2002).

4.4 Institutions on Intelligence in Research and Development

There are many institutions conducting researches using intelligent systems around the world. Some of them work particularly on pharmacy (National Institute for Pharmaceutical Research and Development), ocean (National Institute for Marine Research and Development and Korea Ocean Research and Development Institute-KORDI), robots (The Research and Development Institute for Intelligent Robotic Systems, The Robotics Institute), optoelectronics, analytical chemistry and mechanical engineering (National Institute for Research and Development in Optoelectronics), artificial intelligence (Allen Institute for Artificial Intelligence) and biology (Institute of Biological Sciences, INSB). It is also realized that some international companies have also research and development departments and organizations. So, we narrowed web results by typing the keywords of *institutions*, *organizations*, *associations*, *research and development, R&D and intelligence*, and *intelligent systems*. Some of the institutions are listed alphabetically and briefly introduced in this section.

- **Institut des Systèmes Intelligents et de Robotique/The Institute for Intelligent Systems and Robotics (ISIR)**

The ISIR belongs to the Université Pierre et Marie Curie (UPMC) and the Centre National de la Recherche Scientifique (CNRS). The ISIR works on modeling, designing, analyzing and controlling of dynamic systems (artificial and natural), interactive robotic systems, processing systems, human interactions, neurocomputational models, the machine learning and the bio-inspired systems (http://www.isir.upmc.fr/?lang=en).

- **Institute for Integrated and Intelligent Systems, Griffith University, Australia**

The institute founded in 2003, has three main programs which are “Health Informatics”, “Bioinformatics” and “Environmental Informatics”. Health Informatics program aims to develop healthcare using Information Technology (IT), computer science, and robots, while Bioinformatics program analyzes the molecular mechanisms, DNA and proteins. Environmental Informatics dedicates itself to examine acquiring, processing, modeling, and communicating processes of information used for environmental sciences and management (http://www.griffith.edu.au/engineering-information-technology/institute-integrated-intelligent-systems).

- **Institute for Research and Development India (IRD India)**

The IRD India is an independent, private and non-profit scientific association, committed to promote scientific and educational activities and to improve Computer Science, Information Technology, Electronics, Communication and also Management. The institute contains faculty members such as department heads, professors, research scientists, scholars, managers, engineers, postgraduate and undergraduate students in the fields of engineering and technology. The mission of the institute is to improve and conduct collaborative interdisciplinary researches. The institute organizes conferences, symposium and workshops affiliated with many research and academic institutions in India and has published academic journals in a variety of fields such as Electronics, Electrical and Computer Science, Mechanical and Management (http://www.irdindia.in/index.html).

- **Institute of Robotics and Intelligent Systems, ETH Zurich, Switzerland**

The institute has six laboratories (Multi-Scale Robotics Lab, Autonomous Systems Lab, Sensory-Motor Systems Lab, Bio-Inspired Robotics Lab, Rehabilitation Engineering Lab, Agile and Dexterous Robotics Lab) conducting researches in various areas ranging from nanodevices for biomedicine to autonomous aerial vehicles (http://www.iris.ethz.ch/the-institute.html).

- **Intelligent Systems Research Institute, Tokyo**

The institute makes researches on intelligent system technologies including robotics and smart information processing for assisting human behaviors. The institute has focused on personal care robots and software of the robots especially between 2010 and 2014 (https://unit.aist.go.jp/is/cie/outline/outline_e.html).

- **Korean Institute of Intelligent Systems (KIIS)**

The KIIS founded in 1991 fundamentally makes researchers on fuzzy theory, intelligent systems, neural networks, and information science. The institute aims to provide opportunities for publishing new studies/researches related to the fuzzy and intelligent system theory. Many international conferences and councils such as the IFSA International Science Council in 1993, AFSS International Science Council in 1998 and IEEE International Conference on Fuzzy Systems in 1999 and 2009 were held by the institution (http://eng.fuzzy.or.kr/main/).

- **Leibniz Association-Germany**

The association named after Gottfried Wilhelm Leibniz (1646–1716), is the organisation for a total numbers of 89 research institutes. These institutes perform researches, provide scientific and also research infrastructure, give services in liaison, consultation, and transfer to the public, policymakers, academicians and practitioners. The institutes conduct researches in different areas such as natural sciences, engineering, environment, mathematics, as well as social sciences and economics using intelligent systems (http://www.research-in-germany.de/dachportal/en/Research-Landscape/Research-Organisations/Leibniz-Association.html).

• **Max Planck Institute for Intelligent Systems**

The institute has been functioning in two different sites, Stuttgart and Tubingen, in the areas of computer science, material science and biology. The institute locating in Stuttgart site focuses on the material science analyzing the functioning of materials, their macroscopic behaviour including the atomic, nanoscopic and microscopic scales. Main interest of the institute is nanoscience, and the further focus of the studies are supposed to be in the interface between nanotechnology and biology (http://www.mpg.de/154324/intelligentSystems). The institute locating in Tübingen site aims to make researches in machine learning, image recognition, robotics and biological systems in the near future. The Institute also has a high potential for working on the areas of robotics, medical technology, and innovative technologies (http://www.mpg.de/1342929/intelligenteSystemeTuebingen).

• **SRI International**

SRI International is a non-profit, independent research and innovation center providing basic and applied researches; giving laboratory, advisory, technology development and license services, and venture opportunities. SRI International was named as Stanford Research Institute when it was established in 1946 by Stanford University. When it comes to 1970s, the centre became independent from Stanford University and in 1977 the name of the centre became SRI International. Today the centre is among the most diverse research and development organizations. The centre makes researches employing intelligent systems on Biomedical Sciences and Health, Chemistry and Materials, Computing, Earth and Space, Economic Development, Education and Learning, Energy and Green Tech, Security and Defense, Sensing and Devices. The centre has been a bridge between research universities, laboratories and industries. The headquarter of the centre is in Silicon Valley, and also have locations and offices in Princeton, New Jersey, Washington D.C., Tokyo, and Japan (https://www.sri.com/about).

• **The Helmholtz Association of German Research Centres**

The centre is the largest organization making scientific researches using intelligent systems in the areas of health, environment, energy and even physics on behalf of society, science as well as industry in Germany. The centre has strategic programs in the fields of energy, earth, environment, health, technology, aeronautics, space and transport. According to the association, they provide the most modern scientific infrastructure with large-scale facilities and large amount of instruments which are also in the service of international scientific communities (http://www.helmholtz.de/en/home/).

• **The Institute for Intelligent System (IIS), the University of Memphis' FedEx Institute of Technology**

The IIS examines mainly knowledge and capabilities of intelligent systems including psychological, biological, and artificial systems. The mission of the institute is to bring together researchers coming from different areas such as engineering, communication sciences, computer science, cognitive sciences, biology, education, linguistics, philosophy, physics, and psychology. In 2007, the institute won one of the prestigious awards, Academic Excellence Award, from the Tennessee Board of Regents (http://www.memphis.edu/iis/).

• **UK Intelligent Systems Research Institute** (**UK-ISRI**)

UK-ISRI employing more than 150 scientists and engineers, aims to develop groundbreaking technology solutions. It is one of the members of research-led organizations network. Research areas of this institute are developing software for desktop, mobile and handheld computers as well as web-based computer systems, developing electronics including wireless and wired communication, designing printed circuit board, designing power electronics, verification, simulation and automation (http://www.uk-isri.org/).

4.5 Intelligent Systems in R&D

Intelligent systems are employed in many of the research areas such as production including manufacturing, project planning and scheduling, maintenance, supply chain and product modeling; medical system, transportation, education and so on. By typing *Intelligent Systems, Research and Development, R&D* on Scopus, all types of papers are sorted whether they include these words in their article title, abstract and keywords. The summarized data obtained from Scopus are listed in Table 4.1.

Figure 4.1 illustrates the numbers of published papers including intelligent research and development topic between the years 2000 and 2014 by searching for *Intelligent Systems and R&D* for the sections of *Title, Abstract and Keywords*.

Many of the papers were published in a various kinds of proceedings and journals such as "Proceedings of SPIE the International Society for Optical Engineering" (36 papers), "Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics" (12 papers), "NTT Review" (7 papers), "IEEE Intelligent Vehicles Symposium Proceedings" (6 papers) and "Advanced Materials Research" (5 papers). Some of

Table 4.1 Summarized data obtained from scopus

Search for	Article title	Abstract	Keywords
Intelligent systems	17,970	76,378	117,755
Research and development	22,837	479,817	3
R&D	12,892	46,602	5,589
Intelligent systems, (and) research and development	58	3,807	968
Intelligent systems (and) R&D	8	254	23

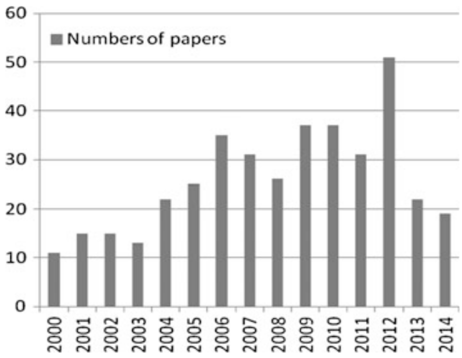


Fig. 4.1 Published papers with respect to publication years

Fig. 4.2 Published papers with respect to the sources

the sources (journals and proceedings) with respect to the total amount of published papers are illustrated in Fig. 4.2.

There are some researchers such as B. Beckman (8 papers), M. Trentini (7 papers), B. Digney (6 papers), J. Collier (4 papers), and H. Ogawa (4 papers) mainly have studied in this topic. It is also observed that *Defence Research Establishment Suffield, University of Tokyo, IEEE, Delft University of Technology, and Sandia National Laboratories-New Mexico* are leading institutions that have published many papers. On the other hand, countries have made enormous amount of publications in this field are illustrated in Fig. 4.3.

In addition, more than 300 papers are classified as conference papers, 130 papers are articles, around 14 papers are review papers and almost 9 papers are listed as

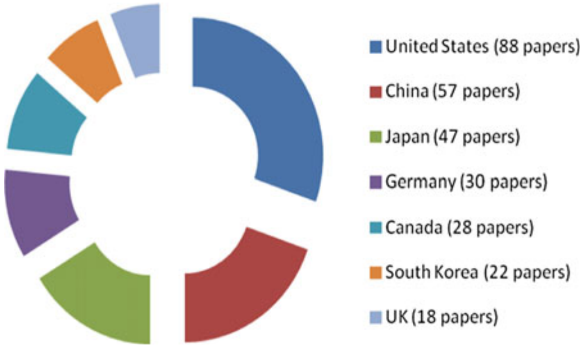


Fig. 4.3 Publications with respect to the countries

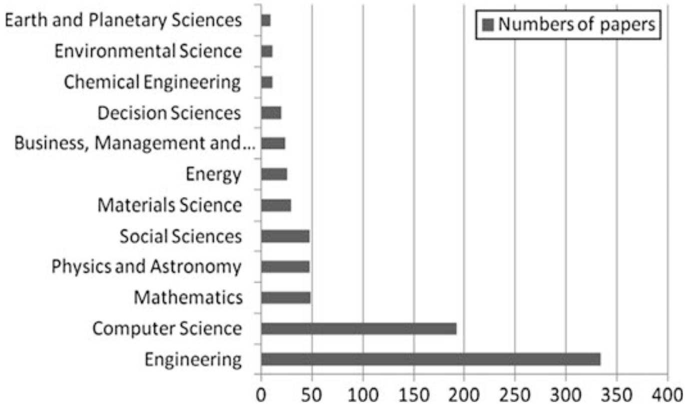


Fig. 4.4 Publications with respect to the subject areas

conference reviews. When the papers are sorted depending on the subject area, it is obtained that many of the papers are published in "Engineering (69.2 %)", "Computer Science (39.8 %)", "Mathematics (10.1 %)", and "Physics and Astronomy (9.9 %)" as shown in Fig. 4.4.

4.6 Intelligent Systems in R&D

In the following, the literature review is performed with regard to the classification of the R&D areas including the most researched problems. In this section, the subject areas are determined as production, medical and pharmaceutical sector, transportation, education, intelligent buildings and defense.

4.6.1 Production

This section is divided into five sub-topics which are manufacturing, project planning and scheduling, supply chain, maintenance, and product design/modeling. The analyses results of these sub-topics are stated as follows:

4.6.1.1 Manufacturing

Traditional manufacturing systems are not capable of dealing with today's constantly changing competitive markets. Traditional manufacturing is rigid, so that is hard to adopt changes caused by global competition and market demands and to modify systems during operations. Additionally, they are not able to form virtual enterprises which are common in most of the manufacturing-based businesses, and are not customer driven systems. These shortcomings cause reduction in productivity, increasing in costs and declining in the market shares. Therefore, intelligent manufacturing systems are introduced to deal with some or all of these drawbacks of traditional manufacturing systems (Oztemel and Tekez 2009).

Intelligent manufacturing systems (Zhang et al. 2014a, b; Hussein and Kumar 2014) includes important issues such as machine learning (Ramik et al. 2014; Micheletti et al. 2013), intelligent robots (Lu and Lin 1996; Lu 2002), intelligent sensors (Taner and Brignell 1997), and intelligent workcells (Ferreira 2003).

In the literature, intelligent systems including particle swarm optimization algorithm (Zhang et al. 2011a, b); Artificial bee colony (ABC) algorithm (Prasanth and Hans Raj 2013a, b); Genetic algorithms (Shen et al. 2015); Ant colony (Jong et al. 2014); Fuzzy logic and applications (Chu et al. 2014); and Tabu search (Ichoua and Pechmann 2014) are presented to solve manufacturing problems.

Table 4.2 expresses total numbers of studies related to intelligent manufacturing as Fig. 4.5 illustrates total numbers of published papers by searching for intelligent manufacturing for *Title-Abstract and Keywords* with respect to the publication years.

Table 4.2 Summarized data for manufacturing

Search for	Article title	Abstract	Keywords
Intelligent manufacturing systems	379	3,395	2,784
Machine learning and intelligence	57	2,437	7,228
Intelligent manufacturing robots	10	480	415
Intelligent sensors	471	1,121	1,202
Intelligent workcells	5	14	–

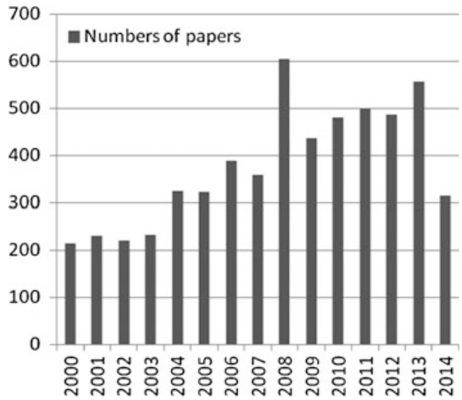


Fig. 4.5 Total numbers of published papers for *intelligent manufacturing*

4.6.1.2 Project Planning and Scheduling

According to the researchers, the data in the real world is non-linear, so traditional tools may not reflect and solve real world applications. Especially, for modeling and solving the complex problems having imprecise patterns and lack of information in many variables, intelligent systems including artificial neural networks, fuzzy neural system and hybrid fuzzy neural system are suggested. Intelligent systems help project managers to make better estimations with regard to project planning schedule, project cost, as well as resource allocation (Relich and Muszynski 2014). Some other researchers present an intelligent scheduling system (ISS) to obtain the near-optimum schedule plan by using simulation techniques for allocating resources and designating priorities to different activities under the consideration of some important factors such as scheduling, project cost, and manpower simultaneously (Chen et al. 2012). In the projects, human resource allocation is a very essential activity requiring a variety of difficult activities such as task scheduling and assigning the teams. In the literature there are some other problems such as resource-constrained project scheduling problems abbreviated as RCPSP.

Some of the intelligent systems such as particle swarm optimization algorithm (Jia and Seo 2013); Genetic algorithms (Alcaraz et al. 2003); Ant colony (Lee 2011); are Fuzzy logic and applications (Kuchta 2010) are presented to solve project planning and scheduling problems in the literature.

Table 4.3 shows the summarized data expressing total numbers of studies on intelligent project planning and scheduling whereas Fig. 4.6 illustrates total numbers of published papers by entering intelligent project planning and scheduling for *Titles and Abstract and Keywords* with respect to the publication years.

Table 4.3 Summarized data for project planning and scheduling

Search for	Article title	Abstract	Keywords
Intelligent project	261	7,033	2,349
Intelligent project planning	9	564	293
Intelligent project scheduling	13	196	117
Intelligent project resource constrained	–	27	31

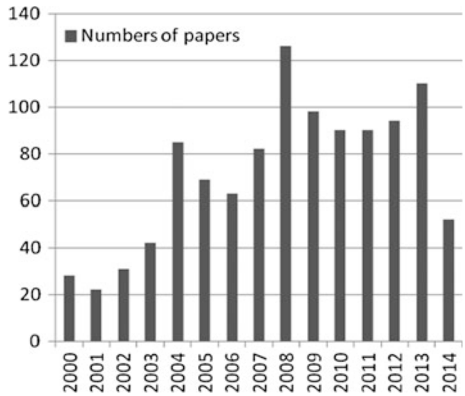


Fig. 4.6 Total numbers of published papers for *intelligent project planning*

4.6.1.3 Supply Chain

In the literature, there are some valuable studies employing intelligent systems to solve a variety of supply chain problems. For instance, supply chain management partner selection improving overall performance of the chain has been one of the important and difficult issues since it requires evaluating both tangible and intangible factors. Some other studies have concentrated on only logistics, supply chain performance and inventory management.

In the literature some of the intelligent systems such as particle swarm optimization algorithm (Mousavi et al. 2014); Genetic algorithms (Firoozi et al. 2013); Ant colony (Tang et al. 2014); Fuzzy logic and applications (Xu and Wei 2013); and Tabu search (Jin et al. 2014) are used for solving supply chain problems.

Table 4.4 expresses total numbers of studies about intelligent supply chain as Fig. 4.7 shows total numbers of published papers by searching for intelligent supply chain for *Title-Abstract and Keywords* with respect to the publication years.

4.6.1.4 Maintenance

Maintenance may cause delays in the manufacturing processes, so that may decrease the performance of the organizations. Thus, the usage of the intelligent maintenance systems (IMS) is important since it avoids potential catastrophic loss,

Table 4.4 Summarized data for supply chain

Search for	Article title	Abstract	Keywords
Intelligent supply chain	108	707	800
Intelligent supplier selection	3	121	58
Intelligent logistics	170	991	29
Intelligent multi-echelon	1	8	6

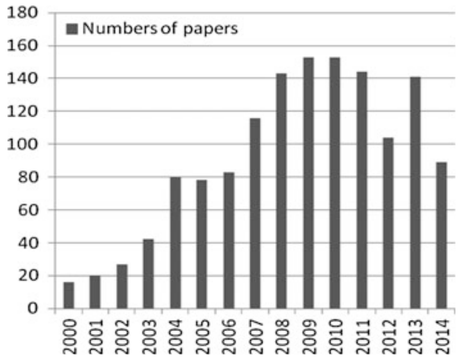


Fig. 4.7 Total numbers of published papers for *intelligent supply chain*

estimates failures and the timing of breakdowns for future, allows improvements in the maintenance processes, and controls status of spare parts and machines (Frazzon et al. 2014).

Traditional maintenance systems may confront with errors in diagnosing, monitoring, and planning of repairing activities whereas IMS removes time consuming errors caused by humans and fault diagnosis, and reduces management overhead costs, extends the life of the machines/equipments, and increases performance of the machines (Singh et al. 2014).

In the literature, some researchers concentrated on developing an intelligent diagnosis method for the detection of the faults as in the studies of Huang and Yu (2013) and Tangjitsitcharoena and Moriwaki (2008). Some researchers such as Lee et al. (2011a, b) and Yuniarto and Labib (2006) studied intelligence self-maintenance which points out the abiliy of the machine itself to control the system regularly, and to immediately repair the systems whenever it is needed (Lee et al. 2011a, b).

In the literature, there are many papers about maintenance employing intelligent systems such as Particle swarm optimization algorithm (Puzis et al. 2014); Artificial bee colony (ABC) algorithm (Subramanian et al. 2012); Genetic algorithms (Shi et al. 2014); Artificial intelligence (Kaplanoğlu 2014); Ant colony (Bielskis et al. 2009); Fuzzy logic and applications (Zhang et al. 2014a, b); and Tabu search (Wang and Liu 2014).

Table 4.5 Summarized data for maintenance

Search for	Article title	Abstract	Keywords
Intelligent maintenance	264	3,007	2,150
Intelligent maintenance scheduling	13	122	58
Intelligent machine monitoring	32	871	569
Intelligent self-maintenance	–	20	7

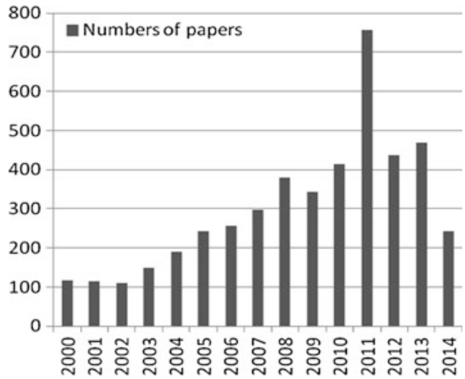


Fig. 4.8 Total numbers of published papers for *intelligent maintenance*

Table 4.5 lists total numbers of studies related to intelligent maintenance while Fig. 4.8 shows total numbers of published papers by searching for intelligent maintenance for *Title-Abstract and Keywords* with respect to the publication years.

4.6.1.5 Product Design

Product design (PD) has been one of the complex and critical issues, requiring understanding customer preferences and customer buying decisions as well as meeting the technical requirements. Problems related to design and inappropriate designs might cause high redesign costs. To select the most appropriate design, researchers suggest adopting intelligent systems in the cases of product design and product improvement (Lee et al. 2011a, b).

In the literature there are many papers with respect to product design, new product development, product modeling by employing intelligent systems such as particle swarm optimization algorithm (Yumin and Zhongyuan 2006); Artificial bee colony (ABC) algorithm (Prasanth and Hans Raj 2013a, b); Genetic algorithms (Tambouratzis et al. 2014); Artificial intelligence (Legardeur et al. 2006); Ant colony (Albritton and McMullen 2007); and Fuzzy logic and applications (Nazari-Shirkouhi et al. 2013).

Table 4.6 illustrates total numbers of studies related to intelligent product design while Fig. 4.9 indicates total numbers of published papers by searching for intelligent product design for *Title-Abstract and Keywords* with respect to the publication years.

Table 4.6 Summarized data for product design

Search for	Article title	Abstract	Keywords
Intelligent product design	35	371	876
Intelligent product modeling	4	46	40
Intelligent new product development	3	44	32

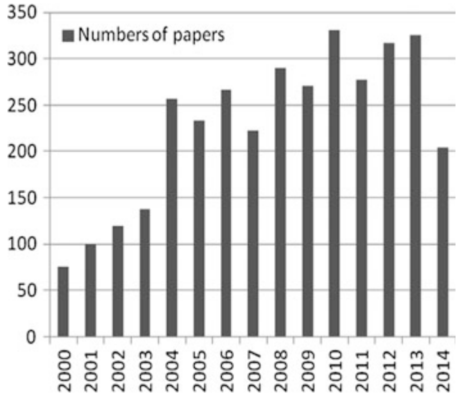


Fig. 4.9 Total numbers of published papers for *intelligent product design*

4.6.2 Medical System

Intelligent systems (IS) have been employed in the field of health care/medical system as an aid to develop the patient care quality (Tilbury et al. 2000) since it gives timely, useful and valid information (Haghighi et al. 2013). There are many papers conducted in the health care industry associated with intelligent systems; however, in the scope of this paper some of the important problem types are stated. For instance, the evaluation of the system has critical importance; for this reason, some researchers used receiver operating characteristic (ROC) analysis for this purpose (Tilbury et al. 2000). On the other hand, some authors have studied providing e-health care support for patients having movement disabilities by using IS, focusing on the dynamic multi-agent system e.g. for collecting data of current position of robot and for sending signals (Bielskis et al. 2008). Some other researchers have analyzed the communication between different emergency teams using different terminology and management of the recorded data (Haghighi et al. 2013). Besides these, others focus on intelligent medical devices for the improvement of elder people by developing an integrated Institutional Review Board (IRB) system connecting hospitals, manufacturers and as well as customers (Hsu et al. 2012). In addition to these, some of the researchers have identified ethical issues with regard to artificial intelligent care providers (Luxton 2014). Also, many researchers have made analysis on intelligent medical diagnosis expert system offering pre/post-care as well as appropriate cure (Kwon et al. 2009).

Table 4.7 Summarized data for medical system

Search for	Article title	Abstract	Keywords
Intelligent medical devices	7	113	52
Intelligent medical system	25	88	42
Intelligent health care system	4	76	79
Intelligent medical diagnosis	15	190	82

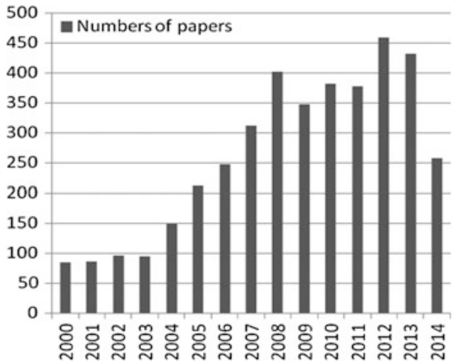


Fig. 4.10 Total numbers of published papers for *intelligent medical system*

In the literature many papers have published with respect to medical system. Mainly researches are focused on *intelligent medical devices, intelligent medical/ health care system and more specifically diagnosis* by using intelligent systems such as particle swarm optimization algorithm (Vázquez et al. 2011); Genetic algorithms (Ahmad et al. 2013); Artificial intelligence (Kumar 2011); and Fuzzy logic and applications (Moshtagh-Khorasani et al. 2009).

Table 4.7 displays total numbers of studies related to intelligent medical system as Fig. 4.10 exhibits total numbers of published papers by searching for intelligent medical system for *Title-Abstract and Keywords* with respect to the publication years.

4.6.3 Transportation

Intelligent Transportation System (ITS) aiming to develop models for reducing CO_2 emissions, consumption of fuel, assuring safety and driving comfort; analyzes the data of driving behavior as well as the flow of traffic, traffic lights, and count-down timers by gathering data related to a real time traffic condition, video records from telematics, digital tachygraphy as well as road-side cameras (Hsu et al. 2014).

In the literature, there are a vast number of studies related to ITS. Some studies have worked on capacity planning and transportation infrastructure which is essential for coordinating traffic by developing a mathematical model (Shah et al. 2012). Some of the studies have focused on speed estimation in roads, highways,

Table 4.8 Summarized data for transportation

Search for	Article title	Abstract	Keywords
Intelligent transportation systems	1,048	5,459	7,790
Intelligent transportation technology	72	1,973	1,268
Intelligent transportation modeling	31	456	464
Intelligent transportation data mining	4	94	118

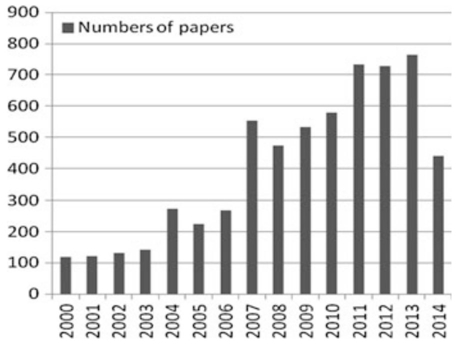


Fig. 4.11 Total numbers of published papers for *intelligent transportation*

urban traffic networks (Liang and Wakahara 2015); vehicle arrival rate and waiting time (Wang et al. 2014a, b, c). On the other hand, some other have analyzed transportation networks with respect to reliable positioning accuracy of vehicles in a network by analyzing The Global Positioning System (GPS), radio-frequency identification (RFID), communications between vehicle-to-vehicle and vehicle-to-infrastructure (Amini et al. 2014). Briefly, the main topics of ITS can be divided into six groups which are *Vehicle-and-road-tracking, Driver-behavior-and-safety, Scenarios-simulation, Traffic-flow-and-traffic-management, Vehicle-control, and Vehicle-navigation* (Cobo et al. 2014).

Mainly researches are concentrated on *transportation* by employing intelligent systems such as particle swarm optimization algorithm (Li and Zhu 2009); Genetic algorithms (Lin et al. 2008); Artificial neural networks (He et al. 2014); and Fuzzy logic and applications (Noori and Jenab 2013).

Table 4.8 represents total numbers of studies related to intelligent transportation as Fig. 4.11 denotes total numbers of published papers by searching for intelligent transportation for *Title-Abstract and Keywords* with respect to the publication years.

4.6.4 Education

As stated by researchers, modern education system is inseparable from computers (Myneni et al. 2013). The integration of computer tools and IS plays an important

Table 4.9 Summarized data for education

Search for	Article title	Abstract	Keywords
Intelligent tutor	88	206	171
Intelligent e-learning	46	69	77
Intelligent learning system	25	48	51
Intelligent distance education	5	7	1
Intelligent education software	3	13	11
Intelligent education services	1	6	5

role in the shift from traditional education/teacher-centered models to student-centered education models (Aparicio et al. 2012). There have been many valuable studies focusing on the development of educational system by employing intelligence systems.

One of the hot topics is e-learning system that can be either synchronous or asynchronous. Intelligent Tutoring System (ITS) can be given as an example to asynchronous e-learning systems. ITS which is actually a software system understanding the needs of students and responding to them, and adaptable to characteristics of individual students, allow individuals to control their learning processes and support every age and occupation anytime and anywhere (Barros et al. 2011). ITS has domain knowledge with respect to teaching and student modelling (Stankov et al. 2008). On the other hand, designing of intelligent distance education systems (Li et al. 2013) and development of education software, which integrates computer graphic technique, computer simulation technique, artificial intelligent, sensor technology, display technology and network multiprocessing technology (Hu and Bi 2013), draw attentions of researchers.

In the literature, intelligent systems such as Genetic algorithms (Liu et al. 2010); Artificial intelligence (Chaudhri et al. 2013); Ant colony (Ma and Tian 2011); and Fuzzy logic and applications (Crockett et al. 2013) are used to bring solutions to intelligent learning systems.

Table 4.9 lists total numbers of studies related to intelligent learning system as Fig. 4.12 demonstrates total numbers of published papers by searching for intelligent learning system for *Title-Abstract and Keywords* with respect to the publication years.

4.6.5 Intelligent Buildings

There is a continuous improvement of intelligent buildings (IB) all over the world. The main difference of intelligent buildings is its capability to incorporate information processing and intelligence in a various stages in design and construction as well as lifetime management (Lu et al. 2009). Intelligent buildings being smart, useful and efficient, offers advantages in comfort, convenience, safety, and long-

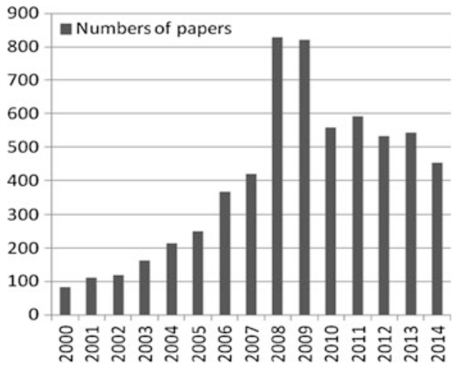


Fig. 4.12 Total numbers of published papers for *intelligent education*

term flexibility as well as marketability when compared to the conventional buildings (Deo 2006).

Conventional mathematical models used for the design of the buildings and the construction process. However, as reasons of computationally intensive models, having large set of equations, and difficulty in defining uncertainty, intelligent systems are used to cope with these pitfalls (Lu et al. 2009). There are some areas such as design of intelligent buildings (He 2014), energy saving scheduling (Guo and Xu 2002), the identification of temperature (Zhang et al. 2011a, b), sustainability assessment of intelligent buildings, monitoring intelligent buildings (Volkov and Latyshev 2014), and automation and control (Li and Zhang 2013), that researchers have concentrated on.

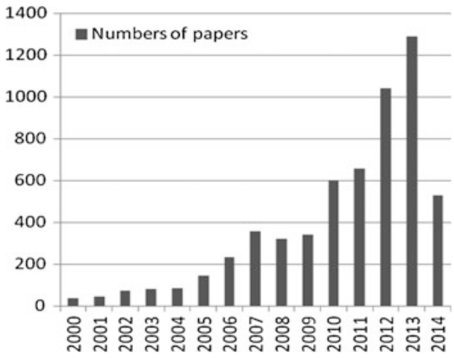
In the literature many of the intelligent systems such as Genetic algorithms (Guo and Xu 2002); Artificial intelligence (Wang et al. 2013); Fuzzy logic and applications (Kahraman and Kaya 2012) and integrated methods such as a feed forward neural network and particle swarm optimization (PSO) algorithm (Chen et al. 2010) are employed to bring solutions to intelligent building systems.

Table 4.10 exhibits total numbers of studies related to intelligent building system as Fig. 4.13 illustrates total numbers of published papers by searching for intelligent building system for *Title-Abstract and Keywords* with respect to the publication years.

Table 4.10 Summarized data for buildings

Search for	Article title	Abstract	Keywords
Intelligent building	439	823	5,965
Intelligent building control	12	35	12
Intelligent building management	10	28	92
Intelligent building technologies	6	20	25
Intelligent building design	7	17	22
Intelligent building monitoring	1	2	50

Fig. 4.13 Total numbers of published papers for *intelligent buildings*



4.6.6 Defense

In the literature there are a limited number of studies conducted in the defense industry using intelligent systems. For instance, one of the studies has made analysis on planning air and ground robot paths depending on aerial and ground visuals by employing modified intelligent water drop (IWD) algorithm (Straub 2014). Other study has concentrated on optimization of a multistage weapon production planning in the defense industry (Zhou and Jiang 2013). Some other study has worked on the defense maintenance which is expected to make proactive obsolescence management of avionics parts (Haider et al. 2006) while other has developed a new framework for a national defense budget planning process and implemented a knowledge-based intelligent decision support system (Wen et al. 2005). On the other hand, some studies have been more technical including intelligent missile guidance system for military academy (Deskovski and Gacovski 2005).

In the literature, intelligent systems such as Genetic algorithms (Wang 2014); Artificial intelligence (Luo et al. 2013); Particle swarm optimization algorithm (Wang et al. 2014a, b, c); and Fuzzy logic and applications (Deskovski and Gacovski 2005) are suggested for solving intelligent defense problems.

Table 4.11 expresses total numbers of studies related to intelligent defense system as Fig. 4.14 shows total numbers of published papers by searching for intelligent defense system for *Title-Abstract and Keywords* with respect to the publication years.

Table 4.11 Summarized data for defense

Search for	Article title	Abstract	Keywords
Intelligent defense systems	5	49	33
Intelligent security defense	3	14	10

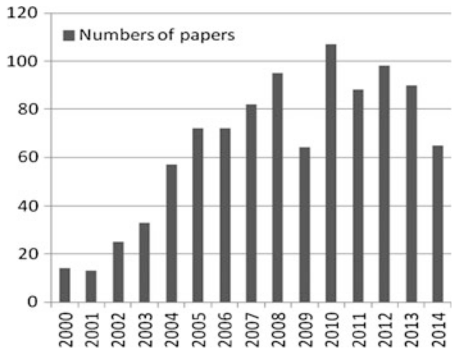


Fig. 4.14 Total numbers of published papers for *intelligent defense*

4.6.7 Mobile Robots

Robotics is one of the fields that many researchers have interested in. Because of the rapid development in technology, intelligent mobile robots requiring the coordination between a variety of expertise areas such as robotics, automation, programming, and electronics have been developed. There are some hot research areas with regard to intelligent mobile robots (IMR). One of the research areas is to design of IMRs which is a complex task requiring to utilize complex functions (Yavuz 2007) and to integrate and adopt physical components, sensors, energy sources, embedded computing and decision algorithms (Michaud 2007).

Some other areas are motion planning for robots (Petrisor and Stanciu 2014) and mobile robot path planning (Wang et al. 2014a, b, c). On the other hand, navigation of mobile robots where basically a mobile robot aimed to reach a goal position by the desired final orientation with regard to the following of the univector field, is another topic that draws attentions of the researchers. As the univector field can not assure intelligent mobile robots to avoid obstacles in the unknown environment, researchers have developed algorithms to train the robots (Viet et al. 2013). Besides these, voice recognition control system which led robots to recognize voices of adults as well as children even in the real life noisy environment, is also other topic that researchers have studied on (Jung et al. 2013).

In the literature, intelligent systems as Genetic algorithms (Yang et al. 2007); Artificial intelligence (Yang et al. 1996); Particle swarm optimization algorithm (Deepak and Parhi 2013); Fuzzy logic and applications (Ballagi et al. 2009); and Neural network (Dezfoulian et al. 2012) are utilized for intelligent mobile robot problems.

Table 4.12 indicates total numbers of studies related to intelligent mobile robots whereas Fig. 4.15 displays total numbers of published papers by searching for intelligent mobile robots for *Title-Abstract and Keywords* with respect to the publication years.

Table 4.12 Summarized data for mobile robots

Search for	Article title	Abstract	Keywords
Intelligent mobile robots	86	193	119
Intelligent mobile robots navigation	13	50	30
Intelligent mobile robots design	11	38	19
Intelligent mobile robots performance	1	15	2
Intelligent mobile robots monitoring	2	4	1

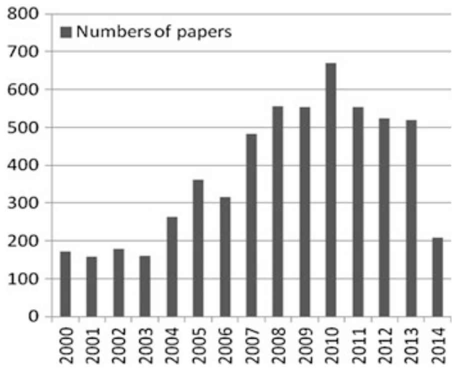


Fig. 4.15 Total numbers of published papers for *intelligent mobile robots*

4.7 Conclusion Remarks and Future Research Suggestions

This chapter examines the topic from engineering management perspective by demonstrating the big picture of the application of Intelligent Systems in a various R&D areas. The chapter aims to fill the gap in the literature by conducting a comprehensive literature review with regard to intelligent R&D. In the chapter, a wide variety of the research areas are covered by determining problem types, presenting the statistical analyses of the review results and illustrating some graphics. The chapter also presents Intelligent R&D intuitions functioning all over the world.

Literature review highlights that the application of intelligent systems in a various kinds of R&D areas shows an increasing trend from 2010 to 2014. It is observed that some of the top studied research areas are changing from production and engineering to medical and pharmaceutical industry, and from defense to robots. The chapter also points out that the bulk of the studies related to intelligent systems in R&D have been done in the US, and it is followed by China and Japan. It is also found out from Scopus that Engineering, Computer Science, Mathematics, Physics and Astronomy are the most studied subjects.

The literature review also indicates that the research areas such as education, robotics, and defense are still demanding more research and development studies including intelligent systems.

In addition, the research expresses that there are many R&D studies applying Artificial intelligence, Genetic algorithm and Fuzzy logic whereas there are a few number of papers conducting Tabu search, Simulated annealing, and Bee ant colony algorithms.

On the other hand, the chapter analyzes Intelligent Systems by considering different Research and Development areas. However, future studies are suggested to be done for a specific research area employing intelligent systems in detail. In addition, in this chapter intelligent R&D is analyzed from an engineering management. The further review studies are encouraged to consider social sciences and humanities. It is also suggested to analyze the relationship between the total numbers of published papers and their economic values. Finally, countries can be analyzed with respect to the applications of intelligent systems in various R&D areas.

References

Ahmad, F., Mat Isa, N.A., Hussain, Z., Osman, M.K.: Intelligent medical disease diagnosis using improved hybrid genetic algorithm—multilayer perceptron network. J. Med. Syst. **37**, 9934 (2013)

Albritton, M.D., McMullen, P.R.: Optimal product design using a colony of virtual ants. Eur. J. Oper. Res. **176**(1), 498–520 (2007)

Alcaraz, J., Maroto, C., Ruiz, R.: Solving the multi-mode resource-constrained project scheduling problem with genetic algorithms. J. Oper. Res. Soc. **54**(6), 614–626 (2003)

Amini, A., Vaghefi, R.M., De La Garza, J.M., Buehrer, R.M.: Improving GPS-based vehicle positioning for intelligent transportation systems. In: Proceedings of IEEE Intelligent Vehicles Symposium, (2014), pp. 1023–1029

Aparicio, F., De Buenaga, M., Rubio, M., Hernando, A.: An intelligent information access system assisting a case based learning methodology evaluated in higher education with medical students. Comput. Educ. **58**, 1282–1295 (2012)

Australia Bureau of Statistics: Research and Experimental Development: Business enterprises, ABS 8104.0 (Canberra) (1996)

Ballagi, Á., Kóczy, L.T., Gedeon, T.D.: Fuzzy communication and motion control by fuzzy signatures in intelligent mobile robots. Stud. Comp. Intell. **241**, 147–1647 (2009)

Barros, H., Silva, A., Costa, E., Bittencourt, I.I., et al.: Steps, techniques, and technologies for the development of intelligent applications based on Semantic Web Services: A case study in e-learning systems. Eng. Appl. Artif. Intel. **24**, 1355–1367 (2011)

Bielskis, A.A., Denisovas, V., Drungilas, D., et al.: Modelling of intelligent multi-agent based E-health care system for people with movement disabilities. Elektronika ir Elektrotechnika **6**, 37–42 (2008)

Bielskis, A.A., Denisovas, V., Drungilas, D., et al.: Pareto ant colony optimization based algorithm to solve maintenance and production scheduling problem in parallel machine case. In: Proceedings of International Conference on Computers and Industrial Engineering, CIE 2009, (2009) pp. 1210–1215

Chaudhri, V.K., Gunning, D., Lane, H.C., Roschelle, J.: Intelligent learning technologies Part 2: applications of artificial intelligence to contemporary and emerging educational challenges. AI. Mag. **34**(4), 10–12 (2013)

Chen, L., Fang, Q.-S., Zhang, Z.-Y.: Research on the identification of temperature in intelligent building based on feed forward neural network and particle swarm optimization algorithm. In:

Proceedings—2010 6th International Conference on Natural Computation ICNC 2010, vol. 4, pp. 1816–1820 (2010)
Chen, S.-M., Griffis, F.H., Chen, P.-H., Chang, L.-M.: Simulation and analytical techniques for construction resource planning and scheduling. Automat. Constr. **21**(1), 99–113 (2012)
Chu, W., Li, Y., Liu, C., Mou, W., Tang, L.: A manufacturing resource allocation method with knowledge-based fuzzy comprehensive evaluation for aircraft structural parts. Int. J. Prod. Res. **52**(11), 3239–3258 (2014)
Cobo, M.J., Chiclana, F., Collop, A., et al.: A bibliometric analysis of the intelligent transportation systems research based on science mapping. IEEE Trans. Intell. Transp. **15**(2), 901–908 (2014)
Crockett, K., Latham, A., Mclean, D., O'Shea, J.: A fuzzy model for predicting learning styles using behavioral cues in an conversational intelligent tutoring system. In: 2013 IEEE International Conference on Fuzzy Systems FUZZ-IEEE 2013, Hyderabad, India (2013)
Deepak, B.B.V.L., Parhi, D.R.: Target seeking behaviour of an intelligent mobile robot using advanced particle swarm optimization. In: Presented on IEEE International Conference on Control, Automation, Robotics and Embedded Systems CARE 2013, Jabalpur, India, 16–18 Dec 2013
Deo, D.S.: Applications of expert system/neural networks/genetic algorithms in an intelligent building complex. J. Inst. Eng. (India): Ar Eng. Div. **87**, 4–9 (2006)
Deskovski, S., Gacovski, Z.: Intelligent missile guidance system developed for training at Macedonian military academy. In: Proceedings on 16th Triennial World Congress of International Federation of Automatic Control IFAC 2005, vol. 16, pp. 1–6. Prague Czech Republic (2005)
Dezfoulian, S.H., Wu, D., Ahmad, I.S.: A generalized neural network approach to mobile robot navigation and obstacle avoidance. Adv. Intel. Syst. Comput. **193**, 25–42 (2012)
Djellal, F., Francoz, D., Gallouj, C., Galluuj, F., Jacquin, Y.: Revising the definition of research and development in the light of the specificities of services. Sci. Public Pol. **30**(6), 415–429 (2003)
Ferreira, A.: Strategies of human-robot interaction for automatic microassembly. Proc. IEEE Int. Conf. Rob. Autom. **3**, 3076–3081 (2003)
Firoozi, Z., Ismail, N., Ariafar, S.H., Tang, S.H., Ariffin, M.K.M.A.: A genetic algorithm for solving supply chain network design model. AIP Conf. Proc. **1557**, 211–214 (2013)
Frazzon, E.M., Israel, E., Albrecht, A., Pereira, C.E., Hellingrath, B.: Spare parts supply chains' operational planning using technical condition information from intelligent maintenance systems. Annu. Rev. Control **38**, 147–154 (2014)
Guo, Q., Xu, Q.-W.: Analysis and modeling of the central air-conditioning system in intelligent buildings. J. B Inst. Technol. **11**(3), 295–297 (2002)
Haghighi, P.D., Burstein, F., Zaslavsky, A., Arbon, P.: Development and evaluation of ontology for intelligent decision support in medical emergency management for mass gatherings. Decis. Support. Syst. **54**, 1192–1204 (2013)
Haider, K., Tweedale, J., Urlings, P., Jain, L.: Intelligent decision support system in defense maintenance methodologies. In: Proceedings of 2nd annual international conference on emerging techonologies ICET 2006, pp. 560–567. Peshawar, Pakistan (2006)
He, J.: Study on the efficient design scheme of intelligent building. Appl. Mech. Mater. 484–485, 695–699 (2014)
He, W., Lu, T., Yu, C.Q.: A novel traffic flow forecasting method based on the artificial neural networks and intelligent transportation systems data mining. Adv. Mat. Res. **842**, 708–711 (2014)
Hsu, C.-L., Tseng, K.C., Chuang, Y.-H.: A secure IRB system for assisting the development of intelligent medical devices. Expert Syst. Appl. **39**, 12512–12521 (2012)
Hsu. C.-Y., Yang, C.-S., Yu, L.-C., et al.: Development of a cloud-based service framework for energy conservation in a sustainable intelligent transportation system. Intern. J. Prod. Econ. http://dx.doi.org/10.1016/j.ijpe.2014.08.014. (2014)
Hu, L., Bi, X.: Education software design of electronic technique that based on virtual reality technology. Adv. Intel. Syst. Comput. **180**, 173–178 (2013)

Huang, S., Yu, H.: Intelligent fault monitoring and diagnosis in electrical machines. Measurement **46**(9), 3640–3646 (2013)

Hussein, H.M.A., Kumar, S.: A framework for development of an intelligent system for design and manufacturing of stamping dies. In: 27th International Conference on CADCAM, Robotics and Factories of the Future 2014; London (2014)

Ichoua, S., Pechmann, A.: Production scheduling for sustainable manufacturing systems. Key Eng. Mat. **572**(1), 235–238 (2014)

Jespersen, S.T., Olsen, P.: Factors influencing the effectiveness of R&D efforts in the Nordic countries. TemaNord 553, Denmark (2007)

Jia, Q., Seo, Y.: An improved particle swarm optimization for the resource-constrained project scheduling problem. Int. J. Adv. Manuf. Tech. **67**(9–12), 2627–2638 (2013)

Jin, M., Ma, R., Yao, L., Ren, P.: An effective heuristic algorithm for robust supply chain network design under uncertainty. Appl. Math. Inf. Sci. **8**(2), 819–826 (2014)

Jong, W.-R., Lai, P.-J., Lo, C.-W.: Applying ant colony system algorithm in the navigation process for plastic injection mould manufacturing scheduling optimization. Int. J. Prod. Res. **52**(9), 2530–2549 (2014)

Jung, S.W., Park, M.Y., Park, I.M., Jung, Y.K., Shin, H.B.: A robust control of intelligent mobile robot based on voice command. In: Presented on the 6th International Conference on Intelligent Robotics and Applications ICIRA 2013, pp. 25–28. Busan, South Korea, Sept 2013

Kahraman, C., Kaya, I.: A fuzzy multiple attribute utility model for intelligent building assessment. J. Civ. Eng. Manag. **18**(6), 811–820 (2012)

Kaplanoğlu, V.: Multi-agent based approach for single machine scheduling with sequence-dependent setup times and machine maintenance. Appl. Soft Comput. **23**, 165–179 (2014)

Krishnakumar, K.: Intelligent systems for aerospace engineering—an overview, NASA Technical Report, Document ID: 20030105746 (2003)

Kuchta, D.: The use of fuzzy numbers in practical project planning and control. Stud. Fuzz. Soft. Comp. **254**, 323–339 (2010)

Kumar, M.: Medical diagnosis using generic intelligent agents. Commun. Comput. Inf. Sci. **125**, 41–48 (2011)

Kwon, P.-J., Kim, H., Kim, U.: A study on the web-based intelligent self-diagnosis medical system. Adv. Eng. Softw. **40**(6), 402–406 (2009)

Lee, H.-Y.: An integrated model for planning development projects using ACO and construction simulation. Civ. Eng. Environ. Syst. **28**(4), 285–300 (2011)

Lee, H.C., Lee, J.M., Seo, J.H.: Design and improvement of product using intelligent function model based cost estimating. Expert Syst. Appl. **38**, 3131–3141 (2011a)

Lee, J., Ghaffari, M., Elmeligy, S.: Self-maintenance and engineering immune systems: Towards smarter machines and manufacturing systems. Annu. Rev. Control **35**(1), 111–122 (2011b)

Legardeur, J., Merlo, C., Fischer, X.: An integrated information system for product design assistance based on artificial intelligence and collaborative tools. Int. J P L Manage. **1**(3), 211–229 (2006)

Li, J., Zhang, Y.: Intelligent building automation and control based on IndasIBMS. In: Proceedings of International Conference on Service Science ICSS 2013, pp. 266–270. Shenzhen, China, 11–13 April 2013

Li, W., Zhu, K.: Research on DCW-PSO algorithm and its application in intelligent transportation systems. In: Proceeding of 5th International Conference on Natural Computation, ICNC 2009, vol. 4, pp. 393–397 (2009)

Li, X.P., Liu, F., Wang, X.J., Zhao, F.N.: Design and implementation of intelligent distance education platform. Adv. Mater. Res. **760–762**, 1728–1732 (2013)

Liang, Z., Wakahara, Y.: Speed-volume relationship model for speed estimation on urban roads in intelligent transportation systems. Adv. Intel. Syst. Comput. **1089**, 685–690 (2015)

Lin, C.-H., Yu, J.-L., Liu, J.-C., Lee, C.-J.: Genetic algorithm for shortest driving time in intelligent transportation systems. In: Proceedings—2008 International Conference on Multimedia and Ubiquitous Engineering, MUE 2008, pp. 402–406. (2008)

Liu, L., Chen, L., Shi, C., Chen, H.: The study of collaborative learning grouping strategy. In: Intelligent Tutoring System, Proceedings of the 14th International Conference on Computer Supported Cooperative Work in Design CSCWD 2010, pp. 642–646 (2010)

Lu, T.-F.: Intelligent systems techniques and their application in manufacturing systems. Expert Syst. **2**, 381–410 (2002)

Lu, T.-F., Lin, G.C.: CAD, vision and sensor based intelligent robot server. Comput. Integr. Manuf. **9**(2), 91–100 (1996)

Lu, X., Clements-Croome, D., Viljanen, M.: Past, present and future mathematical models for buildings: Focus on intelligent buildings (Part 1). Intell. Build. Intern. **1**(1), 23–38 (2009)

Luo, J., Zhu, C., Cui, J., Liu, Z., Zhang, W.: Planning and scheduling for the air defense of warship (Guofang Keji Daxue Xuebao). /J. Natl. Univ. Defen. Technol. **35**(2), 40–45 (2013)

Luxton, D.D.: Recommendations for the ethical use and design of artificial intelligent care providers. Artif. Intell. Med. **62**, 1–10 (2014)

Ma, J., Tian, F.: Intelligent learning ant colony algorithm. Appl. Mech. Mater. 48–49, 625–631 (2011)

Michaud, F.: Engineering education and the design of intelligent mobile robots for real use. Intell. Autom. Soft. Comput. **13**(1), 19–28 (2007)

Micheletti, N., Kanevski, M., Bai, S., Wang, J., Hong, T.: Intelligent analysis of landslide data using machine learning algorithms. Landslide Sci. Pract. Spat. Anal. Model. **3**, 161–167 (2013)

Moshtagh-Khorasani, M., Akbarzadeh-T, M.-R., Jahangiri, N., Khoobdel, M.: An intelligent system based on fuzzy probabilities for medical diagnosis—A study in aphasia diagnosis. J. Res. Med. Sci. **14**(2), 89–103 (2009)

Mousavi, S.M., Bahreininejad, A., Musa, S.N., Yusof, F.: A modified particle swarm optimization for solving the integrated location and inventory control problems in a two-echelon supply chain network. J. Intell. Manuf. (Article in press) (2014)

Myneni, L.S., Narayanan, N.H., Rebello, S., Rouinfar, A., Pumtambekar, S.: An interactive and intelligent learning system for physics education. IEEE Trans. Learn. Technol. **6**(3), 228–239 (2013)

Nazari-Shirkouhi, S., Keramati, A., Rezaie, K.: Improvement of customers' satisfaction with new product design using an adaptive neuro-fuzzy inference systems approach. Neural Comput. Appl. **23**, 333–343 (2013)

Noori, K., Jenab, K.: Fuzzy reliability-based traction control model for intelligent transportation systems. IEEE Trans. Syst. Man Cybern. A **43**(1), 229–234 (2013)

OECD: Organisation for Economic Co-Operation and Development. Frascati manual: Proposed Standard Practice for Surveys on Research and Experimental Development, OECD Publishing, Paris, (2002)

Oztemel, E., Kurt Tekez, E.: A general framework of a reference model for intelligent integrated manufacturing systems (REMIMS). Eng. Appl. Artif. Intell. **22**, 855–864 (2009)

Petrisor, G.-M., Stanciu, L.: Application for robot motion planning. In: 9th IEEE International Symposium on Applied Computational Intelligence and Informatics SACI 2014, pp. 97–100. Timisoara, Romania, (2014)

Prasanth, R.S.S., Hans Raj, K.: Artificial bee colony algorithm integrated with differential evolution operators for product design and manufacturing optimization. Adv. Intel. Syst. C **202**, 323–333 (2013a)

Prasanth, R.S.S., Hans Raj, K.: Artificial bee colony algorithm integrated with differential evolution operators for product design and manufacturing optimization. Adv. Intel. Syst. Comput. **202**, 323–333 (2013b)

Puzis, R., Shirtz, D., Elovici, Y.: A particle swarm model for estimating reliability and scheduling system maintenance. Enterp. Inf. Syst. (Article in press) (2014)

Ramík, D.M., Sabourin, C., Moreno, R., Madani, K.: A machine learning based intelligent vision system for autonomous object detection and recognition. Appl. Intell. **40**(2), 358–375 (2014)

Relich, M., Muszynski, W.: The use of intelligent systems for planning and scheduling of product development projects. Procedia Comput. Sci. **35**, 1586–1595 (2014)

Rudas, I.J., Fodor, J.: Intelligent Systems. Int. J. Comp. Commun. Control **3**, 132–138 (2008)

Sawatani Y, Arimoto T (2013) Value co-creation in R&D. Advances in the Human Side of Service Engineering. In: Spohrer JC, Freund L (ed) Taylor & Francis Group CRC Press, USA
Schalkoff, R.J.: Intelligent Systems: Principles, Paradigms and Pragmatics. Jones and Bartlett Publishers, LLC, USA (2011)
Shah, N., Kumar, S., Bastani, F., Yen, I.-L.: Optimization models for assessing the peak capacity utilization of intelligent transportation systems. Eur. J. Oper. Res. **16**(1), 239–251 (2012)
Shen, Z., Burnham, K.J., Smalov, L.: Optimised job-shop scheduling via genetic algorithm for a manufacturing production system. Adv. Intel. Syst. Comput. **1089**, 89–92 (2015)
Shi, X.-M., Chen, C.-L., Shi, W.-H., Zhang, H.-Q.: Function planning of maintenance equipment based on genetic algorithm (Xi Tong Gong Cheng Yu Dian Zi Ji Shu). Syst. Eng. Electron. **36** (7), 1346–1350 (2014)
Singh, S., Galar, D., Baglee, D., Björling, S.-E.: Self-maintenance techniques: a smart approach towards self-maintenance system. Int. J. Syst. Assur. Eng. Manage. **5**(1), 75–83 (2014)
Stankov, S., Rosic´, M., Zitko, B., Grubisic, A.: TEx-Sys model for building intelligent tutoring systems. Comput. Educ. **51**, 1017–1036 (2008)
Straub, J.: Intelligent water drops for aerospace and defense applications. In: Proceedings of SPIE —The International Society for Optical Engineering, Machine Intelligence and Bio-inspired Computation: Theory and Applications VIII, vol. 9119. Baltimore USA, (2014)
Subramanian, S., Anandhakumar, R., Ganesan, S.: Artificial bee colony based solution technique for generator maintenance scheduling. Aust. J. EE Eng. **9**(2), 109–126 (2012)
Tambouratzis, T., Karalekas, D., Moustakas, N.: A methodological study for optimizing material selection in sustainable product design. J. Ind. Ecol. **18**(4), 508–516 (2014)
Taner, A.H., Brignell, J.E.: Virtual instrumentation and intelligent sensors. Sens. Actuators Phys. **61**, 427–430 (1997)
Tang, L., Jing, K., He, J.: Supply chain scheduling optimization under networked manufacturing based on improved ant colony optimization algorithm (Xitong Gongcheng Lilun yu Shijian). Syst. Eng. Theor. Pract. **34**(5), 1267–1275 (2014)
Tangjitsitcharoen, S., Moriwaki, T.: Intelligent monitoring and identification of cutting states of chips and chatter on CNC turning machine. J. Manuf. Process. **10**, 40–46 (2008)
Tilbury, J.B., Van Eetvelt, P.W.J., Garibaldi, J.M., et al.: Receiver operating characteristic analysis for intelligent medical systems—A new approach for finding confidence intervals. IEEE Trans. Bio-Med. Eng. **47**(7), 952–963 (2000)
Vázquez, E., Ciurana, J., Rodríguez, C.A., et al.: Swarm intelligent selection and optimization of machining system parameters for microchannel fabrication in medical devices. Mater. Manuf. Process. **26**(3), 403–414 (2011)
Viet, H.-H., Choi, S.-Y., Chung, T.-C.: Dyna-QUF: Dyna-Q based univector field navigation for autonomous mobile robots in unknown environments. J. Cent. S. Univ. **20**(5), 1178–1188 (2013)
Volkov, A., Latyshev, K.: Intelligent and complex monitoring in intelligent buildings. Appl. Mech. Mater. **580–583**, 3204–3207 (2014)
Wang, N.: Research on design of free combat attack and defense action based on wireless sensor motion recognition. Appl. Mech. Mater. **602–605**, 2075–2078 (2014)
Wang, S., Liu, M.: Two-stage hybrid flow shop scheduling with preventive maintenance using multi-objective tabu search method. Int. J. Prod. Res **52**(5), 1495–1508 (2014)
Wang, M.Y., Ding, H.W., Liu, Q.L., Yang, Z.J.: The application of polling in intelligent transportation system. Appl. Mech. Mater. **602–605**, 853–856 (2014a)
Wang, X.N., Lin, Q., Chen, J.: Application of artificial intelligence in intelligent buildings. Appl. Mech. Mater. **347–350**, 466–470 (2013)
Wang, Y.-Y., Deng, G.-S., Ma, T., Li, L.: Robot path planning based on wave collision algorithm (Zhongbei Daxue Xuebao). J. N. Univ. China **35**(3), 286–292 (2014b)
Wang, Y.-Z., Zhou, L., Wang, Y., Xu, Y.: Research on patterns of unit behavior based on air defense equipment command task (Binggong Xuebao). Act. Armamentarii **35**(4), 540–546 (2014c)

Wen, W., Wang, W.K., Wang, C.H.: A knowledge-based intelligent decision support system for national defense budget planning. Expert Syst. Appl. **28**(1), 55–65 (2005)

Xu, J., Wei, P.: Production-distribution planning of construction supply chain management under fuzzy random environment for large-scale construction projects. J. Ind. Manage. Optim. **9**(1), 31–56 (2013)

Yang, H.S., Chung, J., Ryu, B.S., Lee, J.: CAIR-2: Intelligent mobile robot for guidance and delivery. AI Mag. **17**(1), 47–53 (1996)

Yangm, S., Fu, W., Li, D., Wang, W.: Research on application of genetic algorithm for intelligent mobile robot navigation based on dynamic approach. In: Proceedings of 2007 IEEE International Conference on Automation and Logistics ICAL 2007, pp. 898–902. Jinan, China, (2007)

Yavuz, H.: An integrated approach to the conceptual design and development of an intelligent autonomous mobile robot. Robot. Auton. Syst. **55**, 498–512 (2007)

Yumin, L., Zhongyuan, Y.: Optimal designing of multi-channel WDM filter using intelligent particle swarm optimization algorithm. In: 6th International Conference Simulated Evolution and Learning, SEAL 2006, Hefei, vol. 4247, pp. 205–212 China, 15–18 Oct 2006

Yuniarto, M.N., Labib, A.W.: Fuzzy adaptive preventive maintenance in a manufacturing control system: A step towards self-maintenance. Int. J. Prod. Res. **44**(1), 159–180 (2006)

Zhang, R., Liu, X., Liu, L., Zhang, X.: Research on an intelligent manufacturing system for tokamak machine. J. Fusion Energy (Article in press) (2014a)

Zhang, W., Pan, X.-H., Zhu, Y., Zhang, Y., Wu, Y.-B.: Manufacturing service open strategy based on intelligent single particle optimization (Jisuanji Jicheng Zhizao Xitong). Comput. Integr. Manuf. **17**(9), 2079–2084 (2011a)

Zhang, Y., Qin, J., Wang, Q., Chen, W., Zhang, H.-B.: Research on maintenance decision-making method of relay protection based on interval numbers grey fuzzy comprehensive evaluation (Dianli Xitong Baohu yu Kongzhi). Power Syst. Prot. C **42**(4), 16–21 (2014b)

Zhang, Z.Y., Cheng, H.M., Zhang, S.G.: An optimization model for the identification of temperature in intelligent building. J. Inform. Technol. Res. **4**(2), 61–69 (2011b)

Zhou, Y., Jiang, J.: A parallel evolution based intelligent optimization algorithm to solve large-scale production planning problem in defense industry. J. Soft. **8**(10), 2474–2481 (2013)

Chapter 5
Innovation Strategy Evaluation Process Using Fuzzy Cognitive Mapping

Ozge Surer, Sezi Çevik Onar and Y. Ilker Topcu

Abstract Innovation is a crucial tool for the firms to compete; thus defining the factors, which affect this process, is necessary to give a quick response to the changes. Therefore, finding a suitable innovation strategy is a vital problem for companies. When the relationships among the innovation strategy selection factors are considered, the innovation strategy evaluation process becomes complicated and necessitates a multi-criteria support. In this work, we concentrate on the conceptual model that reveals the determinants of innovation strategy. First, we explain the factors and their relations with each other based on the literature survey and the experts' opinion. This suggested framework is suitable for every firm and generally accepted. Due to the complex nature and sophisticated environment of the problem on hand, an appropriate multi-criteria decision-making (MCDM) method would be used to model the problem. As a consequence, as there are interrelations among the related factors, we use fuzzy cognitive mapping (FCM) approach which can utilize such network models. To explain the positions of factors in the long run, how they are affected by other factors, scenarios are performed and results are discussed. Our study shows that, although the strategy evaluation process is complex, the decision makers can apply FCM approach easily in the light of our conceptual model.

Keywords Scenario analysis · Innovation strategy · Fuzzy cognitive mapping

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5.1 Introduction

Innovation is the key component in a competitive environment. Innovation provides firms to survive in rapidly changing dynamic conditions and take a better place against competitors in the market (Cheng et al. 2010; Rothwell 1994; Roberts and Amit 2003). The sustainability of firm's innovation success and the continuity of the firm's capabilities depend on the innovation strategy (Guan et al. 2009; Shayne Gary 2005; Burgelman et al. 2003). Since innovation strategy has a vital importance for the enterprises, innovation management is an essential component for the companies (Ortt and van der Duin 2008; Drucker 1999). The factors or the determinants of successful innovation management process have to be examined in terms of deciding appropriate innovation strategy. There are many factors that affect the innovation management process (Damanpour et al. 1989). However, under the dynamic conditions, these factors are dependent to each other. If we take into account a number of criteria in order to make a correct decision, the multi-criteria based evaluation have to be done.

Policy makers and strategists dealing with technology and innovation need to extract knowledge from previously unknown patterns for successful innovation strategies in the sector of new technologies and services. Due to the complexity of innovation systems and their dynamics, we need enhanced tools for the development of innovation process. Artificial intelligence algorithms, neural networks, data mining and machine learning algorithms are the most common intelligent system techniques, which are used to analyze the tremendous amount of data. Fuzzy logic is a fundamental tool for dealing with quantitative, qualitative and multi-dimensional variables (Cevik Onar et al. 2014). Therefore, fuzzy logic can be used to evaluate the variables that affect the innovation system. Data analysis is the integral part of innovation cycle. As the amount of data inside and external sources of organizations grows, transforming data into meaningful actions is an important part of innovation cycle. Data mining techniques such as clustering and classification algorithms will be helpful to identify the main factors. Additionally, we can identify long-run patterns using learning algorithms on past data so that the behavior of uncertainties can be identified, when an innovation is made. Statistical analysis such as multiple factorial analysis and principal component analysis can be beneficial to determine the innovation typology. Therefore, enhanced techniques support the management of innovation for increased yield.

Due to the multi-dimensional structure of innovation management process, it is difficult to evaluate the factors directly. The relationship between factors has to be determined and the effects of factors on other factors should be examined. In our study, the factors and the relations among these factors revealed are generally accepted in the light of the literature survey and the experts' opinions. Fuzzy Cognitive Mapping (FCM) allows

- dynamic modeling of the problem on hand by considering the complex network structure of model, i.e. the effects of factors on innovation
- simulations based on scenarios that can be performed to analyze system fluctuations caused by changes in the factors.

This study is done based on the opinions of 5 experts, who are working in management and innovation. Although, there are lots of works analyzing the effects of factors on innovation strategy separately that are explained in the next sections, we lack general conceptual framework that explains the determinants of innovation management process. The literature suffers from a lack of proper conceptual model and quantitative method for determination of innovation strategy. It gives insight to professionals and researchers by putting forward to generally accepted factors and their relations with each other. On the other hand, this framework is not enough for choosing suitable strategy under specific conditions. The easily adaptable, analytic tool is required. Innovation policy-making requires an effective knowledge management in complex innovation system since valuable information helps policy makers to make successful technological choices. Hence, different methods of Intelligent Systems can be applied to make smarter decisions. Therefore, this chapter contributes to fill the gap in finding a methodology to assess the determination of innovation strategy for every firms and technology leaders in different industry. By means of the general factors and relations, every firm can find the most effective factors in their innovation management process by using Fuzzy Cognitive Map.

The rest of this chapter is organized as follows: Sect. 5.2 contains literature survey about innovation and its application areas. We will give a description of each criterion and sub-criterion that our model includes in the Sect. 5.3. Section 5.4 contains some information related to FCM and our model. The following section gives the results of our study. Finally, conclusion and suggestions are explained.

5.2 Innovation Strategy

OECD (2005) describes an innovation as the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations. Innovation is defined by (Daft 1982; Damanpour and Evan 1984; Damanpour 1992) as the adoption of an idea or behavior, whether a system, policy, program, device, process, product or service, that is new to the adopting organization. Therefore, it can be understood from the definitions that in order to get used to a new system, people need to examine the factors that affect this system. According to these factors, R&D and technology leaders have to choose the appropriate innovation strategy.

There are many studies that examine the types of innovation strategies from different perspectives. Bowonder et al. (2010) group innovation strategies into three. Customer excitement type innovation strategies include platform offerings, co-creation, cycle time reduction and brand value enhancement. Competitive leadership includes technology leveraging, future-proofing, lean development and partnering. Portfolio enrichment includes innovation mutation, creative destruction, market segmentation and acquisition. Freeman and Soete (1997) divide the innovation strategies into six groups. Firms with offensive strategy conquer their competitors by revealing new products through innovation, strategy, technology leadership and market leadership. These types of firms make intensive R&D activities and the number of patents is very high. Defensive strategy for a business means focusing on existing technology rather than a new technological innovation. Defensive innovators are not in the expectation of market leadership, but they do not want to be left behind the technological change. They try to escape high costs of entering the market first. Imitator firms monitor the technologies behind the leaders. Traditional strategy meets the needs of a particular section. In this strategy, firms focus on especially small or niche markets. Product design and product specifications depend on outside the business in the firms that follows dependent strategy. Dependent businesses often operate as a department of the strong company. If the demand is related to the product and service offerings, they make a change. Opportunist firms pursue the opportunities in the new markets. These innovation strategies are more applicable to the field of organizational and marketing strategies. However, we want to make a research in the field of technologic innovation and offer a general model that is suitable for all types of firms.

There are numerous studies associated with innovation strategy selection process. In (Tseng and Wu 2006), the authors propose 5 indicators that are patent count, relative citation ratio, citation-weighted patents, science linkage and scope of innovations for measuring innovation quality and determine their effects on firm's performance in the automobile industry. In this study, the factors are specifically related with intellectual property activities of the companies; however we try to analyze the whole innovation strategy determination process. Clercq et al. (2009) examine the relationship between an innovation strategy and firm performance. In this study, environmental uncertainty, firm size, type of operations, general manager background are considered as control variables and they make some implications about firm performance based on the task conflict and political activity. In another study, Camisón and Villar-López (2014) determine the relationship between organizational innovation and technological innovation capabilities (product and process), and analyze their effect on firm performance. The study by (Gunday et al. 2011) explores the effects of innovation types on the different aspects of firm performance. These researchers focus on mainly the firm performance and innovation strategy relationship and their conceptual models are not enough to assess the all the factors that have an influence on innovation management process.

Table 5.1 Factors in product strategy cluster

Factor	Definition	Studies by
Use of new materials (D1)	Make improvements in products' material which make them more attractive to the purchasers such as the introduction of drip-dry shirts, or breathable waterproof mountain gear	(OECD 2005; Gunday et al. 2011)
Use of new intermediate products (D2)	New intermediate inputs are used to produce a final consumer good	(OECD 2005; Gunday et al. 2011)
Use of new functional parts (D3)	Significant improvements in functional characteristics of a product such as margarine that reduces blood cholesterol levels or yoghurts produced using new types of cultures	(OECD 2005; Gunday et al. 2011)
Use of radically new technology (D4)	Combining existing technologies in new uses, or the use of new knowledge	(OECD 2005; Gunday et al. 2011)
Use of fundamental new functions (D5)	A change in the production function, i.e. a change in the use of factors of production	(OECD 2005; Gunday et al. 2011)

However, in our study we construct a model that reveals the factors in detail and their relationship to each other to determine the importance of them in terms of our objective. OECD's Oslo Manuel classifies the innovation strategy types into four: product, process, organizational and marketing innovation (OECD 2005). However, generally the papers emphasized the relationship and the differences between product and process strategies such as in (Goedhuys and Veugelers 2012; Maine et al. 2012; Gopalakrishnan et al. 1999). According to (Liao et al. 2008; Raymond and St-Pierre 2010), among the innovation strategies, the differences between product and process strategies are more explicit. However, the interrelation between each other should not be forgotten. It is difficult to separate their effects on the performance (Evangelista and Vezzani 2010). Together with their relation, the product and process strategies are in the field of technologic innovation. At the same time, there are not enough studies related to evaluation of process and product strategies. The study done by (Bonanno and Haworth 1998) is about the decision whether a company should choose product or process innovation based on the competition type. Therefore, in our decision model we handle these two strategies. Product innovation strategy can be studied into five operations: use of new materials (D1), use of new intermediate products (D2), use of new functional parts (D3), use of radically new technology (D4) and fundamental new functions (D5). Process innovation can be categorized into three groups: new production techniques (E1), new organizational features (E2) and new professional software (E3) (OECD 2005). In our study, we prioritize two strategies given at Tables 5.1 and 5.2, as well as the factors to make a decision about choosing product and process strategies.

Table 5.2 Factors in process strategy cluster

Factor	Definition	Studies by
New production techniques (E1)	Implementation of new or significantly improved production methods	(OECD 2005; Gunday et al. 2011)
New organizational features (E2)	The introduction of significantly changed organizational structures, the implementation of advanced management techniques, the implementation of new or substantially changed corporate strategic orientations	(OECD, 2005; Gunday et al. 2011)
New professional software (E3)	The development, acquisition, adaptation and use of software. It involves making a scientific or technological advance at the technological performance of a company	(OECD 2005; Gunday et al. 2011)

5.3 Innovation Strategy Evaluation Factors

The product and process strategies are two clusters of our model. Besides, in order to choose correct strategy, the determinants of these two strategies are examined. The factors that influence the strategy of innovation are reviewed from the literature. Veugelers and Cassiman (1999) examine the relation between the innovation sourcing strategies and industry-, firm- and innovation-specific variables. Gupta et al. (1986) develop a framework for innovation success and they identify the factors that influence the integration such as environmental uncertainty, organizational factors and organizational strategy. Peeters and van Pottelsberghe de la Potterie (2006) develop a model to decide a relationship between patenting behavior of a firm and firms' innovation strategies. Firm and sector characteristics are represented as control variables in their model. Innovative capability, contextual factors such as age, size and funding and environment are asserted as the determinants of innovative outcome in (Martínez-Román et al. 2011). Hurley and Hult (1998) divide organizational characteristics into structural characteristics and cultural characteristics that have an influence on innovation capacity. Jiménez-Jimnez and Sanz-Valle (2011) explore the moderating effect on performance, learning and innovation of firm age, firm size, industry and environmental turbulence.

Following a review of the literature, we gather the sector, industry and market related features in one heading that is industry characteristics. In one of the dimensions, environment related factors are combined as environmental uncertainties. The firm characteristics cluster includes organizational, contextual and firm related features. Hence, the literature mainly focuses on three basic aspects that have an influence on firms' innovation strategy. As a result, these three perspectives represent the factors that influence the process of innovation strategy formulation in our model.

5.3.1 Industry Characteristics

Firm’s strategic choice varies depending on the industry in which the company is present. Firms face with different opportunities and challenges in different industries and correspond to this divergence, they need to take action distinctively. In his study, Weerawardena et al. (2006) emphasize that in order to be innovator, firms should analyze the industry structure. In our model, in order to explain competitive environment better, we use the factors in Porter’s model (Porter 1985). In addition to competition related factors, industry-specific characteristics such as technologic level of industry and stage of industry are included in this cluster.

Industry characteristics cluster (A) includes eleven factors: Competition (A1), technologic level of industry (A2), stage of industry (A3), Lack of innovation partnership in industry potential (A4), market generosity (A5), availability of qualified personal in industry (A6), lack of governmental support (A7), supplier power (A8), threat of new entrants (A9), customer power (A10), threat of substitute products (A11).

The definitions of the factors in the industry characteristics cluster and the studies related to these factors can be seen on Table 5.3.

5.3.2 Environmental Uncertainties

If the new things are discovered, the uncertainties will be inevitable. The main thing for the companies is that how they manage uncertainties in order to turn them into opportunity. In his study, Camisón and Villar-López (2014) state that environmental uncertainty has an influence on organizational innovation capability and Clercq et al. (2009) use environmental uncertainty as a control variable, when they determined the relationship between innovation strategy and firm performance. Although some papers handle the uncertainty as a control variable, we divide environmental uncertainty into different groups for a detailed research and finding the most effective environmental uncertainty factor.

Environmental uncertainty cluster (B) contains supply uncertainty (B1), market/demand uncertainty (B2), technological uncertainty (B3), economic uncertainty (B4) and social regulatory uncertainty (B5).

In Table 5.4, we describe the environmental uncertainty factors and give the studies relevant to these factors.

5.3.3 Firm Characteristics

Innovative level of a firm and internal characteristics of that firm are strongly correlated (Romijn and Albaladejo 2002). Mol and Birkinshaw (2009) indicate that

Table 5.3 Factors in industry characteristics cluster

Factor	Definition	Studies by
Competition (A1)	Firm's innovative behavior is directly affected by the level of competitive rivalry in the market	(Souitaris 2002; Werker 2003; Tang 2006; Weerawardena et al. 2006; Martínez-Román et al. 2011; Wu 2012)
Technologic level of industry (A2)	The company can belong to high-tech, low-tech, knowledge-intensive or the other industry level	(Peeters and van Pottelsberghe de la Potterie 2006; Weerawardena et al. 2006; Schubert 2010; Wu 2012)
Stage of industry (A3)	The product or a technology shows the S-pattern on their life cycle. The rate of technological change and the innovation process show difference at each stage	(Werker 2003; Cooper and Edgett 2010; Wonglimpiyarat 2012)
Lack of innovation partnership in industry potential (A4)	The type of technologic alliances can be institutions, technological centers, public support or customers, suppliers as well. The cooperation between partnerships creates a technological opportunity for the innovative firms	(Souitaris, 2002; Romijn and Albaladejo 2002; Weerawardena et al. 2006; Busom and Fernndez-Ribas 2008; Caetano and Amaral 2011; Robin and Schubert 2012; Wu 2012)
Market generosity (A5)	Firms can be more innovative in the growing and high potential market	(Weerawardena et al. 2006; Carbonell and Rodriguez 2006; Werker 2003)
Availability of qualified personal in industry (A6)	Value creation depends on the employee's education, experience and expertise. Therefore, lack of skilled technical personnel in the market and recruitment of them especially influences the high-tech sectors' innovation capability	(Romijn and Albaladejo 2002; Ulusoy 2003)
Lack of governmental support (A7)	Governmental policies and economic support are necessary to promote the innovation activities for the firms	(Moon and Bretschneider 1997; Coriat and Weinstein 2002; Schubert 2010; Wonglimpiyarat 2011)
Supplier power (A8)	Companies, which have an interaction with the supplier's technological expertise, have a technological advantage in terms of time, cost and quality among their rivals	(Bidault et al. 1998; Romijn and Albaladejo 2002; Weerawardena et al. 2006; Johnsen 2009)
Threat of new entrants (A9)	It refers to the threat of new competitors entering the industry. New competitors affect the price and performance race. Hence, firms protect themselves from damage coming from the new entrants by technology and innovation	(Porter 1985; Weerawardena et al. 2006)

(continued)

Table 5.3 (continued)

Factor	Definition	Studies by
Customer power (A10)	When the customer is powerful in the market, it plays a major role in the pricing. Firm's technological behaviors are adjusted based on buyer's price sensitivity	(Porter 1985; Weerawardena et al. 2006)
Threat of substitute products (A11)	Due to the fact that customers have numerous alternatives in today's technology, companies have to be innovative to cope with their competitors	(Porter 1985; Weerawardena et al. 2006)

Table 5.4 Factors in environmental uncertainty cluster

Factor	Definition	Studies by
Supply uncertainty (B1)	Fluctuations in supply of materials, capacity constraints, limited supply source and lead time are the main causes of the supply uncertainty	(Ulusoy 2003)
Market/demand uncertainty (B2)	Unpredictability of demand and changes in competition cause variations in the market. It is difficult to forecast the demand of product under market uncertainty	(Freeman and Soete 1997; Sainio et al. 2012)
Technological uncertainty (B3)	Technologic changes cause the unpredictability of innovative products' development. Organizations sometimes have lack of knowledge about the existence of new technology	(Freeman and Soete 1997; Hall and Martin 2005; Hall et al. 2011)
Economic uncertainty (B4)	Technological investment has a stochastic structure. Internal and external ambiguity in finance is one of the main reasons of economic uncertainty	(Freeman and Soete 1997; Hall and Martin 2005; Hall et al. 2011)
Social regulatory uncertainty (B5)	Ambiguous regulatory environment affects the innovation process	(Hall and Martin 2005; Hall et al. 2011)

size of a firm, education level of a workforce and the geographical scope of the market influence the innovation practices of a firm. Additionally, we analyze the other factors that are grouped in firm characteristic cluster such as employees' expectation and shareholders' expectation.

Firm characteristic cluster (C) includes size of the firm (C1), linkages (External and Internal) (C2), degree of internationalization (C3), technological R&D capability (C4), financial resource (C5), capability of human resource (C6), employees' expectation (C7), shareholders' expectation (C8).

Factors and brief descriptions are given in Table 5.5.

Table 5.5 Factors in firm characteristics cluster

Factor	Definition	Studies by
Size of the firm (C1)	It refers to the total number of employees in a firm	(Veugelers and Cassiman 1999; Galende and De la Fuente 2003; Mol and Birkinshaw 2009; Schubert 2010; Martínez-Románet al. 2011)
Linkages (External and Internal) (C2)	A company can be a national or an international multi-corporate enterprise	(Peeters and van Pottelsberghe de la Potterie, 2006; Schubert 2010)
Degree of internationalization (C3)	A company can trade locally, regionally, nationally or internationally	(Romijn and Albaladejo 2002; Galende and De la Fuente 2003; Peeters and van Pottelsberghe de la Potterie 2006; Mol and Birkinshaw 2009)
Technological R&D capability (C4)	Implementation of R&D projects, success of R&D products, percentage of R&D staff and number of patents granted are the examples of R&D capabilities of a firm	(Romijn and Albaladejo 2002; Wang et al. 2008; Yam et al. 2011)
Financial resource (C5)	It refers to investments on new R&D projects and financial support for innovative thinking	(Romijn and Albaladejo, 2002; Galende and De la Fuente, 2003; Wang et al. 2008; Schubert, 2010; Martínez-Románet al. 2011)
Capability of human resource (C6)	Risk-taking, educated and proactive employees tend to make innovation	(Romijn and Albaladejo 2002; Galende and De la Fuente 2003; Mol and Birkinshaw 2009; Schubert 2010; Martínez-Románet al. 2011)
Employees expectation (C7)	Technology leaders have to think the ways of R&D employees' job satisfaction to increase the innovation activities	(Cheng et al. 2010; Sadikoglu and Zehir 2010; O'Cass and Sok 2013)
Shareholders expectation (C8)	Innovation is the fundamental application for sustainable shareholder growth	(Coriat and Weinstein 2002; Hanvanich et al. 2005)

5.4 Methodology and Application

5.4.1 Fuzzy Cognitive Mapping

Network-based representations of beliefs occupy an important place among the various schemes of knowledge or human belief representation. One of the popular network-based formalisms that have occupied key roles in representing beliefs and capturing causality is Cognitive Mapping (CM). CM is the task of mapping a person's thinking about a problem or issue (Tolman 1948). A cognitive map is the representation of thinking about a problem that follows from the process of mapping (Axelrod 1976; Eden 1988; 1992). ‘Cognition’ is used to refer to the mental models, or belief systems, that people use to perceive, contextualize, simplify, and make sense of otherwise complex problems. ‘Map’, on the other hand, provides graphical descriptions of unique ways in which individuals view a particular domain.

Cognitive maps are cause-effect networks, with nodes representing related concepts or factors articulated by individuals, and edges (arrows) representing directional linkages capturing causal dependencies or relations among concepts (Srinivas and Shekar 1997). In CM, a concept at the tail of an arrow is taken to cause, affect, or influence the concept at the arrowhead. The directional influences can be valued as one of the trivalent values [−1, 0, 1] where −1 indicates a negative causality, 0 no causality relation, and +1 a positive causality. If an increase (decrease) in the value of tail concept leads to an increase (decrease) in the value of head concept, there is a positive causality. Negative causality is just the contrary: an increase (decrease) in the value of head concept leads to a decrease (increase) in the value of head concept.

Cognitive maps can be derived by questionnaire survey, documentary coding and/or interviews. Roberts (1976) suggested that using questionnaire survey for eliciting the opinions of the experts gives the most reliable result. He argued that the process should be in two steps:

1. to define related concepts of the problem on hand, pose questions to the experts with an open ended questionnaire form or have them meet together and discuss
2. to determine the relations among concepts, ask whether there exists a relation or not between each pair of concepts and if relation exists, ask whether the causality is positive or negative.

CM inevitably represents the subjective world of the experts which can cause fuzziness and uncertainty. Fuzzy Cognitive Mapping (FCM), created in 1986 by Kosko, is a soft computing tool that is based on Fuzzy Logic and Neural Network methodologies (Papakostas et al. 2008). FCM can be utilized for modeling complex systems, especially for situations where fuzziness and uncertainty exist. FCM has been studied in various fields of science, such as psychology, planning, geography and management.

Kosko (1986) states that cognitive maps are limited by the trivalent values [−1, 0, 1] which is binding in the fuzzy causality environment. The usage of phrases such as little, partially, usually, a lot, strong, weak, etc. would be beneficial to the analyst during the causality gathering stage. Therefore, at a fuzzy cognitive map, nodes representing concepts and arrows representing impacts among concepts still exist like cognitive maps but additionally the strength of impact is also assessed. Hence, a graphical illustration appears as a weighted graph with feedback that consists of nodes and weighted arcs (Fig. 5.1).

In FCM, apart from CM, edges can be valued in the range of [−1, 1] allowing degrees of influence being represented. When for an edge concept C_i is the tail of

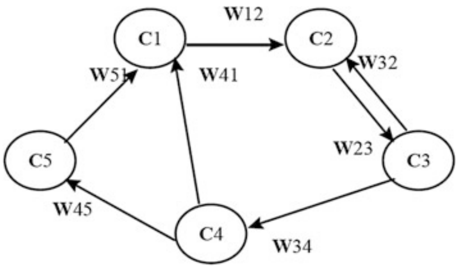

Fig. 5.1 A fuzzy cognitive map

the arrow and concept C_j is the arrowhead (i.e. C_i affects C_j), there will be three possibilities for W_{ij} indicating the causality between C_i and C_j:

- positive causality ($0 < W_{ij} \leq 1$)
- negative causality ($-1 \leq W_{ij} < 0$)
- no relationship, i.e. no arrow between concepts ($W_{ij} = 0$)

In order to have a unique aggregated fuzzy cognitive map of a group of experts, their judgments should be combined. For this purpose the weighted average of the causalities can be computed when experts have different priorities with respect to their expertise. But in most cases, their priorities are considered as equal to each other. For combining the judgments, the aggregation equation is as follows:

$$W_{ij}^{a} = \sum_{k=1}^{n} p_k W_{ij}^{k} \tag{5.1}$$

where W_{ij}^{a} indicates the causality between concepts C_i and C_j at the aggregated fuzzy cognitive map, p_k is the normalized priority of the expert k, and W_{ij}^{k} is the causality between concepts C_i and C_j according to expert k. When experts are not prioritized p_k should be $1/n$.

Fuzzy cognitive maps can be regarded as discrete time series where by formulating the system the values of the concepts are updated periodically in an iterative process (Tsadiras 2007). Sensitivity analysis can be utilized by deriving "what if" questions from fuzzy cognitive maps such as "If there is a change in the value of a concept what happens to others?" (Carvalho and Tomé 1999). Yaman and Polat (2008) formulate this process as:

Cognitive Maps + Quantitative Values + Time = Fuzzy Cognitive Maps

For this purpose, first of all, a mathematical model is formulated beyond the graphical representation. This model consists of an nxn adjacency matrix where there are n concepts. For example, the fuzzy cognitive map given at Fig. 5.1 can be converted into an adjacency (influence) matrix as can be seen in Table 5.6.

Then, a $1 \times n$ state vector (S) can be created by using the degree of activation of the concepts (A_i). There will be an initial state vector (S^0) with the values of concepts (A_i^0) resulted from the fuzzification process of converting crisp input values to fuzzy values (Peña et al. 2007).The values of each concept are influenced

Table 5.6 The adjacency matrix of the fuzzy cognitive map

	C1	C2	C3	C4	C5
C1	0	W12	0	0	0
C2	0	0	W23	0	0
C3	0	W32	0	W34	0
C4	W41	0	0	0	W45
C5	W51	0	0	0	0

by the values of the interconnected concepts with the related weights of interconnection (causality degrees) and by their previous values. To generate new values of concepts at the following states, an iterative equation is used:

$$A_i^{(k)} = f\left(A_i^{(k-1)} + \sum_{j \neq i} A_j^{(k-1)} w_{ji}\right) \tag{5.2}$$

where $A_i^{(\mathrm{k})}$ is the activation level of concept C_i at iteration step k, $A_j^{(k\ -\ 1)}$ is the activation level of the interconnected concept C_j at iteration step k-1, W_{ji} is the weight of interconnection between concepts C_j to C_i, and f is a threshold function (activation function) used to reduce the activation level into a normalized range (Papageorgioua et al. 2006).

Some of the most common threshold functions used are bivalent, trivalent, logistic and sigmoid functions which are given respectively by the following equations (Tsadiras 2007):

$$f(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x > 0 \end{cases} \tag{5.3}$$

$$f(x) = \begin{cases} -1, x \leq -0.5 \\ 0, -0.5 < x < 0.5 \\ 1, x \geq 0.5 \end{cases} \tag{5.4}$$

$$f(x) = \frac{1}{1 + e^{-cx}} \tag{5.5}$$

$$f(x) = \tanh(x) \tag{5.6}$$

At the final step, after determining the type of the threshold function and creating different initial state vectors for several scenarios, the simulations are run to observe and analyze the dynamic behavior of the system under consideration. A simulation ends after a certain number of iterations or when the values of concepts converge to a fixed form.

In Table 5.7, for an illustrative fuzzy cognitive map with 13 concepts, simulation result of a hypothetical scenario indicating a decrease at the 3rd concept is given.

Table 5.7 Simulation result of a hypothetical scenario

Iteration no.	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
1	0.00	0.00	−1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	−0.81	0.00	0.00	0.14	−0.32	0.00	0.00	0.19	0.00	0.50	0.50
3	0.00	0.11	−0.62	0.10	0.11	0.51	−0.81	0.10	0.00	0.21	0.20	0.70	0.90
4	0.00	0.43	−0.48	0.19	0.21	0.82	−0.89	0.40	0.00	0.31	0.60	0.80	1.00
5	0.19	0.59	−0.31	0.37	0.43	0.93	−1.00	0.70	0.00	0.52	0.83	0.90	1.00
6	0.40	0.70	−0.19	0.64	0.62	1.00	−1.00	0.90	0.00	0.74	0.92	0.90	1.00
7	0.69	0.80	0.03	0.83	0.69	1.00	−1.00	0.90	0.00	0.83	0.91	1.00	1.00
8	0.81	0.80	0.24	0.91	0.81	1.00	−1.00	0.90	0.00	0.91	0.93	1.00	1.00
9	0.92	0.82	0.42	0.89	0.89	1.00	−1.00	1.00	0.00	0.91	0.92	1.00	1.00
10	0.91	0.82	0.56	0.88	0.89	1.00	−1.00	1.00	0.00	0.93	1.00	1.00	1.00
11	0.90	0.81	0.72	0.89	0.90	1.00	−1.00	1.00	0.00	0.93	1.00	1.00	1.00
12	0.90	0.81	0.72	0.89	0.90	1.00	−1.00	1.00	0.00	0.93	1.00	1.00	1.00

As can be seen in the table, the state values of the concepts converge at iteration 12. The results can be interpreted as follows:

- a decrease at C_3 will increase the level of C_6, C_8, C_{11}, C_{12}, and C_{13};
- a decrease at C_3will decrease the level of C_7;
- a decrease at C_3 will increase the level of C_1, C_2, C_4, C_5, and C_{10} to some extent;
- in the long run, C_3 has no effect on C_9;

5.4.2 Application of Proposed Innovation Strategy Evaluation Process

In accordance with FCM, our proposed methodology starts with the identification of related concepts (factors) that affect the innovation strategy evaluation process as aforementioned in Sects. 5.2 and 5.3. Following the review of the literature, we come up with five clusters (see Tables 5.1, 5.2, 5.3, 5.4 and 5.5). Then five experts are asked to determine the relationships between the pairs of concepts with a questionnaire survey a part of which is seen at Table 5.8. These experts, whose working field of interest is innovation and management, are working at the industrial engineering departments of the universities in Turkey. They have carried out a lot of business projects as a consultant for many years. Therefore, they are experts in both academic and practical sense.

The aggregated fuzzy cognitive map is constructed by using the responses of experts. For this purpose, first of all the causal degree values are divided by 10; and then, assuming that priorities of experts are equal, the average causalities are computed by utilizing Eq. 5.1. Finally, the adjacency (influence) matrix of the aggregated fuzzy cognitive map is revealed (Table 5.9).

This adjacency matrix is an integrated framework that shed light on the innovation strategy evaluation process for organizations and academicians. First, it is a

Table 5.8 A part of the questionnaire

Increase in A1 "Competition" will cause the following to:	Increase (+)	No effect (0)	Decrease (–)	To what degree	
				Very low (1)	Very high (10)
A2 "Technological level of industry"					
A3 "Stage of industry"					
…					
…					
E3 "New professional software"					

comprehensive conceptual model since it covers many elements from environmental, firm and industrial aspects. On the other hand, it introduces the relations among these factors. On the process of constructing this matrix, all information is verified by the literature survey and experts' opinions. Generally, we can infer from the adjacency matrix that the product and process strategies are influenced by all the factors in the remaining three clusters. Firm characteristics and product-process strategies don't have any effect on the environmental uncertainties. In industry characteristics cluster, competition, innovation partners, threat of new entrants and substitute of products are effected by firm characteristics and product-process strategies.

At the final stage of the proposed process, the type of the threshold function is determined as sigmoid function as sigmoid function has inference capabilities, allows neuron's activation level to be in the whole interval [−1, 1] and can also represent the degree of an increase or a decrease of a concept (Tsadiras 2007). We create different initial states for several scenarios as can be examined in the following section and run simulations to observe and analyze the dynamic behavior of innovation strategy evaluation.

5.5 Findings

We consider a number of scenarios to reveal the effect of factors to the state of the product and process innovation strategies. Also, the centrality degrees are determined in order to reveal the important factors in the cognitive map. Use of new materials (D1) and Competition (A1) have high centrality indicating a strong influence in forming factor behaviors in the map.

Scenario 1: Initial Scenario
Initially, we considered a case where all factors are set to one. This means that all factors are fully activated under this assumption. After 50 iterations the FCM system reaches a final state where all the factors accept size of the firm (C1), lack of innovation partnership in industry potential (A4) and lack of governmental support (A7) exhibit very high values and therefore increase the product and process

Table 5.9 Aggregated adjacency matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	B1	B2	B3	B4	B5	C1
A1		0,50	0,25	-0,75	0,25	0,25	0,00	0,50	0,50	0,75	0,50	0,25	0,25	0,00	0,25	0,00	0,00
A2	0,75		0,25	-0,50	0,50	0,25	0,00	0,00	0,50	0,25	0,25	0,25	0,25	0,00	0,00	0,00	0,00
A3	0,75	0,50		-0,50	0,50	0,50	0,00	0,50	0,50	0,50	0,50	0,25	0,00	0,00	0,25	0,00	0,00
A4	-0,75	-0,25	0,00		0,00	-0,25	0,00	-0,50	-0,25	-0,25	-0,50	0,00	0,00	0,00	-0,25	0,00	0,00
A5	0,75	0,50	0,00	-0,50		0,00	0,00	0,50	0,75	0,50	0,75	0,00	0,50	0,00	0,00	0,00	0,00
A6	0,75	0,50	0,00	0,00	0,00		0,00	0,50	0,50	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00
A7	-0,75	-0,50	0,00	-0,25	-0,75	-0,25		-0,25	-0,75	-0,25	-0,25	-0,25	-0,25	-0,25	-0,25	-0,50	0,00
A8	0,75	0,25	0,00	-0,75	0,25	0,00	0,00		0,25	0,00	0,50	0,50	0,00	0,00	0,00	0,00	0,00
A9	0,75	0,00	0,25	-0,50	0,00	0,00	0,00	0,00		0,25	0,50	0,00	0,00	0,00	0,25	0,00	0,00
A10	0,75	0,25	0,00	-0,75	0,00	0,00	0,00	0,00	0,25		0,25	0,25	0,25	0,25	0,50	0,00	0,00
A11	0,75	0,00	0,00	-0,25	0,25	0,00	0,00	0,00	0,50	0,50		0,00	0,00	0,00	0,25	0,00	0,00
B1	0,75	0,25	0,00	-0,75	0,50	0,00	0,00	0,75	0,50	0,00	0,00		0,00	0,00	0,00	0,00	0,00
B2	0,75	0,00	0,25	-0,25	0,50	0,00	0,00	0,25	0,25	0,50	0,50	0,00		0,00	0,00	0,00	0,00
B3	0,75	0,75	0,25	-0,25	0,50	0,00	0,00	0,25	0,50	0,50	0,50	0,50	0,00		0,25	0,00	0,00
B4	0,75	0,00	0,00	-0,25	0,50	0,25	-0,25	0,50	0,50	0,50	0,50	0,75	0,75	0,50		0,25	0,00
B5	0,75	0,00	0,00	-0,25	0,50	0,00	-0,75	0,00	0,50	0,25	0,50	0,75	0,75	0,50	0,50		0,00
C1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
C2	0,25	0,00	0,00	-0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C3	0,50	0,00	0,25	-0,25	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00
C5	0,25	0,00	0,00	-0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00
C6	0,00	0,00	0,00	-0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C7	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C8	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C9	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
D1	0,25	0,00	0,00	-0,25	0,00	0,00	0,00	0,25	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00
D2	0,25	0,00	0,00	-0,25	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
D3	0,25	0,00	0,00	-0,25	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
D4	0,25	0,00	0,00	-0,25	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
D5	0,25	0,00	0,00	-0,25	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
E1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
E2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
E3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

	C2	C3	C4	C5	C6	C7	C8	C9	D1	D2	D3	D4	D5	E1	E2	E3
A1	0,25	0,50	0,50	0,25	0,25	0,25	0,00	0,00	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
A2	0,00	0,25	0,25	0,50	0,00	0,25	0,25	0,25	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
A3	0,00	0,50	0,25	0,50	0,75	0,50	0,25	0,50	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
A4	0,00	-0,50	-0,75	-0,50	-0,25	-0,25	0,00	-0,25	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75
A5	0,00	0,00	0,25	0,25	0,50	0,00	0,00	0,25	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
A6	0,00	0,50	0,25	0,25	0,00	0,75	0,25	0,00	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
A7	-0,50	-0,50	-0,50	-0,25	-0,50	0,00	-0,25	-0,25	-0,50	-0,50	-0,50	-0,50	-0,50	-0,50	-0,50	-0,50
A8	0,00	0,25	0,00	0,25	0,00	0,00	0,00	0,00	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
A9	0,00	0,25	0,00	0,25	0,00	0,00	0,25	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
A10	0,25	0,50	0,50	0,25	0,25	0,00	0,25	0,50	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
A11	0,00	0,25	0,00	0,25	0,00	0,25	0,00	0,25	0,50	0,25	0,25	0,25	0,25	0,25	0,25	0,50
B1	0,00	0,25	0,25	0,25	0,00	0,00	0,25	0,25	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
B2	0,00	0,25	0,50	0,25	0,00	0,00	0,25	0,25	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
B3	0,00	0,25	0,50	0,50	0,50	0,00	0,00	0,00	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
B4	0,50	0,50	0,50	0,50	0,75	0,50	0,50	0,50	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
B5	0,50	0,50	0,50	0,50	0,75	0,50	0,50	0,50	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
C1	0,25	0,25	0,25	0,50	0,25	0,25	0,50	0,50	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
C2		0,25	0,50	0,50	0,50	0,25	0,25	0,25	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
C3	0,00		0,00	0,25	0,00	0,00	0,00	0,00	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
C4	0,00	0,00		0,25	0,00	0,00	0,00	0,00	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
C5	0,00	0,50	0,00		0,00	0,25	0,00	0,25	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
C6	0,00	0,25	0,00	0,50		0,00	0,00	0,25	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
C7	0,00	0,00	0,00	0,00	0,00		0,25	0,00	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
C8	0,00	0,25	0,00	0,25	0,00	0,00		0,00	0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
C9	0,00	0,25	0,25	0,25	0,00	0,00	0,00		0,75	0,50	0,50	0,50	0,50	0,50	0,50	0,75
D1	0,00	0,00	0,00	0,25	0,00	0,25	0,00	0,00		0,75	0,75	0,75	0,75	0,75	0,75	0,75
D2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50		0,25	0,25	0,25	0,50	0,25	0,25
D3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,50		0,25	0,25	0,50	0,25	0,25
D4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,50	0,50		0,00	0,50	0,25	0,25
D5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,50	0,50	0,50		0,50	0,25	0,25
E1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,25	0,25	0,25	0,25		0,25	0,25
E2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,25	0,00	0,25	0,25	0,25		0,25
E3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,25	0,25	0,25	0,25	0,25	0,00	

innovations. Lack of innovation partnership in industry potential (A4) and lack of governmental support (A7) exhibit very low negative values (see Fig. 5.2).

Scenario 2: **A Hostile Industry Characteristic**
In the second scenario a hostile industry characteristics, where there is thread for new entrance but no innovation partnership in industry and governmental support, is simulated. The factors lack of innovation partnership in industry potential (A4), lack of governmental support (A7), threat of new entrants (A9) are activated and all the other activation levels are set to zero. All the final values of these factors accept lack of innovation partnership in industry potential (A4) and lack of governmental support (A7) decrease in time and converge to −1. Also, the final values for the factor threat of new entrants (A9) converged to −1 (See Fig. 5.2). This shows that, in an industry where neither government nor the partners support are available, both product and process innovations will be negatively affected.

Scenario 3: **Low Capability Level**
In the third scenario a low capability firm, where there is competition but the capabilities of the firm are negatively activated, is simulated. Competition level is positively activated. The initial values for the factors linkages (C2), degree of internationalization (C3), technological R&D capability (C4), financial resource (C5), capability of human resource (C6), employees expectation (C7) and shareholders expectation (C8) are set to −1. The results show that lack of capabilities yields a negative effect on both product and process innovations (See Fig. 5.2).

5.6 Conclusion and Further Suggestions

Innovator firms must not only meet the customer needs, but also keep up with the technological improvements. However, there are some limitations that prevent firms to move freely such as economic constraints and governmental regulations. Under such circumstances, the complexity of innovation environment increases and the related factors should be analyzed to make a decision. The proposed decision model, based on fuzzy cognitive map, is developed to evaluate complex relationships between these factors and their effect on each other in the long run.

This chapter proposes a process, which identifies first the factors influencing the innovation strategy selection process. The determined key factors are assigned into one of the main clusters based on the literature survey. Then, 5 experts, whose working area is management and innovation, fill pairwise relationship matrices and we get adjacency matrix. As a consequence, we come up with the effects of the factors on each other. In order to see the long run effects of different factors, three scenarios are simulated. The results indicate that the innovation process is highly affected by these factors obtained in the literature and they have some certain effects on others based on different scenarios as mentioned in the previous section. The results of our study also implies that, a complex network structure representing

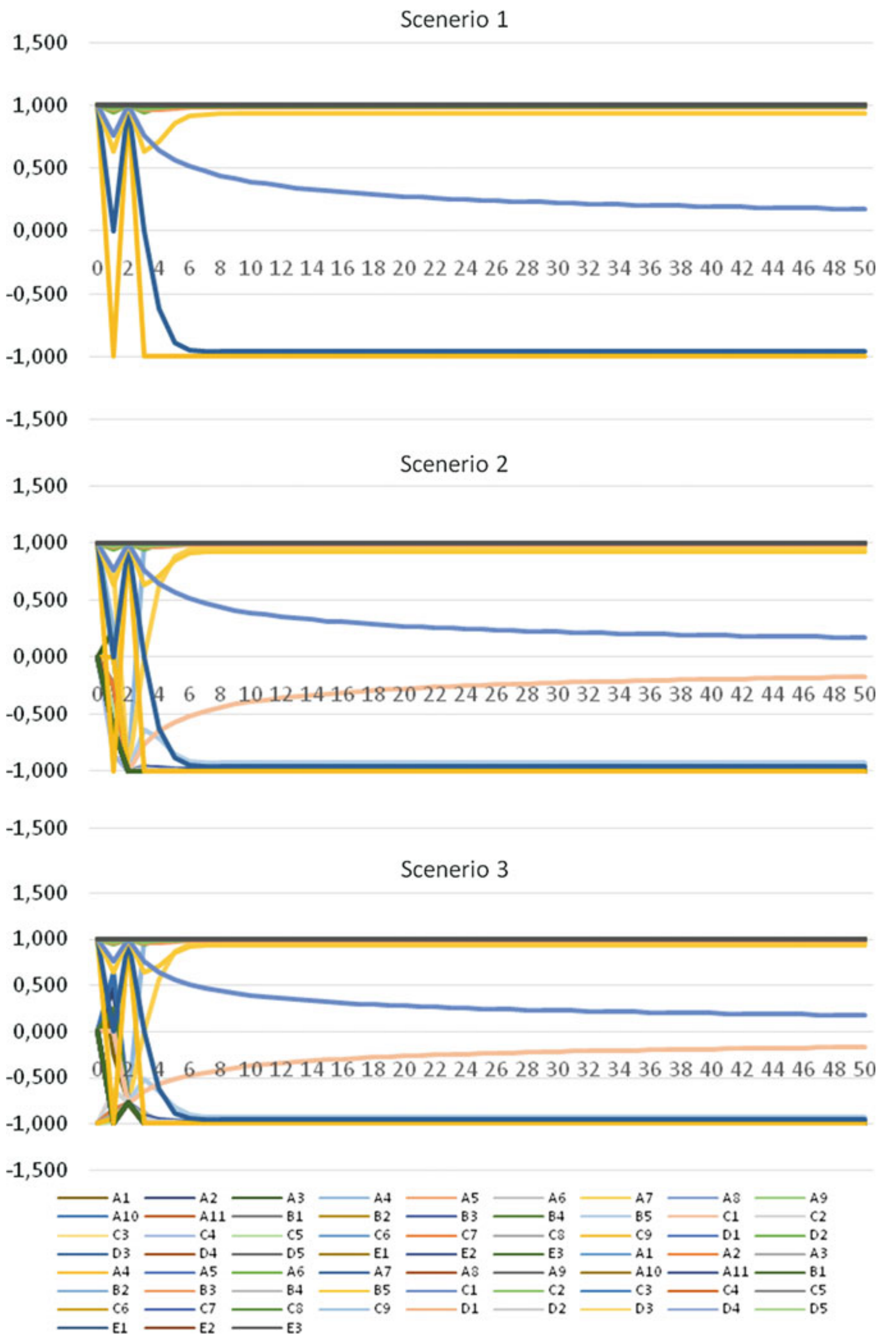

Fig. 5.2 Scenario analyses

strategy evaluation process can be modeled conceptually and let decision makers examine it utilizing FCM approach.

On the other hand, there are some limitations that can be valuable for the future studies. The influence among factors depends on the opinions of a selected group of people. Hence, in order to develop findings and to support them, the number of respondents can be increased or the different group of people can be chosen. Accordingly, the differences between expert groups can be compared. Structuring the fuzzy cognitive map is done towards the experts' idea. However, the system can change over time and some of the key factors can be removed or new factors can be added to the proposed model. In this case, it is available to treat the problem again by the process proposed in this study. For the new cognitive map, new scenarios can be created and examined.

For further suggestions, the use of intelligence tools should be increased to improve decision bases and to foster innovation process in an innovative oriented industry. In order to deploy successful innovations in the white-goods sector, effective knowledge management has been increasingly important; hence intelligent tools such as artificial intelligence, data mining tools and fuzzy expert systems can be applied as a further study in this field. A broader scope research with different experts can be done to compare the results and to see the differences. The system can change over time and some of the key factors can be removed or new factors can be added to the proposed model.

Another research avenue could be using the iterative steps of Analytic Network Process which is a widely applied multi criteria decision making method for complex network problems. As proposed in this study, after identifying the innovation strategy types as well as the related factors based on the literature survey, the relations among these factors can be revealed by the opinions of experts. Then, relative importance of the factors and the priorities of the strategies are assessed based on the pairwise comparison evaluations of the experts.

References

Axelrod, R.: Structure of Decision: The Cognitive Maps of Political Elites. Princeton University Press, Princeton (1976)

Bidault, F., Despres, C., Butler, C.: The drivers of cooperation between buyers and suppliers for product innovation. Res. Policy **26**(78), 719–732 (1998)

Bonanno, G., Haworth, B.: Intensity of competition and the choice between product and process innovation. Int. J. Ind. Organ. **16**(4), 495–510 (1998)

Bowonder, B., Dambal, A., Kumar, S., Shirodkar, A.: Innovation strategies for creating competitive advantage. Res. Technol. Manage. **53**(3), 19–32 (2010)

Burgelman, R.A., Christensen, C.M., Wheelwright, S.C., Maidique, M.A.: Strategic Management of Technology and Innovation. McGraw Hill Higher Education, New York (2003)

Busom, I., Fernndez-Ribas, A.: The impact of firm participation in R&D programmes on R&D partnerships. Res. Policy **37**(2), 240–257 (2008)

Caetano, M., Amaral, D.C.: Roadmapping for technology push and partnership: a contribution for open innovation environments. Technovation **31**(7), 320–335 (2011)

Camisón, C., Villar-López, A.: Organizational innovation as an enabler of technological innovation capabilities and firm performance. J. Bus. Res. **67**(1), 2891–2902 (2014)
Carbonell, P., Rodriguez, A.I.: The impact of market characteristics and innovation speed on perceptions of positional advantage and new product performance. Int. J. Res. Mark. **23**(1), 1–12 (2006)
Carvalho, J.P., Tomé, J.A.B.: Rule based fuzzy cognitive maps and fuzzy cognitive maps—a comparative study. In: Proceedings of the 18th International Conference of the North American Fuzzy Information Processing Society, NAFIPS99, New York, USA (1999)
Cevik Onar, S., Oztaysi, B., Kahraman, C.: Strategic decision selection using hesitant fuzzy TOPSIS and interval type-2 fuzzy AHP: a case study. Int. J. Comput. Intell. Syst. **7**(5), 1002–1021 (2014)
Cheng, C.-F., Lai, M.-K., Wu, W.-Y.: Exploring the impact of innovation strategy on R&D employees job satisfaction: a mathematical model and empirical research. Technovation **30** (78), 459–470 (2010)
Clercq, D.D., Menguc, B., Auh, S.: Unpacking the relationship between an innovation strategy and firm performance: the role of task conflict and political activity. J. Bus. Res. **62**(11), 1046–1053 (2009)
Cooper, R.G., Edgett, S.J.: Developing a product innovation and technology strategy for your business. Res. Technol. Manage. **53**(3), 33–40 (2010)
Coriat, B., Weinstein, O.: Organizations, firms and institutions in the generation of innovation. Res. Policy **31**(2), 273–290 (2002)
Daft, R.: Bureaucratic versus nonbureaucratic structure and the process of innovation and change. Res. Sociol. Organ. **1**(3), 129–166 (1982)
Damanpour, F.: Organizational size and innovation. Organ. Stud. **13**(3), 375–402 (1992)
Damanpour, F., Evan, W.M.: Organizational innovation and performance: the problem of organizational lag. Adm. Sci. Q. **29**(3), 392–409 (1984)
Damanpour, F., Szabat, K.A., Evan, W.M.: The relationship between types of innovation and organizational performance. J. Manage. Stud. **26**(6), 587–601 (1989)
Drucker, P.: Innovate or Die: drucker on financial services. The Economist (1999)
Evangelista, R., Vezzani, A.: The economic impact of technological and organizational innovations: a firm-level analysis. Res. Policy **39**(10), 1253–1263 (2010)
Eden, C.: Messing About in Problems. Pergamon Press, Oxford (1988)
Eden, C.: On the nature of cognitive maps. J. Manage. Stud. **29**, 261–265 (1992)
Freeman, C., Soete, L.: The Economics of Industrial Innovation. The MIT Press Edition, Cambridge (1997)
Galende, J., De la Fuente, J.: Internal factors determining a firm's innovative behaviour. Res. Policy **32**(5), 715–736 (2003)
Goedhuys, M., Veugelers, R.: Innovation strategies, process and product innovations and growth: firm-level evidence from Brazil. Struct. Change Econ. Dyn. **23**(4), 516–529 (2012)
Gopalakrishnan, S., Bierly, P., Kessler, E.H.: A re-examination of product and process innovations using a knowledge-based view. J. High Technol. Manage. Res. **10**(1), 147–166 (1999)
Guan, J.C., Yam, R.C., Tang, E.P., Lau, A.K.: Innovation strategy and performance during economic transition: evidences in Beijing. China Res. Policy **38**(5), 802–812 (2009)
Gunday, G., Ulusoy, G., Kilic, K., Alpkan, L.: Effects of innovation types on firm performance. Int. J. Prod. Econ. **133**(2), 662–676 (2011)
Gupta, A.K., Raj, S.P., Wilemon, D.: A model for studying R&D. marketing interface in the product innovation process. J. Mark. **50**(2), 7–17 (1986)
Hall, J., Matos, S., Silvestre, B., Martin, M.: Managing technological and social uncertainties of innovation: the evolution of Brazilian energy and agriculture. Technol. Forecast. Soc. Change **78**(7), 1147–1157 (2011)
Hall, J.K., Martin, M.J.C.: Disruptive technologies, stakeholders and the innovation value-added chain: a framework for evaluating radical technology development. R&D Manage. **35**(3), 273–284 (2005)

Hanvanich, S., Richards, M., Miller, S.R., Cavusgil, S.T.: Technology and the effects of cultural differences and task relatedness: a study of shareholder value creation in domestic and international joint ventures. Int. Bus. Rev. **14**(4), 397–414 (2005)

Hurley, R.F., Hult, G.T.M.: Innovation, market orientation, and organizational learning: An integration and empirical examination. J. Mark. **62**(3), 42–54 (1998)

Jiménez-Jimnez, D., Sanz-Valle, R.: Innovation, organizational learning, and performance. J. Bus. Res. **64**(4), 408–417 (2011)

Johnsen, T.E.: Supplier involvement in new product development and innovation: taking stock and looking to the future. J. Purch. Supply Manage. **15**(3), 187–197 (2009)

Kosko, B.: Fuzzy cognitive maps. Int. J. Man Mach. Stud. **24**, 65–75 (1986)

Liao, S.-H., Fei, W.-C., Liu, C.-T.: Relationships between knowledge inertia, organizational learning and organization innovation. Technovation **28**(4), 183–195 (2008)

Maine, E., Lubik, S., Garnsey, E.: Process-based vs. product-based innovation: value creation by nanotech ventures. Technovation **32**(3–4), 179–192 (2012)

Martínez-Román, J.A., Gamero, J., Tamayo, J.A.: Analysis of innovation in SMEs using an innovative capability-based non-linear model: a study in the province of Seville (Spain). Technovation **31**(9), 459–475 (2011)

Mol, M.J., Birkinshaw, J.: The sources of management innovation: when firms introduce new management practices. J. Bus. Res. **62**(12), 1269–1280 (2009)

Moon, M.J., Bretschneider, S.: Can state government actions affect innovation and its diffusion? An extended communication model and empirical test. Technol. Forecast. Soc. Change **54**(1), 57–77 (1997)

O'Cass, A., Sok, P.: Exploring innovation driven value creation in B2B service firms: the roles of the manager, employees, and customers in value creation. J. Bus. Res. **66**(8), 1074–1084 (2013)

OECD: Oslo Manual: Proposed guidelines for collecting and interpreting technological innovation data. OECD Oslo Manuel (2005)

Ortt, J.R., van der Duin, P.A.: The evolution of innovation management towards contextual innovation. Eur. J. Innov. Manage. **11**, 522–538 (2008)

Papakostas, G.A., Boutalis, Y.S., Koulouriotis, D.E., Mertzios, B.G.: Fuzzy cognitive maps for pattern recognition applications. Int. J. Pattern Recogn. Artif. Intell. **22**, 1461–1486 (2008)

Papageorgioua, E.I., Stylios, C.D., Groumpos, P.P.: Unsupervised learning techniques for fine-tuning fuzzy cognitive map causal links. Int. J. Hum. Comput. Stud. **64**, 727–743 (2006)

Peeters, C., van Pottelsberghe de la Potterie, B.: Innovation strategy and the patenting behavior of firms. J. Evol. Econ. **16**, 109–135 (2006)

Peña, A., Sossa, H., Gutiérrez, A.: Cognitive maps: an overview and their application for student modeling. Computación y Sistemas **10**(3), 230–250 (2007)

Porter, M.E.: Technology and competitive advantage. J. Bus. Strat. **5**(3), 60–78 (1985)

Raymond, L., St-Pierre, J.: R&D as a determinant of innovation in manufacturing SMEs: an attempt at empirical clarification. Technovation **30**(1), 48–56 (2010)

Roberts, F.S.: The questionnaire method. In: Axelrod, R. (ed.) Structure of Decision: The Cognitive Maps of Political Elites, pp. 333–342. Princeton University Press, Princeton (1976)

Roberts, P.W., Amit, R.: The dynamics of innovative activity and competitive advantage: the case of Australian retail banking, 1981 to 1995. Organ. Sci. **14**(2), 107–122 (2003)

Robin, S., Schubert, T.: Cooperation with public research institutions and success in innovation: evidence from France and Germany. Res. Policy **42**(1), 149–166 (2012)

Romijn, H., Albaladejo, M.: Determinants of innovation capability in small electronics and software firms in southeast England. Res. Policy **31**(7), 1053–1067 (2002)

Rothwell, R.: Towards the fifth-generation innovation process. Int. Mark. Rev. **11**(1), 7–31 (1994)

Sadikoglu, E., Zehir, C.: Investigating the effects of innovation and employee performance on the relationship between total quality management practices and firm performance: an empirical study of Turkish firms. Int. J. Prod. Econ. **127**(1), 13–26 (2010)

Sainio, L.-M., Ritala, P., Hurmelinna-Laukkanen, P.: Constituents of radical innovation exploring the role of strategic orientations and market uncertainty. Technovation **32**(11), 591–599 (2012)

Schubert, T.: Marketing and organisational innovations in entrepreneurial innovation processes and their relation to market structure and firm characteristics. Res. Policy **36**(2), 189–212 (2010)

Shayne Gary, M.: Implementation strategy and performance outcomes in related diversification. Strateg. Manage. J. **26**(7), 643–664 (2005)

Souitaris, V.: Technological trajectories as moderators of firm-level determinants of innovation. Res. Policy **31**(6), 877–898 (2002)

Srinivas, V., Shekar, B.: Applications of uncertainty-based mental models in organizational learning: a case study in the Indian automobile industry. Account. Manage. Inf. Technol. **7**(2), 87–112 (1997)

Tang, J.: Competition and innovation behaviour. Res. Policy **35**(1), 68–82 (2006)

Tolman, E.C.: Cognitive maps in rats and men. Psychol. Rev. **55**(4), 189–208 (1948)

Tsadiras, A.K.: Inference using binary, trivalent and sigmoid fuzzy cognitive maps. In: Proceedings of the 10th International Conference on Engineering Applications of Neural Networks, Thessaloniki, Greece (2007)

Tseng, C.-Y., Wu, L.-Y.: Innovation quality in the automobile industry: measurement indicators and performance implications. Int. J. Technol. Manage. **37**(1), 162–177 (2006)

Ulusoy, G.: An assessment of supply chain and innovation management practices in the manufacturing industries in Turkey. Int. J. Prod. Econ. **86**(3), 251–270 (2003)

Veugelers, R., Cassiman, B.: Make and buy in innovation strategies: evidence from Belgian manufacturing firms. Res. Policy **28**(1), 63–80 (1999)

Wang, C.-H., Lu, I.-Y., Chen, C.-B.: Evaluating firm technological innovation capability under uncertainty. Technovation **28**(6), 349–363 (2008)

Weerawardena, J., O'Cass, A., Julian, C.: Does industry matter? Examining the role of industry structure and organizational learning in innovation and brand performance. J. Bus. Res. **59**(1), 37–45 (2006)

Werker, C.: Innovation, market performance, and competition: lessons from a product life cycle model. Technovation **23**(4), 281–290 (2003)

Wonglimpiyarat, J.: Government programmes in financing innovations: comparative innovation system cases of Malaysia and Thailand. Technol. Soc. **33**(12), 156–164 (2011)

Wonglimpiyarat, J.: Technology strategies and standard competition—comparative innovation cases of Apple and Microsoft. J. High Technol. Manage. Res. **23**(2), 90–102 (2012)

Wu, J.: Technological collaboration in product innovation: the role of market competition and sectoral technological intensity. Res. Policy **41**(2), 489–496 (2012)

Yam, R.C., Lo, W., Tang, E.P., Lau, A.K.: Analysis of sources of innovation, technological innovation capabilities, and performance: an empirical study of Hong Kong manufacturing industries. Res. Policy **40**(3), 391–402 (2011)

Yaman, D., Polat, S.: A fuzzy cognitive map approach for effect-based operations: an illustrative case. Inf. Sci. **179**, 382–403 (2008)

Chapter 6
Knowledge Management: Intelligent In-pipe Inspection Robot Conceptual Design for Pipeline Infrastructure Management

Bo Xing

Abstract Pipeline distribution and production are primary methods of transporting oil, natural gas, chemicals, and water. However, prolonged exposure to natural weather may cause corrosion, crack, and leakage to the pipelines. Therefore, periodical inspection is considered uttermost important. As most mechanised inspection techniques (e.g., non-destructive testing) are only deal with external inspect, they cannot accurately detect significant corrosion or other of defects in the internal. In addition, the inspection tasks can only be applied manually by highly trained operators. Given these circumstances, various concepts of pipeline inspection robots are developed in recent years to enhance the whole maintenance excellence. In this chapter, a multi-agent system (MAS) approach assisted intelligent conceptual design (ICD) platform is adopted for miniature in-pipe inspection robot design synthesizing. The demo case study shows that the proposed MAS-ICD can outperform human designers in many perspectives.

Keywords Pipeline · In-pipe inspection · Miniature robot · Bio-inspired design · Multi-agent system (MAS) · Intelligent conceptual design (ICD) · Principle solution (PS) · Knowledge system

6.1 Introduction

The earliest known pipelines were constructed by the Chinese in 900 BC from bamboo to carry water from the nearby stream back to his or her dwelling. Since then, the term 'pipe' was born and different functional pipelines have been

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manufactured. For example, the first crude oil pipeline in the United States was built in 1859; the first high-pressure, long-distance (i.e., 200 km) pipeline that between Chicago and fields in Indiana was constructed in 1891; and the first gas main was manufactured in Russia in 1946. Also, in modern life, pipelines has far-reaching impacts for citizens, businesses, and industries, since they are broadly used to move life-necessities (e.g., drinking water) and to take way life waste (e.g., sewage). Of course, pipeline system design should safe and reliable. However, no pipeline can be designed in such a way that it would never fail. In fact, they are subject to many troubles which include external interference, corrosion (internal and external), incorrect operations, and weather related. As a consequence, the routine inspection and proactive maintenance of the pipelines turns out to be an essential activity.

Traditionally, the inspection and maintenance activities are carried out by human beings based on maintenance plans and condition monitoring techniques, which means they are conducted only according to the ages or duties of pipelines. In addition, the inspection tools used are dominated by rather simple cable-based video technology which can not sufficiently comply with the qualified inspection demands. The authors of Cordes et al. (1997) claimed that the bottlenecks of these inspection systems are the use of a wire and the limitation of the range of operation. Furthermore, the human errors that occur during inspection and maintenance tasks could also lead to a high risk of accident (Heo and Park 2010).

In recent years, a growing interest exists for developing robots for pipe inspection and maintenance. In Schmidt and Berns (2013), the authors reviewed a large number of different climbing robots for maintenance and inspections of vertical structures, in the meantime, they pointed out a set of requirements that should be considered. In a similar vein, the authors of Qi et al. (2009) also highlighted several major requirements for applying robotic system in inspecting pipelines. Typically, the inspection robots have self-contained sensor logging capabilities with complimentary battery power source (Lee et al. 2009). In addition, they are capable to adapt with a reasonable range of curvature, the structure's material, and thickness. As a result, the applications of robots are considered as a new technical means.

As we know, the most critical step in any product development is the conceptual design. It is generally accepted that up to 85 % of the lifecycle costs of a product are determined during the conceptual design, while at this stage only about 5 % of the lifecycle costs has been spent (Bonnema and van Houten 2006). Generally speaking, conceptual design is the process by which the design is initiated with specifications or constrains, carried to the point of creating a number of possible solutions, and narrowed down to a single best concept (Dieter and Schmidt 2013). Due to its complexity, different methods have been implemented to get good solution. In Chandrasegaran et al. (2013), Al-Ashaab et al. (2012), Fu et al. (2006), the authors reviewed the product design process from a knowledge capture and representation perspective. Others focused on affordance-based design methods

(Fuente et al. 2014; Chen et al. 2013), graph-based methods (Paramasivam and Senthil 2009), bio-inspired approaches (Wilson 2008), and computational algorithms (Kang and Tang 2013; Huang et al. 2013). Furthermore, to provide a case study of a design process and the rational for the design decisions, a multi-agent based design architecture has been widely employed (Cao et al. 2008). In this chapter, we proposed a new framework called MAS-ICD, which is based on multi-agent system (MAS) approach under an appropriate functional knowledge representation (FKR) scheme, to help conceptual designers making decisions.

The remainder of this chapter is organized as follows. Subsequent to the introduction in Sect. 6.1, the background this study is outlined in Sect. 6.2. Then, the encountered challenges are presented in Sect. 6.3. The detailed description of the proposed methodology, and an explanation of how to physically implement it can be found in Sects. 6.4 and 6.5, respectively. Next, Sect. 6.6 conducts an experimental case study to demonstrate the feasibility of our proposed approach. Finally, the conclusions drawn in Sect. 6.7 close this study.

6.2 Background

Pipeline inspection is the cornerstone of many industrial and engineering systems. The main objective is to maximize throughput and prolong the life of a pipeline system while ensuring public safety and respecting the environment. In general, design of pipeline involves selection of pipeline diameter, thickness, and material to be used (Guo et al. 2014). The early methods of inspection involved acoustic technique, AE technique, thermography technique, vibration technique, and high frequency ultrasound technique. However, those techniques are highly expensive and mainly focused on detecting external cracks and defects. In addition, the accuracy and efficiency of most inspection activities are greatly dependent upon the experience of the operators. Furthermore, some pipeline systems are deployed in an inaccessible and hazardous environment. As a result, some authors [e.g., (Prasad et al. 2012; Sheng et al. 2008; Granosik et al. 2005)] pointed out that implementing automated robots to monitor the inside of the pipes and channels are considered as one of the most attractive solutions.

Nowadays, research and development on the in-pipe inspection robot systems has been actively carried out based on different designs and are used in various domains. For example, the authors of Jin et al. (2004) developed inspection robots for detecting defects inside the pipeline. Roh and Choi (2005) proposed several prototypes of in-pipe robots that to pass through sharp curves inside underground pipelines. An inchworm-like micro robot for pipe inspection has been invented in Lim et al. (2008) and Sabzehmeidani et al. (2010). In Kwon et al. (2007), a foldable inspection robot has been manufactured. A fully autonomous sewer robot called MAKRO has been designed and built by a German group of two research institutes and two industrial partners (Rome et al. 1999). Other examples about in-pipe robot please refer to Kang et al. (2013), Liu et al. (2013), Miyagawa et al. (2007), Oya and Okada (2005), Ong et al. (2003), Moghaddam et al. (2011), Zhang and Yan (2007), Choi and Roh (2007), Lee et al. (2012), Tur and Garthwaite (2010), Horodinca et al. (2002), Jun et al. (2004), Qi et al. (2010), Roslin et al. (2012).

In addition, multi-robot systems (or swarm robotics) can be a competitive alternative to a single robot solution, as they offer a higher level of robustness due to redundancy and the potential for individual simplicity. In 2000, researcher Marco Dorigo began the studies on swarm robotics called "Swarm-Bots" (Mondada et al. 2005; Trianni et al. 2006; Dorigo et al. 2004; Mondada at al. 2005; Mondada et al. 2004; Dorigo et al. 2006). Since then this topic came into a new period of development. This is also confirmed by a recent published study (Tan and Zheng online) which provided a comprehensive review of the existing literature about swarm robotics. Furthermore, as cloud computing became more and more popular, moving robot related projects into the cloud environment (i.e., cloud robotics) is on the way (Kamei et al. 2012; Goldberg et al. 2013; Tian et al. 2014; Pagallo 2013; Guizzo 2011; Waibel et al. 2011).

To summarize, there are three significant reasons to adopt the intelligent robots for inspection activities (Xu et al. 2011): first, there is little doubt that the primary motivation for introducing robots is economic; second, it is liked with operational efficiency and product quality; third, it replaces the human workers in carrying out risky tasks in a hazardous environment.

6.3 The Challenges Faced by In-pipe Inspection Robot Conceptual Design

In practice, for a set of desired functions possed by an artefact, a collection of suitable principle solutions (or PSs for short) that fulfill such requirement will be generated via conceptual design. Here, a PS referrs to the fundamental functioning mechanism of a system that can offer a desired functionality. Ideally, designers should explore a wide range of interdisciplinary knowledge space for finding novel and suitable PSs. Nevertheless, the traditional model of education is a mono-disciplinary-based system which assumes that graduates will work as specialists only in pre-chosen areas. As a result, a human designer often identifies strongly with his/her own specialized field and is usually very ignorant (if not too dismissive) of other disciplines. Consequently, when facing to join a multi-functional team for developing complicated man-made systems, traditionally uni-discipline trained desingers often feel ill-prepared (if not incompetent). Therefore, the key challenge confront us is how to increase the efficacy of a conceptual design by referring a knowledge pool composed of multi-discipline information.

6.4 Proposed Methodology

Having the abovementioned study motivation and encountered challenges in mind, there is an urgent need of an intelligent conceptual design platform which can be used to meet the product development requirement. When it comes to in-pipe inspection robot design, due to the fact that the integrated control system, locomotion mechanisms, actuators, and suction structures are inevitably complex, it is necessary for designer to have an intelligent assistant conceptual design platform. In light of this requirement, in this work, we attempt to introduce a synthesis conceptual design methodology, namely, MAS-ICD, which is based on multi-agent system (MAS) approach under an appropriate functional knowledge representation (FKR) scheme.

6.4.1 How to Represent Functional Knowledge?

Prior to the introduction to our MAS-ICD approach, a fundamental functional knowledge representation (FKR) scheme must be established first. In line with previous literature, “function” here is mainly used to stand for a general relationship between a system’s input and output (Haik and Stamford 2011). For the rest part of this sub-section, the employed FKR scheme will be deliberated.

Similar to most existing studies, our FKR scheme also built on a philosophy concept, i.e., a flow transformation, and thus, a crucial issue is how knowledge flows in various disciplines can be represented via a general model. In our FKR scheme, the knowledge flow representation model consists of two stages, namely, a flow_name representation stage, and an attribute_value representation stage. To avoid vagueness, in flow_name representation stage, a standard and taxonomy-based physical variable name is used to denote a flow. For instance, a physical variable name “*angular_velocity*” can be used to denote the corresponding “*rotation*” knowledge flow. Meanwhile, an attribute_value representation stage is also introduced to further depict a knowledge flow’s detailed features. Due to the fact that discipline dependent knowledge may generate similar flows but each carries a different detailed feature set, the introduction of attribute_value representation mechanism can thus offer domain experts a freedom of allocating distinct sets of attributes and qualitative values to separate types of flows.

It is commonly accepted that providing a domain independent method for representing the known PSs’ functional knowledge is difficult, if not impossible. The reason behind this lies in that PSs in separate subjects may deal with distinct types of transformations. To address this issue, a four-part integrated FKR scheme is employed in this study which comprises the following elements:

- input/output_flow_name_pair,
- input_flow_attribute_constraints,

- output_flow_attribute_constraints, and
- flow_attributes_association_rules.

6.4.1.1 Input/Output_Flow_Name_Pair

The input/output_flow_name_pair, denoted by (In_F, Out_F), is used to stand for a flow_name's transformation from input to output generated by a known PS, where In_F and Out_F denote the input_flow_name and output_flow_name, respectively.

6.4.1.2 Input_Flow_Attribute_Constraints

The input_flow_attribute_constraints of a PS pose a restriction on what values of an input flow's attributes could have and these constraints can then be used by MAS-ICD as a benchmark for determining whether or not a PS matches an input flow during the process of design synthesizing. For instance, in our robot conceptual design scenario, if a DC motor (powered by direct current) is decided to be used, then the "*type*" attribute of its input electrical current flow should have a value of "DC", which means if an electrical current flow's "*type*" attribute carries an "AC (i.e., alternating current)" value, the PS would not match this particular input flow.

6.4.1.3 Output_Flow_Attribute_Constraints

Similarly, the output_flow_attribute_constraints denotes values of an output flow's attributes could have. Such constraints are helpful in selecting the possible values of a certain output flow's attributes during the process of design synthesizing.

6.4.1.4 Flow_Attributes_Association_Rules

In this study, a known PS's associated flow_attributes_association_rules is employed to denote the correlations between the attribute values of an input flow's and an output flow's. The advantage of using flow_attributes_association_rules representation lies in that it make it possible for domain experts to input complex correlated rules into the knowledge pool based on their past experiences.

6.4.2 What Is Multi-agent System Approach?

An MAS is an approach that uses different autonomous software agents to complete some specific goals (Xing et al. 2014; Russell et al. 2010). In an MAS system, the interaction between agents is dependent on situations. For example, agents can work collaboratively for reaching a common goal, while they may individually behave competitively if the sub-goals of each agent are conflicting.

6.4.3 How Does MAS-ICD Work?

In this chapter, a multi-agent system based intelligent conceptual design (MAS-ICD) framework, which aims at parallel computing for synthesizing conceptual design, has been developed. Figure 6.1 illustrates the structure of the proposed MAS-ICD.

As shown in Fig. 6.1, MAS-ICD mainly consists of the following two sub-components:

- PS knowledge management component which is composed of an agent whose responsibility is knowledge management; and
- Conceptual design synthesis component which is composed of a task management agent, a group of exploring-filtering-exploiting (EFE for short) agents, and several backtracking agents.

6.4.3.1 A Breakdown of MAS-ICD

Since each agent type plays a different role in the proposed MAS-ICD framework, a detailed description is introduced as below:

- Knowledge management agent (KMA): The KMA agent has two main responsibilities, i.e., modelling PS knowledge as a domain expert, and allocating PSs to distinct sub-knowledge categories. The allocated PS(s) will then be utilized by separate EFE agent. When a PS is being allocated to a targeted

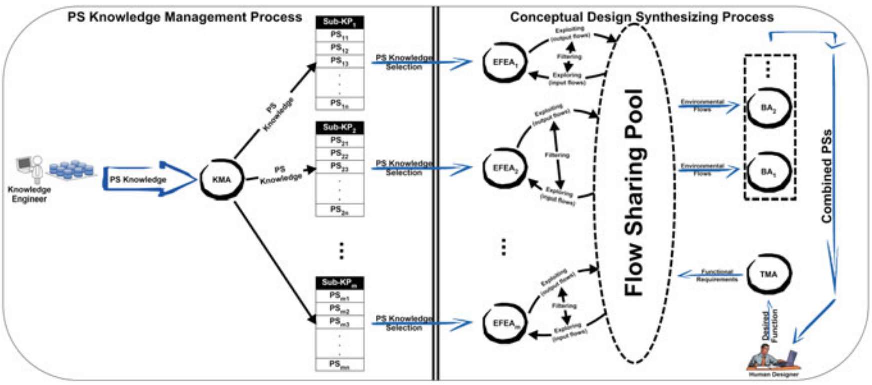

Fig. 6.1 The abstract sturcture of MAS-ICD

sub-knowledge category, the following two factors will be considered by KMA agent: First, avoiding assigning PSs (with high degree of function similarities) to the same sub-knowledge category. The benefit of this mechanism lies in that each of these PSs can be parallel utilized by various EFEA agent during the process of conceptual design synthesizing. Second, balancing the total number of PSs in the meantime under each sub-knowledge category.

- Task management agent (TMA): In the proposed MAS-ICD, the TMA also plays multiple roles. Once a designer expresses an interest of achieving a desired function, the subsequent functional requirements imposed by such function will be interpreted as some initial input flows, which will be then release into the Flow Share Pool (FSP). The purpose of FSP is to store various flows as a data sharing repository. In addition to this, i.e., translating requests into different flows, TMA also takes in charge of activating EFE and BA agents. Apart from these tasks, TMA also continuously monitors the whole process of design synthesizing to prevent some extreme events.
- Exploring-filtering-exploiting agent (EFEA): In MAS-ICD, EFEA agents play a key role in achieving parallel conceptual design synthesizing process. Each EFEA is responsible for a sub-knowledge pool (sub-KP) which contains a set of PSs, and it will independently perform EFE mechanism in scenario dependent ways, e.g., exhaustive, or good-enough, etc. Typically, an EFEA will first inquire the FSP about acquiring a bunch of previously unvisited flows during the design synthesizing process. As soon as this is done, EFEA will work on them via EFE strategy. The output flows generated from this process will then be released back into the FSP for screening by other specialized EFEA agents. As with this continuously circulated EFE cycle, a parallel high efficient conceptual design synthesizing process can thus be achieved.
- Backtracking agent (BA): In this study, the following two responsibilities are assigned to BA: checking fitness degree, and following-up design trace. By fitness degree, we are looking at if the functional requirement(s) of an input flow in FSP could match the output flow's functional availability; while for the second role, when a suitable environmental flow in FSP is identified, BA agent will track the design EFE path back to its origin for forming combined PSs.

6.4.3.2 Agents' Cooperation Mechanism

MAS-ICD consists of four types of agents, i.e., KMA, TMA, EFEA, and BA. As we can see that KMA mainly works solely on managing PSs in the sub-knowledge categories, and thus it seldom interacts with other types of agents. In other words, the cooperation mechanism primarily exists between TMA, EFEA, and BA.

After a desired function is described by a designer, the activation of TMA agent will be performed and after which a set of initial input flows will be established. In this study, we will flexibly treat a desired function as a series of constraints imposed on input and output flows, respectively. Having this in mind, the FSP (several initial input flows will be released into it by TMA) can be conceptualized as tuple in the following form:

$$FSP ::= \left\langle Flow, \left(Agent_{origin}, PS_{origin}\right), \{Agent_{EEFA}\}, i_{depth}, backtracked_B \right\rangle \quad (6.1)$$

where *Flow* represents a flow exiting in FSP; the combination, $\left(Agent_{origin}, PS_{origin}\right)$, stands for both the original EFEA agent and PS of a flow (in align with that an EFEA works on a PS to generate a flow); a set of EFEA that have worked on various flows by following an EFE strategy (in accordance with our previous definition, i.e., different EFEA agents can explore separate environmental flows) is denoted by $\{Agent_{EEFA}\}$; a search depth of a flow is indicated by factor $i_{depth}(i = 0, 1, \ldots, n)$; and $backtracked_B$ uses a Boolean value to express whether a BA has performed its duty.

As we know, each EFEA agent generally collects a bunch of environmental flows (previously unvisited) from FSP. Here a private flow pool (PFP) is introduced for each individual EFEA agent to keep its collected flows. In this study, PFP is conceptualized as a triple in the following form:

$$PFP ::= \left\langle Flow_{out}, Flow_{in}, PS_{working} \right\rangle \quad (6.2)$$

where $Flow_{out}$ and $Flow_{in}$ denote the generated output flow and the collected local input flow, respectively; and $PS_{working}$ stands for a working PS that facilitate the flow transformation from input to output. When an output flow was released by an EFEA to FSP for a further exploration and exploitation, not only its birth information will be embedded in the flow itself, but also an identification tag (from an EFEA agent who has processed it) will be added on.

In the meantime of EFEA agent being activated, the BA will also be put into action. As we mentioned earlier, each BA will work simultaneously and independently on a flow obtained from FSP to check its usability. If a desired flow is identified, it will track such flow's predecessors and the correlated PSs via the implanted information. Through this iterative process, a combined PS can thus be form. When a flow has been backtracked, the value of $backtracked_B$ will be subsequently set as true.

6.4.4 Why Employing MAS-ICD for Conceptual Design?

An old style of intelligent conceptual design (abbreviated as OLD-ICD) process typically works as follows: As soon as a desired function is inputted by designer, OLD-ICD will create a set of all possible input flows which are then released to its surrounding environment. Then OLD-ICD begins to explore the knowledge flows in its environment and filter the flows that have been previously visited. Right after this, OLD-ICD will examine its PS knowledge pool for all candidate PSs (subject to some pre-obtained knowledge sets) that can work on this particular flow. For each exploitable PS, OLD-ICD will then apply its action knowledge to the targeted environmental flow with a result of generating some output flows. Such output flows will again be injected into OLD-ICD's environment as new input flows waiting for a further conceptual design synthesizing. This process will be repeated until stopping criteria are met, e.g., all flows in the environment have been explored, a predetermined search depth is reached, etc. Once this process is stopped, all flows found in the environment will be examined to check their suitability satisfying the functional requirements on the output flow.

Compared with the OLD-ICD, MAS-ICD enjoys some advantages compared with other approaches found in the literature: First, the entire conceptual design synthesizing process is a parallel procedure, which means that the multiple subprocesses are executed in a parallel instead of sequential manner. Second, each time MAS-ICD can absorb more than one environmental flow for design exploration, which means that the to-be-explored flow queue will be kept in a reasonable size. Third, MAS-ICD can thus apply more than one PS to each environmental flow, which means that the stored PSs in the knowledge pool can be cross-referenced more efficiently. Last but not the least, MAS-ICD can follow up more than one environmental flow for creating a combined PS.

6.5 MAS-ICD Implementation

In this study, the proposed MAS-ICD platform is implemented in an environment supported by techniques such as Microsoft ASP.NET, Microsoft Windows Communications Foundation (WCF) and Microsoft SQL Server Database. A brief introduction regarding the MAS-ICD implementation and some preliminary implementing results are provided as below.

6.5.1 System Architecture of MAS-ICD

The physical structure of our MAS-ICD platform is depicted in Fig. 6.2. Human designers (e.g., domain experts, design veterans/novices, etc.) can interact with the MAS-ICD platform via Internet browsers. The Web server offers some necessary graphic user interfaces (GUIs) for facilitating such interactions, e.g., displaying design synthesizing results to inquiry designers when it is ready. Users' inputs is normally stored on a Web server which can later be approached by various designing agents. The participating agents in our platform are designed as WCF services. They can be activated upon requests, and the cooperation between each agent is facilitated via our lab intranet environment.

Initially, seed PSs are put into the knowledge pool by domain experts. The later on revisiting, modifying, and updating of these PSs are done through an intermediary, i.e., KMA. Since KMA is equipped with enough necessary information (both locally and globally), it can thus assign each PS to a suitable sub-knowledge

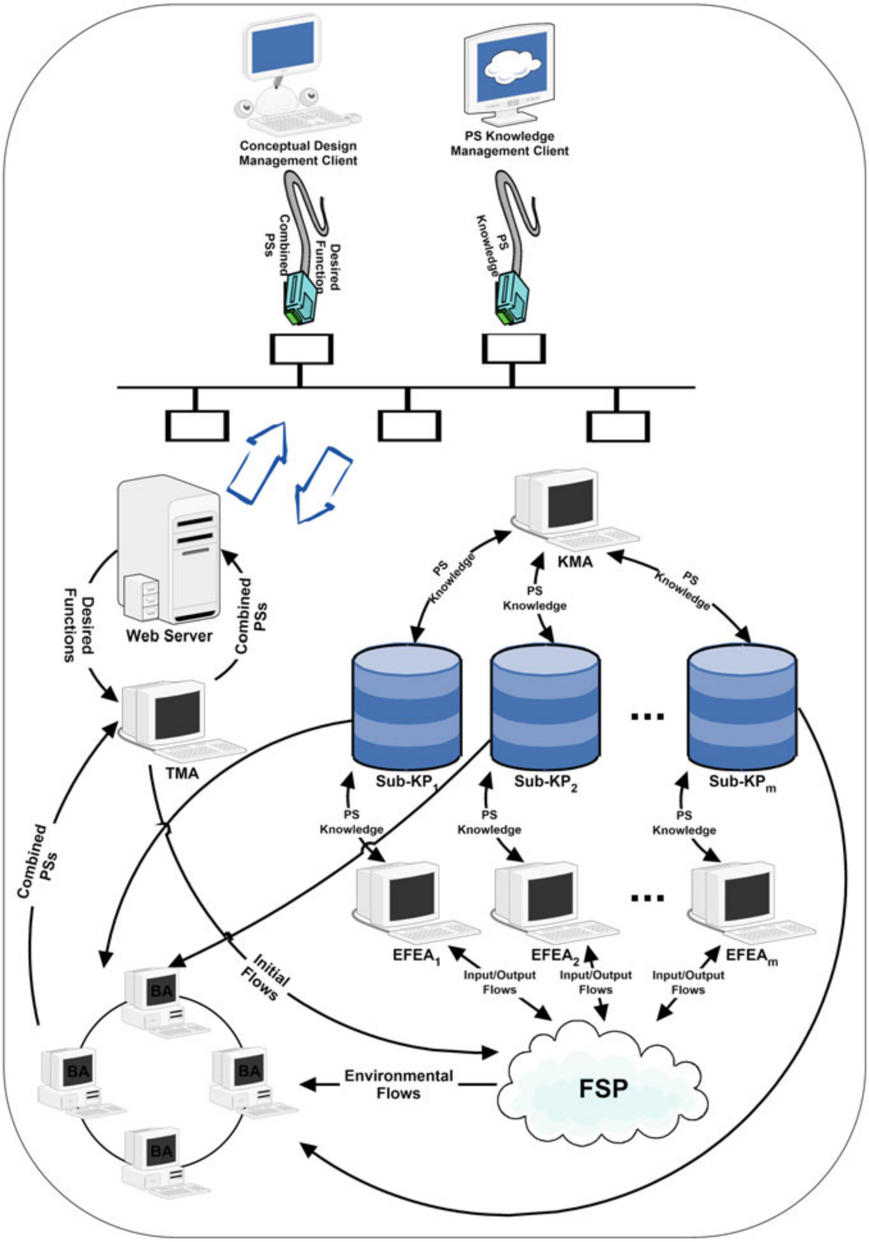

Fig. 6.2 The physical structure of MAS-ICD

category. As soon as an inquiry about a desired function appears on Web server, TMA agent will be triggered to acquire the corresponding functional requirements. TMA agent will then create a set of input flows and send them to the FSP.

Normally, TMA agent has the necessary information (e.g., IP address, service identification/port, etc.) and is located in the central server for the purpose of controlling other participating agents (e.g., EFEA and BA).

In a similar manner, EFEA agents, implemented as various pieces of PS-seeking service, are deployed in separate computers to accelerate searching (as illustrated in Fig. 6.2). Each EFEA agent can first utilize its own related service to get the input flows from FSP, and then, select suitable PS candidates from EFEA's private sub-knowledge category to work on the input flows. Finally, EFEA will be responsible for dispatching the processing results (i.e., output flows) and the relative PS identification information to FSP. Please note that although an EFEA's individual sub-knowledge category is shown beyond its own residential computing environment, such sub-knowledge category actually stays in the same computer.

Finally, as one can imagine, a BA agent is implemented as a backtracking service which is also separately deployed in a computer for increasing the speed of backtracking and solution creating process. A communication channel exists between BA and TMA so that as soon as the solution creating process is done by BA agents, the combined PSs can be returned directly to TMA which will translate such data into displayable information shown to enquirers.

6.5.2 WCF Assisted Agent Implementation

In this work, the agents (e.g., EFEA, BA, etc.) that involved in the process of design synthesizing are implemented with the support of WCF techniques. The fundamental WCF communication model between a service provider and a service requester is composed of the following three components:

- Service: Serving as the key part of a WCF application, "service" can be simply treated as a remote function that is callable by a host application (as explained below);
- Host: A "host" application can be in distinct forms such as console application and a typical windows application; and
- Endpoints: The "endpoints" are referred to as what a WCF service exhibits which often make the functions (offered by a service) accessable.

In this work, a service provider refers to a computer that distributes a WCF service, while a computer that invokes the distributed service for setting up a communication can be treated as a service requester.

6.5.3 Implementation Results

In order to test our implementation strategy, a mock-up hardware establishment mapping the proposed MAS-ICD platform is created in our lab Intranet environment. Such establishments consists of the following elements:

- Server centre: Hosting TMA and FSP;
- Desktop computer 1: Hosting KMA;
- Desktop computers 2–6: Hosting different EFEA agents; and
- Desktop computers 7–10: Hosting BA agents.

All these instruments are physically connected with each other via a local area network for completing the following tasks (a) how to manage a flow's attributes; (b) how to input a PS's functional knowledge; (c) and (d) how the constraints related to the input/output flows of a desire function can be specified; and (e) how the final synthesized results can be displayed to requesters.

In order to give the conceptual design a better support, the author of this study have enriched the PS knowledge pool with more than 500 PSs across different disciplines such as mechanical engineering, computer science, hydraulic engineering, mechatronics, electrical and electronics engineering, chemical engineering, biology engineering. Under this situation, 100 PSs or so can be assigned to each EFEA agent.

6.6 Applying MAS-ICD to Intelligent In-pipe Inspection Robot Conceptual Design

In order to further verify the usability of the proposed MAS-ICD, an in-pipe inspection robot conceptual design case study is used in this work. According to our scenario requirements, one of the desired function for this test case can be stated as: "transforming the output of an electrically powered actuator to a forward-and-backward movement". By using the previously introduced functional knowledge representation method, the desired function can be interpreted as a bunch of input flow constraints, and a group of output flow constraints, respectively. The following description will demonstrate how MAS-ICD can fulfil the conceptual design task.

Initially, the TMA agent creats several original input flows based on the appropriate input flow constraints. The established flows are then released to FSP which is followed by the activation of EFEA and BA agents. In align with previously described physical environment establishment, there are five EFEA agents in our demo MAS-ICD platform. By exploring the FSP, each EFEA agent can collect several streams of environmental flows which can be further attended. A circular process can be envisioned here as collecting flows → submitting outputs → recollecting flows → resubmitting outputs … This progress will only stop until terminating criteria are met, e.g., reaching maximal search depth. In terms of BA agents, unlike their peers, different BA agent will utilize separate environmental flows for backtracking. When an environmental flow that meets the prescribed functional requirements is discovered by a BA agent, it has to track the flow path back to the original point for finding the combined PS.

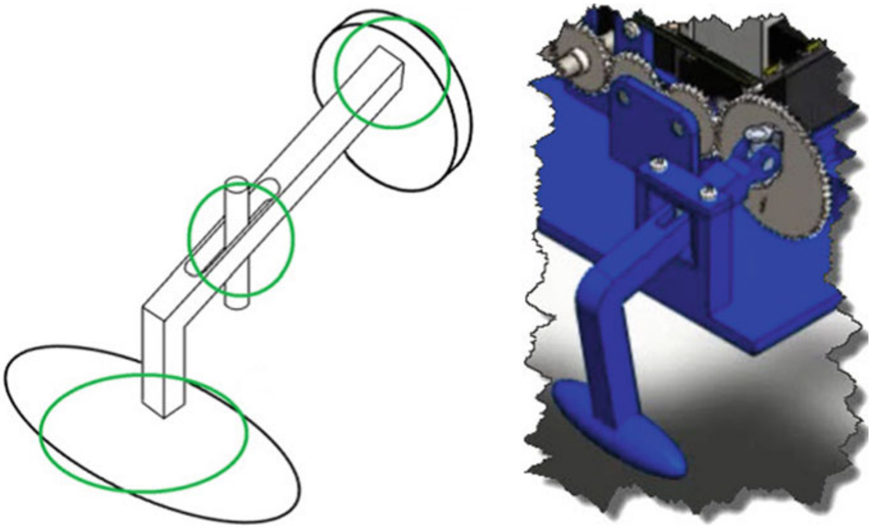

Fig. 6.3 Crocodile walking style inspired mechanism design and its 3D conceptualization

In this case study, with the PSs that we have organized from different disciplines, some complicated combined PSs (see Fig. 6.3) can be found by MAS-ICD which would otherwise by no means be achievable by manual design group.

As per our explanation, it can be seen that the proposed MAS-ICD can successfully achieve interdisciplinary design synthesis. The benefits of employing MAS-ICD are at least twofold: First, compared with the students manual design group, the proposed smart design platform can significantly increase the efficiency of the whole conceptual design process. Second, the design results achieved by MAS-ICD is better off than those outputs obtained by its counterpart manual design group. For instance, the students all admit that they are more or less stuck on traditional motion transferring concepts such as wheel and track type of designs.

6.7 Discussions

In this study, a multi-agent system approach assisted intelligent conceptual design framework, namely, MAS-ICD, is developed to assist with the knowledge flows' exploration and exploitation during the process of in-pipe inspection robot conceptual design synthesizing. The main contributions achieved by this research are summarized as follows while the highlighted future work can also be found thereafter.

6.7.1 Contributions

One of the major contributions obtained via this research lie in that it creates a sophisticated intelligent platform for facilitating smart robot conceptual design process. This is a novel contribution to conceptual design literature. Meanwhile the in-pipe inspection robot case study presented at the end of this study not only demonstrates the suitability of the propose MAS-ICD platform, but also fills the gaps found in in-pipe inspection robot design literature.

6.7.2 Future Work

Although the proposed MAS-ICD successfully fulfill the allocated design task, the robot design itself is a complicated process which requires its designers to consider a large amount of objectives (maybe conflicting in many situations) before an optimal final design can be achieved, e.g., budget constraints vs. technology advancement, and maneuverability versus payload requirement. These fast accumulated design variables often let the integrated designing agents face an enormous amount of knowledge flows that are accumulated too much to be handled. In this sense, some advanced optimization techniques such as innovative computation intelligence (Xing and Heidelberg 2014) and metaheuristics (Yang 2008) can be brought into enhance the capability of involved agents.

In addition to this, when multiple combined PSs are available, the evaluation of those PSs so that one or more most suitable solution(s) can be picked becomes an issue. Therefore designing a systematic approach for evaluating the obtained combined PSs would be a useful and interesting future research direction.

6.8 Conclusions

The in-pipe inspection is a hot research area and its related automated miniature scanning robot development is currently drawing many attentions. Although designers are often required to generate innovative design solutions in possession of desired functions, due to the fact that lack in sufficient interdisciplinary knowledge, such design tasks often becomes a challenge for human designers. This problem is not getting resolved even the most knowledgeable personnel is available because manually and exhaustively searching the knowledge space can be too time-consuming and labor-intensive. Quickly screening the literature, we find many studies (Lee et al. 2009; Roh and Choi 2005; Sabzehmeidani et al. 2010; Kang et al. 2013; Liu et al. 2013; Ong et al. 2003; Moghaddam et al. 2011; Zhang and Yan 2007; Choi and Roh 2007; Lee et al. 2012; Horodinca et al. 2002; Jun et al. 2004; Roslin et al. 2012) dedicated to in-pipe inspection robot design, but very few of them, if not any, addresses the issue that we have just mentioned above. Bearing this in mind, in this study, a smart conceptual design platform has been developed to fill this gap. Through a demo case study, the author believes that proposed MAS-ICD can indeed achieve a higher efficiency and better robustness than traditional manual design approach.

References

Al-Ashaab, A., Molyneaux, M., Doultsinou, A., Brunner, B., Martínez, E., Moliner, F., et al.: Knowledge-based environment to support product design validation. Knowl. Based Syst. **26**, 48–60 (2012)

Bonnema, G.M., van Houten, F.J.A.M.: Use of models in conceptual design. J. Eng. Des. **17**, 549–562 (2006)

Cao, D.X., Zhu, N.H., Cui, C.X., Tan, R.H.: An agent-based framework for guiding conceptual design of mechanical products. Int. J. Prod. Res. **46**, 2381–2396 (2008)

Chandrasegaran, S.K., Ramani, K., Sriram, R.D., Horváth, I., Bernard, A., Harik, R.F., et al.: The evolution, challenges, and future of knowledge representation in product design systems. Comput. Aided Des. **45**, 204–228 (2013)

Chen, Y., Huang, J., Zhang, Z., Xie, Y.: A part affordance-based approach for capturing detailed design knowledge. Comput. Aided Des. **45**, 1617–1629 (2013)

Choi, H.R., Roh, S.-G.: In-pipe robot with active steering capability for moving inside of pipelines. In: Habib, M.K. (ed.) Bioinspiration and Robotics Walking and Climbing Robots, Chapter 23, pp. 375–402. InTech, Rijeka, ISBN 978-3-902613-15-8 (2007)

Cordes, S., Berns, K., Eberl, M., Ilg, W., Suna, R.: Autonomous sewer inspection with a wheeled, multiarticulated robot. Robot. Auton. Syst. **21**, 123–135 (1997)

Dieter, G.E., Schmidt, L.C.: Engineering Design, vol. 5. McGraw-Hill, ISBN: 978-0-07-339814-3 (2013)

Dorigo, M., Tuci, E., Trianni, V., Groß, R., Nouyan, S., Ampatzis, C. et al.: SWARM-BOT: design and implementation of colonies of self-assembling robots. In: Yen, G.Y., Fogel, D.B. (eds.) Computational Intelligence: Principles and Practice, pp. 103–135. IEEE Computational Intelligence Society, New York, (2006)

Dorigo, M., Trianni, V., Şahin, E., Groß, R., Labella, T.H., Deneubourg, J.-L., et al.: Evolving self-organizing behaviors for a swarm-bot. Auton. Robots **17**, 223–245 (2004)

Fu, Q.Y., Chui, Y.P., Helander, M.G.: Knowledge identification and management in product design. J. Knowl. Manage. **10**, 50–63 (2006)

Fuente, J.D.L., Gustafson, S., Twomey, C., Bix, L.: An affordance-based methodology for package design. Packag. Technol. Sci. **6,** 1–15 (2014)

Goldberg, K., Kehoe, B., Patil, S., Abbeel, P.: Cloud Robotics and Automation: A Survey of Related Work. EECS Department, University of California, Berkeley, UCB/EECS-2013–52013 (2013)

Granosik, G., Hansen, M.G., Borenstein, J.: The omnitread serpentine robot for industrial inspection and surveillance. Int. J. Ind. Rob. **IR32-2**, 139–148 (2005)

Guizzo, E.: Robots with their heads in the clouds. Spectrum **48**, 16–18 (2011)

Guo, B., Song, S., Ghalambor, A., Lin, T.R.: Offshore Pipelines: Design, Installation, and Maintenance, 2nd ed. Gulf Professional Publishing, Elsevier Inc., Waltham, ISBN: 978–0-12-397949-0 (2014)

Haik, Y., Shahin, T.: Engineering Design Process, 2nd edn. Cengage Learning, Stamford, ISBN 978-0-495-66814-5 (2011)

Heo, G., Park, J.: A framework for evaluating the effects of maintenance-related human errors in nuclear power plants. Reliab. Eng. Syst. Saf. **95**, 797–805 (2010)

Horodinca, M., Doroftei, I., Mignon, E., Preumont, A.: A simple architecture for in-pipe inspection robots. In: Proceedings of International Colloquium on Mobile and Autonomous Systems, pp. 61–64. Magdeburg, Germany (2002)
Huang, H.-Z., Liu, Y., Li, Y., Xue, L., Wang, Z.: New evaluation methods for conceptual design selection using computational intelligence techniques. J. Mech. Sci. Technol. **27**, 733–746 (2013)
Jin, T., Que, P., Tao, Z.: Development of magnetic flux leakage pipe inspection robot using hall sensors. In: Proceedings of the International Symposium on Micro-Nanomechatronics and Human Science, pp. 325–329, Oct. 3–Nov. 2004
Jun, C., Deng, Z., Jiang, S.: Study of locomotion control characteristics for six wheels driven in-pipe robot. Paper presented at the IEEE International Conference on Robotics and Biomimetics, pp. 119–124. Shenyang, China, 22–26 Aug. 2004
Kamei, K., Nishio, S., Hagita, N., Sato, M.: Cloud networked robotics. IEEE Netw. Mag. **26** 28–34 (2012)
Kang, Y., Tang, D.: Matrix-based computational conceptual design with ant colony optimisation. J. Eng. Des. **24**, 429–452 (2013)
Kang, Y.K., Park, J.W. , Yang, H.S.: Analytical approach of the in-pipe robot on branched pipe navigation and its solution. World Acad. Sci. Eng. Technol. **77**, 449–453 (2013)
Kwon, Y.-S., Jung, E.-J., Lim, H., Yi, B.-J.: Design of a reconfigurable indoor pipeline inspection robot. Presented at the International Conference on Control, Automation and Systems, pp. 712–716. COEX, Seoul, 17–20 October 2007
Lee, J.-S., Roh, S.-G., Kim D.W., Moon, H., Choi, H.R.: In-pipe robot navigation based on the landmark recognition system using shadow images. In: Proceedings of IEEE International Conference on Robotics and Automation, Kobe, Japan, 12–17 May 2009
Lee, D., Park, J., Hyun, D., Yook, G., Yang, H.-S.: Novel mechanisms and simple locomotion strategies for an in-pipe robot that can inspect various pipe types. Mech. Mach. Theor. **56**, 52–68 (2012)
Lim, J., Park, H., An, J., Hong, Y.-S., Kim, B., Yi, B.-J.: One pneumatic line based inchworm-like micro robot for half-inch pipe inspection. Mechatronics **18**, 315–322 (2008)
Liu, Q., Ren, T., Chen, Y.: Characteristic analysis of a novel in-pipe driving robot. Mechatronics **23**, 419–428 (2013)
Miyagawa, T., Iwatsuki, N.: Characteristics of in-pipe mobile robot with wheel drive mechanism using planetary gears. In: Proceedings of International Conference on Mechatronics and Automation, pp. 3646–3651 (2007)
Moghaddam, M.M., Arbabtafti, M., Hadi, A.: In-pipe inspection crawler adaptable to the pipe interior diameter. Int. J. Robot. Autom. **26**, 135–145 (2011)
Mondada, F., Bonani, M., Guignard, A., Magnenat, S., Studer, C., Floreano, D.: Superlinear physical performances in a SWARM-BOT. In: Capcarrere, M. (ed.) ECAL 2005, LNAI 3630, pp. 282–291. Springer, Heidelberg (2005)
Mondada, F., Gambardella, L.M., Floreano, D., Nolfi, S., Deneubourg, J.-L., Dorigo, M.: The cooperation of swarm-bots: physical interactions in collective robotics. IEEE Robot. Autom. Mag. **12**(3), 21–28 (2005)
Mondada, F., Pettinaro, G.C., Guignard, A., Kwee, I.W., Floreano, D., Deneubourg, J.-L., et al.: Swarm-bot: a new distributed robotic concept. Auton. Robots **17**, 193–221 (2004)
Ong, J.K., Bouazza-Marouf, K., Kerr, D.: Fuzzy logic control for use in in-pipe mobile robotic system navigation. Proc. Inst. Mech. Eng. Part I: J. Syst. Control Eng. **217**, 401–419 (2003)
Oya, T., Okada, T.: Development of a steerable, wheel-type, in-pipe robot and its path planning. Adv. Robot. **19**, 635–650 (2005)
Pagallo, U.: Robots in the cloud with privacy: a new threat to data protection? Comput. Law Secur. Rev. **29**, 501–508 (2013)
Paramasivam, V., Senthil, V.: Analysis and evaluation of product design through design aspects using digraph and matrix approach. Int. J. Interact. Des. Manuf. **3**, 13–23 (2009)
Prasad, E.N., Kannan, M., Azarudeen, A., Karuppasamy, N.: Defect identification in pipe lines using pipe inspection robot. Int. J. Mech. Eng. Robot. Res. **1**, 20–31 (2012)

Qi, H., Zhang, X., Chen, H., Ye, J.: Tracing and localization system for pipeline robot. Mechatronics **19**, 76–84 (2009)
Qi, H., Ye, J., Zhang, X., Chen, H.: Wireless tracking and locating system for in-pipe robot. Sens. Actuators A **159**, 117–125 (2010)
Roh, S.-G., Choi, H.R.: Differential-drive in-pipe robot for moving inside urban gas pipelines. IEEE Trans. Rob. **21**, 1–17 (2005)
Rome, E., Hertzberg, J., Kirchner, F., Licht, U., Christaller, T.: Towards autonomous sewer robots: the MAKRO project. Urban Water **1**, 57–70 (1999)
Roslin, N.S., Anuar, A., Jalal, M.F.A., Sahari, K.S.M.: A review: hybrid locomotion of in-pipe inspection robot. Procedia Eng. **41**, 1456–1462 (2012)
Russell, S.J., Norvig, P., Artificial Intelligence: A Modern Approach, 3rd ed. Pearson Education, Inc, Upper Saddle River, ISBN 978-0-13-604259-4 (2010)
Sabzehmeidani, Y., Mailah, M., Hussein, M., Tavakolpour, A.R.: Intelligent control and modelling of a micro robot for in-pipe application. World Acad. Sci. Eng. Technol. **48**, 449–454 (2010)
Schmidt, D., Berns, K.: Climbing robots for maintenance and inspections of vertical structures—a survey of design aspects and technologies. Robot. Auton. Syst. **61**, 1288–1305 (2013)
Sheng, W., Chen, H., Xi, N.: Navigating a miniature crawler robot for engineered structure inspection. IEEE Trans. Autom. Sci. Eng. **5**, 368–373 (2008)
Tan, Y., Zheng, Z.: Research advance in swarm robotics. Defence Technology. http://dx.doi.org/10.1016/j.dt.2013.03.001 (in press)
Tian, S., Saitov, D., Lee, S.G.: Cloud robot with real-time face recognition ability. Adv. Sci. Technol. Lett. **51**, 77–80 (2014)
Trianni, V., Nolfi, S., Dorigo, M.: Cooperative hole avoidance in a swarm-bot. Robot. Auton. Syst. **54**, 97–103 (2006)
Tur, J.M.M., Garthwaite, W.: Robotic devices for water main in-pipe inspection: a survey. J. Field Robot. **27**, 491–508 (2010)
Waibel, M., Beetz, M., Civera, J., D'Andrea, R., Elfring, J., Gálvez-López, D., et al: Roboearth. IEEE Robot. Autom. Mag. **18**(2), 69–82 (2011)
Wilson, J.O.: A systematic approach to bio-inspired conceptual design. Doctor of Philosophy, Department of Mechanical Engineering, Georgia Institute of Technology (2008)
Xing, B., Gao, W.-J., Marwala, T.: Chapter 11: Multi-agent framework for distributed leasing-based injection mould remanufacturing. In: Memon, Q.A. (ed.) Distributed Networks: Inteligence, Security, and Applications. CRC Press, Boca Raton, ISBN 978-1-4665-5958-5 (2014)
Xing, B., Gao, W.-J: Innovative Computational Intelligence: A Rough Guide to 134 Clever Algorithms. Springer, Heidelberg, ISBN 978-3-319-03403-4 (2014)
Xu, F., Wang, X., Wang, L.: Cable inspection robot for cable-stayed bridges: design, analysis, and application. J. Field Robot. **28**, 441–459 (2011)
Yang, X.-S.: Nature-Inspired Metaheuristic Algorithms, 2nd edn. Luniver Press, UK, ISBN 978-1-905986-28-6 (2008)
Zhang, Y., Yan, G.: In-pipe inspection robot with active pipe-diameter adaptability and automatic tractive force adjusting. Mech. Mach. Theor **42**, 1618–1631 (2007)

Part IV
Intelligent Systems in Management

Chapter 7
Artificial Intelligence Techniques in Human Resource Management—A Conceptual Exploration

Stefan Strohmeier and Franca Piazza

Abstract Artificial Intelligence Techniques and its subset, Computational Intelligence Techniques, are not new to Human Resource Management, and since their introduction, a heterogeneous set of suggestions on how to use Artificial Intelligence and Computational Intelligence in Human Resource Management has accumulated. While such contributions offer detailed insights into specific application possibilities, an overview of the general potential is missing. Therefore, this chapter offers a first exploration of the general potential of Artificial Intelligence Techniques in Human Resource Management. To this end, a brief foundation elaborates on the central functionalities of Artificial Intelligence Techniques and the central requirements of Human Resource Management based on the task-technology fit approach. Based on this, the potential of Artificial Intelligence in Human Resource Management is explored in six selected scenarios (turnover prediction with artificial neural networks, candidate search with knowledge-based search engines, staff rostering with genetic algorithms, HR sentiment analysis with text mining, résumé data acquisition with information extraction and employee self-service with interactive voice response). The insights gained based on the foundation and exploration are discussed and summarized.

Keywords Artificial intelligence · Computational intelligence · Human resource management · Artificial neural network · Genetic algorithm · Knowledge representation · Knowledge discovery · Data mining · Text mining · Sentiment analysis · Interactive voice response

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7.1 Introduction: AI Techniques in HR Management?

Human resources are widely perceived as one of the most important assets of any organization, and managing this asset successfully is, consequently, considered a crucial managerial duty (e.g., Devannah et al. 1984). Managing human resources comprises a broad range of different tasks, including staffing, management of employee performance, development of employee qualifications and careers, and compensation of employee efforts. In human resource management (HRM), as in any other domain, adequate techniques are crucial; proven techniques understood as systematic instructions for solving domain tasks enable humans to cope successfully with the multifarious requirements of a given domain. As a well-established and increasingly professionalized domain, HRM makes use of a broad and heterogeneous set of techniques. In addition to domain-specific techniques, this also refers to techniques that are "imported" from other domains, for instance, psychometric tests from organizational psychology (e.g., Wolf and Jenkins 2006), optimization from operations research (e.g., Ernst et al. 2004) or online analytical processing from information systems (e.g., Burgard and Piazza 2009). A further prominent discipline offering techniques that might be applied in HRM is artificial intelligence (AI) (e.g., Jantan et al. 2010). For AI, the literature offers a heterogeneous set of suggestions as to how specific AI techniques could be applied for specific HR tasks, for instance, how to use data mining techniques in employee selection (e.g., Chien and Chen 2008), intelligent agent techniques in employee development (e.g., Giotopoulos et al. 2007) or information extraction techniques in employee recruiting (e.g., Kaczmarek et al. 2005). Such contributions yield diverse and detailed insights into the potentials of individual AI techniques for individual HR tasks and, thus, are valuable. Yet, such contributions are not able to offer an overview of the general potential, i.e., which AI techniques generally exist, to which HR tasks these could be generally applied and which general conditions exist for a successful application. Thus, the current chapter aims to be the first exploration of the general potential of AI techniques in HR management. For this purpose, a brief foundation elaborates on the central functionalities of AI techniques and the central requirements of HR management based on the task-technology fit approach (Sect. 7.2). Based on this, the potential of AI techniques in HR management is explored in six selected application scenarios (Sect. 7.3). Finally, the insights gained based on the foundation and exploration are discussed and summarized (Sect. 7.4).

7.2 Foundation: "Fit" of AI Techniques and HR Management

7.2.1 Task-Technology Fit

Any general exploration of application potentials of specific techniques in a specific domain should be based on general insights into the overarching conditions and effects of an application. For this purpose, the task-technology fit approach (TTF) (Goodhue and Thompson 1995) offers a simple and useful foundation. Basically, the approach aims to explain the success of information technology and claims the task-technology fit ("correspondence between task requirements and the functionality of the technology") as the major criterion for success ("mix of improved efficiency, improved effectiveness and/or higher quality") (Goodhue and Thompson 1995, p. 218). The approach has been successfully applied to a broad set of application domains and technological categories (Furneaux 2012), and should be suitable for investigating the potential of AI techniques (which are interpretable as technologies because they are mandatorily implemented as technological applications) in HR management (which is interpretable as a set of interrelated tasks). As a basis for further exploration, the general requirements of HR tasks and the general functionalities of AI techniques are briefly elaborated on in the following.

7.2.2 Requirements of HR Tasks

As a prominent managerial domain, HRM is defined and categorized differently throughout the literature. Understanding the employees as the major source of organizational performance and competitive advantage and the systematic alignment of all employee related activities for business strategy constitute common characteristics of the concept since its beginnings (e.g., Devannah et al. 1984; Jackson et al. 2014). As a working definition, HRM thus can be generally described as a subset of management tasks that are related to potential or current employees to obtain contributions that directly or indirectly support the strategy and performance of an organization.

This implies a multitude of detailed tasks, which are categorized heterogeneously throughout the literature. Concentrating on major complexes of tasks with clear strategic relevance, staffing, performance management, development, and compensation, constitute commonly considered interrelated tasks of HRM (e.g., Devanna et al. 1984). Staffing in general refers to the provision of the quantity and quality of employees necessary for business. This implies numerous sub-tasks, such as requirements planning, recruiting, selection and onboarding of new employees, and, if needed, also relocations and dismissals of current employees. Moreover, assignment planning and day-to-day assignment of employees also constitute further sub-tasks of staffing. Performance management consists of the systematic planning, appraisal and attainment support of collective and individual objectives. Planning implies the downward cascading of (strategic) organizational objectives to individual objectives. Performance appraisal subsequently aims at a concomitant or periodical achievement evaluation of these objectives, while attainment support aims at diverse support measures that enable and facilitate individual goal achievement. Development aims at consequent advancement of individual employee qualifications as well as employee careers. Qualification development refers to the continuing training of employees to equip them with the qualifications necessary for the achievement of their goals, including the ability to cope with stress, work burdens, and conflicts, among others. Beyond the qualifications, career development aims at planning and realizing medium term positions/successions in a way that matches organizational needs as well as individual potentials and ambitions. Finally, compensation refers to remuneration of employees, including concepts of profit sharing and pension plans. Remuneration aims at a fair and motivating payment of employees corresponding with individual qualification requirements and performance contributions. Profit sharing aims at employee participation in the financial success of a company. Pension plans aim to extend the financial funding of employees in the retention phase.

Each of these HR task categories can be supported by intelligent techniques in two basic interrelated ways that are automation and information (Zuboff 1985). Automation of an HR task aims at the (partial) task performance transfer from humans to machines. Human qualification and effort thereby are replaced by machines, while the same tasks can usually be performed quicker and at less cost (Zuboff 1985). Thus, in the past, significant efforts were made to constantly push the automation of HRM. Information of an HR task is based on its preceding automation and aims at producing valuable insights about the task that was automated. This enhanced knowledge offers decision support for human deciders and, therefore, should improve the overall decision quality (Zuboff 1985). Thus, there have also been diverse endeavors to utilize the inherent information potential for HR decision support.

In summary, the automation and information of staffing, performance management, development and compensation constitute major task requirement categories, as depicted in Fig. 7.1.

Staffing		Performance Management		Development		Compensation	
Automation	Information	Automation	Information	Automation	Information	Automation	Information

Fig. 7.1 Categorization of major HR task requirements

7.2.3 Functionalities of AI Techniques

Based on the problems of defining general intelligence properly, AI constitutes a multifarious and fragmented area of computer science, and there is heterogeneity and even certain confusion regarding the proper definition and categorization of AI techniques (e.g., Duch 2007; Kahraman et al. 2010; Wang 2008). Narrow definitions focus on structural or behavioral analogies with natural intelligence, i.e., an intelligent technique is structured and/or behaves as a natural intelligent system (Wang 2008). This allows for a clear determination of relevant techniques (which are usually in the categories of neural, fuzzy and evolutionary techniques, as well as hybrids of them) and also a clear demarcation to general computer sciences, while this narrow understanding is increasingly termed as "computational intelligence" (e.g., Duch 2007; Kahraman et al. 2010). Broader definitions focus on functional or capability-oriented analogies with natural intelligence, i.e., the technique performs certain functions and/or has certain capabilities of natural intelligent systems (Wang 2008). This expands the set of incorporated techniques and allows the consideration of "classic" AI techniques, such as knowledge representation; yet, this also aggravates a clear demarcation of "intelligent techniques" from further computational techniques and therewith a proper demarcation of AI from general computer science. To cover the range of existing intelligent techniques, the current chapter adopts a broad understanding and defines AI techniques as machine-processable instructions to solve tasks that would require clear cognitive capabilities if solved by humans. Based on this definition, it becomes possible to categorize AI techniques based on the cognitive capability they refer to. In this respect, knowledge, thought and language constitute major cognitive functions that comprise different categories of related AI techniques, which are briefly introduced in the following.

Understanding *knowledge* as awareness and understanding certain relevant facts, the generation, preservation and processing of knowledge constitute clear cognitive capabilities. Major AI techniques that are related to knowledge can be categorized into knowledge discovery, knowledge representation and knowledge processing. Knowledge discovery (also "machine learning", "pattern recognition" or "data mining") refers to the process of identifying novel, potentially useful and valid information in data (Fayyad et al. 1996). For this purpose, a broad range of knowledge discovery techniques is available, with classification, association, segmentation and prognosis techniques constituting prominent categories (e.g., Wu et al. 2008). Knowledge representation refers to the mapping of a set of relevant propositions ("knowledge") to formal symbols in a way that allows computers to use these formal symbols when solving tasks (e.g., Brachman and Levesque 2004; Davis et al. 1993). Major varieties are declarative (representation of mere facts) and procedural (representation of procedures to utilize knowledge) knowledge representation. For knowledge representation, there is a larger set of techniques, with frames, semantic nets and ontologies constituting prominent example categories (e.g., Tanwar et al. 2010). Knowledge processing (also "reasoning" or "inferencing") aims at utilizing knowledge represented in a computer to produce new knowledge.

Knowledge processing therewith is dependent on existing knowledge representations as a basis and input for reasoning (e.g., Brachman and Levesque 2004). There are different techniques for reasoning, while deductive, inductive and abductive reasoning constitute major categories (e.g., Brachman and Levesque 2004).

Understanding *thought* as the purposeful internal processing of existing knowledge to produce new knowledge and solve problems, thought constitutes a further clearly cognitive capability relevant in AI. As is explicitly defined here, thought is related to knowledge in a twofold manner because it utilizes existing knowledge as input and aims at producing new knowledge as output. For this reason, particularly techniques that process knowledge have to be additionally classified as thought-related as well. Moreover, techniques for searching solutions (also "solving optimization problems") constitute a second crucial category of thought-related techniques. Basically, these techniques aim at formalizing "hard problems" and solving them based on intelligently searching a search space for an optimal, or at least a feasible, solution (Kahraman et al. 2010). For this purpose, a broader set of intelligent techniques, such as the A* search algorithm, hill climbing algorithms, particle swarm optimization and genetic algorithms, is suggested (e.g., Kahraman et al. 2010; Luger 2005).

Finally, understanding *language* as the use of a complex system of spoken or encoded elements for communication, language usage constitutes a further clearly cognitive capability. Referring to language, text processing and speech processing constitute major categories of intelligent language-related techniques (also subsumed as "natural language processing [NLP]"). Text processing techniques aim at supporting tasks related to written language, such as topic extraction, text summarization, text translation, or text classification, among others. For this purpose, a set of text processing techniques, such as tokenization, lemmatization, and part of speech tagging, are available (e.g., Jurafsky and Martin 2008). Speech processing techniques aim at supporting tasks related to spoken language, in particular automatic speech recognition and automatic speech synthesis but also further tasks, such as speaker recognition and verification or hearing aid provision, among others. A broader set of different techniques is available, with Hidden Markov Models constituting a prominent example in the area of speech recognition (e.g., Benesty et al. 2008).

In summary, the discovery, representation and processing of knowledge, the search for solutions, and the processing of text and speech constitute major categories of AI functionality, as depicted in Fig. 7.2.

As it is possible to realize an AI application based on only one technique from one category, several techniques are increasingly combined and therefore constitute hybrid techniques (e.g., Kahraman et al. 2010).

Knowledge-Related Techniques			Thought-Related Techniques	Language-Related Techniques	
Knowledge Discovery	Knowledge Representation	Knowledge Processing	Solution Searching	Text Processing	Speech Processing

Fig. 7.2 Categorization of major functionalities of AI techniques

7.3 Exemplification: Scenarios of AI Techniques in HR Management

7.3.1 Overview

Against the backdrop of the task-technology fit approach, the intended conceptual exploration of potentials implies the investigation of technological functionalities, task characteristics, the potential fit of both and the resulting consequences. Any exploration, however, is confronted with the multifariousness of individual AI techniques, of individual HR tasks and, consequently, of imaginable task technique-combinations. The resulting exploration task, thus, is huge and far beyond the scope of a single contribution. On this account, a conscious selection of six different application scenarios of AI techniques in HR is discussed below (see Fig. 7.3).

While this does not allow any final tackling of the topic, it enables various first explorative insights. The scenarios were selected based on two criteria: Firstly, the portfolio of application scenarios should cover the range of AI techniques as well as the range of HR tasks rather than concentrate on one or a few techniques and/or one or a few tasks. Secondly, the examples should constitute "mature" application scenarios, i.e., applications of AI in HR that are already elaborated, tested and, at least occasionally, also adopted in practice, rather than "futuristic" scenarios with uncertain practical feasibility. In the following, it is briefly discussed for each scenario which functionalities the respective AI technique offers and whether and how these fit with requirements of the respective HR task.

7.3.2 Turnover Prediction with Artificial Neural Networks

Artificial Neural Networks (ANNs) are information processing systems that comprise a certain number of information processing units (also "cells," "neurons") that incorporate mathematical functions and are connected by directed weighted links (e.g., Rojas 1996). ANNs constitute a category of knowledge discovery that is able to solve clustering, classification, estimation and prediction tasks. The information processing units are usually organized in layers, with an input layer to provide the

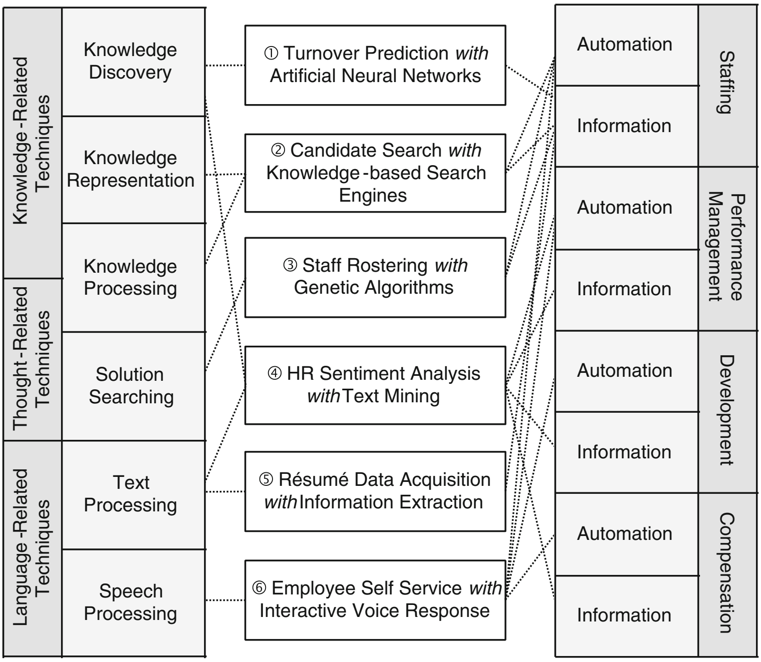

Fig. 7.3 Selected scenarios of AI techniques in HR management

input data, one or more hidden layers to process the data through the neural network and an output layer to provide the result. ANNs are inspired by an analogy to the brain, where information processing is based on neurons that are connected to each other and transmit the degree of activation through nerve fibers to other neurons (e.g., Rojas 1996). They learn from training examples and reorganize their internal structure (architecture) comprising the units, layers and directed weighted links to generate good outputs. When the output meets a certain quality criterion, the architecture of the ANN is fixed and can be used for prediction tasks. Further intelligent techniques are occasionally used to realize ANNs, for instance, genetic algorithms are applied to adapt the weights of the links during the learning process (e.g., Sexton et al. 2005). Due to their internal structure, ANNs are able to approximate any mathematical function (e.g., Hornik et al. 1990; Leshno et al. 1993) and, thus, to discover complex patterns within data. However, the ANNs themselves are complex and nontransparent and work as "black boxes", delivering good outputs but few explanations.

An application scenario of ANNs in HRM is the prediction of employee turnover. Employee turnover refers to the voluntary resignation of employees based on their own reasons and explicitly excludes dismissals based on employer reasons or unavoidable separations, such as retirement, death or permanent disability. This phenomenon, especially dysfunctional turnover (good performing employees leave, while poor performing employees stay), is of crucial interest for organizations because of the decreased productivity associated with it (e.g., Sexton et al. 2005). Moreover, dysfunctional turnover leads to increasing staffing costs because new employees have to be searched for, hired and trained to fill vacant positions. Against this background, turnover prediction offers the potential to identify the employees that are likely to leave and therewith enables the development of individual employee retention measures. The turnover prediction task can be modeled as a classification task where the output variable realizes the two discrete classes "yes" and "no" relating to turnover. To apply the ANN, a training dataset is required that contains historic employee data concerning turnover as well as other potentially relevant data influencing turnover, such as age, seniority, salary, qualifications, position, gender, family status, etc. In a first step, the ANN is trained on a training set, i.e., a partition of the available employee data, to reveal systematic associations between the input variables influencing turnover and the respective output variable representing turnover. As they can approximate any function, ANNs are also able to discover highly complex patterns of employee turnover. The quality of the generated ANN can be assessed by using a test set, a partition of the employee dataset left out from the training process, which can reveal insights into the error, such as the percentage of employees wrongly classified as "leavers." A sensitivity analysis can further show the importance of the influence factors and allows for identification of the factors that most influence the employee turnover. The generated ANN hence can be applied to predict which employees are likely to leave and also can deliver information about the relevant factors influencing turnover (e.g., Sexton et al. 2005).

ANNs obviously fit with the task of turnover prediction as they address the nature of the underlying classification and prediction task. An ANN can predict which concrete employees are likely to leave as well as uncover unknown factors that influence turnover. Therewith, valuable predictive information for staffing that enables proactive management of the turnover of employees is offered and that cannot be offered by conventional techniques, such as merely querying employee databases. Predicting and proactively managing turnover can avoid, or at least alleviate, the severe downsides of "dysfunctional turnover," including drops in organizational productivity and the costs of recruiting and introducing new employees. In summary, turnover prediction with ANNs supports the information of staffing and allows for a proactive HRM. While the factual practical application of ANNs in turnover prediction is not revealed in the literature, several evaluations and prototypes reveal "application maturity" of the scenario in applying a knowledge discovery technique in HRM (e.g., Fan et al. 2012; Quinn et al. 2002; Sexton et al. 2005; Somers 1999).

7.3.3 *Candidate Search with Knowledge-Based Search Engines*

Knowledge-based search engines (also frequently called “semantic search engines”) basically offer functionality for searching the web for content. Compared to conventional search, however, not only the search string entered but also semantically related concepts, such as synonyms, hypernyms and hyponyms, are automatically considered (e.g., Mangold 2007). Thus, a knowledge-based search functions as if it would understand the semantic meaning of the searched content and, thus, improves the search result quality. Therewith it also reduces the often complex and time consuming search process. The basic AI techniques that are used to enable knowledge-based search are ontologies as a technique of knowledge representation and related reasoners as a technique of knowledge processing. Ontologies represent knowledge of a certain domain in the form of concepts, relations, instances and rules (e.g., Guarino et al. 2009). Concepts refer to classes of objects that are relevant for the domain. Relations refer to associations between concepts. Depending on the domain, any desired relation can be mapped, while specific types of relations between concepts refer to superiority and subordination of concepts, allowing for the distinguishing of sub-concepts, concepts and super-concepts. Instances are concrete individual members of a certain object class described by a certain concept. Rules, finally, represent causal relationships between concepts and/or instances that can be used for inferring new knowledge. Usually, ontologies also comprise synonyms for concepts and instances. In this way, knowledge of a certain domain can be represented, and ontologies thus constitute a particular knowledge representation technique (e.g., Guarino et al. 2009). Reasoners use knowledge of the ontology and, dependent on the basic application objective, also external case-dependent data to generate new knowledge (e.g., Abburu 2012; Bock et al. 2008). For instance, applying a rule (A ⇒ B) from the ontology on an object that meets the premise “A” allows concluding that it also meets the conclusion “B”; in this way, new knowledge can be created. The combination of ontologies and reasoners allows for a knowledge-based search that yields results comparable to that of intelligent humans with deep domain knowledge (e.g., Guha et al. 2003).

An application scenario of knowledge-based search-engines in HRM is searching for candidates (e.g., Mochol et al. 2007). Due to labor market shortages, many organizations actively search for suitable candidates on the web, e.g., on web-based job boards. Due to the redundancy and heterogeneity of human language, searching for suitable candidates based on conventional search engines frequently turns out to be both incomplete and effortful. Problems of conventional search arise, in particular, if the relevant terminology of the organization and the candidate deviate from each other—which is a regular occurrence in e-recruiting. The searching organization has to then employ an abundance of search terms, yet it still cannot know with certainty that suitable candidates are not being overlooked. A knowledge-based search engine utilizing a domain-ontology and a reasoner can improve candidate search processes, as rendered in Fig. 7.4.

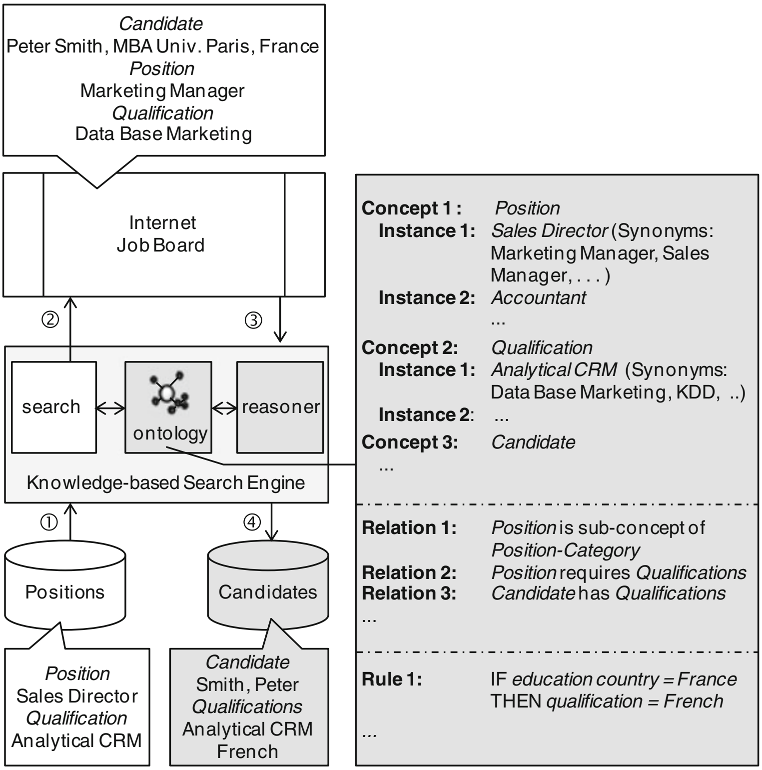

Fig. 7.4 Candidate search with knowledge-based search engines

Organization and candidate use a deviating terminology to describe relevant aspects, such as offered and desired positions, required and offered qualifications, etc. The recourse on a domain ontology allows the search engine to "recognize" that the vacant position "sales director" semantically corresponds with a searched position "marketing manager" among others, and it offers a suitable search result that a conventional search engine would not be able to. If a reasoner is used in addition, this might offer additional information, such as deducing French language qualifications from the fact the candidate was educated in France.

Knowledge-based search engines therewith visibly fit with the task of searching for candidates who describe their desired position and offered qualifications in natural language and, thus, in a heterogeneous and multifarious terminology that can be handled by knowledge-based search. Knowledge-based search engines are able to automate parts of the search task and also offer valuable information for supporting pre-selection decisions; thus, the automation and information of staffing is supported. Compared to conventional search, central improvements relate to efficiency (increased speed and decreased effort) and quality (increased accuracy of results) of candidate search (e.g., Strohmeier et al. 2011). Knowledge-based search is a mature technology that is at least occasionally applied in HRM, for instance, several web-based job boards offer semantic search of jobs and candidates.

7.3.4 Staff Rostering with Genetic Algorithms

Genetic algorithms are problem-solving techniques inspired by biological processes comprising variation and selection to optimize "survival of the fittest". As a major application realm, parameter optimization problems are those in which the variables representing the parameters are typically encoded by bit strings (e.g., Sivanandam and Deepa 2008; Whitley 1994). Genetic algorithms generate solutions according to a specified objective function and problem specific constraints. In the first step, an initial population is generated (randomly, for example) where each member of the population is represented by a bit string (also referred to as a "genotype" or "chromosome"). Algorithms further perform the phases of selection, crossover and mutation (e.g., Linoff and Berry 2011; Sivanandam and Deepa 2008; Whitley 1994). Within the *selection* phase, only the fittest members in a population survive to pass their genetic material on to the next generation. A fitness value for each member is calculated based on the objective function of the optimization problem. The better the fitness value relative to other members, the more copies survive to the next generation. The size of the population remains constant from one generation to the next. Therefore, the fittest members are selected and copied, while those with the lowest fitness value do not survive. The subsequent phase, *crossover*, is the phase analogous to reproduction in nature and aims at creating new members of the population from existing ones by combining pieces of them. There are several crossover strategies, such as single-point, two-point, n-point or uniform crossover. The new members are different from the existing ones but do not necessarily fit better. However, when a new combination turns out to have a high fitness value, it is likely to be replicated in future generations. *Mutation* aims at realizing changes that cannot result from selection and crossover alone, for example, by flipping a randomly selected bit. Selection and crossover depend on initial conditions and randomness that might prevent potential successful combinations from being generated and considered in succeeding generations. Like in nature, mutations are likely to be harmful and destructive; therefore, mutation should be rarely applied. If the initial population provides a good coverage of the solution space, selection and crossover are sufficient. Selection, crossover (and mutation) form a new generation, which will be evaluated again, leading to an iterative process. Common stop criteria for genetic algorithms are a fixed number of generations, a time limit or the absence of improvements. Genetic algorithms are stochastic heuristic search methods that simultaneously consider many points in the search space, and therefore the probability of finding only local optima is reduced (e.g., Kahraman et al. 2011). Genetic algorithms can therefore be categorized as a thought-related intelligent technique.

An application scenario of genetic algorithms in HRM is staff rostering (also "employee scheduling"). Staff rostering addresses the generation of optimal assignments of employees to shifts matching the qualitative and quantitative requirements of the tasks with the qualitative and quantitative disposability of the employees (e.g., Ernst et al. 2004). In many branches, such as manufacturing, service or health care, a flexible and efficient generation of valid staff rosters is a crucial task. The resulting optimization problem refers to multiple criteria, such as costs, job-person fit and employee preferences, and is characterized by multiple constraints regarding domain specific aspects, such as maximum working time, recreation times and qualification requirements, among others. For example, each employee works at most one shift per day, while the overall monthly working time should meet a particular tolerance limit around the target working time. Further examples for constraints are that a maximum number of consecutive working days should not be exceeded, that the night and weekend shifts should be distributed among the employees according to their contracts and in respect to a fair distribution and that employee preferences should be considered as much as possible. Constraints can be incorporated in the calculation of the fitness value as penalty costs by lowering the fitness value if a higher fitness value indicates a better member and vice versa. Rosters can be encoded as strings representing the individual members of the population. Performing the genetic algorithm, i.e., selection, crossover and mutation, leads then to generations of improved rosters, and the roster with the best fitness value can be finally selected (e.g., Aickelin and Dowsland 2000).

Genetic algorithms obviously fit with the task of staff rostering as they address its very nature as an optimization problem and provide feasible rosters considering a multitude of constraints. They are able to automate the rostering task and to informate regarding valid rosters. Genetic algorithms clearly outperform any manual scheduling. Given that various publications indicate the successful application of genetic algorithms in staff rostering (e.g., Aickelin and Dowsland 2000; Gonçalves et al. 2005; Kim et al. 2014; Moz and Vaz Pato 2007; Souai and Teghem 2009), and given that genetic algorithms are actually integrated in commercial staff rostering software (e.g., Ernst et al. 2004), a mature scenario of applying an intelligent solution search technique in HRM can be presented.

7.3.5 Sentiment Analysis with Text Mining

Text mining (also "text analytics") offers different functionalities related to unstructured text documents (e.g., Aggarwal and Zhai 2012): Topic detection and tracking identifies topics in documents, lists text documents that are related to the same topic, and assigns new documents to already identified topics. Text summarization summarizes the content of a text document in a brief summary. Text classification classifies text documents into predefined categories. An application example of text classification is sentiment analysis: Sentiment analysis (also "opinion mining") aims at the automatic extraction of sentiments and opinions that are expressed in unstructured text documents and, thus, classifies text documents into the categories “positive sentiments” and “negative sentiments” (e.g., Liu and Zhang 2012; Pang and Lee 2008). In this way, it becomes possible to condense sentiments expressed in numerous texts, such as employer reviews on employer rating web sites. The basic intelligent techniques used to realize sentiment analysis is a combination of text preprocessing and subsequent text classification. Text preprocessing refers to the decomposition of the text into single terms (“tokenization”), the linguistic categorization of these terms (“tagging”), their reduction to the root form (“lemmatization”), and their transformation into a vector that renders the relative frequency of all identified terms (“vector space model”). These vector models can then be used as input for text classification, while support vector machines are algorithms that are frequently employed for classification. As is usual in knowledge discovery, the classification algorithm has to first be “trained” based on training documents. Thus, these training documents are first preprocessed to obtain a vector space model of each document that can be used by the algorithm to induce rules for documents expressing positive or negative sentiments or opinions (e.g., Liu and Zhang 2012). After the classification algorithm training, the documents that need to be analyzed also have to be transferred into vector space models via preprocessing before the rules are used to classify the analysis documents as expressing either positive or negative sentiments. The combination of preprocessing as an intelligent text processing technique and classification as an intelligent knowledge discovery technique allows for analyzing and summarizing sentiments expressed in documents, while text mining therewith can be uncovered as an inherently hybrid technique.

An application scenario of text mining in HRM is sentiment analysis (e.g., Strohmeier et al. 2015). Knowing sentiments of employees, managers, applicants and further HR stakeholders relating to numerous HR-relevant aspects, such as compensation ratios, career possibilities, quality of training, leadership style, work climate, etc., constitutes valuable information on the strengths and weaknesses of HRM as perceived by the major stakeholders. Such opinions and sentiments are increasingly expressed in numerous web-based documents on employer rating websites, social networks, blogs, etc. Text mining can realize the task of analyzing sentiments, as rendered in Fig. 7.5.

Initially, suitable training documents must be crawled, preprocessed and transferred into vectors that a classification algorithm can use as input to learn classification rules that render typical vectors for the respective sentiment classes, such as “sentiments staffing: negative” or “sentiments compensation: positive”. These rules are then applied on preprocessed analysis documents to classify them into a specific class. These individual results can be aggregated in a bar diagram that shows positive and negative ratings. If text documents for several companies c1, c2, … are analyzed, results can also be compared. Moreover, depending on existing text documents, more detailed and refined information can be gained. For instance, the refined knowledge on how the compensation policy (i.e., types, amount and structure of compensation) is judged by employees and applicants will offer valuable insights into strengths and weaknesses and thus support strategic compensation decisions.

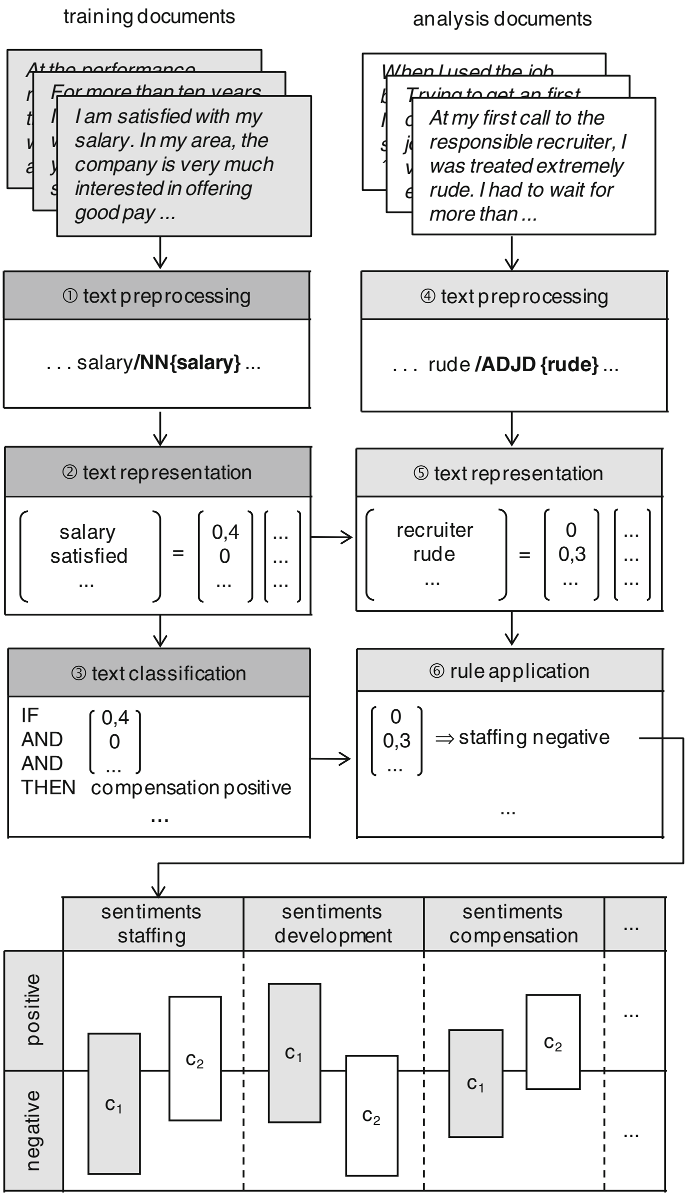

Fig. 7.5 Sentiment analysis with text mining (adopted from Strohmeier et al. 2015)

Text mining therewith fits with the task of the analysis of HR-related sentiments expressed in unstructured text data. Compared to a manual realization, central improvements relate to efficiency because even a very large number of texts that are beyond manual processing can be easily analyzed; however, the individual training of the system also implies initial effort before any application. Visibly, the scenario therewith aims at supporting the information in all HR functions. Currently, there are diverse concepts and prototypes of HR sentiment analysis (e.g., Aqel and Vadera 2010; Brindha and Santhi 2012) and also pioneering commercial offers of HR software vendors. Text mining thus constitutes an intelligent technique that is on the verge of application in HRM.

7.3.6 Résumé Data Acquisition with Information Extraction

Information extraction aims at automatically finding and extracting, structured information from unstructured or semi-structured text (e.g., Jiang 2012; Sarawagi 2008). The fundamental tasks of information extraction are named entity recognition and relation extraction. A named entity is a token (i.e., a character or a group of characters) or a sequence of tokens that denotes a real world entity, such as a certain person, organization or qualification. Relations span two or more entities related in a specific way, such as "is employee of." Information extraction requires several text preprocessing steps, such as tokenization, part of speech tagging and lemmatization (see Sect. 3.5). There are several methods to perform information extraction that can be roughly categorized into rule-based and statistical methods (e.g., Jiang 2012; Sarawagi 2008). Rule-based extraction methods rely on a (manually defined or automatically learnt) set of rules with hard predicates, while statistical methods are based on a weighted sum of predicates to identify and extract entities and entity relationships. Information extraction enables the automatic identification and extraction of named entities and entity relations in a text and therewith constitutes a particular category of intelligent language technique focusing on text processing.

An application scenario in HRM is résumé data acquisition (also "CV parsing"). Within the recruiting process, organizations regularly receive a plethora of résumés in terms of text documents. These text documents then have to be processed by humans, i.e., the relevant information has to be manually extracted and entered into HR information systems to continue the recruiting process. Information extraction aims at automating this process by an automatic identification and extraction of relevant information from the résumés of job applicants, such as name, address, job titles, work periods, names of previous organizations, qualifications, etc., to provide and process this information in HR information systems (e.g., Kaczmarek et al. 2005; Karamatli and Akyokus 2010; Sen et al. 2012; Yu et al. 2005). Résumés are usually semi-structured text documents providing information in different blocks, such as personal information, educational information, work experience, etc. Hence, instead of searching the whole text, structuring the document into the respective blocks of information eases the automatic identification and extraction of the respective entities (e.g., Sen et al. 2012; Yu et al. 2005). For example, the entity "candidate name" can be found within the personal information block, whereas entities of qualifications can be found within the educational information block. Because résumés are provided in diverse text data formats, such as pdf, txt, etc., résumé information extraction should be able to handle different formats. The identification of a specific single entity can then be performed, for example, with rule-based methods where the rule optionally captures the context before the start and after the end of an entity and matches the tokens in the entity. Identifying a person's degree from university can hence be based, for example, on rules capturing the string "university" around "master" or "bachelor" within the educational information block. Résumé information extraction might also incorporate knowledge representation techniques, such as ontologies (see Sect. 3.3), to consider semantic aspects in information extraction (e.g., Çelik and Elçi 2013), therewith constituting an improved hybrid approach. Résumé information extraction usually provides the extracted information in diverse conventional formats, such as HR-XML, XML or JSON, which can be easily imported into HR information systems, such as recruiting systems.

Résumé data acquisition with information extraction evidently fits with the HR task of ascertaining résumé data from text documents and entering them into HR information systems. It automates the time consuming manual ascertainment by humans, including reading résumés, extracting relevant data and entering them into respective HR information systems. Therefore, résumé processing with information extraction evidently aims at automating staffing. Central improvements are the increased speed of further processing of applicant data, offering the potential to decrease respective costs. Résumé data acquisition with information extraction shows a high level of maturity because diverse domain specific systems have been offered by various vendors for several years.

7.3.7 Employee Self-service with Interactive Voice Response

Interactive voice response (IVR) aims at the interaction of humans and computers via voice. Such voice-based interactions can be realized via direct voice contact of the human and the computer or mediated voice contact via telephone or networks, such as the web. Basic intelligent technologies that underlie IVR are automated speech recognition and automated speech synthesis (e.g., Benesty et al. 2008). Automated speech recognition (also "speech to text [STT]") aims at the conversion of spoken language into machine-readable strings. The speech recognition process comprises different steps (Deng and Li 2013; Gulzar et al. 2014): Initially the human speech signal has to be received and stored in an audio file. Using differing extraction algorithms, typical features of speech signals are extracted and transformed into mathematical models of the signal in the form of a vector. These vectors are used as input for recognition algorithms that associate the vector to text; as an example, Hidden Markov Models are frequently used for recognition (for an overview of different extraction and recognition techniques, see Gulzar et al. 2014). As a result of automated speech recognition, the speech utterance of the human user is transformed into its textual correlation, which is machine-readable and, thus, can be used by the computer for further action. To transform computer output into voice, automated speech synthesis (also "text to speech [TTS]") is employed. Automated speech synthesis is realized in different steps (Schroeter 2008): Initially, the input text document has to be preprocessed, which includes tasks such as text structure identification (e.g., number and type of sentences) or text normalization (e.g., handling of abbreviations and acronyms). A subsequent phonetic analysis prepares the speech by grapheme-to-phoneme conversion, i.e., determining the pronunciation of each word. Based on this, a prosodic analysis determines the adequate intonation, duration, and loudness, among other aspects. The still symbolic output of these analyses steps is used by speech synthesizers that actually perform the articulation. Major types of synthesizers are articulatory (the synthesizer uses a computer model of the human vocal tract and its parts to simulated articulation), formant (the synthesizer computes the waveform of the intended acoustic output) and concatenating (the synthesizer concatenates units of recorded sounds from a database).

An application scenario of interactive voice response in HRM is employee self-service (ESS). ESS aims at the technology-based shifting of HR tasks from HR professionals to employees. Basically, ESS is perceived as a concept that transfers operational tasks, such as updating personal data, changing benefits, or registering for training measures, etc., to employees, with the major objective of efficiency gains (e.g., Marler et al. 2009). Major technologies used to realize ESS are telephony- and web-based systems. Telephony-based ESS enables employees to carry out tasks remotely using mobile and fixed-net telephones. A typical application example is time bookings of employees that work outside the company within the frame of attendance management. It becomes immediately clear that IVR constitutes the basic enabling technology of telephony-based ESS. IVR enables the employee to interact with diverse HR backend systems, such as time and attendance management systems, to fulfill the respective task. Inputs, such as requests, data input, etc., can be directly made by voice, and respective outputs of the system can again be offered by voice. While telephony-based ESS arguably constitutes the main application scenario, IVR might be well used also in web-based ESS, for instance, for speech-based search of content on an HR portal or for realizing chat-bots that answer HR related questions.

As an intelligent speech processing technique, IVR therewith visibly fits with the task of enabling the voice-based interaction of employees with a broader set of HR backend systems. For simpler operational HR tasks throughout the respective HR functions, it becomes possible to automate the interaction tasks of human HR professionals and, thus, to realize ESS concepts. Major improvements relate to efficiency gains, in particular cost and time savings in the HR department (e.g., Marler et al. 2009). Moreover, the permanent availability of HR services "around the clock" also constitutes an improvement. IVR has been a mature technology in HR for some time and is—with some international differences—also broadly applied.

7.4 Discussion: Potential of AI Techniques in HR Management

Against the backdrop of the task-technology fit approach, an application of AI techniques is successful if the AI techniques offer functionalities that correspond with the requirements of the HR task. The discussion of mature application scenarios could uncover that, across different technique and task categories, fitting combinations could be found. This basically underscores the assumption of the broad application potential of AI techniques in all categories of HR tasks. However, it also became very clear that these application potentials are far from being explored and, all the more, far from being practically exploited; also, not each AI technique is suitable in HR management, and not each HR task can be solved by an AI technique. While, ultimately, the fit of technique and task has to be laboriously elaborated on an individual basis, some concretizations can be made on the categorical level in the following.

Starting with knowledge discovery techniques, the above scenario of using artificial neural networks for turnover prediction reveals that this category mainly fits with the requirement of informating HR throughout the respective tasks. In particular, knowledge discovery techniques can be used to complement conventional querying approaches that yield historic-descriptive information (that describes existing phenomena) with explanative information (that gives reasons for existing phenomena) and predictive information (that predicts future phenomena) (Strohmeier and Piazza 2010). This potential of complementing existing HR information techniques is also underscored by the growing research on knowledge discovery techniques in HRM that refers to a remarkably broad portfolio of individual technique task-combinations (Strohmeier and Piazza 2013).

Combining knowledge representation and knowledge processing techniques, in the last decade of the last century, there were expectations towards establishing knowledge-based "expert systems" in HRM (e.g., Inoue 1993; Lawler and Elliot 1996). However, these expectations could not be met in practice given that expert system technology was not more broadly developed and applied. Yet, within the framework of semantic (web) technologies, knowledge-based techniques experienced a phase of revival in HRM, as also demonstrated with the application scenario of knowledge-based candidate search. The scattered research on semantic technologies in HRM mostly refers to semantic search, retrieval and matching in recruiting (mostly candidates and jobs) or development (mostly learners and courses), while explicit research reviews are missing (e.g., Ontology Outreach Advisory 2007; Janev and Vraneš 2010). Given this, the potential of knowledge discovery and processing techniques has to be determined more abstractly as fitting the task of establishing interoperability between humans and machines or between different machines that use deviating designations, therewith enabling further communication and "understanding". Evidently, this abstract potential might apply to a broad set of concrete automation as well as information tasks across all HR functions.

Solution searching techniques refer to quantifiable optimization tasks, while in HR different assignment tasks can be subsumed under this category. As exemplified with the scenario of staff rostering, assignment tasks exist mainly in staffing (assignment of employees to tasks, projects, shifts, position, units, etc.). Moreover, career and succession planning as a subcategory of development comprises the related task of assigning employees to different career positions over time. Further HR-related assignment tasks, for instance, assignment of instructors, rooms and learners in employee development, are imaginable yet not investigated thus far. For several decades, such tasks have been already addressed by optimization techniques from operations research. Yet, given that that these problems often qualify as NP-hard, they are not solvable by optimization. Solution searching techniques from AI thus constitute an important heuristic alternative for HR assignment problems (Ernst et al. 2004).

Text processing techniques correspond with the existence of a broad variety of HR-relevant text documents, such as employee mailings, application documents, references, written memos, or performance appraisals, among others, and related HR tasks. A first general potential is the automation of a broad variety of document-related operational tasks, such as searching, ranking, categorizing, extracting, comparing or summarizing text documents, among others. The scenario of automatically extracting CV data constitutes an example for this automation potential. A second general potential is in providing decision-supporting information by analyzing text documents. The scenario of sentiment analysis in web documents constitutes an example of this potential. Following a general trend in business intelligence, in this way, information based on structured data can be complemented with information based on unstructured data also in HR management (e.g., Strohmeier et al. 2015).

Finally, speech processing techniques offer the basic potential of speech-based human machine interaction as elaborated on in the scenario of interactive voice response for employee self-service. Basically, the potential of speech processing exists in situations where keyboard-operated computing is uncomfortable or difficult, such as in mobile computing.

Aiming at harnessing these potentials in the future mandatorily implies the tasks of evaluating the success potentials and developing a domain-driven application of AI techniques in HRM. Evaluating the success potential does firstly imply a thorough estimation of whether the providable functionality actually fits with HR tasks that are practically relevant. Moreover, given that HRM already disposes of a broader set of well-established techniques for a broader set of HR tasks, the intended application of an AI technique has to be compared with already existing HR techniques. Any AI technique needs to be more effective (improved results) and/or more efficient (less implementation effort) than the already established HR techniques; otherwise, an application is useless. For example, the application of neural networks to predict employee turnover might achieve valid results in predicting the probability of employees leaving the organization. If, however, established techniques, such as simple interviews of employees and line managers, deliver the same or even improved results, an application of an ANN is not useful. In this way, AI techniques not only need to fit with HR task requirements but also have to outperform the existing techniques. Developing a domain-driven application constitutes a second necessary step. Just providing the "pure" AI technique and expecting that HR professionals adjust the technique to their needs and then utilize it does not usually work. The adaption of any AI technique to a practical HR task constitutes a voluminous and challenging task sui generis that requires both deep HR knowledge and deep AI knowledge. An excellent possibility to realize this is to directly embed AI functionality in domain-specific HR information systems (Strohmeier and Piazza 2013). This allows HR professionals to apply the AI technique within their familiar domain context without having sophisticated technical and/or methodical AI skills. Providing such "custom-fit" HR applications constitutes a prominent method of harnessing thus far unexploited potentials of AI techniques in a way that is actually accepted and, therefore, actually creates value for HRM.

References

Abburu, S.: A Survey on ontology reasoners and comparison. Int. J. Comput. Appl. **57**(17), 33–39 (2012)

Aggarwal, C.C., Zhai, C.X.: An introduction to text mining. In: Aggarwal, C.C., Zhai, C.X. (eds.) Mining Text Data, pp. 1–10. Springer, Berlin (2012)

Aickelin, U., Dowsland, K.A.: Exploiting problem structure in a genetic algorithm approach to a nurse rostering problem. J. Sched. **3**(3), 139–153 (2000)

Aqel, D., Vadera, S.: A framework for employee appraisals based on sentiment analysis. In: Proceedings of the 1st International Conference on Intelligent Semantic Web-Services and Applications (2010)

Benesty, J., Sondhi, M.M., Huang, Y.A.: Introduction to speech processing. In: Benesty, J., Sondhi, M.M., Huang, Y. (eds.) Springer Handbook of Speech Processing, pp. 1–4. Springer, Berlin (2008)

Bock, J., Haase, P., Ji, Q., Volz, R.: Benchmarking OWL reasoners. In: Proceedings of the ARea2008 Workshop, Tenerife, Spain, June (2008)

Brachman, R.J., Levesque, H.J.: Knowledge Representation and Reasoning. Morgan Kaufmann, Burlington (2004)

Brindha, G.R., Santhi, B.: Application of opinion mining technique in talent management. In: Proceedings of 2012 International Conference on Management Issues in Emerging Economies (ICMIEE), pp. 127–132 (2012)

Burgard, M., Piazza, F.: Data warehouse and business intelligence systems in the context of e-HRM. In: Torres-Coronas, T., Arias-Oliva, M. (eds.) Encyclopedia of HRIS: Challenges in e-HRM, pp. 223–229. Hershey, PA (2009)

Çelik, D., Elçi, A.: An ontology-based information extraction approach for résumés. In: Zu, Q., Hu, Q., Elçi, A. (eds.) Pervasive Computing and the Networked World, Joint International Conference ICPCA/SWS 2012, pp. 165–179. LNCS 7719, Springer, Berlin (2013)

Chien, C.F., Chen, L.F.: Data mining to improve personnel selection and enhance human capital: a case study in high-technology industry. Expert Syst. Appl. **34**(1), 280–290 (2008)

Davis, R., Shrobe, H., Szolovits, P.: What is a knowledge representation? AI Mag. **14**(1), 17–33 (1993)

Deng, L., Li, X.: Machine learning paradigms for speech recognition: an overview. IEEE Trans. Audio Speech Lang. Process. **21**(5), 1–30 (2013)

Devanna, M.A., Fombrun, C.J., Tichy, N.: A framework for strategic human resource management. In: Fombrun, C.J., Tichy, N., Devanna, M.A. (eds.) Strategic Human Resource Management, pp. 33–51. Wiley, New York (1984)
Duch, W.: What is Computational Intelligence and where is it going? Challenges for Computational Intelligence, pp. 1–13. Springer, Berlin (2007)
Ernst, A.T., Jiang, H., Krishnamoorthy, M., Sier, D.: Staff scheduling and rostering: a review of applications, methods and models. Eur. J. Oper. Res. **153**(1), 3–27 (2004)
Fan, C.Y., Fan, P.S., Chan, T.Y., Chang, S.H.: Using hybrid data mining and machine learning clustering analysis to predict the turnover rate for technology professionals. Expert Syst. Appl. **39**(10), 8844–8851 (2012)
Fayyad, U., Piatetsky-Shapiro, G., Smyth, P.: From data mining to knowledge discovery in databases. AI Mag. **17**(3), 36–53 (1996)
Furneaux, B.: Task-technology fit theory: a survey and synopsis of the literature. In-formation Systems Theory, pp. 87–106. Springer, New York (2012)
Goodhue, D.L., Thompson, R.L.: Task-technology fit and individual performance. MIS Q. **19**(2), 213–236 (1995)
Giotopoulos, K.C., Alexakos, C.E., Beligiannis, G.N., Likothanassis, S.D.: Integrating agents and computational intelligence techniques in E-learning environments. Int. J. Soc. Hum. Sci. Eng. **1** (7), 412–419 (2007)
Gonçalves, J.F., de Magalhães Mendes, J.J., Resende, M.G.C.: A hybrid genetic algorithm for the job shop scheduling problem. Eur. J. Oper. Res. **167**(1), 77–95 (2005)
Guarino, N., Oberle, D., Staab, S.: What is an ontology? In: Staab, S., Studer, R. (eds.) Handbook on Ontologies, pp. 1–17. Springer, Berlin (2009)
Guha, R., McCool, R., Miller, E.: Semantic search. In: Proceedings of the 12th ACM International conference on World Wide Web, pp. 700–709. May 2003
Gulzar, T., Singh, A., Rajoriya, D.K., Farooq, N.: A systematic analysis of automatic speech recognition: an overview. Int. J. Curr. Eng. Technol. **4**(3), 1664–1675 (2014)
Hornik, K., Stinchcombe, M., White, H.: Universal approximation of an unknown mapping and its derivatives using multilayer feedforward networks. Neural Networks **3**(5), 551–560 (1990)
Inoue, Y.: Intelligent human resource management system: applications of expert system technology. Int. J. Appl. Expert Syst. **1**(3), 213 (1993)
Jackson, S.E., Schuler, R.S., Jiang, K.: An aspirational framework for strategic human resource management. Acad. Manage. Ann. **8**(1), 1–56 (2014)
Janev, V., Vraneš, S.: Applicability assessment of semantic web technologies in human resources domain. Inf. Res. Manage. J. **23**(3), 27–42 (2010)
Jantan, H., Hamdan, A.R., Othman, Z.A.: Intelligent techniques for decision support system in human resource management. In: Devlin, G. (ed.) Decision Support Systems, Advances in, pp. 261–276. InTech, Rijeka (2010)
Jiang, J.: Information extraction from text. In: Aggarwal, C.C., Zhai, C. (eds.) Mining Text Data, pp. 11–41. Springer, New York (2012)
Jurafsky, D., Martin, J.H.: Speech and Language Processing, 2nd edn. Prentice Hall, Pearson (2008)
Kaczmarek, T., Kowalkiewicz, M., Pikorski, J: Information Extraction from CV. In: Proceedings of the 8th International Conference on Business Information Systems, pp. 3–7 (2005)
Kahraman, C., Kaya, I., Çevikcan, E.: Intelligence decision systems in enterprise information management. J. Enterp. Inf. Manage. **24**(4), 360–379 (2011)
Kahraman, C., Kaya, I., Çinar, D.: Computational intelligence: past, today, and future. In: Ruan, D. (ed.) Computational Intelligence in Complex Decision Systems, pp. 1–46. Atlantis Press, Paris (2010)
Karamatli, E., Akyokus, S.: Resume information extraction with named entity clustering based on relationships. In: International Symposium on Innovations in Intelligent Systems and Applications (2010)
Kim, S., Ko, Y., Uhmn, S., Kim, J.: A strategy to improve performance of genetic algorithm for nurse scheduling problem. Int. J. Soft. Eng. Appl. **8**(1), 53–62 (2014)

Lawler, J.J., Elliot, R.: Artificial intelligence in HRM: an experimental study of an expert system. J. Manag. **22**(1), 85–111 (1996)

Leshno, M., Lin, V.Y., Pinkus, A., Schocken, S.: Multilayer feedforward networks with a nonpolynomial activation function can approximate any function. Neural Networks **6**(6), 861–867 (1993)

Linoff, G.S., Berry, M.J.A.: Data Mining Techniques. Wiley, Indianapolis (2011)

Liu, B., Zhang, L.: A survey of opinion mining and sentiment analysis. In: Aggarwal, C.C., Zhai, C.X. (eds.) Mining Text Data, pp. 415–463. Springer, Berlin (2012)

Luger, G.F.: Artificial intelligence: Structures and strategies for complex problem solving. Pearson education, Edinburgh (2005)

Mangold, C.: A survey and classification of semantic search approaches. Int. J. Metadata Semant. Ontol. **2**(1), 23–34 (2007)

Marler, J.H., Fisher, S.L., Ke, W.: Employee self-service technology acceptance: a comparison of pre-implementation and post-implementation relationships. Pers. Psychol. **62**(2), 327–358 (2009)

Mochol, M., Jentzsch, A., Wache, H.: Suitable employees wanted? Find them with semantic techniques. In: Proceedings of Workshop on Making Semantics Web For Business at European Semantic Technology Conference (ESTC2007), Vienna, Austria (2007)

Moz, M., Vaz Pato, M.: A genetic algorithm approach to a nurse rerostering problem. Comput. Oper. Res. **34**(3), 667–691 (2007)

Ontology Outreach Advisory: HR semantics roadmap. The Semantic Challenges and Opportunities in the Human Resource domain. White Paper (2007)

Pang, B., Lee, L.: Opinion mining and sentiment analysis. Found. Trends Inf. Retrieval **2**(1–2), 1–135 (2008)

Quinn, A., Rycraft, J.R., Schoech, D.: Building a model to predict caseworker and supervisor turnover using a neural network and logistic regression. J. Technol. Hum. Serv. **19**(4), 65–85 (2002)

Rojas, R.: Neural Networks—A Systematic Introduction. Springer, Berlin (1996)

Sarawagi, S.: Information extraction. Found. Trends Databases **1**(3), 261–377 (2008)

Schroeter, J.: Basic principles of speech synthesis. In: Benesty, J., Sondhi, M.M., Huang, Y. (eds.) Springer Handbook of Speech Processing, pp. 413–428. Springer, Berlin (2008)

Sen, A., Das, A., Ghosh, K., Ghosh, S.: Screener: a system for extracting education related information from resumes using text based information extraction system. In: International Conference on Computer and Software Modeling, vol. 54, pp. 31–35 (2012)

Sexton, R.S., McMurtrey, S., Michalopoulos, J.O., Smith, A.M.: Employee turnover: a neural network solution. Comput. Oper. Res. **32**(10), 2635–2651 (2005)

Sivanandam, S.N., Deepa, S.N.: Introduction to Genetic Algorithms. Springer, Heidelberg (2008)

Somers, M.J.: Application of two neural network paradigms to the study of voluntary employee turnover. J. Appl. Psychol. **84**(2), 177–185 (1999)

Souai, N., Teghem, J.: Genetic algorithm based approach for the integrated airline crew-pairing and rostering problem. Eur. J. Oper. Res. **199**(3), 674–683 (2009)

Strohmeier, S., Piazza, F.: Informating HRM: a comparison of data querying and data mining. Int. J. Bus. Inf. Syst. **5**(2), 186–197 (2010)

Strohmeier, S., Piazza, F.: Domain driven data mining in human resource management: a review of current research. Expert Syst. Appl. **40**(7), 2410–2420 (2013)

Strohmeier, S., Piazza, F., Neu, C.: Trends der human resource intelligence und analytics. In: Strohmeier, S. Piazza, F. (eds.) Human Resource Intelligence und Analytics. Grundlagen, Anbieter, Erfahrungen und Trends, pp. 338–367. Springer Gabler, Wiesbaden (2015)

Strohmeier, S., Gasper, C., Müller, D.: Entwicklung und Evaluation semantischer Jobportale - Ein "Design Science"- Ansatz. In: Heiß, H.-U., Pepper, P., Schlingloff, H., & Schneider, J. (eds.) Proceedings INFORMATIK 2011 (LNI 192), Berlin, 137–155 (2011)

Tanwar, P., Prasad, T.V., Aswal, M.S.: Comparative study of three declarative knowledge representation techniques. Int. J. Comput. Sci. Eng. **2**(07), 2274–2281 (2010)

Wang, P.: What do you mean by “AI”? In: Artificial General Intelligence, 2008: Proceedings of the First AGI Conference, vol. 171, p. 362. IOS Press (2008)
Whitley, D.: A genetic algorithm tutorial. Stat. Comput. **4**(2), 65–85 (1994)
Wolf, A., Jenkins, A.: Explaining greater test use for selection: The role of HR professionals in a world of expanding regulation. Hum. Resour. Manage. J. **16**(2), 193–213 (2006)
Wu, X., Kumar, V., Quinlan, J.R., Ghosh, J., Yang, Q., Motoda, H., Steinberg, D.: Top 10 algorithms in data mining. Knowl. Inf. Syst. **14**(1), 1–37 (2008)
Yu, K., Guan, G., Zhou, M.: Resume information extraction with cascaded hybrid model. In: Proceedings of the 43rd Annual Meeting of the ACL, pp. 499–506 (2005)
Zuboff, S.: Automate/informate: the two faces of intelligent technology. Org. Dyn. **14**(2), 5–18 (1985)

Chapter 8
Analyzing Dynamic Capabilities via Fuzzy Cognitive Maps

Veysel Çoban, Sezi Çevik Onar and Ayberk Soyer

Abstract Today, free trade, internet, and mobile technologies have given rise to global markets with high levels of change. In order to survive in such fluid environments, firms need to be able to quickly adapt themselves to rapid changes. The concept of "dynamic capabilities" deals with the organizational capacity to understand the need for change, plan response to change, and finally, implement these plans. Although dynamic capabilities are crucial for the survival of an organization, there is no comprehensive study of the factors related to dynamic capabilities and their effect on a firm's success. Complexity and vagueness of these concepts precludes developing a comprehensive model. The computational intelligence techniques such as fuzzy models, artificial neural networks, and genetic algorithms can be utilized to handle this complexity and vagueness. Therefore, a Fuzzy Cognitive Map based (FCM-based) model is proposed in this chapter to overcome the modeling difficulty. The factors related to dynamic capabilities, which are collected from an extensive literature review, are defined as concepts and their fuzzy relations are represented as causal links in a graph structure.

Keywords Dynamic capabilities · Fuzzy cognitive map · Competitive advantage · Environmental change

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8.1 Introduction

Today, as markets are increasingly being globalized, technology is rapidly advancing, and customer needs are changing over time, uncertainty in the business environment has increased significantly, which in turn has given rise to increased competition among firms. In order to survive in such dynamic and uncertain environments, individual firms need to adopt new approaches to be able to respond and adapt to environmental changes. In other words, to be able to cope with a rapidly changing business environment, firms should be managed in such a way that they always have an efficient set of strategic options that can be executed as market conditions change. One way of accomplishing this challenging task, and thus achieving and sustaining competitive advantage, is having the ability (i) to understand customer needs and market dynamics, (ii) to address opportunities/ threats in the environment, and (iii) to change existing resources and capabilities. Teece et al. (1997) named this ability as "dynamic capability," and defined it as the firm's ability to integrate, build, and reconfigure internal and external capabilities to achieve new and innovative forms of competitive advantage.

In the search for sources of sustained competitive advantage, some researchers proposed the Resource Based View (RBV) (Barney 1991; Peteraf 1993; Wernerfelt 1984, among others), which asserts that resources that are valuable, rare, inimitable, and cannot be strategically substituted, form the basis of competitive advantage. Adopting a static point of view, RBV does not incorporate the evolution of resources over time. On the other hand, another group of researchers (Teece et al. 1997; Eisenhardt and Martin 2000; Helfat 1997; Helfat and Peteraf 2003; Teece 2007; Wang and Ahmed 2007, among others), adopting a dynamic point of view, extended RBV to dynamic markets and claimed that adapting, integrating, and reconfiguring existing firm-specific capabilities and developing new capabilities enable firms to fulfill requirements of a fast changing environment, and thus, to gain competitive advantage. In the literature, a firm's capacity "to understand the need of change, plan a response to change requirements, and implement these plans" is conceptualized as dynamic capabilities (Eisenhardt and Martin 2000; Helfat 1997; Helfat and Peteraf 2003; Teece 2007; Teece and Pisano 1994).

In the 2000s and beyond, many researchers extended Teece et al. (1997)'s seminal study and provided new and conflicting views about the definition, antecedents, and consequences of the dynamic capability concept (Eisenhardt and Martin 2000; Helfat 1997; Helfat and Peteraf 2003; Teece 2007; Wang and Ahmed 2007; Ambrosini and Bowman 2009; Barreto 2010; Helfat et al. 2007; Helfat and Winter 2011; Winter 2003; Wu 2006; Zollo and Winter 2002; Zott 2003). Although dynamic capabilities are suggested to be crucial for organizational success and survival, there is not a single comprehensive study on the determinants and effects of dynamic capabilities. Therefore, in this chapter, a Fuzzy Cognitive Map (FCM) model, which allows modeling the behavior of a complex system of causal reasoning, is proposed to analyze the factors related to dynamic capabilities. As FCM is based on fuzzy logic, which is one of the main computational intelligence techniques (some of the other techniques are neural networks, evolutionary computation, swarm intelligence, hybrid systems, etc.), the developed FCM model helps to reflect the intelligent behavior of the concepts related to dynamic capabilities in complex and changing environments. The proposed FCM model provides a graphical representation (in the form of a signed fuzzy diagraph) and allows modeling and control of the causal relationships between the factors related to dynamic capabilities. All relevant factors that are considered in the FCM model, the causal relationships among these factors, and the weights of these causal relationships are identified through a comprehensive literature survey. Consequently, in order to predict the reactions to possible changes in the system, the constructed FCM model is used to perform qualitative simulations under different scenarios. The results provide the basis for clarifying the relationships among the dynamic capabilities and other related factors.

The remainder of this chapter is organized as follows. In Sect. 8.2, the literature on dynamic capabilities is reviewed briefly. Section 8.3 introduces FCMs, followed by Sect. 8.4, in which an application of the FCM is presented to investigate relationships among the factors in the FCM model. Finally, Sect. 8.5 summarizes the conclusions of this chapter.

8.2 Dynamic Capabilities

The concept of dynamic capability dates back to 1994. Collis (1994) highlighted the importance of "capability of developing new capabilities." The "dynamic capability" concept was first described by Teece and Pisano (1994) and Iansiti and Clark (1994). Iansiti and Clark (1994) defined the concept as "the capacity of an organization to consistently nurture, adapt, and regenerate its knowledge base, and to develop and retain the organizational capabilities that translate that knowledge base into useful actions". In a similar vein, Teece et al. (1997) described dynamic capabilities as a "firm's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments".

Although there are many studies on dynamic capabilities, a common definition of the concept is still missing. Eisenhardt and Martin (2000) defined dynamic capabilities as "the firm's processes that use resources to integrate, configure, gain and release resources to match and even create market change." Zollo and Winter (2002) claimed that dynamic capabilities emerge from learning mechanisms; namely, experience accumulation, knowledge articulation, and knowledge codification processes. Apart from various definitions (See Table 8.1), there are many different models that attempt to explicate the concept of dynamic capabilities (Teece 2007; Wang and Ahmed 2007; Barreto 2010; Helfat et al. 2007; Winter 2003; Zahra et al. 2006). Therefore, this chapter aims to clarify the concept of "dynamic capabilities" and reveal the factors affecting it.

Table 8.1 Dynamic capability definitions

Article	Definition
Collis (1994)	The capability that wins tomorrow is the capability to develop the capability that innovates faster (or better), and so on
Iansiti and Clark (1994)	The capacity of an organization to consistently nurture, adapt, and regenerate its knowledge base, and to develop and retain the organizational capabilities that translate that knowledge base into useful actions
Teece and Pisano (1994)	Subset of the competences/capabilities, which allow the firm to create new products and processes, and respond to changing market circumstances
Teece et al. (1997)	A firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments
Helfat (1997)	Dynamic capabilities enable firms to create new products and processes and respond to changing market conditions
Eisenhardt and Martin (2000)	A firm's processes that use resources—specifically the processes to integrate, reconfigure, gain and release resources—to match and even create market change. Dynamic capabilities thus are the organizational and strategic routines by which firms achieve new resource configurations as markets emerge, collide, split, evolve, and die
Zollo and Winter (2002)	A learned and stable pattern of collective activity through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness
Winter (2003)	Capabilities that operate to extend, modify or create ordinary capabilities
Zahra et al. (2006)	The abilities to reconfigure a firm's resources and routines in the manner envisioned and deemed appropriate by its principal decision-maker(s)
Teece (2007)	Dynamic capabilities can be disaggregated into the capacity (1) to sense and shape opportunities and threats, (2) to seize opportunities, and (3) to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets
Wang and Ahmet (2007)	A firm's behavioral orientation constantly to integrate, reconfigure, renew and recreate its resources and capabilities and, most importantly, upgrade and reconstruct its core capabilities in response to the changing environment to attain and sustain competitive advantage
Helfat et al. (2007)	Capacity of an organization to purposefully create, extend and modify its resource base
Barreto (2010)	A firm's potential to solve problems systematically, formed by its propensity to sense opportunities and threats, to make timely and market-oriented decisions, and to change its resource base

8.2.1 Factors Affecting Dynamic Capabilities

In order to reveal the factors affecting dynamic capabilities, a detailed literature review was conducted and 70 articles were reviewed in detail. These articles were chosen mainly from 44 different academic journals (e.g., British Journal of Management, Strategic Management Journal, Journal of Business Research, Journal of Management Studies, and Decision Science Journal), which were published between 1994–2014 (30 of these articles were published in journals indexed in the Social Sciences Citation Index).

All relationships among the factors related to dynamic capabilities were discovered and listed according to the corresponding articles. After listing all factors, these factors were aggregated according to their common properties. As a result, 28 factors were taken into consideration, such as "Dynamic Capabilities", "Environment", "Capability", "Innovation Capability", "Knowledge Management", "Lack of learning Mechanism", "Lack of Path Dependency", "Performance", and so on. All these 28 factors were defined according to their referred articles (See Table 8.2), and were used to create the relationship matrix given in Table 8.3.

Table 8.3 was generated according to the number of articles that asserted relevant relationships among factors. Then, using these frequencies of relations, the relationship degrees among the factors were calculated. Some representative examples for the relationships in Table 8.3, discussed in relevant articles, are given below:

- Firm specific resources, such as physical, human, and organizational assets (Barney 1991; Wernerfelt 1984) affect the performance of the firm via dynamic capabilities (Wu 2006).
- Dynamic capabilities affect the firm's existing resource base (Teece et al. 1997; Eisenhardt and Martin 2000; Helfat 1997).
- Dynamic capabilities positively affect firm performance (Teece et al. 1997; Eisenhardt and Martin 2000; Makadok 2001).
- Path dependency that refers to the firm's previous investments and its repertoire of routines (Teece et al. 1997; Teece and Pisano 1994) affects dynamic capabilities (Teece et al. 1997; Wang and Ahmed 2007; Ambrosini and Bowman 2009).
- Firm performance affects the innovation capabilities (i.e., the capabilities that create something new) (Helfat et al. 2007; Zahra et al. 2006).
- Knowledge resources and learning mechanisms, which are related to each other, positively affect the dynamic capabilities and firm performance (Chien and Tsai 2012).
- Dynamic capabilities have a significant effect on competitive advantage (Teece et al. 1997; Teece 2007; Ambrosini and Bowman 2009; Helfat et al. 2007; Li and Liu 2014; Helfat and Peteraf 2009).
- Dynamic capabilities are affected by environmental dynamism (Helfat et al. 2007; Helfat and Winter 2011; Zahra et al. 2006).
- Dynamic capabilities affect sustained competitive advantage, especially in high-velocity markets (Eisenhardt and Martin 2000; Ambrosini and Bowman 2009; Zahra et al. 2006).

Table 8.2 Factors related to dynamic capabilities

Factors	Definitions	Articles
Asset/Resources (A&R)	Resources are firm-specific assets that are difficult to imitate and transfer among firms because of their costs and tacit knowledge (Teece and Pisano 1994)	Teece and Pisano (1994), Ambrosini and Bowman (2009), Wu (2006), Zott (2003), Zahra et al. (2006), Ambrosini et al. (2009), Basu et al. (2013), Green et al. (2008), Kuuluvainen (2012), McKelvie and Davidsson (2009), Easterby-Smith and Prieto (2008), Lin and Wu (2014)
Collaboration Capability (CoLLC)	The ability to reduce the interfunctional and interorganizational conflict and develop the distinctive relational advantage of a firm (Allred et al. 2011)	Allred et al. (2011), Cao (2011)
Competitive Advantage (CA)	A state of organizations to cope with environmental changes and provide better products or services to customers than competitors (Li and Liu 2014)	Teece et al. (1997), Eisenhardt and Martin (2000), Teece and Pisano (1994), Li and Liu (2014), Cavusgil et al. (2007), McCulloch and Pitts (1943), Parayitam and Guru-Gharana (2010), Schilke 2014)
Coordination Capability (CoorC)	The ability of orchestration and deploying of tasks, resources, and activities (Pavlou and El Sawy 2011)	Pavlou and El Sawy (2011), Hung et al. (2007, 2010)
DCs	A firm's ability to integrate, build, and reconfigure its internal and external competences to respond environmental changes (Teece et al. 1997)	Teece et al. (1997), Eisenhardt and Martin (2000), Wang and Ahmed 2007), Teece and Pisano (1994), Ambrosini and Bowman (2009), Wu (2006), Zollo and Winter (2002), Zott (2003), Zahra et al. (2006), Ambrosiniet et al. (2009), Basu et al. (2013), Green et al. (2008), Kuuluvainen (2012), McKelvie and Davidsson (2009), Easterby-Smith and Prieto (2008), Lin and Wu (2014), Li and Liu (2014), Cavusgil et al. (2007), Parayitam and Guru-Gharana (2010), Pavlou and El Sawy (2011), Hung et al. (2007, 2010), Adner and Helfat (2003), Agarwal and Selen (2009), Anand et al. (2009), Aramand and Valliere (2012), Barrales-Molina et al. (2013), Blyler and Coff (2003), Chien and Tsai (2012), Dixit and Bhowmick (2010), Døving and Gooderham

(continued)

Table 8.2 (continued)

Factors	Definitions	Articles
		(2008) Drnevich and Kriauciunas (2011), Ellonen et al. (2011), Gómez and Ballard (2013), Hou and Chien (2010), Hsu and Wang (2012), Jiao et al. (2013), Lee et al. (2011), Macpherson et al. (2004), Makkonen et al. (2014), Malik and Kotabe (2009), Marsh and Stock (2006), Newey and Zahra (2009), Pablo et al. (2007), Parthasarathy et al. (2011), Piening (2013), Prieto et al. (2009), Simon (2010), Sirmon and Hitt (2009), Wilden et al. (2013), Wilkens et al. (2004), Yung-Chul (2013), Zhou and Li 2010)
Decentralization (DT)	Decentralized organizations that have local autonomy are awake to market and technological developments (Teece 2007)	Teece (2007), Cao (2011)
Entrepreneurship Capability (EC)	Innovative activities that are designed to create profitability and growth (Macpherson et al. 2004)	Zahra et al. (2006), Macpherson et al. (2004), Newey and Zahra (2009)
Environmental Dynamism (ED)	The rate of the environmental change (Prieto et al. 2009)	Peteraf (1993), Helfat and Peteraf (2003), Helfat and Winter (2011), McKelvie and Davidsson (2009), Easterby-Smith and Prieto (2008), Cavusgil et al. (2007), McCulloch and Pitts (1943), Pavlou and El Sawy (2011), Anand et al. (2009), Drnevich and Kriauciunas (2011), Ellonen et al. (2011), Gómez and Ballard (2013), Hou and Chien (2010), Hsu and Wang (2012, Macpherson et al. (2004), Makkonen et al. (2014), Marsh and Stock (2006), Parthasarathy et al. (2011), Piening (2013), Prieto et al. (2009), Sirmon and Hitt (2009), Axelrod et al. (1976), Helfat and Peteraf (2009), Kim et al. (2011), Makadok (2001)
Environmental Munificence (EM)	Supporting policies that help firms in identifying, selecting, and implementing new technologies, financial incentives, product quality standards, and complementary downstream capabilities (Malik and Kotabe 2009)	Malik and Kotabe (2009)

(continued)

Table 8.2 (continued)

Factors	Definitions	Articles
Flexibility (FX)	The ability of the firm to renew its routines to adapt to the new conditions, to sense and to respond quickly to external changes (Barrales-Molina et al. 2013)	Barrales-Molina et al. (2013), Kim et al. (2011)
Governance (GN)	Procedures to monitor the transfer of technology and intellectual property (Teece 2007)	Teece (2007), Cao (2011)
Human Resources (HR)	Employees are equipped with learned skills via education, training, or learning more generally (Adner and Helfat 2003)	Kuuluvainen (2012), McKelvie and Davidsson (2009), Easterby-Smith and Prieto (2008), Adner and Helfat (2003), Gómez and Ballard (2013), Hsu and Wang (2012), Macpherson et al. (2004), Kim et al. (2011), Hawass (2010)
Improvement Capability (ImpC)	The ability to improve current processes and learn new ones (Anand et al. 2009)	Zollo and Winter (2002), Zahra et al. (2006) McKelvie and Davidsson (2009), Anand et al. (2009), Pablo et al. (2007), Simon (2010)
Innovation Capability (InnC)	The ability of creation of something new such as a new idea, a new device, or a new design (Parthasarathy et al. 2011)	Schilke (2014), Barrales-Molina et al. (2013), Ellonen et al. (2011), Macpherson et al. (2004), Marsh and Stock (2006), Parthasarathy et al. (2011), Prieto et al. (2009), Protogerou and Caloghirou (2011), Piening (2011)
Integration Capability (IntC)	The ability of coordination, selection, and combination of the resources (Zahra et al. 2006)	Zahra et al. (2006), Simon (2010), Hawass (2010), Govind Menon 2008)
Knowledge Management (KM)	The creation, transfer, retention, and utilization of a firm's explicit and tacit knowledge assets (Cepeda and Vera 2007)	Teece (2007), Easterby-Smith and Prieto (2008), Cao (2011), Barrales-Molina et al. (2013), Newey and Zahra (2009), Cepeda and Vera 2007)
Knowledge Resources (KR)	A firm's customer-related knowledge resources that consists of customer perceptions of the firm's products, promotion, and market segments and competitor-related knowledge resources that includes the competitors' promotions, market segments and customers (Chien and Tsai 2012)	Zahra et al. (2006), McKelvie and Davidsson (2009), Easterby-Smith and Prieto (2008), Chien and Tsai (2012), Macpherson et al. (2004), Wilkens et al. (2004), Cepeda and Vera (2007)

(continued)

Table 8.2 (continued)

Factors	Definitions	Articles
Learning Mechanism (LM)	The experience accumulation and deliberate cognitive processes involving the articulation and codification of knowledge derived from reflection upon past experiences (Zollo and Winter 2002). (Absence of Learning Mechanism—ALM)	Eisenhardt and Martin (2000), Zollo and Winter (2002), Zahra et al. (2006), Kuuluvainen (2012), Easterby-Smith and Prieto (2008), Cavusgil et al. (2007), Hung et al. (2007), Anand et al. (2009), Barrales-Molina et al. (2013), Chien and Tsai (2012), Lee et al. (2011), Wilkens et al. (2004), Yung-Chul (2013), Hawass (2010), Govind Menon (2008), Lichtenthaler and Muethel (2012)
Managerial Capability (ManC)	The abilities of a manager that are used to build, integrate, and reconfigure organizational resources and competences (Adner and Helfat 2003)	Basu et al. (2013), Green et al. (2008), Schilke (2014), Pavlou and El Sawy (2011), Adner and Helfat (2003), Blyler and Coff (2003), Makkonen et al. (2014), Kim et al. (2011), Cepeda and Vera (2007)
Marketing Capability (MarC)	The ability to serve customers through the collection of knowledge, skills and resources related to the market needs of the firm (Protogerou and Caloghirou 2011)	Allred et al. (2011), Hou and Chien (2010), Macpherson et al. (2004), Protogerou and Caloghirou (2011)
Operational Capability (OpC)	The capabilities of a firm which are geared towards the operational functioning of the firm, including both staff and line activities (Cepeda and Vera 2007)	Teece et al. (1997), Teece and Pisano (1994), Zahra et al. (2006), Allred et al. (2011), Pavlou and El Sawy (2011), Aramand and Valliere (2012), Drnevich and Kriauciunas (2011), Ellonen et al. (2011), Newey and Zahra (2009), Piening (2011, 2013), Protogerou and Caloghirou (2011), Cepeda and Vera (2007)
Ordinary Capability (OrC)	The capabilities of a firm which permit a firm to 'make a living' in the short term (Winter 2003)	Eisenhardt and Martin (2000), Winter (2003), Zott (2003), Ellonen et al. (2011), Piening (2011)
Path Dependency (PD)	A firm's previous investments and repertoire of routines that constrains firm's future behavior (Sirmon and Hitt 2009)	Peteraf (1993), Teece and Pisano (1994), Zahra et al. (2006), Green et al. (2008), Cavusgil et al. (2007), Piening (2013, 2011), Sirmon and Hitt (2009)
Performance (P)	Performance represents how effectively a capability performs its intended function and how well a capability enables an organization to make a living by creating,	Wang and Ahmed (2007), Ambrosini and Bowman (2009), Wu (2006), Zott (2003), Zahra et al. (2006), Basu et al. (2013), Easterby-Smith and Prieto (2008), Lin and Wu (2014), Allred et al. (2011),

(continued)

Table 8.2 (continued)

Factors	Definitions	Articles
	extending, or modifying its resource base (Helfat 1997)	Parayitam and Guru-Gharana (2010), Pavlou and El Sawy (2011), Hung et al. (2007, 2010), Adner and Helfat (2003), Agarwal and Selen (2009), Blyler and Coff (2003), Chien and Tsai (2012), Døving and Gooderham (2008), Drnevich and Kriauciunas (2011), Gómez and Ballard (2013), Hou and Chien (2010), Hsu and Wang (2012), Jiao et al. (2013), Macpherson et al. (2004), Makkonen et al. (2014), Malik and Kotabe (2009), Marsh and Stock (2006), Newey and Zahra (2009), Piening (2013), Simon (2010), Sirmon and Hitt (2009), Wilden et al. (2013), Yung-Chul (2013), Zhou and Li (2010), Kim et al. (2011), Protogerou and Caloghirou (2011)
Reconfiguration Capability (RC)	A firm's ability to creatively recombine different knowledge-based resources and technologies in order to develop new product applications and innovations (Hawass 2010)	Teece et al. (1997), Teece (2007), Teece and Pisano (1994), Ambrosini et al. (2009), Easterby-Smith and Prieto (2008), Cao (2011), Cavusgil et al. (2007), Dixit and Bhowmick (2010), Marsh and Stock (2006), Simon (2010), Zhou and Li (2010), Kim et al. (2011), Hawass (2010), Govind Menon (2008), Lichtenthaler and Muethel (2012)
Relational Resources (RR)	Relational resources are described as the social capital, networks and alliances, and relational capitals of the firms	Wu (2006), Cao (2011), Adner and Helfat (2003), Agarwal and Selen (2009), Blyler and Coff (2003), Macpherson et al. (2004), Pablo et al. (2007)
Seizing Capability (SeiC)	The ability to address new opportunities that are sensed through new products, processes, or services (Teece 2007)	Teece et al. (1997), Teece (2007), Cao (2011), Macpherson et al. (2004), Lichtenthaler and Muethel (2012)
Sensing Capability (SenC)	The ability to perceive new opportunities through a scanning, creation, learning, and interpretation activities in environmental dynamism (Teece 2007)	Teece (2007, Cao (2011), Aramand and Valliere (2012), Gómez and Ballard (2013), Macpherson et al. (2004), Lichtenthaler and Muethel (2012)

Table 8.3 Relationship matrix of the factors

	A&R	CoLLC	CA	CoorC	DCs	DT	EC	ED	EM	FX	GN	HR	ImpC	InnC	IntC	KM	KR	ALM	ManC	MarC	OpC	OrC	PD	P	RC	RR	SeiC	SenC
A&R					10												1				1			4		1		
CoLLC																								2	1			1
CA																								1				
CoorC					2													1						2				
DCs	3		5							3		1	2	8	1		1	2	4	3	6	3		24	3	1		2
DT																									2			
EC	1				2													1						1				
ED	1		2		23									1							4		1	3	5	3		
EM																								2				
FX																									1			
GN																									2			
HR					7					1						1			2					1	2	1		
ImpC					4																							
InnC			2		1																			3	1		1	1
IntC																		1			1				2			
KM	1				4													3			1	1			3			
KR					4											1		1			2							
ALM				1	12								2			1	1				1				5		1	1
ManC			1		4					1		1					1							2	1	1		
MarC																								4			1	1
OpC			4		2									2										8				1
OrC					1									1							1			3				
PD					7									1							1	1						
P							1																					
RC	2		1		3										1									5				
RR					6							1							2									1
SeiC					5																			2	1			
SenC					2																1						1	

8.3 Fuzzy Cognitive Maps

Fuzzy Cognitive Mapping (FCM) is a commonly used method for modeling dynamic systems, which is introduced by Kosko (1986) with the combination of fuzzy logic and artificial neural networks. It is based on Zadeh's (1965) fuzzy logic and Axelord's (1976) cognitive maps. In FCM, expert knowledge and judgment is utilized to construct models of complex systems that consist of many dimensions and factors. FCM has learning capabilities, which improve its structure and computational behavior (Papageorgiou and Salmeron 2014). Development of a FCM requires five basic steps, which are summarized below (See Fig. 8.1).

Step 1: *Identify the concepts and causal relationships among these concepts.*

FCMs graphically represent complex systems that symbolize the cause and effect relationships among concepts, and define the behavior of concepts and systems in dynamic circumstances. FCMs are mainly developed based upon expert knowledge and experience related to the operation and behavior of the system under investigation. In this step, an expert or a group of experts is asked to determine the concepts and the causalities among these concepts as well. Then, if a group of experts is involved in the decision making process, individual FCMs obtained from each expert are combined into an augmented FCM.

In FCMs, each concept (C_i) is represented by nodes, and the causal relationships among the concepts are represented with the signed, directed and weighted arcs

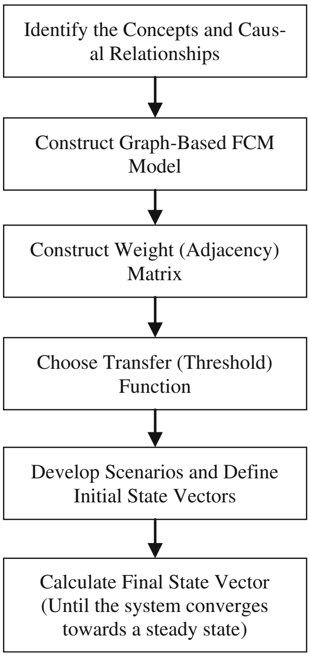

Fig. 8.1 Basic steps of FCM

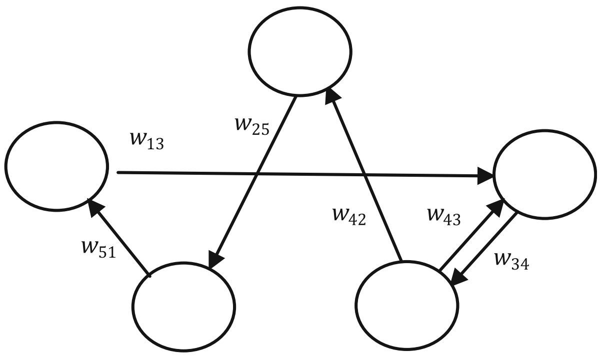

Fig. 8.2 A simple FCM

between the corresponding nodes (C_i, C_j). A simple FCM example, which consists of five concepts $(C_1, C_2, C_3, C_4, C_5)$ and six directed and weighted arcs, is illustrated in Fig. 8.2.

Step 2: *Define the strength of the causal relationships and construct the weight (adjacency) matrix.*

In FCMs, a directed arc representing the type of causal relation between the relevant concepts, C_i and C_j, is described with a weight of w_{ij}. Then, all these strengths of cause and effect relationships are together represented in a weight matrix **W** of size nxn, where each element in this matrix corresponds to $w_{ij}s$, and all diagonal elements $(i.e., w_{ii}s)$ equal to zero (i.e., a concept cannot cause itself).

$$\mathbf{W} = \begin{array}{c} \\ C_1 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_n \end{array} \\ \begin{bmatrix} 0 & \dots & w_{1n} \\ \vdots & \ddots & \vdots \\ w_{n1} & \dots & 0 \end{bmatrix} \end{array}$$

The sign of the causal relation between the concepts C_i and C_j shows a direction of the relationship, which can have three different states: a positive causality, where $w_{ij} > 0$; a negative causality, where $w_{ij} < 0$; or no causality, where $w_{ij} = 0$. For example, if the sign of the causal relationship between two concepts C_i and C_j is positive, an increase (decrease) in the value of concept C_i will cause an increase (decrease) in the value of concept C_j.

The weight matrix **W** corresponding to the FCM given in Fig. 8.2 can be written as:

$$\mathbf{W} = \begin{bmatrix} 0 & 0 & w_{13} & 0 & 0 \\ 0 & 0 & 0 & 0 & w_{25} \\ 0 & 0 & 0 & w_{34} & 0 \\ 0 & w_{42} & w_{43} & 0 & 0 \\ w_{51} & 0 & 0 & 0 & 0 \end{bmatrix}$$

The values in a FCM may be fuzzy numbers, where the concepts take the values in the interval [0, 1] and the weights of the interconnections belong to the interval [−1, 1]; or crisp numbers whose domains are assumed to be normalized into the interval [0, 1]. These two options does not have any influence on the computational methods that stand behind the reasoning process based on FCM (Papageorgiou et al. 2012; Glykas 2010).

Step 3: *Choose the transfer (threshold, activation) function.*

According to the nature of the problem, a transfer function is chosen to normalize the weight values to the range [0, 1] or [−1, 1] in order to make comparisons between nodes. There are four most frequently used transfer functions in the literature.

(i) Sign (Bivalent) Function: A bivalent transfer function (Eq. 8.1) gives either "0" or "1" values for the activation level of each concept, which are equivalent to "active" or "inactive", respectively.

$$f_{sign}(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x \geq 0 \end{cases} \tag{8.1}$$

(ii) Trivalent Function: A trivalent transfer function (Eq. 8.2) gives more information on the activation levels, as it includes negative activation. Concepts in a trivalent threshold function can have three state values (i.e.,"1", "0", and "−1"), which are equivalent to "positive effect", "no effect", or "negative effect", respectively.

$$f_{tri}(x) = \begin{cases} 1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases} \tag{8.2}$$

(iii) Sigmoid (Logistic) Function: Sigmoid function (Eq. 8.3) is a continuous transfer function, which gives values of concepts in the range [0, 1].

$$f_{sigm}(x) = \frac{1}{1 + e^{-\lambda x}} \tag{8.3}$$

(iv) Hyperbolic Tangent Function: Hyperbolic tangent function (Eq. 8.4) is also a continuous sigmoid-shaped function which gives values of concepts in the range [−1, 1].

$$f_{hyp}(x) = \tanh(\lambda x) = \frac{e^{\lambda x} - e^{-\lambda x}}{e^{\lambda x} + e^{-\lambda x}} \tag{8.4}$$

Sigmoid and hyperbolic tangent functions use a constant parameter $\lambda > 0$ to adjust a proper shape of the function. Researchers should define a specific λ value fitting the context under investigation. For larger λ values $(i.e., \lambda \geq 10)$ sigmoid approximates a discrete function, for smaller λ values ($i.e., \lambda \leq 1$) it approximates a linear function, and for λ values closer to 5, it provides a good degree of normalization (Bueno and Salmeron 2009). As indicated above, for each λ value, the sigmoid function changes in the interval [0, 1] and the hyperbolic tangent function changes in the interval [−1, 1] (Papageorgiou 2013).

Step4: *Develop scenarios for the simulation of FCM model and define initial state vectors*

In order to explore the impact of possible changes in the system under investigation and to observe whether the system converges towards a steady state, alternative scenarios, in which specific factors in the initial state are activated and the behavior of the system in the last state is observed, are developed for the simulation of FCM model. In this way, the effects of the activated factors on the other factors can be observed over the last state vector.

In a FCM, each concept takes its activation level as A_i^0, where A_i^t represents the value of concept C_i in time t, in the interval [−1, 1]. Therefore, $A^t = \left[A_1^t, A_2^t, \ldots, A_n^t\right]$, which gathers the values of n concepts involved in the FCM, indicates the state vector of the FCM at time t. Consequently, following the development of the scenarios, the relevant initial state vectors (i.e., A^0) for each of these scenarios are defined in this step.

Step 5: *Calculate the final state vector*

The state vector A^t, containing the distribution of the states of the concepts at time t, is updated as :

$$A^{t+1} = \left[A_1^{t+1}, A_2^{t+1}, \ldots, A_n^{t+1}\right] \tag{8.5}$$

where A^{t+1} represents the new state vector of the FCM at time t + 1 and can be calculated by using the equation given below (McCulloch and Pitts 1943):

$$A_i^{t+1} = f\left(A_i^t + \sum\nolimits_{j=1, \mathrm{j} \neq \mathrm{i}}^{n} A_j^t \times w_{ji}\right) \tag{8.6}$$

As mentioned above, f in Eq. 8.6 is a threshold function that is used to normalize the values of the concepts, and hence, to facilitate the qualitative comparisons between these concepts (Bueno and Salmeron 2009).

Once A^t is updated, the resulting state vector A^{t+1} is considered as an initial vector for the next iteration; and activation levels of the concepts are calculated in successive iterations until the system converges towards a steady state; in other words, until the difference between two consecutive state vectors is smaller than or equal to 0.0001 ($A^{t+1} - A^t \leq 0.0001$). The state vector obtained at the end of these iterations represents the final states of the concepts in FCM.

To illustrate the calculation of the final state vector, hyperbolic tangent function (with $\lambda = 1.0$) is chosen as a threshold function and adjacency matrix for the simple FCM given in Fig. 8.2 is assumed to be:

$$\mathbf{W} = \begin{bmatrix} 0 & 0 & -0.51 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.74 \\ 0 & 0 & 0 & 0.33 & 0 \\ 0 & 0.45 & -0.17 & 0 & 0 \\ 0.26 & 0 & 0 & 0 & 0 \end{bmatrix}$$

For an example scenario in which only the first concept is activated (i.e., initial state vector $A^0 = [1\,0\,0\,0\,0]$), value of the concept C_3 in the first iteration is calculated as follows:

$$A_3^1 = \tanh\left(A_3^0 + \sum_{j=1, j\neq 3}^{5} A_j^0 \times w_{j3}\right)$$

$$A_3^1 = \tanh\left(\left[A_3^0\right] + \left[\left(A_1^0 \times w_{13}\right) + \left(A_2^0 \times w_{23}\right) + \left(A_4^0 \times w_{43}\right) + \left(A_5^0 \times w_{53}\right)\right]\right)$$

$$A_3^1 = \tanh([0] + [(1 \times -0.51) + (0 \times 0) + (0 \times -0.17) + (0 \times 0)])$$

$$A_3^1 = \tanh(-0.51) = -0.470$$

Values of the other concepts in the first iteration are calculated similarly, and are presented below:

$$A^1 = [0.762 \quad 0.000 \quad -0.470 \quad 0.000 \quad 0.000]$$

Then, the state vector that is calculated in the first iteration being accepted as an initial vector for the next iteration, values of the concepts are calculated in successive iterations until $A^{t+1} - A^t \leq 0.0001$. After approximately 20 iterations, the values of all concepts converge at a steady state, which is given below.

$$A^{20} = [0.760 \quad -0.825 \quad -0.774 \quad -0.773 \quad 0.909]$$

8.4 Application

FCMs offer the opportunity to define key variables affecting a system and to indicate causal relationships among them. Moreover, by using FCMs relative strengths of variables can also be defined. Therefore, in this chapter, the factors related to dynamic capabilities, the causal relations among these factors, and the strengths of each factor are tried to be revealed by FCM. In order to identify the concepts and causal relationships among these concepts, and eventually, to develop a FCM, 70 articles published in academic journals were reviewed. Initially, factors affecting dynamic capabilities were defined. Then, each article was reviewed in detail and a relationship map of the factors discussed in each article, was formed. Based on these individual relationship maps, the final FCM was developed, where the relationships among the factors were represented by the frequencies of relations in individual relationship maps. The relationship degrees among these factors were calculated by dividing the relevant frequency of relations to the maximum frequency of relation in Table 8.3. For example, frequency of relation between "Entrepreneurship Capability" and "Dynamic Capabilities" factors was found as two, indicating that two articles (i.e., Newey and Zahra's (2009) and Macpherson et al. (2004)'s articles), have asserted this relation. This frequency of relation of two was then divided to the maximum frequency of relation in Table 8.3, which was 24, giving the result of 0.083 for the relevant relationship degree. The relationship degrees among other factors are similarly calculated and presented in Table 8.4. Therefore, besides the identification of the concepts and causal relationships, the relationship degrees among the factors affecting dynamic capabilities was also calculated by using the information gathered from 70 articles reflecting the experts' opinions.

The effect of each factor on the other factors was determined as "negative" or "positive" and the degree of this effect was defined by using the calculated relationship degrees. For example, causality between "Operational Capability (OC)" and "Performance (P)" factors was defined as positive with the relationship degree of 0.333; similarly, the causality between "Absence of Learning Mechanism (ALM)" and "Dynamic Capabilities (DCs)" factors was defined as negative, with the relationship degree of 0.500. Consequently, based on these relationship degrees, a FCM was constructed in Pajek Software (web 1) (2014) (See Fig. 8.3). Dotted lines in the constructed FCM represent negative causality among the relevant factors, where solid lines represent positive causality.

The constructed FCM consisted of 28 different factors (where five of them were transmitters and remaining 23 were ordinary factors) and 122 connections. Directions of causality among factors can be expressed as in-degree (i.e., directed into a node) or out-degree (i.e., directed out from a node). Centrality values reflect the importance of the factors on the map (See Fig. 8.4). Figure 8.4 indicates that "DCs" is a central factor, where a specific number of factors affect "DCs", and some other factors are affected by "DCs" as well. "Environmental Dynamism" and "Absence of Learning Mechanism" were also among the important factors that had higher out-degree values indicating a strong influence in forming factor behaviors in the map. On the other hand, "Performance" and "Reconfiguration Capability" factors were highly affected by the other factors and therefore had higher in-degree values. Figure 8.4 also points out that "Decentralization", "Environmental Munificence", and "Governance" factors had weak interactions and had no stimulation effect on the other factors in FCM.

In order to explore the impact of possible changes in the system and to observe whether the system converges towards a steady state, FCM was used to perform qualitative simulations. Alternative scenarios have been considered for the simulation of FCM model. Scenarios consisted the activation of specific factors in the initial state and the observation of the behavior of the system in the last state. In this

Table 8.4 Relationship degrees among the factors

	A&R	CoLLC	CA	CoorC	DCs	DT	EC	ED	EM	FX	GN	HR	ImpC	InnC	IntC	KM	KR	ALM	ManC	MarC	OpC	OrC	PD	P	RC	RR	SeiC	SenC
A&R					0.42												0.04				0.04			0.17		0.04		
CoLLC																								0.08	0.04			0.04
CA																								0.04				
CoorC					0.08													0.04						0.08				
DCs	0.13		0.21							0.13		0.04	0.08	0.33	0.04		0.04	0.08	0.17	0.13	0.25	0.13		1.00	0.13	0.04		0.08
DT																									0.08			
EC	0.04				0.08													0.04						0.04				
ED	0.04		0.08		0.96									0.04							0.17		0.04	0.13	0.21	0.13		
EM																								0.08				
FX																									0.04			
GN																									0.08			
HR					0.29					0.04						0.04			0.08					0.04	0.08	0.04		
ImpC					0.17																							
InnC			0.08		0.04																			0.13	0.04		0.04	0.04
IntC																		0.04			0.04				0.08			
KM	0.04				0.17													0.13			0.04	0.04			0.13			
KR					0.17											0.04		0.04			0.08							
ALM				0.04	0.50								0.08			0.04	0.04				0.04				0.21		0.04	0.04
ManC			0.04		0.25					0.04		0.04					0.04							0.08	0.04	0.04		
MarC																								0.17			0.04	0.04
OpC			0.17		0.08									0.08										0.33				0.04
OrC					0.04									0.04							0.04			0.13				
PD					0.29									0.04							0.04	0.04						
P							0.04																					
RC	0.08		0.04		0.13										0.04									0.21				
RR					0.25							0.04							0.08									0.04
SeiC					0.21																			0.08	0.04			
SenC					0.08																0.04						0.04	

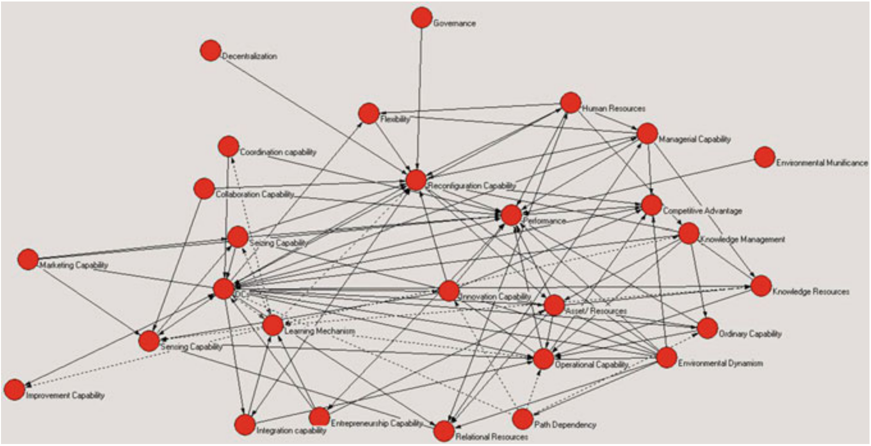

Fig. 8.3 Graphical representation of the relational FCM

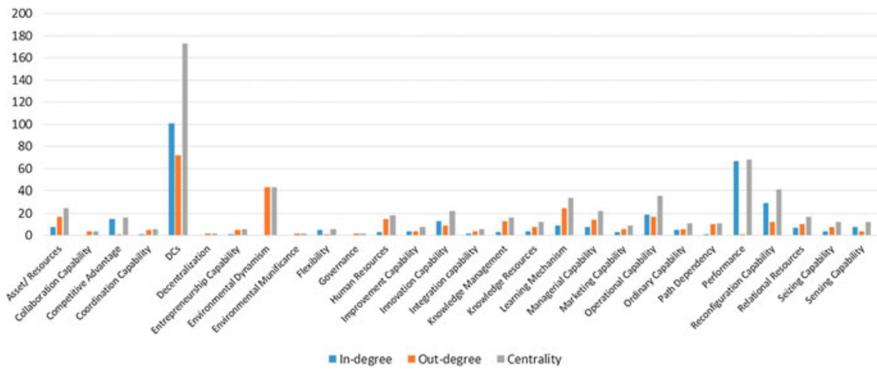

Fig. 8.4 In-degree, out-degree, and centrality values of the factors

way, the effects of activated factors on the other factors could be observed over the last state vector.

Initial states of the factors in each scenario were defined differently in four distinct cases: (i) One factor simulation, (ii) 27 factor simulation, (iii) all factor simulation, and (iv) multiple factor simulation. The details of these four cases are outlined in the subsections below.

As explained in the previous section, firstly, for each of the scenarios identified in each case, an initial state vector A^0 was formed and then multiplied by the adjacency matrix given in Table 8.4 representing the experts' opinions about the relationships among factors. The function given in Eq. 8.6 together with the hyperbolic tangent threshold function given in Eq. 8.4 were used respectively to recalculate an outcome vector, which was accepted as an initial vector for the next iteration. Lambda value in the hyperbolic tangent threshold functions was set to 1.0, to be able to see the subtle changes at the steady state. These iterations continued until the difference between two consecutive state vectors was smaller than or equal to 0.0001 (i.e., $A^{t+1} - A^{t} \leq 0.0001$) and the resulting vector calculated in the last iteration represented the final values of the factors.

8.4.1 Case 1: One Factor Simulations

In each scenario of case 1, the factors were activated one by one (only one at a time), and all the rest were set to zero. Then the impact of these activations were explored sequentially. An example initial state vector A^0 representing the initial states of the factors for the scenario, in which "DCs" factor was activated, is given below.

$$A^0 = [0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0\,0]$$

The vector indicating the degree of effects of the factors on the "DCs" factor is given below. Note that, although this vector is a column vector, it is shown here as a row vector for lack of space.

$$\mathbf{w}_{\cdot 5} = \begin{bmatrix} w_{1,5} & w_{2,5} & w_{3,5} & w_{4,5} & w_{5,5} & \ldots & w_{24,5} & w_{25,5} & w_{26,5} & w_{27,5} & w_{28,5} \end{bmatrix}$$

$$\mathbf{w}_{\cdot 5} = [0.417 \;\; 0.000 \;\; 0.000 \;\; 0.833 \;\; 0.000 \;\; \ldots \;\; 0.000 \;\; 0.125 \;\; 0.250 \;\; 0.208 \;\; 0.083]$$

As an example, value of the "DCs" factor in the first iteration is calculated as follows:

$$A_5^1 = \tanh\left(A_5^0 + \sum\nolimits_{j=1,\mathrm{j}\neq 5}^{28} A_j^0 \times w_{j,5}\right)$$

$$A_5^1 = \tanh\left(\left[A_5^0\right] + \left[\left(A_1^0 \times w_{1,5}\right) + \left(A_2^0 \times w_{2,5}\right) + \cdots + \left(A_{27}^0 \times w_{27,5}\right) + \left(A_{28}^0 \times w_{28,5}\right)\right]\right)$$

$$\begin{aligned} A_5^1 = \tanh([1] + [(0 \times 0.417) + (0 \times 0.000) + (0 \times 0.000) + (0 \times 0.833) + \cdots \\ + (0 \times 0.125) + (0 \times 0.250) + (0 \times 0.208) + (0 \times 0.083))] \end{aligned}$$

$$A_5^1 = \tanh(1) = 0.762$$

Values of the other factors in the first iteration are calculated similarly, and are presented below:

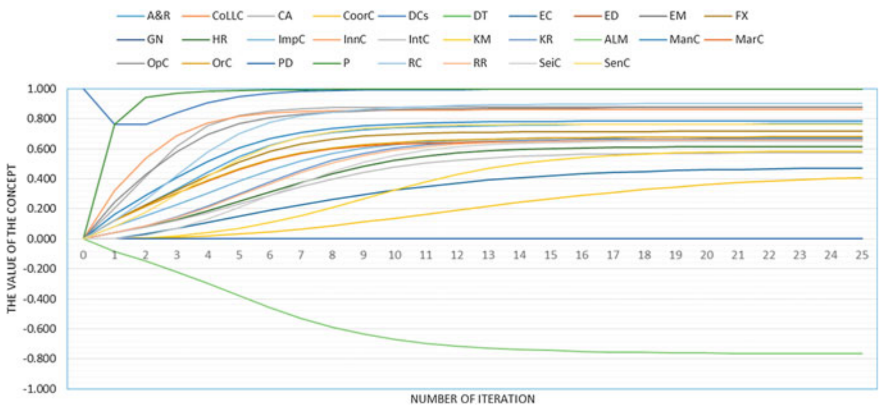

Fig. 8.5 Sample result of the FCM simulation process for the case 1 (Scenario 5)

$$A^1 = [0.124 \;\; 0.000 \;\; 0.205 \;\; 0.000 \;\; 0.762 \quad \cdots \quad 0.762 \;\; 0.124 \;\; 0.042 \;\; 0.000 \;\; 0.083]$$

Then, the state vector calculated in the first iteration being accepted as an initial vector for the next iteration, values of the factors are calculated in successive iterations until $A^{t+1} - A^t \leq 0.0001$. After approximately 25 iterations, the values of all factors converge at a steady state, which is given below (See Fig. 8.5).

$$A^{25} = [0.765 \;\; 0.000 \;\; 0.880 \;\; 0.408 \;\; 0.996 \quad \ldots \quad 0.996 \;\; 0.902 \;\; 0.658 \;\; 0.652 \;\; 0.764]$$

As mentioned above, 28 different scenarios in which only one factor was activated individually at a time were simulated in the first case. The results of these simulations are summarized below:

- All individual factors had a strong effect on "DCs". Apart from other factors, "Path Dependency" and "Absence of Learning Mechanism" had a reverse effect on "DCs".
- "Performance", "Operational Capability", "Reconfiguration Capability", "Innovation Capability", and "Competitive Advantage" factors were strongly affected from the activation of each other factor individually.
- "Coordination Capability", "Entrepreneurship Capability", and "Path Dependency" factors were weakly affected from the activation of each other factor individually.
- "Collaboration Capability", "Decentralization", "Environmental Dynamism", "Environmental Munificence", and "Governance" factors were not affected from the activation of any other factor and their values did not changed in time.
- "Absence of Learning Mechanism" and "Path Dependency" factors had a negative effect on other factors, resulting a decrease in the values of other factors in time. "Absence of Learning Mechanism" was affected negatively (i.e., its value had decreased in time) from the activation of other factors. On the other hand, "Path Dependency" factor was only affected negatively from the activation of "Environmental Dynamism" factor in a same manner.

8.4.2 Case 2: 27 Factor Simulations

In this case, FCM model was run with 28 different initial state vectors in which all factors except one were activated and the other one was set to zero. For example, in the scenario whose results are given in Fig. 8.6, "Asset/Resources" factor was set to zero, and all other factors were set to one. Then, the impact of each scenario (i.e., how the system reacted under the given conditions) was explored and the corresponding results are summarized below.

- In the scenario in which "DCs" factor's activation level was set to zero, the other activated factors increased the final state value of "DCs".
- When "Competitive Advantage", "Innovation Capability", "Operational Capability", "Performance", and "Reconfiguration Capability" factors' activation levels were set to zero, the final values of these factors had increased in time and converged to one.
- On the other hand, when "Collaboration Capability", "Decentralization", "Environmental Dynamism", "Environmental Munificence", and "Governance" factors' activation levels were set to zero, the final values of these factors had not changed and remained at zero.
- When "Absence of Learning Mechanism" and "Path Dependency" factors' activation levels were set to zero, the final value of these factors decreased in time.

8.4.3 Case 3: All Factor Simulation

In this case, all factors' initial values were set to one (i.e., 28 factors were fully activated under this assumption) and how the system reacted under given condition was explored. The results of this case are summarized below (See Fig. 8.7 for resulting final state values).

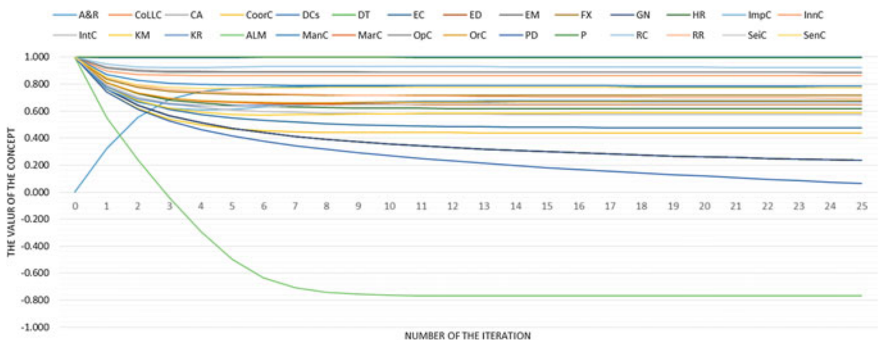

Fig. 8.6 Sample result of the FCM simulation process for case 2 (Scenario 1)

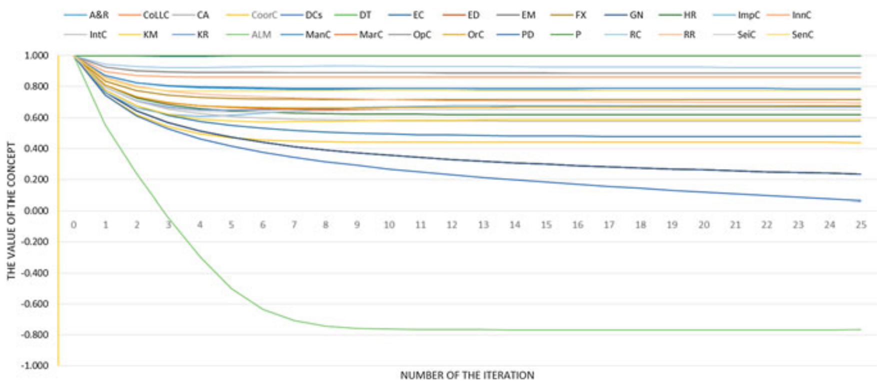

Fig. 8.7 Result of the FCM simulation process for case 3 (Scenario 1)

- The lowest decreases in the state values were observed in “DCs”, “Performance”, “Competitive Advantage”, and “Operational Capability” factors.
- On the other hand, the highest decreases in the state values were observed in “Collaboration Capability”, “Decentralization”, “Environmental Munificence”, “Environmental Dynamism”, “Governance”, and “Path Dependency” factors.

8.4.4 Case 4: Multiple Factor Simulations

In-between the above-mentioned cases, a number of scenarios were developed in which the factors were combined to assess their joint influence on the other factors. Particularly, the system was observed to determine the effects of the different combinations of “DCs”, “Environmental Dynamism”, “Performance”, “Absence of Learning Mechanism”, and “Path Dependency” factors. For example, in the initial state of the scenario whose results are given in Fig. 8.8, only “Environmental Dynamism”, “Absence of Learning Mechanism”, and “Path Dependency” factors were set to one. The results of all these simulations are summarized below.

- In general, “Absence of Learning Mechanism” and “Path Dependency” jointly had negative strong effect on most of the remaining factors. When the initial values of these concepts were set to one, the final values of the other concepts decreased in time, except “Collaboration Capability”, “Decentralization”, “Environmental Dynamism”, “Environmental Munificence”, and “Governance” factors, as they had weak connection with other factors.
- The activation of “DCs” and/or “Environmental Dynamism” factors, removed the negative effect of “Absence of Learning Mechanism” and “Path Dependency” in the system. They stimulated “Learning Mechanism” and reduced the dependency to the past.

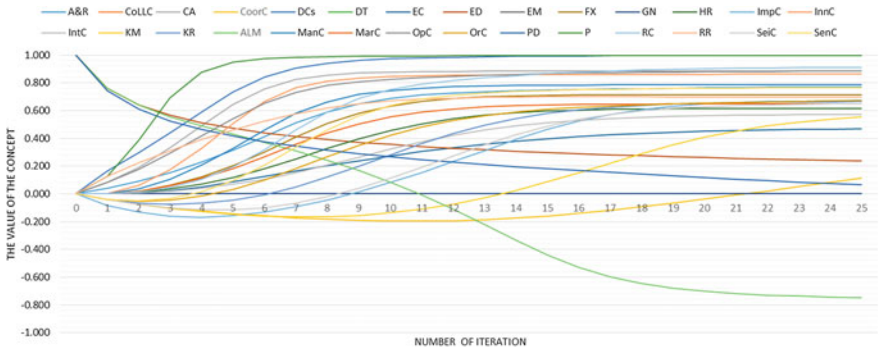

Fig. 8.8 Sample result of the FCM simulation process for case 4 (Scenario 1)

- When the initial activation levels of “DCs” and “Environmental Dynamism” factors were set to zero, the negative effect of “Path Dependency” could not be removed by activating different combinations of other factors.
- The negative effect of “Absence of Learning Mechanism” could not be removed by activating any individual factor, except “DCs” and “Environmental Dynamism”. This result revealed the importance of “Learning Mechanism” in a system and its effects on the other factors.
- In the scenarios where some of the factors (such as “Asset/Resources”, “Human Resources”, “Knowledge Management”, “Knowledge Resource”, “Managerial Capability” and “Seizing Capability”) were activated together, the negative effect of “Absence of Learning Mechanism” factor on the system could be removed.
- In the scenarios where “Path Dependency” and “Absence of Learning Mechanism” factors were combined with other factors, “DCs” and “Performance” factors had high final state values because of their high centrality properties.
- In the scenarios in which “Collaboration Capability”, “Decentralization”, “Environmental Munificence”, and “Governance” factors were combined with other factors, the negative effect of “Absence of Learning Mechanism” could not be removed.

8.5 Conclusion

In order to survive in today’s dynamic and uncertain environments, firms are facing more challenges than ever before in terms of coping with the rapidly changing business environment and achieving a sustainable competitive advantage. Therefore, sensing what is happening in the environment (i.e., realizing opportunities and threats), addressing these opportunities and threats through new products, processes, or services (Teece 2007), and reconfiguring the existing capability set to match the changing environment, becomes crucial for organizational survival and success. This ability of a firm, 'to sense and shape opportunities and threats, to seize opportunities, and to outperform competitors through enhancing, combining, protecting, and, when necessary, reconfiguring the capability set' is defined as dynamic capabilities (Teece et al. 1997).

Following the introduction of the dynamic capability concept by Teece and Pisano (1994) and Iansiti and Clark (1994), dynamic capability scholars provided many new and somewhat conflicting views about the definition, antecedents, and consequences of the concept. However, currently there exists no previous comprehensive study exploring the factors affecting dynamic capabilities and the causal relations among these factors. In this chapter, by using the results of a comprehensive literature survey as a basis, a FCM model was proposed to reveal the factors affecting the dynamic capability concept and the causal relations among these factors, together with their relative strength. Firstly, following the identification of factors affecting dynamic capabilities, the relationships among these factors were graphically represented as causal links according to the results of the literature review. Secondly, using the frequencies of relationships calculated from these articles, degrees of relationships among the relevant factors were generated.

In order to explore the impact of possible changes and to observe whether the system converged toward a steady state, many different scenarios were considered in qualitative simulation of dynamic capability FCM model. In all these scenarios, different combinations of factors were activated and remaining factors were set free to interact. After approximately 20 iterations, the last state vector of each scenario indicated the following results:

- Factors apart from "Path Dependency" and "Absence of Learning Mechanism" factors had a strong positive effect on "DCs". On the other hand, "Path Dependency" and "Absence of Learning Mechanism" factors had a negative effect on "DCs". When the activation level of "DCs" factor was set to zero, final state value of it converged to one in each scenario. Therefore, it can be concluded that the "DCs" is a central factor in the proposed FCM model.
- "Environmental Dynamism", "Innovation Capability", "Operational Capability", "Performance", "Reconfiguration Capability", and "Competitive Advantage" factors were the other strongly affected critical factors in the map.
- Weak interaction effects observed on the "Collaboration Capability", "Decentralization", "Environmental Munificence", and "Governance" factors suggests that they can be removed from the FCM model, or they can be considered as a part of other central factors.
- "Absence of Learning Mechanism" and "Path Dependency" had a negative effect on other factors. In other words, they decrease the final state values of the other factors in the system in time. However, these effects are compensated by "DCs" and "Environmental Dynamism".

- “Asset/Resources”, “Flexibility”, “Human Resources”, “Improvement Capability”, “Knowledge Management”, “Managerial Capability”, “Relational Resources”, “Seizing”, and “Sensing Capabilities” are the key factors in the map. They stimulate each other and the remaining factors, and increase the final state value of “DCs” and reduce the effect of “Absence of Learning Mechanism”.

According to the result of this chapter, it can be concluded that FCM is a useful tool for modeling dynamic capabilities, as it provides a means for modeling such a complex concept and representing uncertain knowledge in the modeling process. As a future study, ordinary fuzzy sets, intuitionistic fuzzy sets, grey relational analysis, or other similar approaches with the ability to better model the hesitation and uncertainty, and other components of computational intelligence techniques such as evolutionary computation, swarm intelligence, hybrid systems can be used.

References

Adner, R., Helfat, C.E.: Corporate effects and dynamic managerial capabilities. Strateg. Manage. J. **24**(10), 1011–1025 (2003)

Agarwal, R., Selen, W.: Dynamic capability building in service value networks for achieving service innovation. Decis. Sci. **40**(3), 431–475 (2009)

Allred, C.R., et al.: A dynamic collaboration capability as a source of competitive advantage. Decis. Sci. **42**(1), 129–161 (2011)

Ambrosini, V., Bowman, C.: What are dynamic capabilities and are they a useful construct in strategic management? Int. J. Manage. Rev. **11**(1), 29–49 (2009)

Ambrosini, V., Collier, N., Bowman, C.: Dynamic Capabilities: An Exploration of how Firms Renew Their Resource Base. Blackwell, 2009

Anand, G., et al.: Dynamic capabilities through continuous improvement infrastructure. J. Oper. Manage. **27**(6), 444–461 (2009)

Aramand, M., Valliere, D.: Dynamic capabilities in entrepreneurial firms: a case study approach. J. Int. Entrepreneurship **10**(2), 142–157 (2012)

Axelrod, R.: Structure of decision: the cognitive maps of political Elites. Princeton University Press, Princeton (1976)

Barney, J.: Firm resources and sustained competitive advantage. J. Manage. **17**(1), 99–120 (1991)

Barrales-Molina, V., Bustinza, O.F., Gutiérrez-Gutiérrez, L.J.: Explaining the causes and effects of dynamic capabilities generation: a multiple-indicator multiple-cause modelling approach. Br. J. Manage. **24**(4), 571–591 (2013)

Barreto, I.: Dynamic capabilities: a review of past research and an agenda for the future. J. Manage. **36**(1), 256–280 (2010)

Basu, S., et al.: Dynamic capabilities or positioning? integrating environmental and resource-led antecedents of firm performance. J. Manage. Mark. Res. **12**, (2013)

Blyler, M., Coff, R.W.: Dynamic capabilities, social capital, and rent appropriation: ties that split pies. Strateg. Manage. J. **24**(7), 677–686 (2003)

Bueno, S., Salmeron, J.L.: Benchmarking main activation functions in Fuzzy cognitive maps. Expert Syst. Appl. **36**(3, part 1), 5221–5229 (2009)

Cao, L.: Dynamic capabilities in a turbulent market environment: empirical evidence from international retailers in China. J. Strateg. Mark. **19**(5), 455–469 (2011)

Cavusgil, E., Seggie, S.H., Talay, M.B.: Dynamic capabilities view: foundations and research agenda. J. Mark. Theor. Pract. **15**(2), 159–166 (2007)

Cepeda, G., Vera, D.: Dynamic capabilities and operational capabilities: a knowledge management perspective. J. Bus. Res. **60**(5), 426–437 (2007)

Chien, S.Y., Tsai, C.H.: Dynamic capability, knowledge, learning, and firm performance. J. Organ. Change Manage. **25**(3), 434–444 (2012)

Collis, D.J.: Research note: how valuable are organizational capabilities? Strateg. Manage. J. **15** (S1), 143–152 (1994)

Dixit, M.R., Bhowmick, B.: Discontinuity in the Environment, Firm Response, and Dynamic Capabilities. Indian Institute of Management, Ahmedabad (2010)

Døving, E., Gooderham, P.N.: Dynamic capabilities as antecedents of the scope of related diversification: the case of small firm accountancy practices. Strateg. Manage. J. **29**(8), 841–857 (2008)

Drnevich, P.L., Kriauciunas, A.P.: Clarifying the conditions and limits of the contributions of ordinary and dynamic capabilities to relative firm performance. Strateg. Manage. J. **32**(3), 254–279 (2011)

Easterby-Smith, M., Prieto, I.M.: Dynamic capabilities and knowledge management: an integrative role for learning? Br. J. Manage. **3**, 235 (2008)

Eisenhardt, K.M., Martin, J.A.: Dynamic capabilities: what are they? Strateg. Manage. J. **21**(10–11), 1105–1121 (2000)

Ellonen, H.-K., Jantunen, A., Kuivalainen, O.: The role of dynamic capabilities in developing innovation-related capabilities. Int. J. Innov. Manage. **15**(03), 459–478 (2011)

Glykas, M.: Fuzzy Cognitive Maps: Advances in Theory, Methodologies, Tools and Applications. Springer, Berlin (2010)

Gómez, L.F., Ballard, D.I.: Communication for the long term: information allocation and collective reflexivity as dynamic capabilities. J. Bus. Commun. **50**(2), 208–220 (2013)

Govind Menon, A.: Revisiting dynamic capability. IIMB Manage. Rev. **20**(1), 22–33 (2008) (Indian Institute of Management Bangalore)

Green, S.D., Larsen, G.D., Kao, C.C.: Competitive strategy revisited: contested concepts and dynamic capabilities. Constr. Manage. Econ. **26**(1), 63–78 (2008)

Hawass, H.H.: Exploring the determinants of the reconfiguration capability: a dynamic capability perspective. Eur. J. Innovation Manage. **13**(4), 409–438 (2010)

Helfat, C.E.: Know-how and asset complementarity and dynamic capability accumulation: the case of r&d. Strateg. Manage. J. **18**(5), 339–360 (1997)

Helfat, C.E., et al., Dynamic Capabilities: Understanding Strategic Change in Organizations. Wiley, New York (2007)

Helfat, C.E., Peteraf, M.A.: The dynamic resource-based view: capability lifecycles. Strateg. Manage. J. **24**(10), 997–1010 (2003)

Helfat, C., Peteraf, M.: Understanding dynamic capabilities: progress along a developmental path. Strateg. organ. **7**(1), 91 (2009)

Helfat, C.E., Winter, S.G.: Untangling dynamic and operational capabilities: strategy for the (N) ever-changing world. Strateg. Manage. J. **32**(11), 1243–1250 (2011)

Hou, J.-J., Chien, Y.-T.: The effect of market knowledge management competence on business performance: a dynamic capabilities perspective. Int. J. Electron. Bus.Manage. **8**(2), 96 (2010)

Hsu, L.-C., Wang, C.-H.: Clarifying the effect of intellectual capital on performance: the mediating role of dynamic capability. Br. J. Manage. **23**(2), 179–205 (2012)

Hung, R.Y.Y., Chung, T.T., Lien, B.Y.H.: Organizational process alignment and dynamic capabilities in high-tech industry. Total Qual. Manage. Bus. Excellence **18**(9–10), 1023–1034 (2007)

Hung, R.Y.Y., et al.: Dynamic capability: impact of process alignment and organizational learning culture on performance. J. World Bus. **45**(3), 285–294 (2010)

Iansiti, M., Clark, K.B.: Integration and dynamic capability: evidence from product development in automobiles and mainframe computers. Ind. Corp. Change **3**(3), 557–605 (1994)

Jiao, H., et al.: When should organizational change be implemented? the moderating effect of environmental dynamism between dynamic capabilities and new venture performance. J. Eng. Tech. Manage. **30**(2), 188–205 (2013)
Kim, G., et al.: IT capabilities, process-oriented dynamic capabilities, and firm financial performance. J. Assoc. Inf. Syst. **12**(7), 487–517 (2011)
Kosko, B.: Fuzzy cognitive maps. Int. J. Man Mach. Stud. **24**(1), 65–75 (1986)
Kuuluvainen, A.: International growth of a finnish high-tech SME: a dynamic capabilities approach. Res. Econ. Bus. Cent. East. Eur. **4**(2), 26–40 (2012)
Lee, P.-Y., Chen, H.-H., Shyr, Y.-H.: Driving dynamic knowledge articulation and dynamic capabilities development of service alliance firms. Serv. Ind. J. **31**(13), 2223–2242 (2011)
Li, D.-Y., Liu, J.: Dynamic capabilities, environmental dynamism, and competitive advantage: evidence from China. J. Bus. Res. **67**(1), 2793–2799 (2014)
Lichtenthaler, U., Muethel, M.: The role of deliberate and experiential learning in developing capabilities: insights from technology licensing. J. Eng. Tech. Manage. **29**(2), 187–209 (2012)
Lin, Y., Wu, L.-Y.: Exploring the role of dynamic capabilities in firm performance under the resource-based view framework. J. Bus. Res. **67**(3), 407–413 (2014)
Macpherson, A., Jones, O., Zhang, M.: Evolution or Revolution? Dynamic Capabilities in a Knowledge-Dependent Firm. Wiley Subscription Services, Inc., New York, p. 161 (2004)
Makadok, R.: Toward a synthesis of the resource-based and dynamic-capability views of rent creation. Strateg. Manage. J. **22**(5), 387–401 (2001)
Makkonen, H., et al.: Dynamic capabilities and firm performance in a financial crisis. J. Bus. Res. **67**(1), 2707–2719 (2014)
Malik, O.R., Kotabe, M.: Dynamic capabilities, government policies, and performance in firms from emerging economies: evidence from India and Pakistan. J. Manage. Stud. **46**(3), 421–450 (2009)
Marsh, S.J., Stock, G.N.: Creating dynamic capability: the role of intertemporal integration, knowledge retention, and interpretation. J. Prod. Innov. Manage **23**(5), 422–436 (2006)
McCulloch, W., Pitts, W.: A logical calculus of the ideas immanent in nervous activity. Bull. math. biophys. **5**(4), 115–133 (1943)
McKelvie, A., Davidsson, P.: From resource base to dynamic capabilities: an investigation of new firms. Br. J. Manage. **20**(s1), S63–S80 (2009)
Newey, L.R., Zahra, S.A.: The evolving firm: how dynamic and operating capabilities interact to enable entrepreneurship. Br. J. Manage. **20**, S81–S100 (2009)
Pablo, A.L., et al.: Identifying, enabling and managing dynamic capabilities in the public sector. J. Manage. Stud. **44**(5), 687–708 (2007)
Web 1. Pajek, Program for large network analysis (2014). http://vlado.fmf.uni-lj.si/pub/networks/pajek/(15.01.2015). Accessed 15 Jan 2015
Papageorgiou, E., Salmeron, J.: Methods and algorithms for Fuzzy cognitive map-based modeling. In: Papageorgiou, E.I. (ed.) Fuzzy Cognitive Maps for Applied Sciences and Engineering, pp. 1–28. Springer, Berlin (2014)
Papageorgiou, E.I.: Fuzzy Cognitive Maps for Applied Sciences and Engineering: From Fundamentals to Extensions and Learning Algorithms. Springer Publishing Company, Incorporated, p. 310 (2013)
Papageorgiou, E.I., et al.: Formalization of treatment guidelines using Fuzzy cognitive maps and semantic web tools. J. Biomed. Inform. **45**(1), 45–60 (2012)
Parayitam, S., Guru-Gharana, K.: Economics of resource based and dynamic capabilities view: a contemporary framework. Acad. Strateg. Manage. J. **9**(1), 83–94 (2010)
Parthasarathy, R., Chenglei, H., Aris, S.: Impact of dynamic capability on innovation, value creation and industry leadership. IUP J. Knowl. Manage. **9**(3), 59–73 (2011)
Pavlou, P.A., El Sawy, O.A.: Understanding the elusive black box of dynamic capabilities. Decis. Sci. **42**(1), 239–273 (2011)
Peteraf, M.A.: The cornerstones of competitive advantage: a resource-based view. Strateg. Manage. J. **14**(3), 179–191 (1993)

Piening, E.P.: Insights into the process dynamics of innovation implementation: the case of public hospitals in Germany. Public Manage. Rev. **13**(1), 127–157 (2011)
Piening, E.P.: Dynamic capabilities in public organizations. Public Manage. Rev. **15**(2), 209–245 (2013)
Prieto, I.M., Rodríguez-Prado, B., Revilla, E.: Building dynamic capabilities in product development: how do contextual antecedents matter? Scand. J. Manage. **25**(3), 313–326 (2009)
Protogerou, A., Caloghirou, Y., Lioukas, S.: Dynamic capabilities and their indirect impact on firm performance. Ind. Corp. Change. **21** (2011)
Schilke, O.: On the contingent value of dynamic capabilities for competitive advantage: the nonlinear moderating effect of environmental dynamism. Strateg. Manage. J. **35**(2), 179–203 (2014)
Simon, A.: Resources, dynamic capabilities and Australian business success. J. Glob. bus. technol. **6**(2), 12–31 (2010)
Sirmon, D.G., Hitt, M.A.: Contingencies within dynamic managerial capabilities: interdependent effects of resource investment and deployment on firm performance. Strateg. Manage. J. **30** (13), 1375–1394 (2009)
Teece, D.J.: Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. Strateg. Manage. J. **28**(13), 1319–1350 (2007)
Teece, D., Pisano, G.: The dynamic capabilities of firms: an introduction. Ind. Corp. Change **3**(3), 537–556 (1994)
Teece, D.J., Pisano, G., Shuen, A.: Dynamic capabilities and strategic management. Strateg. Manage. J. **18**(7), 509–533 (1997)
Wang, C.L., Ahmed, P.K.: Dynamic capabilities: a review and research agenda. Int. J. Manage. Rev. **9**(1), 31–51 (2007)
Wernerfelt, B.: A resource-based view of the firm. Strateg. Manage. J. **5**(2), 171 (1984)
Wilden, R., et al.: Dynamic capabilities and performance: strategy, structure and environment. Long Range Plan. **46**(1–2), 72–96 (2013)
Wilkens, U., Menzel, D., Pawlowsky, P.: Inside the black-box: analysing the generation of core competencies and dynamic capabilities by exploring collective minds. An organisational learning perspective. Manage. Rev. **15**, 8–26 (2004)
Winter, S.G.: Understanding dynamic capabilities. Strateg. Manage. J. **24**(10), 991–995 (2003)
Wu, L.-Y.: Resources, dynamic capabilities and performance in a dynamic environment: Perceptions in Taiwanese IT enterprises. Inf. Manage. **43**(4), 447–454 (2006)
Yung-Chul, K.: Learning Orientation, dynamic capabilities and performance in Korean high-tech ventures. Adv. Manage. **6**, 54–61 (2013)
Zadeh, L.A.: Fuzzy sets. Inf. Control **8**(3), 338–353 (1965)
Zahra, S.A., Sapienza, H.J., Davidsson, P.: Entrepreneurship and dynamic capabilities: a review, model and research agenda*. J. Manage. Stud. **43**(4), 917–955 (2006)
Zhou, K.Z., Li, C.B.: How strategic orientations influence the building of dynamic capability in emerging economies. J. Bus. Res. **63**(3), 224–231 (2010)
Zollo, M., Winter, S.G.: Deliberate learning and the evolution of dynamic capabilities. Organ. Sci. **13**(3), 339–351 (2002)
Zott, C.: Dynamic capabilities and the emergence of intraindustry differential firm performance: insights from a simulation study. Strateg. Manage. J. **24**(2), 97 (2003)

Chapter 9
Using Data Envelopment Analysis and Fuzzy Logic as Intelligent Risk-Based Decision Making Support for Virtual Organizations

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Abstract Collaboration is key to foster and leverage business. Management techniques regarding organizational issues involved in collaborative working between partners require special attention. Particularly, Virtual Organizations (VO) have raised as cornerstone to enable intelligent attendance to Collaboration Opportunities (CO). Therefore, the VO concept has emerged as one of the most promising forms of collaboration among companies by providing a way of sharing their costs, benefits and risks, in order to attend particular goals. In general, organizational goals are achieved through management processes, whose result depends on the performance of several areas such as planning, design, development and decision making. Particularly, intelligent decision making can be accomplished using techniques that take into account information regarding indicators on the environment being analysed. Therefore, this chapter elaborates on the decision making using Data Envelopment Analysis (DEA) and Fuzzy Logic on partners' selection process complying particularly with the risks involved in VO formation process.

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9.1 Introduction

In the last years, a wide variety of new organizational forms has emerged as a result of many socioeconomic challenges faced by society (Esposito and Evangelista 2014). In fact, companies are specializing themselves and collaborating with each others, thus leading them to a more effective competition with other entities or groups in the markets. At the same time, the advances and the use of information and communication technologies (ICT) clearly facilitated the process of collaboration between companies, by providing a way in which the distance is no longer a major problem (Camarinha-Matos et al. 2009).

Among several forms of collaboration, the so called Virtual Organizations (VOs) have been indicated as appropriate to address these issues, by providing a more dynamic and flexible way to deal with the market demands. A VO consists in a temporary alliance of autonomous, heterogeneous and usually geographically dispersed organizations that come together to share skills (or key competencies) and resources in order to attend to Collaboration Opportunity (CO) (Mowshowitz 1997). There are four main phases regarding VO life cycle: formation, operation, evolution and dissolution (Camarinha-Matos and Afsarmanesh 1999). This chapter focuses at the formation phase, which is seen as critical to ensure the correct VO operation and evolution.

One of the issues regarding the formation of VOs that have to be faced refers to how their partners are selected. In this chapter, a VO is seen as a set of Service Providers (SPs) that have previously agreed to collaborate in a mutual goal. It is also assumed that SPs are members of long-term alliances (like Virtual Breeding Environments—VBEs) (Afsarmanesh and Camarinha-Matos 2005) so sharing some minimum and common collaboration, working, quality and performance principles.

Several works in the literature have approached the problem of selecting partners for VO composition via an analysis focused on members' competences and capabilities (Baldo et al. 2009; Junior and Rabelo 2013; Sari et al. 2008). Nevertheless, there is another critical factor that must be considered for the successful formation of a VO, which refers to measure the risk of each SP, and consequently to the overall VO. However, there is a lack of more systematic and integrated methods to handle the several dimensions of risk, which includes both VO intra and inter-organizational aspects.

In this sense, this chapter aims to elaborate on a method that analyzes and measures the risks for a set of SPs to compose a VO, through the combination of Data Envelopment Analysis (DEA) (Charnes et al. 1978) and Fuzzy Logic (Zadeh 1965). By means of a set of quantitative analysis, VO managers can have better information to decide about which SPs should be effectively discarded or not on a given business CO and, additionally, the identified risks can be managed and mitigated throughout the VO formation process.

The remaining chapter is organized as follows: Sect. 9.2 presents the problem context and related work. Section 9.3 specifies the proposed risk analysis method.

Section 9.4 presents the set of experiments conducted to evaluate the proposed method and also presents the final results. Finally, Sect. 9.5 concludes the chapter and outlines some future work.

9.2 Problem Context and Related Work

Risk management has emerged as an important contribution to most fields related to decision making and control management. When dealing with a network of inter-relationships between organizations (e.g., a VO), risk management should be associated with the entire network (Jüttner 2005). It means that, in addition to the traditional environmental and organizational sources of risk, the VOs face a third category, called network risk, which is associated with the interactions between the participants (Alawamleh and Popplewell 2010).

The concept of risk is vast and can be handled in several perspectives (March and Shapira 1987; Moskowitz and Bunn 1987). In brief, risk can be defined as the probability the occurrence of an event that causes a negative or positive impact on the organization's goals when it takes place (Vose et al. 2008). Specifically in this work, the risk is characterized by the potential for one or more members, which are able to compose a VO, do not to perform correctly the tasks assigned to them with respect to the requirements thus jeopardizing the VO composition. It implies directly in a need to identify and measure the risks associated with VOs, through a systematic and well-defined process.

In the research review, a number of risk analysis methods has been identified as potentially suitable for VOs, namely Failure Mode and e Effects Analysis (FMEA), Fault Tree Analysis (FTA), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Event Tree Analysis (ETA), Bayesian Networks, Causal Network Event Analysis (CNEA) and Ishikawa Diagram (Ericson et al. 2005; Rhee and Ishii 2003; Rychlik and Rydén 2006; Saaty 2004; Vose et al. 2008). Two methods were selected as the most suitable ones for this work: Data Envelopment Analysis (DEA) (Charnes et al. 1978) and Fuzzy Logic (Zadeh 1965). DEA is able to handling multiple entries and model them in form of productivity, which is interesting in the context of this work, given that KPIs are used for evaluate the risk of the SPs and the risk is associated to their abilities to comprise the requirements. Further, using a fuzzy system allows risk experts define their own rules, adjusting them according to the interests of the organization.

These approaches are used together in a wide range of applications in the literature (Ahmady et al. 2013; Amindoust et al. 1682; Hajiagha et al. 2013; Mirhedayatian et al. 2013; Payan and Shariff 2013; Puri and Yadav 1437). In (L and Mustafa 2013; Markovits-Somogyi 2011; Tavakkoli-Moghaddam and Mahmoodi 2010), it was used fuzzy logic to derive a common set of weights in order to discriminate more properly the efficient and non-efficient DMUs. In (Hatami-Marbini et al. 2011), the authors proposed an interactive evaluation process for measuring the efficiencies of a set of DMUs considering the decision makers' preferences. For this purpose, it was developed a linear programming with fuzzy parameters. Wang and Yan (Wang and Yan 2013) proposed a method to evaluate relative effectiveness of manufacturing mode of manufacturing system, using fuzzy for representing uncertain input and output parameters of complex manufacturing system. In the same way, many researchers have proposed fuzzy methods for dealing with imprecise data in DEA (Alem et al. 2013; Fathi and Izadikhah 2013; Khalili-Damghani and Taghavifard 2013; Mugera 2013; Saati et al. 2013; Tavana et al. 2013).

More specifically in the risk analysis subject, some recent works are found in the literature. Zhou et al. (2008) propose a model of real estate investment risk evaluation based on fuzzy DEA method, in order to implement the multiple factors and multi-target assessment of real estate investment risk. Azadeh and Alem (2010) present a flexible approach for supply chain risk and vendor selection as well as a decision making scheme for choosing appropriate method for supplier selection under certainty, uncertainty and probabilistic conditions. Finally, Chen et al. (2013) use Fuzzy DEA for estimating efficiency scores conforms to the characteristic of risk anticipation. In the same way, this work aims to evaluate the overall risk of a VO by applying a Fuzzy DEA method for estimating the SPs' efficiency scores, which is based on VOs' risk sources as input.

In this way, there is a number of works related to risk analysis for VOs. In (Alawamleh and Popplewell 2010, 2012), thirteen general risk sources in VOs were identified, which four of them were selected for this work due to their relevance: *trust*, *communication*, *collaboration* and *commitment* (Alawamleh and Popplewell 2010). In this work, they are modeled as Key Performance Indicators (KPIs), and their values are provided accordingly (Junior and Rabelo 2013). Also, it is assumed that every SP has a set of historical values for each one of these KPIs, regarding to past VO participations.

In Grabowski and Roberts (1998), the problem of risk mitigation in VO was discussed, and four processes were identified to improve the level of VOs performance reliability. In Li and Liao (2007) two sources of risks were specified (external and internal), and risk occurrence likelihood in the life span of a VO was calculated based on them. Min et al. (2007) and Fei and Zhixue (2010) considered the fuzzy characteristics and the project organization mode of VOs to propose Multi Strategy Multi Choice (MSMC) risk programming models. In Paszkiewicz and Picard (2011) was presented a competence model to support efficiently the process of partner's selection, which works in the context of Service-Oriented Virtual Organization Breeding Environments. Huang et al. (2013) showed the relationships between most appropriate decision mechanisms to improve the overall performance of risk management in VOs. In addition, two mechanisms of decision making have been introduced, one of them being centralized and the other distributed.

Specifically in a context where SPs are involved, in a previous work (Vieira et al. 2014) it was presented a method for risk analysis in VOs, which uses the same criteria used to perform risk analysis in this work. That method, called MARTP, initially performs an analysis of individual risk for all pre-selected SPs, using Event Tree Analysis (ETA) (Ericson et al. 2005). Then, it calculates and analyzes the overall risk of VO, considering the SPs collectively, using Fault Tree Analysis (FTA) (Ericson et al. 2005).

9.3 Merging DEA and Fuzzy Logic

The VO formation is triggered by the emergence of a CO, and thereafter consists of several steps. More specifically, the SPs' Search and Selection step is key for the success of VO formation (Alawamleh and Popplewell 2010) and can be divided into two stages. The first stage is responsible for selecting, among all VBE participants, SPs that fulfill the CO requirements. Then, at the second stage, these selected SPs are submitted to the risk analysis, which is the focus of this work.

In the example shown in Fig. 9.1, it is supposed the formation of a VO requiring three different services (A, B and C). Thus, given a VBE with a set of several SPs, those that offer the services A, B and C are joined into clusters (C_A, C_B and C_C). Then, the first stage of the proposed method selects an SP for each service (SP_A, SP_B and SP_C) according procedures presented by (Junior and Rabelo 2013). The second stage receives the historical values of all SPs both selected and not selected

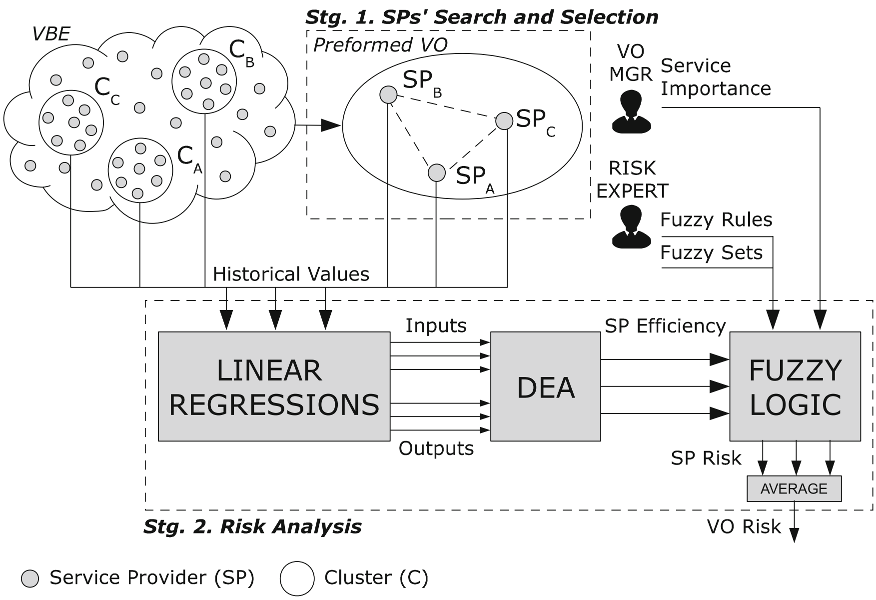

Fig. 9.1 Overview of the proposed method

for the three services, which it is needed due to DEA compare all the SPs of a same service. Next, these values are submitted to linear regressions for providing the necessary data for DEA to determine the efficiency of the selected SPs.

Besides the efficiency of SPs based on their historical KPI values, the method also considers the importance of each service. The importance means the impact a failure has on the operation of VO as a whole, and its value is defined by the VO manager (Camarinha-Matos and Afsarmanesh 2008). Then, given these information, fuzzy logic is used to calculate the risk of the VO failure due to a failure of a particular SP. Finally, the VO risk is calculated by averaging the individual risk of its SPs. The entire procedure for calculating the risk of each SP will be presented in the following subsections.

9.3.1 Data Envelopment Analysis

Data Envelopment Analysis (DEA) (Charnes et al. 1978) is an approach for evaluating the *relative efficiency* of a set of peer entities called Decision-Making Units (DMUs) (Cooper et al. 2011). The DMU concept is defined to allow flexibility in its use over a wide range of possible applications, and in general is regarded to any entity that can be evaluated in terms of its abilities to convert inputs into outputs (Cooper and Seiford 2005). These evaluations take a variety of forms, such as cost per unit, profit per unit, and so on, which are stated as one of the most common efficiency measure, called *productivity*, and can be calculated through the ratio *output/input*. This ratio is usually referred to as "partial productivity measure", distinguished from "total productivity measure". This latter, takes into account multiple inputs and multiple outputs and it is composed by the ratio between the weighted sum of the outputs, and the weighted sum of the inputs, making need to determine the weights of each input and output.

In order to avoid the necessity to inform these weights, DEA measures the *relative* efficiency of the DMUs. In this sense, the efficiency of the DMUs is relative to that is more productive, that is, the difference between it and the most efficient DMU. This is calculated by solving a Linear Programming (LP) problem. Thus, consider n DMUs to be evaluated. Each DMU consumes m different inputs to produce s different outputs. More specifically, DMU_j consumes a quantity x_{ij} of the input $i \in [1, m]$ and produces quantity y_{rj} of the output $r \in [1, s]$. Also assume $x_{ij} \geq 0$ and $y_{rj} \geq 0$. Finally, considering that n optimizations are required, one for each DMU_o over analysis, where $o = 1, 2, \ldots, n$, the LP that solve this problem is P.1 (Cooper et al. 2011).

$$\begin{aligned} & \max z_o = \sum_{r=1}^{s} u_r y_{ro} - \mu_o \\ & \text{subject to} \\ & \sum_{i=1}^{m} v_i x_{io} = 1 \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - \mu_o \leq 0 \\ & u_r, v_i \geq 0, \mu_o \in R \end{aligned} \tag{P.1}$$

where z_0 is the relative efficiency of DMU_o, u_r and v_i are, respectively, the input and output weights, and μ_o is a real scale factor.

As already mentioned, the role of DEA in this work is to calculate the efficiency of the SPs selected to form a new VO. In this way, the SPs are regarded as DMUs and therefore they must consume some input to produce some output. In order to define what are those inputs and outputs, it is important to highlight that the efficiency of an SP should be measured regarding to its risk level, which is characterized by its potential to not comply with the VO requirements (Sect. 9.2). That is, the lower the risk of an SP to fail with its responsibilities, the greater should be its efficiency. Since the input and output variables are the basis for calculation of the SPs' efficiency, the relation between the risk level and efficiency is established by defining these variables accordingly risk analysis criteria. In this work, this is done by an analysis of the historical series of the SPs.

9.3.1.1 Determining Input/Output Values

According to (Vose et al. 2008), variability of a data set is a major component responsible for the difficulty in predicting future events, being considered a risk factor. Therefore, the greater the variability of the historical values of an SP, the greater the unpredictability on its future values, increasing the risk associated to this SP. The input and output values are related to the KPI predictability of the SP and, in this work, they are measured by repeated calculations of linear regressions over the historical values, obtaining the so called estimated values, as seen in Fig. 9.2.

More specifically, for each risk KPI of a specific SP, it is calculated a linear regression for the first two participations in a VO, in order to estimate the value of the third, and then for the first three, estimating the fourth, and so on, until the $m-1$ participations, where the value of the last participation is estimated. The procedures for obtaining the input and output values will be presented as follows:

Let $K = \{K_1, K_2, K_3, K_4\}$ the set of KPIs earlier mentioned (trust, communication, collaboration and commitment), respectively. Let also $H_{ki} = \{h_1, h_2, \ldots, h_m\}$ the set of historical (real) KPI values and $X_{ki} = \{x_1, \ldots, x_{m-1}\}$ the set of estimated

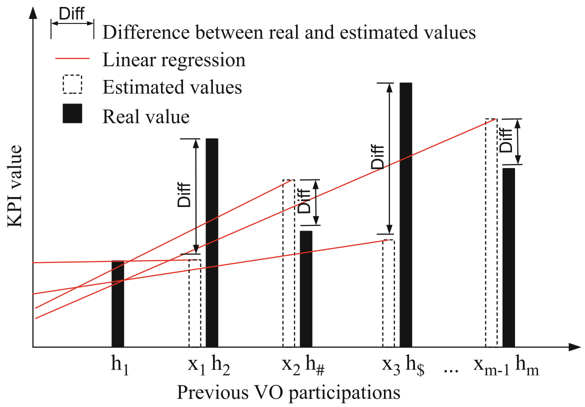

Fig. 9.2 Calculating input and output values through linear regressions

values of the KPI i for the SP k on the m past VO participations, Fig. 9.2 illustrates that process.

The efficiency of an SP takes into account the difference between the real and estimated values, that is, the efficiency should be increased when the SP performance is greater than the expectation. Thus, from the point of view of inputs and outputs adopted by DEA, the average of the estimated values can be considered as inputs and the average of the actual values as outputs.

However, considering only the average is not sufficient, because an SP can have high average but also large fluctuations in their historical KPI values, which makes it a riskier SP. Therefore, the final calculation of the inputs and outputs also takes into account the standard deviation of the data. Since the purpose of the DEA is to maximize the ratio outputs/inputs, the standard deviation of historical values (outputs) is subtracted from the mean. Therefore, the greater the deviation, the smaller the resulting value, and consequently the worse the efficiency. Likewise, the average of the estimated values (input) is added to the standard deviation.

Moreover, aiming to increase the efficiency of increasing historical, average historical values are proportionally increased to the $(m + 1)$th expected value (obtained by calculating the linear regression for all historical values). Thus, when historical values are increasing, the expected value (and consequently the efficiency) will be higher than for decreasing data. Since $\overline{X_{ki}}$ and $\overline{H_{ki}}$ correspond, respectively, to the average of the estimated and real values for KPI i from SP k, the input and output variables to be used by DEA are given by Eqs. (9.1) and (9.2), respectively.

$$I_{ki} = \overline{X_{ki}} + \sigma(X_{ki}) \tag{9.1}$$

$$O_{ki} = (\overline{H_{ki}} + \overline{H_{ki}} * x_{m+1}) - \sigma(H_{ki}) \tag{9.2}$$

Then, these input and output values are used for solving, for each service, the linear programming problem earlier presented, providing the efficiency of each selected SP. The SPs' efficiency is then used as input for the fuzzy system presented on the next step.

9.3.2 Fuzzy Logic

This step aims to calculate the individual risk of the selected SPs, i.e., the risk of the entire VO fails due to a failure of a specific SP. This analysis takes into account two factors: (1) efficiency of the SP; (2) impact of the failure of an SP on the VO as a whole. As determined in the preceding step, the higher the efficiency of the SP, the lower its risk of failure. Also, if the service provided by that SP is not crucial to the VO, i.e., the impact of a failure is not so great on the success of the VO as a whole, the lower the risk of t he VO failure due to that SP.

It can be noted that both factors are derived from human evaluation, where the first is calculated by DEA from historical values (which were assigned by the partners in past participations in VOs), and the second should be informed by the VO Manager (as shown in Fig. 9.1). Fuzzy logic (Zadeh 1965) is specially helpful when involving human assessment, which is the case for risk management, where humans usually evaluate the risk by using linguistic expressions like "high" or "low" (Dikmen et al. 2007). Moreover, the handling of linguistic expressions in the definition of the expert rules or of the available information have been one of the main applications of fuzzy theory (Yager and Zadeh 1992). This becomes important since defining expert rules is key for solving a wide range of real world problems, which in most cases needs a systematic representation of human knowledge (Wang 1997).

Therefore, fuzzy logic is used in this work for establishing, through a set of expert rules, a relation between the two factors earlier presented. To accomplish that, first of all, it is necessary define fuzzy sets and label them using the called *linguistic variables*, which should be done preferably by a risk expert in order to get more accurate results. However, in this work they will be empirically defined and based on literature review (Wang et al. 2009).

The following linguistic variables were defined: *provider efficiency*, *service importance* and *VO risk*. Each variable can take five values: Very Low (VL), Low (L), Moderate (M), Very High (VH) and Extremely High (EH). Table 9.1 presents

Table 9.1 Set of fuzzy rules proposed in this work

Service importance	Provider efficiency				
	EH	VH	M	L	VL
	VO risk				
Extremely High (EH)	M	VH	VH	EH	EH
Very High (VH)	L	M	VH	VH	EH
Moderate (M)	L	L	M	VH	VH
Low (L)	VL	L	L	M	VH
Very Low (VL)	VL	VL	L	L	M

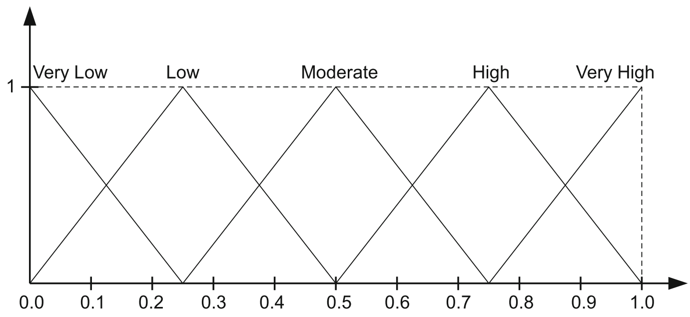

Fig. 9.3 Membership function for all the fuzzy sets

the set of 25 rules used in this work (result of all combinations of values for the three linguistic variables), which represents the influence of the relationship between the SP efficiency and the service importance for the VO as a whole. The rules have the form of the following example: *"If the provider efficiency is very low and the service importance is extremely high, then the VO risk is extremely high"* ("EH" in first line, last column).

The set of rules have been defined, it is also necessary to define the membership function and the defuzzification method. That done, the fuzzy system is able to make inferences over the entries, which are numeric values that represent the SP efficiency and the service importance, and determine the VO risk for that SP. According (Dikmen et al. 2007), the triangular membership function (represented in Fig. 9.3) is one of the most used, and thus applied in this work for all fuzzy sets. For the same reason, the Center of Gravity (CoG) method was used for defuzzification process (Roychowdhury and Pedrycz 2001).

Since the fuzzy parameters are defined, then the process of inference can be started. This process should be performed n times, one for each selected SP, and for each run the outcome corresponds to the risk R_i of the VO failure due to a SP_i failure. Finally, the overall VO risk, i.e., the risk of the VO failure due to one or more SPs, is calculated by Eq. (9.3).

$$R_{VO} = \sum_{i=1}^{n} \frac{R_i}{n} \tag{9.3}$$

9.4 Results and Discussion

This section aims to evaluate the proposed method and compare it with the MARTP (Vieira et al. 2014). This analysis is performed through simulation process and is focused on how both methods measure the risk of SPs that have different historical trends. For example, it is expected that an SP that has more constant historical KPI

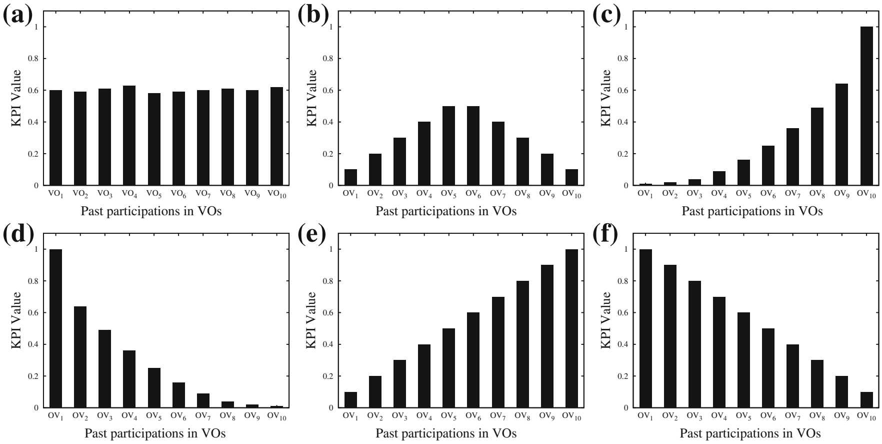

Fig. 9.4 Shape of the probability distributions used for forming the SPs' historical values, **a** Linear. **b** Triangular. **c** Exponential (increasing). **d** Exponential (decreasing). **e** Beta (increasing). **f** Beta (decreasing)

values and a reasonable average, present less risk than an SP whose performance is decreasing. Therefore, it is interesting to analyze whether the methods reflect the expectations or not.

For this purpose, the simulation scenario is composed by SPs with historical KPI values based on different probability distributions (Montgomery and Runger 2011): *linear*, *triangular*, *exponential increasing*, *exponential decreasing*, *beta increasing* and *beta decreasing*. The SPs historical values are generated by using the "shape" of these distributions (Fig. 9.4), which is obtained from a *frequency distribution* calculation.

The simulation considers the services A, B and C (i.e., three clusters (see Sect. 9.3)) each with six SPs (one for each distribution). Hence, six potential VOs are formed by one SP of each service, as in Fig. 9.5.

Since all SPs are generated and joined into potential VOs, both the methods are applied for analyzing the risk level of the SPs and the VO formed by them, whose results is shown in Table 9.2. There, the cells correspond to the risk of the SPs and the VOs, as well as the mean and standard deviation. The results were obtained by considering importance as 30, 50 and 70 % for services A, B and C, respectively. Values outside this range proved unrepresentative for the proposed analysis.

Furthermore, aiming to statistically enable the set of computationally generated SPs, the set of historical KPI values of each SP is the result of the average of K sets of historical values generated based on a distribution. In order to maintain the representativeness of the data set, it was employed the sample size calculation of (Montgomery and Runger 2011) to determine the minimum sample size $K = 42$, considering a confidence level of 95 %.

Hence, from the results shown in Table 9.2, it can be seen that in average, both methods have resulted in different risk levels (either to the SPs as to VOs as a

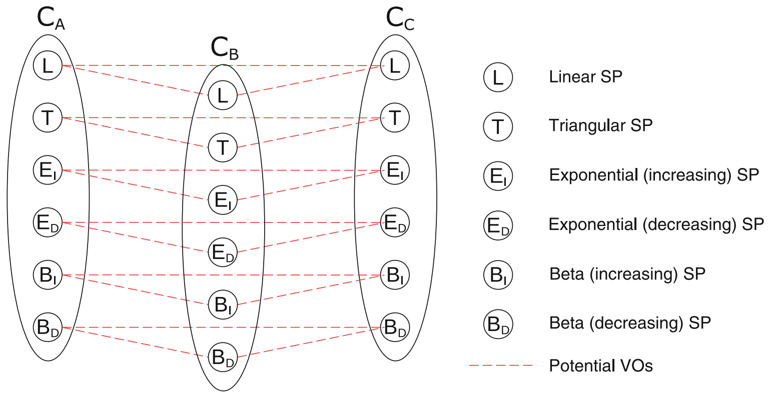

Fig. 9.5 Potential VOs formed by SPs of services *A*, *B* and *C*

Table 9.2 Risk level for VOs composed by SPs with historical values based on different distributions for both methods under analysis

	MARTP				Proposed method			
Distribution	SP_A	SP_B	SP_C	VO	SP_A	SP_B	SP_C	VO
Linear	0.56	0.00	0.00	0.19	0.00	0.00	0.00	0.00
Triangular	0.13	0.13	0.00	0.09	0.40	0.61	0.68	0.56
Exponential (Incr.)	0.45	0.22	0.00	0.22	0.25	0.47	0.65	0.45
Exponential (Decr.)	1.00	1.00	1.00	1.00	0.62	0.75	0.75	0.70
Beta (Incr.)	0.00	0.00	0.00	0.00	0.20	0.20	0.43	0.27
Beta (Decr.)	0.51	0.51	0.58	0.53	0.56	0.75	0.75	0.68
Mean	0.44	0.31	0.26	0.34	0.33	0.46	0.54	0.44
Standard deviation	0.35	0.38	0.43	0.37	0.23	0.30	0.29	0.27

whole) when considered different historical behaviors. As expected, the distributions exponential and beta (decreasing) obtained higher averaged risk level in relation to the other historical behaviors for both methods (1.00 and 0.53, respectively for MARTP method; 0.70 and 0.68, respectively for the proposed method), which is easily explained by the provision of their values (i.e., values start high and are decreasing along the time series). It appears that the opposite is also true, i.e., the distributions exponential and beta (increasing) presented lower averaged risk level for both methods (0.22 and 0.00 to the MARTP method; 0.45 and 0.27 for the proposed method). The triangular distribution in turn showed differences in the risk level for both methods (0.09 to the MARTP method and 0.56 for the proposed method).

Finally, given that the proposed method has the variability of historical KPI data as a criterion to measure risk, the SPs that were modeled by linear distribution showed a risk level much lower compared to other SPs (0.00). This result is consistent, because these SPs showed good performance and stability during all previous VO participations, so there is no reason for them to have an increase in their risk levels.

However, except for this particular case, it is important to note that 0 or 100 % rarely exist in practice, and the method proposed in this work demonstrates to take this aspect into account. One can clearly see the dissonance between the mean values of risk presented by both methods. While the method proposed in this work provides more balanced average values, the MARTP computes most values as 0 or 1, which explains the larger standard deviations for it. Moreover, it can be seen that, for the proposed method, the SP risk increases as its service importance also increases (mean of 0.33, 0.46 and 0.54 for service importance 30, 50 and 70 %, respectively).

9.5 Final Considerations

In general, risk analysis has become an inherent problem in Virtual Organization (VO) formation since bad choices can lead to impairment as a whole. Therefore, the delimitation of strategies for risk assessment are key to ensure the success of the VO. In this way, the main contribution of this work is to propose and develop a hybrid method that combines Data Envelopment Analysis (DEA) and Fuzzy Logic to quantify and measure the risk in a number of Service Providers (SPs) that are going to compose a VO.

In order to assess the performance of the proposed method, simulations were performed involving pre-selected sets of SPs. The simulations explored the comparison between the proposed method and the method previously proposed in (Vieira et al. 2014). The results shown that:

- the proposed method may be more or less critical for the assessment of SPs in a given VO, and this analysis is strongly dependent on the importance of the service assigned to each SP. In this sense, the VO manager plays a key role in the evaluation of the VO process, since it is the one that informs which service will have greater or lesser importance;
- the DEA has shown a good alternative for analyzing the risk in large sets of SPs, given its ability to compare a given SP with all the others that offer the same service category. It allows to know, among all other possibilities, if a given SP is a good choice or not, thus providing a more realistic assessment of the whole process;
- the proposed method provides more balanced results for the averaged risk of the VOs, as well as more resilient analysis regarding the variation in the historical behaviors of each SP in relation to MARTP method. This aspect becomes desirable in practice because there are many scenarios where SPs will present different distributions in its historical values.

Likewise, the proposed method presented many advantages compared to other methods in the literature. The first one is the ability to prioritize services according to their real importance to the success of the VO. In this case, the use of the fuzzy theory become advantageous, by supporting the manipulation of inaccurate data provided by humans. In real circumstances, one can modify the fuzzy rules to fit them to the interests of the VO. The criterion for determining the inputs and outputs of the method (which considers the variation in historical values of each SP) comprises another contribution of this work. Thus, the risk of a SP is related not only to their level of performance, but also its predictability. It should also be noted that the SPs are all members of a long-term alliance (VBE), which tends to tremendously facilitate collaboration between them and their measurement and performance management, which are key elements in the proposed method.

The method was evaluated in a simulated manner and using hypothetical data. In fact, it is very difficult to obtain data from companies and VOs, especially those related to its performance and historical behavior. Therefore, as a future work, it has been designed to test the method in real scenarios in order to compare it with other methods that have the same goal. It is also intended to test the method using different fuzzy rules in order to assess any changes in its behavior. Finally, we aim to integrate the proposed method in a framework for VO formation process.

References

Afsarmanesh, H., Camarinha-Matos, L.M.: A framework for management of virtual organization breeding environments. In: Proceedings of the 6th Working Conference on Virtual Enterprises (PRO-VE'05), Valencia, Spain, pp. 35–48 (2005)

Ahmady, N., Azadi, M., Sadeghi, S.A.H., Saen, R.F.: A novel fuzzy data envelopment analysis model with double frontiers for supplier selection. Int. J. Logist.-Res. App. **16**(2), 87–98 (2013)

Alawamleh, M., Popplewell, K.: Risk sources identification in virtual organisation. In: Popplewell, K., Harding, J., Poler, R., Chalmeta, R. (eds.) Enterprise Interoperability IV, pp. 265–277. Springer, London (2010). doi:10.1007/978-1-84996-257-5_25

Alawamleh, M., Popplewell, K.: Analysing virtual organisation risk sources: an analytical network process approach. Int. J. Networking Virtual Organ. **10**(1), 18–39 (2012)

Alem, S.M., Jolai, F., Nazari-Shirkouhi, S.: An integrated fuzzy dea–fuzzy ahp approach: a new model for ranking decision–making units. Int. J. Oper. Res. **17**(1), 38–58 (2013)

Amindoust, A., Shamsuddin, A., Saghafinia, A.: Using data envelopment analysis for green supplier selection in manufacturing under vague environment. In: Advanced Materials Research, vol. 622, pp. 1682–1685. Trans Tech Publications, Switzerland (2013)

Azadeh, A., Alem, S.: A flexible deterministic, stochastic and fuzzy data envelopment analysis approach for supply chain risk and vendor selection problem: Simulation analysis. Expert Syst. Appl. **37**(12), 7438–7448 (2010). doi:http://dx.doi.org/10.1016/j.eswa.2010.04.022

Baldo, F., Rabelo, R.J., Vallejos, R.V.: A framework for selecting performance indicators for virtual organisation partners search and selection. Int. J. Prod. Res. **47**(17), 4737–4755 (2009)

Camarinha-Matos, L., Afsarmanesh, H.: The virtual enterprise concept. In: Camarinha-Matos, L., Afsarmanesh, H. (eds.) Infrastructures for Virtual Enterprises, IFIP, The International Federation for Information Processing, vol. 27, pp. 3–14. Springer, US (1999)

Camarinha-Matos, L.M., Afsarmanesh, H.: On reference models for collaborative networked organizations. Int. J. Prod. Res. **46**(9), 2453–2469 (2008)

Camarinha-Matos, L.M., Afsarmanesh, H., Galeano, N., Molina, A.: Collaborative networked organizations – concepts and practice in manufacturing enterprises. Comput. Ind. Eng. **57**(1), 46–60 (2009). doi:http://dx.doi.org/10.1016/j.cie.2008.11.024

Charnes, A., Cooper, W., Rhodes, E.: Measuring the efficiency of decision making units. Eur. J. Oper. Res. **2**(6), 429–444 (1978)

Chen, Y.C., Chiu, Y.H., Huang, C.W., Tu, C.H.: The analysis of bank business performance and market risk–applying fuzzy DEA. Econ. Model. **32**(0), 225–232 (2013). doi:http://dx.doi.org/10.1016/j.econmod.2013.02.008

Cooper, W.W., Seiford, L.M., Tone, K.: Introduction to Data Envelopment Analysis and Its Uses: With Dea-Solver Software and References. Springer, New York (2005)

Cooper, W.W., Seiford, L.M., Zhu, J.: Handbook on Data Envelopment Analysis. Springer, US (2011)

Dikmen, I., Birgonul, M.T., Han, S.: Using fuzzy risk assessment to rate cost overrun risk in international construction projects. Int. J. Project Manage. **25**(5), 494–505 (2007)

Ericson, C.A., et al.: Hazard Analysis Techniques for System Safety. Wiley, New York (2005)

Esposito, E., Evangelista, P.: Investigating virtual enterprise models: literature review and empirical findings. Int. J. Prod. Econ. **148**, 145–157 (2014)

Fathi, N., Izadikhah, M.: Evaluation of decision making units in the presence of fuzzy and non-discretionary. Appl. Math. Sci. **7**(25–28), 1387–1392 (2013)

Fei, L., Zhixue, L.: A fuzzy comprehensive evaluation for risk of virtual enterprise. In: 10th International Conference on Internet Technology and Applications, Corfu, Greece, pp. 1–4 (2010)

Grabowski, M., Roberts, K.H.: Risk mitigation in virtual organizations. J. Comput.-Mediat. Commun. **3**(4), 704–721 (1998)

Hajiagha, S.H.R., Akrami, H., Zavadskas, E.K., Hashemi, S.S.: An intuitionistic fuzzy data envelopment analysis for efficiency evaluation under uncertainty: case of a finance and credit institution. E M Ekon. Manag. **16**(1), 128–137 (2013)

Hatami-Marbini, A., Saati, S., Tavana, M.: Data envelopment analysis with fuzzy parameters: an interactive approach. Int. J. Oper. Res. Inf. Syst. **2**(3), 39–53 (2011)

Huang, M., Wang, X., Lu, F.Q., Bi, H.L.: A coordination of risk management for supply chains organized as virtual enterprises. Math. Probl. Eng. **2013** (2013). doi:http://dx.doi.org/10.1155/2013/931690

Junior, O.C.A., Rabelo, R.J.: A KPI model for logistics partners' search and suggestion to create virtual organisations. Int. J. Networking Virtual Organ. **12**(2), 149–177 (2013)

Jüttner, U.: Supply chain risk management: understanding the business requirements from a practitioner perspective. Int. J. Logist. Manag. **16**(1), 120–141 (2005)

Khalili-Damghani, K., Taghavifard, B.: Sensitivity and stability analysis in two–stage dea models with fuzzy data. Int. J. Oper. Res. **17**(1), 1–37 (2013)

Liang, M.Z.A., Mustafa, A.: Fuzzy interpretation of efficiency in data envelopment analysis and its application in a non-discretionary model. Knowl.-Based Syst. **49**(0), 145–151 (2013). doi: http://dx.doi.org/10.1016/j.knosys.2013.05.001

Li, Y., Liao, X.: Decision support for risk analysis on dynamic alliance. Decis. Support Syst. **42**(4), 2043–2059 (2007)

March, J.G., Shapira, Z.: Managerial perspectives on risk and risk taking. Manage. Sci. **33**(11), 1404–1418 (1987)

Markovits-Somogyi, R.: Ranking efficient and inefficient decision making units in data envelopment analysis. Int. J. Traffic and Transp. Eng. **1**(4), 245–256 (2011)

Min, H., Xue-Jing, W., Lu, F., Xing-Wei, W.: Multi-strategies risk programming for virtual enterprise based on ant colony algorithm. In: Proceedings of the 1st International Conference on Industrial Engineering and Engineering Management, Singapore, pp. 407–411 (2007)

Mirhedayatian, M., Jelodar, M., Adnani, S., Akbarnejad, M., Saen, R.: A new approach for prioritization in fuzzy ahp with an application for selecting the best tunnel ventilation system. Int. J. Adv. Manuf. Technol. **68**(9–12), 2589–2599 (2013). doi:10.1007/s00170-013-4856-6

Montgomery, D.C., Runger, G.C.: Applied Statistics and Probability for Engineers. Wiley, Hoboken, NJ (2011)
Moskowitz, H., Bunn, D.: Decision and risk analysis. Eur. J. Oper. Res. **28**(3), 247–260 (1987)
Mowshowitz, A.: Virtual organization. Commun. ACM **40**(9), 30–37 (1997). doi:10.1145/260750.260759
Mugera, A.W.: Measuring technical efficiency of dairy farms with imprecise data: a fuzzy data envelopment analysis approach. Aust. J. Agr. Resour. Econ. **57**(4), 501–520 (2013). doi:10.1111/1467-8489.12008
Paszkiewicz, Z., Picard, W.: Modelling competences for partner selection in service-oriented virtual organization breeding environments. arXiv preprint arXiv:1111.5502 (2011)
Payan, A., Shariff, M.: Scrutiny malmquist productivity index on fuzzy data by credibility theory with an application to social security organizations. J. Uncertain. Syst. **7**(1), 36–49 (2013)
Puri, J., Yadav, S.P.: A concept of fuzzy input mix-efficiency in fuzzy DEA and its application in banking sector. Expert Syst. Appl. **40**(5), 1437–1450 (2013). doi:http://dx.doi.org/10.1016/j.eswa.2012.08.047
Rhee, S.J., Ishii, K.: Using cost based fmea to enhance reliability and serviceability. Adv. Eng. Inform. **17**(3), 179–188 (2003)
Roychowdhury, S., Pedrycz, W.: A survey of defuzzification strategies. Int. J. Intell. Syst. **16**(6), 679–695 (2001)
Rychlik, I., Rydén, J.: Probability and Risk Analysis: An Introduction for Engineers. Springer, New York (2006)
Saati, S., Hatami-Marbini, A., Tavana, M., Agrell, P.J.: A fuzzy data envelopment analysis for clustering operating units with imprecise data. Int. J. Uncertain. Fuzz Knowl.-Based Syst. **21** (01), 29–54 (2013)
Saaty, T.L.: Decision making—the analytic hierarchy and network processes (AHP/ANP). J. Syst. Sci. Syst. Eng. **13**(1), 1–35 (2004)
Sari, B., Sen, T., Kilic, S.: AHP model for the selection of partner companies in virtual enterprises. Int. J. Adv. Manuf. Technol. **38**(3–4), 367–376 (2008)
Tavakkoli-Moghaddam, R., Mahmoodi, S.: Finding a common set of weights by the fuzzy entropy compared with data envelopment analysis–a case study. Int. J. Ind. Eng. Prod. Res. **21** (2010)
Tavana, M., Shiraz, R.K., Hatami-Marbini, A., Agrell, P.J., Paryab, K.: Chance-constrained DEA models with random fuzzy inputs and outputs. Knowl.-Based Syst. **52**(0), 32–52 (2013). doi: http://dx.doi.org/10.1016/j.knosys.2013.05.014
Vieira, R.G., Junior, O.C.A., Fiorese, A.: A risk analysis method for selecting service providers in P2P service overlay networks. In: Proceedings of the 16th International Conference on Enterprise Information Systems, Lisboa, Portugal, pp. 200–211 (2014)
Vose, D.: Risk Analysis: A Quantitative Guide. Wiley, New York (2008)
Wang, L.X.: A Course in Fuzzy Systems and Control. Prentice-Hall Inc, Upper Saddle River (1997)
Wang, Y.F., Yan, H.S.: A fuzzy DEA/AR method for manufacturing mode selection. Adv. Mater. Res. **694**, 3618–3625 (2013)
Wang, Y.M., Chin, K.S., Poon, G.K.K., Yang, J.B.: Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean. Expert Syst. Appl. **36**(2), 1195–1207 (2009)
Yager, R.R., Zadeh, L.A.: An introduction to fuzzy logic applications in intelligent systems. Springer, New York (1992)
Zadeh, L.: Fuzzy sets. Inf. Control **8**(3), 338–353 (1965). doi:http://dx.doi.org/10.1016/S0019-9958(65)90241-X
Zhou, S.J., Zhang, Z.D., Li, Y.C.: Research of real estate investment risk evaluation based on fuzzy data envelopment analysis method. In: Proceedings of the 2008 International Conference on Risk Management&Engineering Management, ICRMEM '08, IEEE Computer Society, Washington, DC, USA, pp. 444–448 (2008). doi:10.1109/ICRMEM.2008.113

Part V
Production Management

Chapter 10
Intelligent Systems in Maintenance Planning and Management

Konsta Mikael Sirvio

Abstract Maintenance can be divided into reactive and preventive. In reactive maintenance damage is corrected after it has occurred. On the other hand, predictive maintenance anticipates the damage in the future. Predictive maintenance can be periodic with fixed time intervals or predictive with forecasted failure times. Maintenance planning is intelligent when maintenance needs are predicted and optimised. Intelligent maintenance systems require data collection, data transfer, data storage, data processing and Decision Support Systems to be in place. Machine learning algorithms in forecasting and optimisation can take increasing quantity of collected data into consideration in intelligent maintenance planning. Two types of forecasting models—time-series and causal methods can be used for intelligent maintenance planning. Optimisation algorithms can be divided into local and population search methods. Hybrid methods combining more than one algorithm have been used efficiently for maintenance planning. Maintenance planning is important in the transport sector and various models and methods have been applied both in road and vehicle maintenance. In practice, it is important to have accurate deterioration and cost models in place. In research, both data-driven and mathematical models have been applied, but data-driven methods are becoming more practical as computation is increasingly more feasible.

Keywords Intelligent maintenance planning · Predictive maintenance · Maintenance optimisation · Road maintenance planning · Vehicle maintenance planning

10.1 Introduction

Maintenance has been carried out since first man-made tools and premises existed. Although maintenance has ever increasing importance its value is not always recognized at the higher decision-making level, which is noticeable especially in

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public expenditure. Politicians prefer allocation of money to new construction while the existing infrastructure deteriorates. Shift to maintenance-focused attitude and intelligent maintenance planning is still under way being affected by various current trends.

Since the scarcity of the years after WWII developed nations have lived in increasing abundance, which has led to consumerism among certain sub-populations. Materialism as a driving force in consumer demand has left little to maintenance philosophy when the consumer products are advisedly designed to break down within a limited time period in order to maintain the demand of new products (Pangburn and Stavrulaki 2014). However, due to the Green Move and increased awareness of scarcity of natural resources and production's detrimental effect to the nature there is increasing popularity of sustainable consumption of durable and ethically produced goods (Ardente and Mathieux 2012). The same philosophy applies slowly also to public spending and to means of production. In globally increased competition multinational companies need to deliver high value added to the customers with the least costs taking legislative issues into consideration.

Intelligent maintenance of valuable production lines is one solution to decrease costs (Frazzon et al. 2014). Intelligent maintenance of valuable end consumer goods is another solution to increase value to the customer and therefore demand. This is in line with the general economic shift from goods production to service delivery, where service business in general including maintenance has growth markets and higher potential. Overall, awareness has increased total lifecycle costs of products that combine not only the purchase price, but also the recurring maintenance costs and wider impacts (Hoogmartens et al. 2014).

In order to understand how intelligent systems can help in maintenance planning and management we need to conceptualise maintenance. The English word maintain comes from the French ***maintenir***, which is combined of two words: ***main*** (hand) and ***tenir*** (to hold). The French term originates from the Latin word ***mantene*** (I support), which is a combination of (with the hand) + ***teneõ*** (I hold). Thus, maintenance refers to action done with hands in the past and from the 15th century onwards the word has referred to action of upholding. Instead of production or construction, maintenance keeps the machine or asset in working condition. The target condition is one of the main issues in maintenance planning as in the old philosophy both the current and target condition were unknown unlike in the intelligent maintenance philosophy. Thus, we can argue that maintenance should have come from the head and not from hands, as it is rather difficult to set the target levels for condition that maintenance should address. Development of information and communication technology is perhaps the main driver for intelligent maintenance systems. Maintenance philosophy has evolved from reactive (or corrective) to preventive maintenance. Especially in the past, but also today cars and roads are repaired once broken down. However, preventive maintenance has increasingly taken place, where asset maintenance is applied prior to system breakdowns. This is not an easy task since lifespan of different parts of complex engineering objects differ and lifespan of each of them is variable.

Preventive maintenance can be either periodic or predictive maintenance. In periodic maintenance asset parts are examined and/or maintained according to predefined time schedule that can be based on mathematical risk models (Sheu et al. 1995). In predictive maintenance, however, each maintenance activity is predicted taking into consideration information on the asset (f.ex. current condition) and on the environment (f.ex. weather) (Zhou et al. 2007). Even if the predictions are correct the maintenance costs can be higher than in periodic maintenance if individual targets are maintained separately. The idea of optimised maintenance takes this into consideration by maximising the target function of the whole system under maintenance scheme. Target function maximisation can be equivalent to minimisation of the total lifecycle costs of products.

In terms of technical aspects intelligent planning requires four elements to be in place. The first three are main technical enablers for intelligent maintenance planning. Examples are reported for example by Widodo and Yang (2011), Pereira and Carro (2007). The fourth aspect squeezes out the benefits from the technical enablers for management (Muller et al. 2008; Campos 2009).

1. Sensor technology for data collection
2. Communication technology for data transfer
3. Computation technology including machine learning for data processing
4. Management tools and practices integrating the previous three

The overall framework of a maintenance management system is presented in Fig. 10.1. Data is collected from the engineering system and its environment. Collected data is transferred and stored. Data processing is needed for the actual decision making and the maintenance decisions are concretised as maintenance activities.

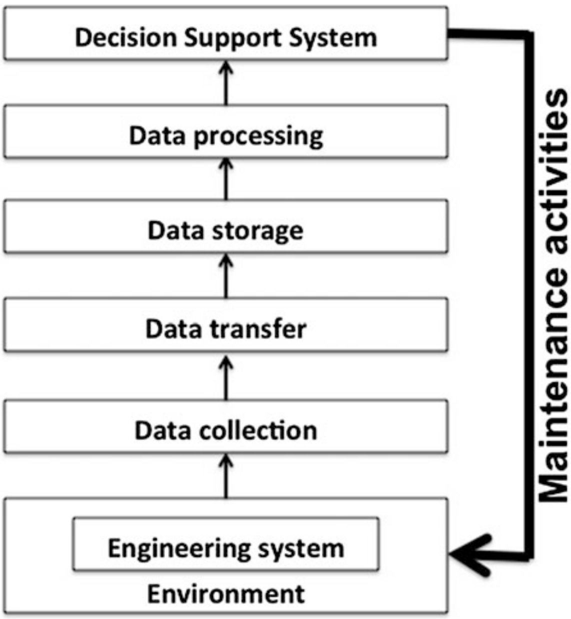

Fig. 10.1 Maintenance management system

The emphasis of this Chapter is on machine learning—the actual so-called intelligence applied to intelligent planning. In terms of machine learning algorithms, intelligent planning covers mostly forecasting and optimisation algorithms. Recent development in neural network and kernel methods can provide more accurate forecasting results in dynamic situations, while meta-heuristic optimisation makes optimisation feasible in real-world applications. Examples from different fields such as road and factory maintenance show that even if novel algorithms exist there are still problem areas in practical applications concerning cost modelling and data collection among other issues.

10.2 Maintenance Management: Towards Predictive Optimised Maintenance

The idea of asset management is to keep the asset in operational condition by using maintenance activities that also preserves the value of the asset. An asset has C number of components that each has an internal state $s_c(t), c \in [1, C]$ at any given time t. In asset management framework the state should be defined so that it indicates possibly required maintenance e.g. operational condition.

A maintenance management system is a set of principles and tools utilised to manage the maintenance of assets. The principles form the overall applied maintenance strategy. In reactive strategy maintenance is not planned and applied to a component until it is necessary to get a system operational again. In proactive strategy, however, system failure is prevented by maintenance that is done before system failure. Determination of the time can be condition-based or time-based as illustrated in Fig. 10.2. Maintenance can be replacement or repair of the system component.

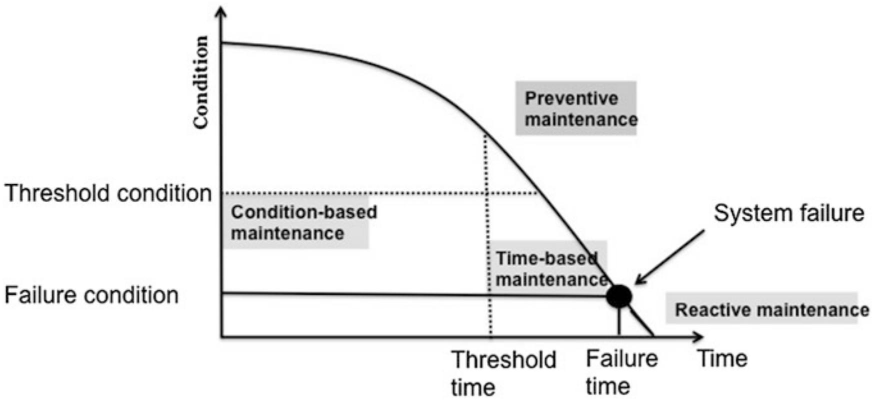

Fig. 10.2 Preventive versus reactive maintenance

Improved determination of the correct maintenance time can be done by predictive maintenance, where the target can be condition or failure time. Predictive maintenance can give more accurate maintenance times, but also higher costs. Optimised maintenance aims at not only effectiveness of the system, but also efficiency by cost minimisation. The system itself usually operates in continuous state space—continuous time environment, but the model of the system utilised for maintenance planning can be either continuous or discrete in terms of time and state.

10.2.1 Corrective Maintenance Systems

Corrective maintenance (CM) is a maintenance strategy, where maintenance takes place after a time period after component or system failure. Corrective maintenance is also called reactive maintenance (Ahmad and Kamaruddin 2012). In reactive maintenance state of the maintenance target is not forecasted and often the present state is not known. However, when a breakdown of the system occurs the information of the failure is transmitted to the responsible party of the maintenance. In reactive maintenance system there is a delay related to transmittal of the information of the failure as well as reaction delay. A failure causes a maintenance cost, C_M depending on the repair target and method. During a failure an opportunity cost is resulted, C_O since the commodity in unavailable. For the decision-maker the main decision variable is the reaction time, t_R, if the maintenance methods and maintenance time, t_M as well as information transmittal time, t_I are pre-determined. The optimisation problem can then be formulated from the viewpoint of the decision-maker by

$$Min\ C_M + C_O, \tag{10.1}$$

where $C_M = f(t_R)$ and $C_O = g\left(t_I + t_M + t_g\right)$. Maintenance costs is a function of reaction time by two ways: (1) fast mobilisation of resources are often costlier and (2) delay of maintenance can lead to a situation with several failures geographically co-located bringing thus economies of scale in maintenance of all of them at the same maintenance time.

Even though many Road Agencies have moved towards preventive maintenance corrective maintenance still has a vital role for exceptional events usually related to natural phenomena such as flooding, earthquakes and storms that cannot be forecasted long time in advance.

10.2.2 Preventive Maintenance Systems

Unlike reactive maintenance preventive maintenance is proactive action that prevents failure of a system and need for reactive maintenance. Preventive maintenance actions are often less expensive than reactive maintenance activities. The objective of preventive maintenance is to prevent the failure cost efficiently. The optimisation problem can be presented by

$$Min\ C_M + C_f p_f(C_M, t_M), \tag{10.2}$$

where C_M are discounted future maintenance costs and C_f are discounted future failure costs. Probability of a failure, P_f depends on the maintenance costs and scheduling of maintenance, t_M. Preventive maintenance can be divided into time-based maintenance (TBM) and condition-based maintenance (CBM) depending on the criterion triggering a maintenance action (Ahmad and Kamaruddin 2012). Time-based maintenance can also be called planned maintenance (PM) or scheduled maintenance, where maintenance actions are planned beforehand. In condition-based maintenance action is triggered when the asset deteriorates beyond the set threshold value. The term periodic maintenance is used in road maintenance literature and practice. It is preventive maintenance that has both condition and time-based triggering (Ahmad and Kamaruddin 2012).

A prerequisite for preventive maintenance is that the threshold for condition-based maintenance or time interval for time-based maintenance is set so that failure is avoided. In principle, preventive maintenance can be considered predictive maintenance as failure time is predicted by some means. However, the predictions can be coarse rules-of-thumb and therefore in this study maintenance is considered predictive if maintenance needs for each component in the system is predicted separately using internal or external information. Internal information refers to the component's state such as condition at any given time and external information refers to the state of the environment such as weather conditions.

10.2.2.1 Time-Based Preventive Maintenance

The idea with time-based preventive maintenance is that there are certain maintenance time intervals for each component of a system. And when the time interval, T has been exceeded a maintenance action is triggered as shown in Fig. 10.3. Time-based maintenance relies often on a simplified assumption that deterioration of the system component follows a deterministic path and therefore the threshold time remains constant.

In the ideal TBM model the system deterioration is deterministic and the threshold time remains constant. In that case the failure costs are irrelevant and the threshold time is minimum time span lower than the failure time. If the overall engineering system to be maintained consists of several system components with variable threshold times for maintenance the optimisation problem can be formulated as:

$$Min \sum_{t=F(T_i)} \left(\frac{1}{1+r}\right)^i C_M(i, T_i), \tag{10.3}$$

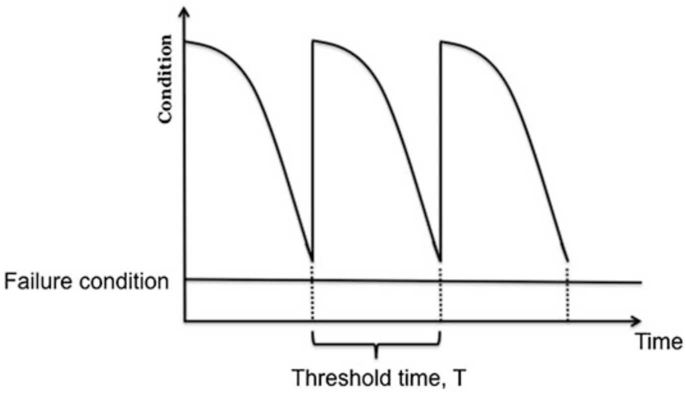

Fig. 10.3 Time-based preventive maintenance

where $T_i < T_{F_i}$, $F(T_i) \leq T$ and $i \in [1, I]$. The idea is to minimise the discounted maintenance costs, C_M that depend on the system component, i and threshold time for maintenance of each component, T_i Discount rate, r remain constant in the simplified problem formulation. The threshold times do not exceed component failure times, T_{F_t} to avoid system failures. Function $F(T_i)$ is cumulated maintenance threshold times, which does not exceed the total system lifetime, T.

10.2.2.2 Condition-Based Preventive Maintenance

In deterministic situation condition-based preventive maintenance is similar to timebased preventive maintenance. The only difference is that the model is conceptualised by system condition, which can be mapped to threshold time of maintenance as presented in Fig. 10.4.

With multiple-component system there is a threshold value for each system component and when decision-making is concerned the threshold conditions need to be mapped to maintenance threshold times and the problem formulation for maintenance optimisation is similar to time-based preventive maintenance.

10.2.3 Predictive Maintenance

10.2.3.1 Problem Formulation

Predictive maintenance can be either condition or time-based. Both the failure time or system condition can be predicted and maintenance actions targeted prior to the failure time. In time-based predictive maintenance the next failure time, T_F^{t+1} is forecasted:

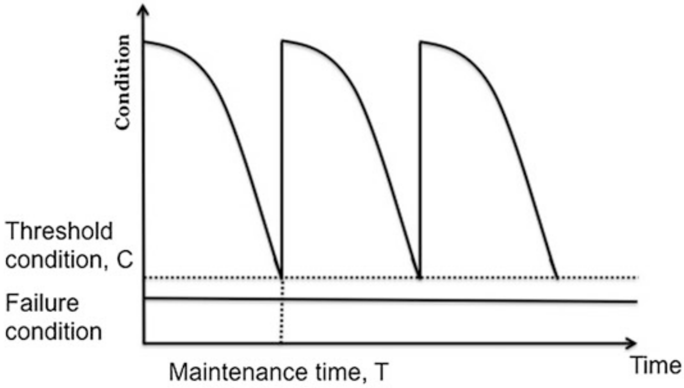

Fig. 10.4 Condition-based preventive maintenance

$$T_F^{t+1} = f\left(T_F^t, X^t\right) + \varepsilon^{t+1}, \tag{10.4}$$

where the failure time is a function, f of previous failure times, T_F^t and a vector of historical values of internal state variables and external variables, X^t. Due to the stochastic nature of the problem there is an error term, ε^{t+1} related to the forecasted value. The error term should be minimised:

$$Min\ \varepsilon^{t+1} = T_F^{t+1} - f\left(T_F^t, X^t\right) \tag{10.5}$$

In case of condition forecasting it is possible to forecast multiple time-steps ahead in which case the problem is formulated as:

$$Min\ \varepsilon^{t+k} = S^{t+k} - f(S^t, X^t), \tag{10.6}$$

where S^{t+k} is the observed state i.e. condition of the system at time $t+k$ and f presents the function forecasting the state at the same time, but using information up to the present time, t. The vector, X^i contains historical information of the system or external variables. Forecasting results at a series of forecasted states of the system, $S^{t+1}, \ldots, S^{t+k}$ and once system failure condition is reached the forecasting should stop and maintenance time determined.

10.2.4 Optimised Predictive Maintenance

Optimised predictive maintenance is based on the same principle as predictive maintenance, but instead of implementing the maintenance directly according to the predictions optimisation takes place first. Optimisation can be multi-objective, but this study simplifies the problem to one objective, maintenance costs. Growing number of research papers on maintenance optimisation have been done since the 1960s (Dekker and Kourentzes 1996).

The objective is to minimise the overall costs including maintenance and failure costs of all the system components:

$$Min\sum_{i=1}^{I}\sum_{t=1}^{T}\left(\frac{1}{1+r}\right)^{t}C_M(i,t)+\sum_{i=1}^{I}\sum_{t=1}^{T}\left(\frac{1}{1+r}\right)^{t}p_F(i,t)C_F(i,t), \quad (10.7)$$

where C_F are the failure costs that depend on the system component, i and maintenance times, t. The failure costs are multiplied by the probability of a failure, p, which also depends on the component and time. Failure probability is related to the forecasting error of the maintenance times. Maintenance costs, C_M depend similarly on the component and time as the condition or maintenance activity may differ.

Maintenance and failure cost functions can be theoretical or empirical. Theoretical functions are simplifications of the reality and therefore induce error in the optimisation solution. Empirical functions, on the other hand, can be very difficult to estimate and they can change over time. If pavement overlay is concerned, for example, the road agency or a private company can do the work. The work price depends on the market situation and is not constant over time. If the work is done internally, the costs can include direct and indirect costs. Direct costs such as direct labour and materials change over time, while indirect costs such as management and office rents allocated to the project can be vaguely argued.

10.3 Computational Problem Solving: Forecasting and Optimisation Algorithms

According to Moore's law the number of transistors doubles in an integrated circuit approximately every 2 years causing exponential growth in computational power (Moore 1965). Intelligent maintenance management relies heavily on computational problem solving having forecasting and optimisation algorithms in the core of the problem. In some applications the amount of collected data is voluminous and of high frequency, which requires efficient data pre-processing and computing power.

10.3.1 Forecasting

System prognosis i.e. state forecasting techniques can be divided into qualitative and quantitative methods. Qualitative methods can be better used to predict disruptive changes in the system by visioning the future state of affairs taking into consideration various aspects and fields. Qualitative forecasting can be based on expert opinions such as Delphi method (Wakefield and Watson 2014).

Quantitative forecasting is more relevant in actual operations of intelligent maintenance management systems since the forecasted maintenance needs to be planned usually on a relatively short time span. Quantified future state of the system under maintenance can be forecasted using only historical state variable values, a mixture of values of the state variable and external variable or only external variable values. Quantitative forecasting method can be based on a physical model, where the phenomenon approximately follows a certain mathematical function. However, many phenomena are affected by external factors in a complex way and a physical model is not available or is not reliable. In that case historical values of state variables create the basis for quantitative forecasting and conceptually we are talking about data-driven models (Alzghoul et al. 2014).

Quantitative forecasting algorithms can be divided into time-series forecasting models and causal models or combination of the both (Crone and Kourentzes 2010). In time-series models the historical values of the state variable are taken as input to forecast the future values assuming that the data generation process remains relatively constant (homoscedastic). Causal models assume that the forecasted variable is affected by external factors that are taken as input in the forecasting. Selection of the method is usually based on the following criteria depending on the application:

1. Estimated forecasting accuracy
2. Computational speed
3. Availability and quality of the data

Since forecasting cannot reach 100 % accuracy there is forecasting error involved. Although many methods provide point estimates giving a single value of the forecasted variable it is often useful to utilise probabilistic approach and provide confidence intervals for the forecasted estimates.

10.3.1.1 Time-Series Forecasting Models

The objective in time-series forecasting is to minimise the forecast error of the state variable using only the historical values of the same variable. Since the forecast can be done multiple time steps ahead in the future there can also be multiple forecast errors. Thus the forecasting problem can be formulated as follows:

$$Min \sum_{j=t+1}^{T} \sum_{i=1}^{I} w_i \varepsilon_i^j = \sum_{j=t+1}^{T} \sum_{i=1}^{I} w_i \left(f_i^j(X) - x_i^j \right), \tag{10.8}$$

where x is the state variable, t is the current time and T is the timespan of the forecast. i number of state variables can be measured and forecasted. Equation (10.8) gives an overall error measure for model comparison and selection by summing up temporal error terms of several state variables weighted by w_i. Function f indicates the data generation process from the state vector of historical values, X that contain values between $[1, t]$.

Often, different elements are identified in time series including the linear element i.e. trend that shows the long-term direction of a time-series, cyclical variation with clearly identifiable repeating local maxima and minima as well as irregular variation.

Time-series analysis has long resorted to the heritage of Box-Jenkins methods that identify autoregression and moving average components of the series. These ARIMA models have been developed further to take other aspects into consideration such as multiple time series i.e. VARIMA models, seasonal effects i.e. SARIMA models (De Gooijer and Hyndman 2006).

10.3.1.2 Causal Forecasting Models

In causal forecasting models the state variable is generated by external variables and often the model is formulated as a regression problem that consists of the dependent (state) variable and independent (external) variables. In regression analysis dependency of the state variable on external variables is estimated either by linear or non-linear methods. The problem can be formulated similarly to time-series forecasting with the difference that other but the state variable i.e. a vector of historical external variables, Z is present as well as additional summation of individual past observations, k of the state variable.

$$Min \sum_{j=t+1}^{T} \sum_{k=1}^{N} \sum_{i=1}^{I} w_i \varepsilon_{i,k}^{j} = \sum_{j=t+1}^{T} \sum_{k=1}^{N} \sum_{i=1}^{I} w_i \left(f_i^j(\beta, X, Z) - x_{i,k}^{j} \right), \qquad (10.9)$$

Here, β is a vector of regression coefficients for both the state variable X and external variables Z.

10.3.1.3 Solution Methods

Artificial Neural Networks (ANN) forms a family of solution algorithms in forecasting problems. Typically ANN consists of multiple layers of information processing units, perceptrons. Multi-layer perceptron (MLP) neural networks are general methods belonging to supervised learning methods used also for forecasting (Crone and Kourentzes 2010). Also, simpler forms of neural networks such as radial basis function (RBF) networks can be used as well as more complex neural networks with several layers that are called deep belief networks (Kuremoto et al. 2014).

Another promising direction in forecasting is based on the variation of Support vector machines (SVM) specifically modified from dichotomous classification to continuous regression problems. Support vector regression (SVR) can be computationally complex, but variations such as least squares support vector regression have reduced the computation time maintaining high accuracy (Jingqing et al. 2008).

Bayesian networks have been successfully applied in condition forecasting in maintenance management systems. Bayesian networks are directed acyclic graphs that can be used to estimate probability distribution of the value of a dependent variable, i.e. posterior distribution using historical occurrences of dependent and independent variables and Bayesian inference based on conditional probability formula (Zaidan et al. 2015).

Quantitative methods are mainly based on the historical values, which means that existing historical data should be available to train the forecasting model. Nonparametric resampling techniques should be used in fitting the model parameters for models, where exact mathematical probability distributions are not know, which is often the case with system condition variables. A popular resampling method for predictive model training is cross-validation, where the data is divided into separate training and testing data sets. Fitting the model on training data set can lead to overfitting and therefore a testing set is used to validate the model to see if it generalises well on different data (Bergmeir et al. 2014).

10.3.2 Optimisation Algorithms

Optimisation problems have strong mathematical background, where the aim is to reach the global optimum by exact methods such as linear programming, Newton's method or Gradient descent. Maintenance management systems, however, resort to real collected data and phenomena that are not necessarily in a functional form. In addition to that the problem is usually formulated as a discrete optimisation problem and a solution is needed to a combinatorial optimisation problem, where the size of the solution space is so large that global optimum cannot be reached. Therefore, heuristic and metaheuristic methods have gained popularity.

Metaheuristic algorithms make few assumptions about the problem to be solved. They do not guarantee a global optimum, but the found local optimum is usually very good especially for real world practical cases since uncertainties are involved related to data quality and cost models (Hertz and Widmer 2003). Several metaheuristic algorithms have been applied in complex optimisation including Genetic Algorithms (Jans and Degraeve 2007), Ant Colony Optimisation (Tavares Neto and Godinho Filho 2013), Tabu Search (Zhou et al. 2011), Simulated Annealing (Zhou et al. 2011) and Swarm Intelligence (Evins 2013). Hybrid methods combine both global and local search strategies and can result to better results so that the search can escape local minima (Zhou et al. 2011).

Meta-heuristic algorithms are exploiting two principles: local search and population search. Heuristic is an experimental and problem-specific method while metaheuristic is more general algorithmic presentation applicable to a wide range of

Table 10.1 Metaheuristic methods

Method name	Search strategy	Parameters
Ant colony optimisation	Population search	Pheromone evaporation parameter, pheromone trail increase
Genetic algorithm	Population search	Mutation rate, population size, recombination method, offspring selection method
Harmony search	Population search	Harmony memory size, value choosing rate from the memory, neighbouring value choosing rate, the amount between two neighbouring values in discrete candidate set, the amount of maximum change in pitch adjustment
Particle swarm optimisation	Population search	Swarm size, maximum travelling velocity, importance of personal best solution, importance of neighbourhood best solution
Simulated annealing	Local search	Initial temperature, acceptance probability, cooling ratio, distance parameter
Tabu search	Local search	Tabu list size, neighbourhood size, tabu list content type
Variable neighbourhood search	Local search	–

problems aiming at searching a sufficiently good solution in the solution space by predetermined strategy. Metaheuristic algorithms can be divided to local and population search algorithms. Local search algorithms aim at improving a single solution in the nearby search-space, while population search algorithms aim at targeting larger volume of the search-space and learning from the best solution candidates (Hertz and Widmer 2003). Hybridised methods combine the two strategies in the way that once a population search algorithm finds a good solutions they are improved by local search algorithms. The methods are usually stochastic by nature and require parameters to be decided. Table 10.1 summarises some of the most popular metaheuristic methods.

Intelligent maintenance planning often leads to a combinatorial optimisation problem and afore-mentioned algorithms can be applied. Simpler cases can be solved using more traditional methods such as linear or dynamic programming.

10.4 Development of Data Collection, Transfer and Storage

10.4.1 Data Collection Framework

The target asset for maintenance management system has an internal state affecting maintenance decision-making. Internal state is usually affected by external state i.e. the environment. Definition of the state depends on the asset and factors affecting maintenance needs, but main categories of the internal state variables of a system component are the following:

1. Condition
2. Operations

Condition state can be based on wearing out of a system component or malfunctioning of electrical or mechanical component. Operations state may consist kinetics and location of the component such as rotation speed, accumulated travelling distance or current 3D location. Besides the internal factors, external state variables can be manifold such as:

1. Humidity
2. Pressure
3. Temperature
4. Interaction with substances

Since data collection and related activities can be expensive compromises are made. The compromises are made between the following three dimensions:

1. Extent
2. Frequency (interval)
3. Precision

Data extent refers to separate state variables. There can be several different condition variables related to each system component, but only few of them are important. Determination of data collection extent should be based on the importance of each variable in terms of risk of system failure and impact on service level.

Data collection frequency is another important factor that does affect not only the collection costs, but also complexity and duration of data processing. Direct costs are caused by the required sensor technology, energy utilisation, and data transfer and data storage costs. Indirectly, longer processing times in maintenance decision-making can cause lower service levels or higher system failure risk.

Data precision is the third decision variable in data collection. Obviously, quality of the output of maintenance management systems depends on the quality of the data and imprecise data can fail system operations even if the decision-making algorithms were accurate.

Decision-making over the three dimensions of data collection are often made bearing in mind the following impacts:

1. Cost
2. Volume
3. Speed

The higher the data collection speed and the bigger the data volume are the higher is the cost for data collection. Data volume is directly affected by the extent and frequency of data collection.

10.4.2 Sensor Technology

Methods for data collection can be non-invasive that just measure system functioning or invasive, where system operation is somehow changed before state data is collected. Non-invasive positioning methods are different for indoors and outdoors applications. Global Positioning System (GPS), Glonass and Galileo are global navigation satellite systems that are used for outdoors positioning. The accuracy of the GPS for civil use is some metres, but with differential correction it can be improved to 10 cm. Altitude accuracy is generally much lower. Less accurate, less expensive and less power consuming method is to utilise cellular base stations. Indoors locating is developing and current methods have been based on utilisation of pre-installed RFID tags whose location is known, WiFi network signals as well as inertial measurements.

System operation is an important state function of several systems and development in terms of cost and miniaturisation has taken place in terms of three dimensional accelerometers and gyroscopes. Condition of system components is another state variable and several methods can be used depending on the system. Laser technology is common in case of road condition surveys as well as 3D accelerometers. Electromagnetic measurements such as radar technology is relevant especially in civil engineering as Ground Penetrating Radars can be used to monitor structural strengths (Liu and Kleiner 2013).

Nano-electronics decreases the size of the sensors, while development of the production technology and increasing demand reduce the cost of sensors increasing thus feasibility of intelligent maintenance management systems.

10.4.3 Data Transfer and Storage

Data transfer can take place between a data collection sensor and data storage as well as between data storage and the decision support software, which does the actual maintenance planning. The maintenance management system can be based on centralised or decentralised data storage. In a decentralised data storage the data collection unit can include data storage unit such as solid-state drive. Other option is to centrally store the data in a Cloud-server, for example. Figure 10.5 presents a decentralised method on the left and centralised on the right hand side. Data transfer method can be based either on pushing the data to decision making or pulling it from the data storage. Data transfer method does not depend on the centralisation of the data storage.

Data transfer method can also be partly push and partly pull depending on the criticality of the information. If a critical system component (SC) is replaced immediately after breakdown that information is pushed to decision-making while more regular predictive maintenance decisions can be based on information that is pulled by a predetermined frequency.

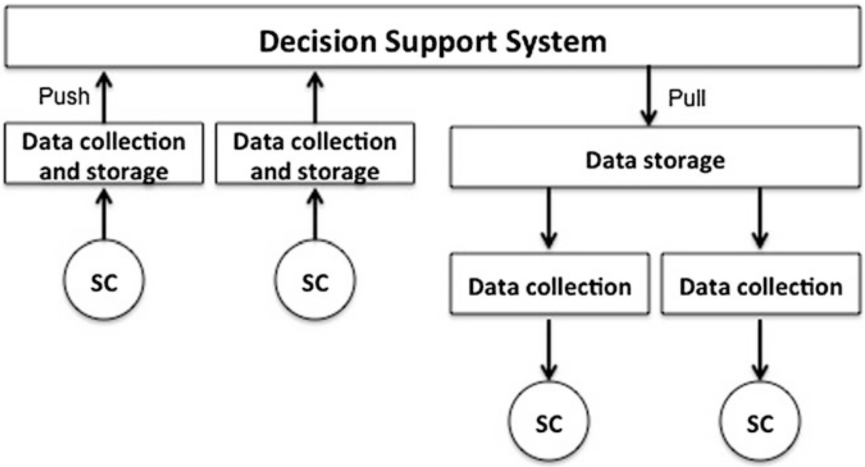

Fig. 10.5 Pushing or pulling of data for decision-making

In terms of technology the development has taken place not only in wireless data transfer speed, but also data storage capacity while the price has been decreasing. In practice the data transfer can be based on different technology such as Radio Frequency Identification (RFID), Wi-Fi, Cellular data service, mobile satellite communications or Bluetooth depending on the application and requirements such as speed, cost and data transfer distance.

All the decision-making does not need to take place centrally, but local decisions can be taken closer to the actual system component and data source. Since system components are often inter-connected in a complex way communication and coordination between components need to take place in order to achieve functioning multi-agent systems (Pirttioja 2008).

10.5 Existing Research on Engineering Maintenance Management

Two distinct research fields are examined, where the first concerns road maintenance planning and the second covers vehicle maintenance planning. Even that same planning methods can be used to a certain extent the system and data collection differs significantly. Table 10.2 summarises the main difference from data perspective.

Road data is collected approximately once a year while vehicle data can be transmitted always when the vehicle is on the move. Road condition deteriorates gradually and there is no complete system failure, which can be the case with vehicles.

Table 10.2 Differences between road and vehicle maintenance planning

	Road maintenance planning	Vehicle maintenance planning
Data collection frequency	Low	High
Level of centralisation	Centralised data collection	Decentralised data collection
Nature of condition variable	Continuously forecasted condition state	Dichotomously forecasted condition state
Data transfer methodology	Data pull	Data push

10.5.1 Road Maintenance Planning

Roads are the most valuable assets of many countries, but preservation of the assets have been partly neglected due to constrained budgets. Still, road networks are vital for economic, cultural and social development of most of the countries facilitating communication and transfer of goods and people. Since the first man-made roads, the techniques for construction and maintenance have gradually improved. Development of Information Technology on the other hand has greatly facilitated planning of maintenance. Certain criteria have always been used in selection of the target roads for maintenance, yet the efficiency can be improved with more sophisticated methods.

Once a road is constructed there are regular maintenance costs incurring to the Road Agency (RA). Road users pay on the usage of roads. In some countries there are direct costs of the right to use the road from the road owner in terms of road tolls. Even if road tolls did not exist road users pay for the capital costs of the vehicle and operating costs such as fuel and maintenance. Travel time is another cost element that the users and the society as whole pay. Travel time is an opportunity cost of road users not being able to dedicate their time to something more productive while driving a car. Accident costs are also often included in travel cost analysis as they directly affect the livelihood of the participants as well as the welfare society. Overall, it has been proved that the poorer the road condition is the higher the road user costs are Amos (2006). Relationship between the accident risk and thus the costs and road condition is not as straightforward as the several studies indicate (Pulugurtha et al. 2013; Izquierdo et al. 2013).

On the other hand, the better the road condition is the higher are the costs of the maintenance for the Road Agency as road condition deteriorates over time. Thus, road maintenance is an optimisation problem, where the overall costs to the society i.e. Road Agency costs and road user costs should be minimised. Road network forms a system, where each segment of the network is in a certain state at certain time. The state can be presented by several condition variables measured on the road segment. The state can be either discrete or continuous. The time dimension can also be either discrete or continuous. Often International Roughness Index (IRI) is used as the state variable (Chu and Chen 2012). Also, the pavement condition index (PCI) (Sahin et al. 2014), present serviceability rating (PSR) (Chootinan et al. 2006), road surface condition (Álvarez et al. 2007) and ride quality index (RQI)

(Zhang and Gao 2012) have been used. In some studies the condition change i.e. condition deterioration model is assumed to be linear (Gu et al. 2012), while on the others more complex mathematical functions such as sigmoidal curves have been used (Sahin et al. 2014). Markov processes have been popular to grasp the stochastic nature of the condition change (Chootinan et al. 2006). Some studies do not claim a specific mathematical form of function for deterioration, but multivariate regression models (Sirvio and Hollmén 2014).

The minimum granularity of the road segments models have been applied to depends on collected information. Different granularities have been used such as 100 m (Sirvio and Hollmén 2011), 1000 m (Chootinan et al. 2006) and road section length (Sahin et al. 2014). It seems that currently network level planning is mostly done on information aggregated to 100 m long segments, where the state variables remain constant (Sirvio and Hollmén 2011). Road condition data collection interval depends on the importance of the road and the variable in question. Important variable such as IRI on important roads can be collected twice a year, but more often data is collected once a year.

First studies approached the problem solving by optimal control theory (Friesz and Fernandez 1979). Solving of the optimisation problem depends on the formulation of the problem. A simplified formulation with continuous time and state (and thus explicit mathematical functions) has been solved by Newton-Raphson method (Gu et al. 2012). In case of discrete problem it becomes combinatorial and other methods such as Genetic Algorithms (GA) are used to solve them (Chootinan et al. 2006). The problem has been often formulated as Markov decision process (MDP) and solved by linear programming (Zhang and Gao 2012) or variations of dynamic programming (Medury and Madanat 2013).

Even though there are several studies that formulate intelligent maintenance planning approach for road maintenance the approach is not followed in practice due to several reasons. First of all, political motivations shift the maintenance not according to optimised solution, but to projects increasing politicians' popularity. Another obstacle is customary practices that change slowly in the public sector that is usually responsible for major road networks. Another problem is that software solutions implementing intelligent, optimised maintenance planning do not exist on the market and development of customised solutions is slow and costly. It also seems that cost models related to the dependence of road user costs on road condition and road agency costs of maintenance as well as lifecycle maintenance costs of roads depending on the condition are too simplified. Cost models also depend on how road maintenance is organised between public and private sectors and therefore the same cost models may not be applicable between different countries.

10.5.2 Vehicle Maintenance Planning

In vehicle and machine maintenance literature terminology is borrowed from the medical science as diagnosis and prognosis are used for determination of current and future states. The most obvious and widely used prognostics is to predict how much time is left before a failure occurs (or, one or more faults) given the current machine condition and past operation profile. The time left before observing a failure is usually called remaining useful life (RUL). This is especially the case when critical components such as motor are concerned. However, body parts deteriorate gradually similarly to infrastructure, where the final failure may take very long time. Research efforts have been especially put on aeronautical vessels. A framework for diagnostics and prognostics with various algorithmic methods applied on structural damages was presented in the study (Lopez and Sarigul-Klijn 2010). Another study concentrates on gas turbine engines of civil aircrafts and proposes a hierarchical Bayesian regression model for prognostics and Turbine Gas Temperature as the diagnosed condition variable (Zaidan et al. 2015).

Data collection of induction motors used also in electric vehicles can be based on vibration signals, electromagnetic fields, induced voltage, surge test, motor circuit analysis, acoustic emission, air gap torque, instantaneous angular speed and motor current signatory analysis. In a study motor current signatory analysis was used to predict stator winding faults and eccentricity problems using a hybrid method of fuzzy min-max network combined with random forest ensemble (Seera et al. 2014).

A holonic cooperative approach for diagnosing complex transportation systems was proposed and applied in train transport system, where the complex system is divided into sub-systems, whose diagnosis is performed by a cooperative manner. Several algorithms were presented for the problem solving, but First Principle Reasoning (FPR) was selected since process history was not yet available (Le Mortellec et al. 2013).

A review of diagnostics and prognostics systems in real use was presented for ground, air and space vehicles. Even if several diagnostics tools have been applied there is a limited number of functioning prognostics tools and more development needs to take place (Esperon-Miguez et al. 2013).

In comparison with roads, vehicles are also valuable assets, whose maintenance has raised attention. Similarly to the road maintenance, vehicle maintenance is seldom intelligent in terms of having optimised, predictive maintenance system. Current practice of passenger cars follows a preventive, time-based maintenance scheme, where each maintenance activity is pre-determined depending on either utilisation time or travelled distance. There are several challenges to be tackled. First of all, only recently cars have started to be connected to external server computers that can store data of the state of different components. Several state variables of different components is already passed between car components via CAN-bus, but the deterioration models of the components are under-developed and do not take into consideration environmental variables, for example. As there is no unanimity of the models it is unclear what data should be collected and stored for maintenance planning. Internal car data is also subject to privacy issues and therefore it is difficult to form the deterioration models in real environment using data-driven methods with model training. Status quo is beneficial to car manufacturers and service repair shops since extensive data collection and processing is costly and the more there are vehicle maintenance activities (that could be reduced by intelligent maintenance) the more repair shops earn.

10.6 Practical Example of Intelligent Road Maintenance Planning

Crack sealing, pothole patching, edge break repair and vegetation control are part of routine maintenance, which is usually done in fixed time intervals. Routine maintenance is relatively cheap and surface defects are usually still collected by visual survey. Therefore, instead of routine maintenance, efforts of intelligent maintenance planning should be applied in periodic maintenance i.e. new asphalt overlays of the road due to higher costs and easier forecasting of road deterioration measured by IRI. In this simplified example only one maintenance treatment using one criterion is decided over 15 years. The optimised function consists of maintenance costs and Vehicle Operating Costs (VOC) of road users that are assumed to rise linearly with IRI of the road.

For simplification let us assume a linear deterioration model for the road, whose IRI profile looks like in Fig. 10.6 at the beginning of the planning period. The mean IRI is 1.14 m/km.

Genetic Algorithms are chosen to optimise the maintenance plan. The idea of the algorithm is presented in Fig. 10.7. First the initial population is selected (1) out of which the fittest genomes (2) are chosen for recombination (3). The resulted offspring is susceptible to mutation (4). The possibly mutated offspring is placed back in the population and the whole process is iterated until the stopping criterion is met.

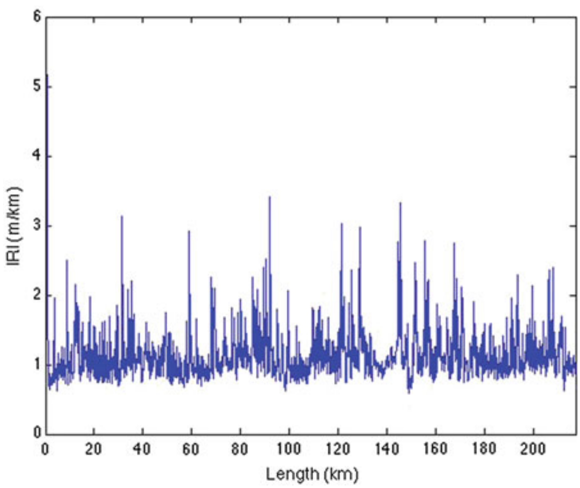

Fig. 10.6 Initial condition of the road measured by IRI

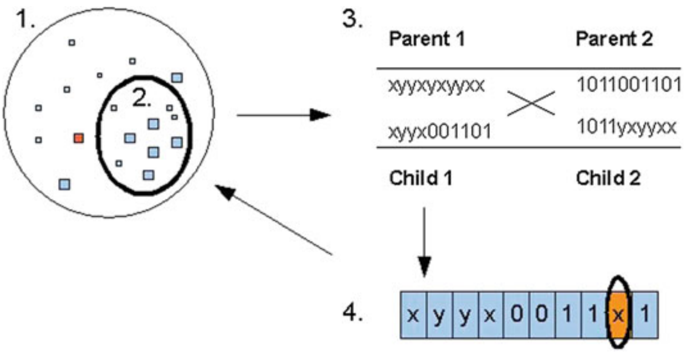

Fig. 10.7 Phases of genetic algorithm

In the example offspring is selected in elitistic way. Parameter values and assumptions are presented in Table 10.3.

The problem can be encoded to the genomes having the spatial element in rows and temporal element in columns leading to a 2175 × 15 matrix. The matrix has value 1 if road maintenance is performed during a certain year and segment and 0 otherwise.

As a result the total costs for road administration and for road users for the 15 years are 1.89 billion euros and the average road condition changes according to Fig. 10.8. Due to high traffic volume it is beneficial to maintain the road in good condition.

Table 10.3 Parameters and assumptions

Parameters and assumptions	Unit	Value
Road length	Km	217.5
Road width	m	10
Unit cost	Euros/m2	10
Minimum project length	m	100
Annual IRI deterioration	m/km	0.3
IRI after maintenance	m/km	0.8
Discount factor	%	5
Average annual daily traffic in the beginning	Vehicles/day	15,000
Traffic growth rate	%	3
Average vehicle operating costs after maintenance	Euros/100 km	11.34
Average vehicle operating costs per IRI increase of 1 m/km	Euros	1.05
Maintenance duration	Years	15
GA mutation rate	%	10
GA population size	–	25

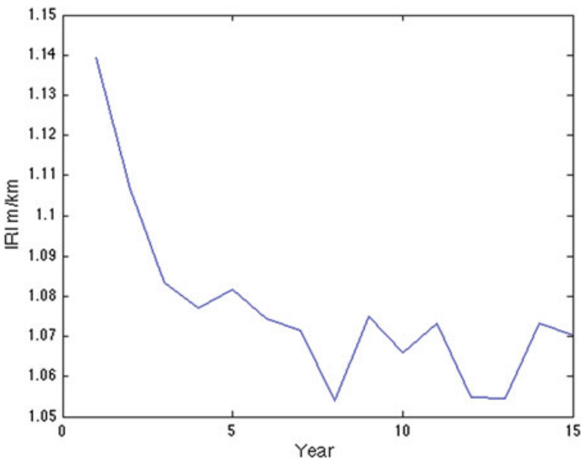

Fig. 10.8 Development of road condition

10.7 Discussion

The more valuable the engineering system is the more it would benefit from an intelligent maintenance management system and predictive optimised maintenance. Although, all the technical know-how and components already exist they are not yet effectively combined. The research goes slowly into practice due to several practical obstacles. Availability of data in real world applications is required to form data driven deterioration models by forecasting algorithms. Since complex engineering systems are formed of several system components it is time-consuming to establish separate deterioration models for each of them. Components such as car motor parts are also continuously developed and therefore deterioration models should be adaptive. When new components come into the market there is no data collected to estimate the remaining useful life in real environment. Useful paths of research could be hybrid deterioration models taking into consideration a mathematical engineering model combined with collected data of real use and environment.

Another research issue concerns the cost models related to maintenance optimisation since the models depend on the market situation and practical arrangements of maintenance functions. It is not efficient to create an accurate cost model to a situation, where the work in general is inefficiently organised. Current trend of maintenance outsourcing can create a discontinuity between the organisations and thus on maintenance planning and the cost models for maintenance activities can be highly dependent on the maintenance market situation.

Viable algorithmic solutions already exist and many of them have been proven in practice. However, computing power becomes an obstacle for complex systems with several system components, from which several data elements are collected in high frequency. Besides aforementioned training problem of forecasting algorithms another problem is related to parameter selection and selection of best methods for the system in question. In terms of algorithmic accuracy, hybrid methods seem to be the best choice.

Data availability by development of data collection and storage methods along with Cloud computing will hopefully enhance research activities related to intelligent maintenance planning. However, proprietary data has a limited effect compared to open data, which would be beneficial not only to the research community, but to industries as well.

References

Ahmad, R., Kamaruddin, S.: An overview of time-based and condition-based maintenance in industrial application. Comput. Ind. Eng. **63**, 135–149 (2012)

Álvarez, P., Lopéz-Rodríguez, F., Canito, J., Moral, F., Camacho, A.: Development of a measure model for optimal planning of maintenance and improvement of roads. Comput. Ind. Eng. **52**, 327–335 (2007)

Alzghoul, A., Backe, B., Löfstrand, M., Byström, A., Liljedahl, B.: Comparing a knowledgebased and a data-driven method in querying data streams for system fault detection: a hydraulic drive system application. Comput. Ind. **65**, 1126–1135 (2014)

Amos, D.: Pavement smoothness and fuel efficiency: an analysis of the economic dimensions of the Missouri smooth road initiative. Organizational Results Research Report. Missouri Department of Transportation, Jefferson City, USA (2006)

Ardente, F., Mathieux, F.: Environmental assessment of the durability of energy-using products: method and application. J. Clean. Prod. **74**, 62–73 (2012)

Bergmeir, C., Costantini, M., Bentez, J.: On the usefulness of cross-validation for directional forecast evaluation. Comput. Stat. Data Anal. **76**, 132–143 (2014)

Campos, J.: Development in the application of ICT in condition monitoring and maintenance. Comput. Ind. **60**, 1–20 (2009)

Chootinan, P., Chen, A., Horrocks, M., Bolling, D.: A multi-year pavement maintenance program using a stochastic simulation-based genetic algorithm approach. Transp. Res. Part A **40**, 725–743 (2006)

Chu, J., Chen, Y.-J.: Optimal threshold-based network-level transportation infrastructure life-cycle management with heterogeneous maintenance actions. Transp. Res. Part B **46**, 1123–1143 (2012)

Crone, S., Kourentzes, N.: Feature selection for time series prediction a combined filter and wrapper approach for neural networks. Neurocomputing **73**, 1923–1936 (2010)

Dekker, R., Kourentzes, N.: Applications of maintenance optimization models: a review and analysis. Reliab. Eng. Syst. Saf. **51**, 229–240 (1996)

Esperon-Miguez, M., John, P., Jennions, I.: A review of integrated vehicle health management tools for legacy platforms: challenges and opportunities. Prog. Aerosp. Sci. **56**, 19–34 (2013)

Evins, R.: A review of computational optimisation methods applied to sustainable building design. Renew. Sustain. Energy Rev. **22**, 230–245 (2013)

Frazzon, E., Israel, E., Albrecht, A., Pereira, C., Hellingrath, B.: Spare parts supply chains operational planning using technical condition information from intelligent maintenance systems. Ann. Rev. Control **38**, 147–154 (2014)

Friesz, T., Fernandez, J.: A model of optimal transport maintenance with demand responsiveness. Transp. Res. **13B**, 317–339 (1979)

De Gooijer, J., Hyndman, R.: 25 years of time series forecasting. Int. J. Forecast. **22**, 443–473 (2006)

Gu, W., Oyang, Y., Madanat, S.: Joint optimization of pavement maintenance and resurfacing planning. Transp. Res. Part B **46**, 511–519 (2012)
Hertz, A., Widmer, M.: Guidelines for the use of meta-heuristics in combinatorial optimization. Eur. J. Oper. Res. **151**, 247–252 (2003)
Hoogmartens, R., Passel, S., Acker, K., Dubois, M.: Bridging the gap between LCA, LCC and CBA as sustainability assessment tools. Environ. Impact Assess. Rev. **48**, 27–33 (2014)
Izquierdo, F., Ramírez, B., Rodríguez, E.: The interurban DRAG-Spain model: the main factors of influence on road accidents in Spain. Res. Transp. Econ. **37**, 57–65 (2013)
Jans, R., Degraeve, Z.: Meta-heuristics for dynamic lot sizing: a review and comparison of solution approaches. Eur. J. Oper. Res. **177**, 1855–1875 (2007)
Jingqing, J., et al.: Adaptive and iterative least squares support vector regression based on quadratic renyi entropy. In: Proceeding of the 2008 IEEE International Conference on Granular Computing, GrC 2008, Hangzhou, China (2008)
Kuremoto, T., Kimura, S., Kobayashi, K., Obayashi, M.: Time series forecasting using a deep belief network with restricted Boltzmann machines. Neurocomputing **137**, 47–56 (2014)
Le Mortellec, A., Clarhaut, J., Sallez, Y., Berger, T., Trentesaux, D.: Embedded holonic fault diagnosis of complex transportation systems. Eng. Appl. Artif. Intell. **26**, 227–240 (2013)
Liu, Z., Kleiner, Y.: State of the art review of inspection technologies for condition assessment of water pipes. Measurement **46**, 1–15 (2013)
Lopez, I., Sarigul-Klijn, N.: A review of uncertainty in flight vehicle structural damage monitoring, diagnosis and control: challenges and opportunities. Prog. Aerosp. Sci. **46**, 247–273 (2010)
Medury, A., Madanat, S.: Incorporating network considerations into pavement management systems: a case for approximate dynamic programming. Transp. Res. Part C **33**, 134–150 (2013)
Moore, G.: Cramming more components onto integrated circuits. Electronics **38**, 114–117 (1965)
Muller, A., Marquez, A., Iung, B.: On the concept of e-maintenance: review and current research. Reliab. Eng. Syst. Saf. **93**, 1165–1187 (2008)
Pangburn, M., Stavrulaki, E.: Take back costs and product durability. Eur. J. Oper. Res. **238**, 175–184 (2014)
Pereira, C., Carro, L.: Distributed real-time embedded systems: recent advances, future trends and their impact on manufacturing plant control. Ann. Rev. Control **31**, 81–92 (2007)
Pirttioja, T.: Applying agent technology to constructing flexible monitoring systems in process automation. Helsinki University of Technology Automation Technology Series A: Research Reports No. 32, Espoo, Finland (2008)
Pulugurtha, S., Ogunro, V., Pando, M., Patel, K., Bonsu, A.: Preliminary results towards developing thresholds for pavement condition maintenance: safety perspective. Procedia Soc. Behav. Sci. **104**, 302–311 (2013)
Sahin, H., Narciso, P., Hariharan, N.: Developing a five-year maintenance and rehabilitation (M&R) plan for HMA and concrete pavement networks. APCBEE Procedia **9**, 230–234 (2014)
Seera, M., Lim, C., Nahavandi, S., Loo, C.: Condition monitoring of induction motors: a review and an application of an ensemble of hybrid intelligent models. Expert Syst. Appl. **41**, 4891–4903 (2014)
Sheu, S.-H., Griffith, W., Nakagawa, T.: Theory and methodology. Extended optimal replacement model with random minimal repair costs. Eur. J. Oper. Res. **85**, 636–649 (1995)
Sirvio, K., Hollmén, J.: Forecasting road condition after maintenance works by linear methods and radial basis function networks. In: Honkela, T., Duch, W., Girolami, M., Kaski, S. (eds.) Proceedings (Part II) of the 21st International Conference on Artificial Neural Networks. Espoo, Finland (2011)
Sirvio, K., Hollmén, J.: Multi-step ahead forecasting of road condition using least squares support vector regression. In: Proceedings of European Symposium on Artificial Neural Networks, Computational Intelligence, and Machine Learning (ESANN), Bruges, Belgium (2014)
Tavares Neto, T., Godinho Filho, M.: Literature review regarding ant colony optimization applied to scheduling problems: guidelines for implementation and directions for future research. Eng. Appl. Artif. Intell. **26**, 150–161 (2013)

Wakefield, R., Watson, T.: A reappraisal of Delphi 2.0 for public relations research. Publ. Relat. Rev. **40**, 577–584 (2014)
Widodo, A., Yang, B.-A.: Machine health prognostics using survival probability and support vecor machine. Expert Syst. Appl. **38**, 8430–8437 (2011)
Zaidan, M., Harrison, R., Mills, A., Fleming, P.: Bayesian hierarchical models for aerospace gas turbine engine prognostics. Expert Syst. Appl. **42**, 539–553 (2015)
Zhang, X., Gao, H.: Road maintenance optimization through a discrete-time semi-Markov decision process. Reliab. Eng. Syst. Saf. **103**, 110–119 (2012)
Zhou, X., Xi, L., Lee, J.: Reliability-centered predictive maintenance scheduling for a continuous monitored system subject to degradation. Reliab. Eng. Syst. Saf. **92**, 530–534 (2007)
Zhou, A., Qu, B.-Y., Li, H., Zhao, S.-Z., Suganthan, P., Zhang, Q.: Multiobjective evolutionary algorithms: a survey of the state of the art. Swarm Evolut. Comput. **1**, 32–49 (2011)

Chapter 11
Fuzzy Inventory Models for Deteriorating Items Under Different Types of Lead-Time Distributions

Harish Garg

Abstract In this chapter, a fuzzy inventory model for deteriorating items with shortages under fully backlogged condition is formulated by utilizing uncertain, vague and imprecise data. Fuzzy set theory has been used for handling the uncertainty in the data and hence the corresponding inventory parameters are assumed to be triangular fuzzy numbers. The main purpose of this work is to find out the quantity lot size (Q) and reorder point (R) level, which minimize the total annual inventory cost function in fuzzy environment. During the formulation of the model, the lead time is considered to be zero and the reorder level follows the different types of distribution namely uniform, exponential and Laplace distribution. Graded mean representation is used to defuzzify the total cost function and results obtained by these methods are compared with the crisp and the numerical results. A numerical example is given in order to show the applicability of the proposed model for different values of defective rate (θ) and the backorder ratio (β). Finally, sensitivity analysis is carried out to explore the effect of changes in the values of some of the system parameters.

Keywords Fuzzy sets · Inventory models · Lead time · Probability

11.1 Introduction

Today's competitive business environment requires manufacturers to design, develop, test, manufacture, and deploy high-reliability products in less time at lower cost. For achieving this, billions of dollars are being spent annually worldwide to develop reliable and efficient products. With the advance in technology, a designer always wants to manufacture the equipment and systems of greater capital cost, complexity and capacity which results in increasing the reliability of the system. In

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that direction, inventory problems are common in manufacturing, maintenance service and business operations in general. Many models have been proposed to deal with a variety of inventory problems. Traditionally, economic order quantity (EOQ) models dealing with continuous review inventory problems often assume that the demand during the stockout period is either completely back-ordered or completely lost. However, the classical analysis of inventory control considers three costs for holding inventories. These costs are the ordering cost, carrying cost and shortage cost. The classical analysis builds a model of an inventory system and calculates the EOQ (economic order quantity) which minimize these three costs so that their sum is satisfying minimization criterion. The basic characteristics of an inventory control problem consider two vital factors: (i) correct formulation of objective function based on the versatile nature of the associated costs and demand functions, (ii) proper choice of optimization technique by a decision maker (DM) who can choose his/her best policy to overcome the bottlenecks of the problem associated with the model. Thus, for this reason, there is a growing interest in the investigations of the inventory problem in various systems during last decades which affects on the system performance directly. A brief literature review regarding the inventory model using crisp as well as fuzzy environment is given below.

11.1.1 Crisp Inventory Models: Literature Review

Several optimization techniques in deterministic models have been used in the modern development of inventory control and management problems. Harris (1913) stated that in order to find the optimal solution for the EOQ formulae it is necessary to use higher mathematics (i.e., differential calculus). However, several scholars have attempted to develop classical inventory models without using this classical optimization technique. Instead, they have developed the inventory models using either a tabular, graphical or an algebraic approach. Grubbstrom (1995) was the first researcher to develop the EOQ formulae without backlogging without calculus. Since then, Grubbstrom and Erdem (1999) and Cárdenas-Barrón (2001) have developed the EOQ with backlogging, EPQ without backlogging and EPQ with backlogging, respectively. However, Ronald et al. (2004) and Chang et al. (2005) believe that the algebraic procedure that Grubbstrom and Erdem (1999) and Cárdenas-Barrón (2001) propose is too sophisticated and complex for ordinary high school students or people that have no knowledge of calculus. Despite the fact that Ronald et al. (2004) have made an effort to simplify the algebraic development of Grubbstrom and Erdem (1999) and Cárdenas-Barrón (2001), their algebraic solution procedure is still complex for ordinary people who do not know derivatives. Finally, Chang et al. (2005) developed the EOQ and EPQ with backlogging in an even simpler manner. Wee et al. (2003) applied the algebraic procedure to derive the EOQ with a temporary sale price considering the maximization of a savings cost function. Sphicas (2006) derived the EPQ with backlogging considering the two classical backlogging costs without derivatives and identified and analyzed two cases: too expensive backlogs and attractive backlogs. A complete review of different optimization methods used in the inventory field can be seen in Cárdenas-Barrón (2011).

Several researchers Barbosa and Friedman (1978), Ghosh et al. (2011), You and Hsieh (2007), Wang et al. (2010) formulated various types of objective function for an EOQ model by considering the demand rate of the customers as a suitable function of time, selling price, on-hand inventory level and promotional effort. Giri et al. (1996) developed a generalized EOQ model for deteriorating items with shortages, in which both the demand rate and the holding cost are continuous functions of time. The optimal inventory policy is derived assuming a finite planning horizon and constant replenishment cycles. Ray and Chaudhuri (1997) take the time value of money into account in analyzing an inventory system with stock-dependent demand rate and shortages. Chen (1998) proposed an inflationary model with time proportional demand and Weibull distribution for deteriorating items using dynamic programming. Fergany and El-Wakeel (2004) considered a probabilistic single-item inventory problem with varying order cost under two linear constraints. Hala and El-Saaddani (2006) analyzed a constrained single period stochastic uniform inventory model with continuous distribution of demand and varying holding cost. Sana (2010) also presented another EOQ model over an infinite time horizon for perishable items where demand is price dependent and partial backorder is permitted. Based on the partial backlogging and lost sale cases, the author develops the criterion for the optimal solution for the replenishment schedule and proves that the optimal ordering policy is unique. EL-Sodany (2011) presented a periodic review probabilistic inventory system with zero lead time under constraint and varying holding cost. Kotb and Fergany (2011) presented a geometric approach for solving the multi-item EOQ model with varying holding cost. Sana (2011) proposed a model which deals with a stochastic economic order quantity (EOQ) model over a finite time horizon where uniform demand over the replenishment period is price dependent. The selling price is assumed to be a random variable that follows a probability density function. De and Sana (2013) developed a research that deals with a backorder EOQ model with promotional index for fuzzy decision variables. Ghasemi and Nadjafi (2013) developed classical EOQ models by considering holding cost as an increasing function of the ordering cycle length. Sarkar and Sarkar (2013) proposed an improved inventory model with partial backlogging, time varying deterioration and stock-dependent demand. Mirzazadeh (2013) developed an inventory model under stochastic inflationary conditions with variable probability density functions (pdfs) over the time horizon. He also assumed that the demand rate is dependent on the inflation rates. Chowdhury et al. (2014) presented an inventory model for perishable items with stock and advertisement sensitive demand. Singh and Pattnayak (2014) developed a two-warehouse inventory model for deteriorating items with linear demand under conditionally permissible delay in payment. Sivashankari and Panayappan (2014) studied a production-inventory model with reworking of imperfect production, scrap, and shortages. Soleimani-Amiri et al. (2014) compared two methods for calculating the optimal total cost in an inventory model with time value of money and inflation for deteriorating items. Balkhi (2004) presented a production lot-size inventory model where the production, demand, and deterioration rates are known, continuous, and differentiable functions of time. Shortages are allowed, but only a fraction of the stockout is backordered, and the rest is lost.

11.1.2 Fuzzy Inventory Models: Literature Review

In the traditional EOQ model, the parameter which are involved in the setup cost, the holding cost, shortage cost etc., are treated as a crisp numbers. Conventional theory is based on the probabilistic and binary state assumptions. Although the probability approach has been applied successfully for many real world engineering, reliability problems, but still there are some limitations to the probabilistic method. For instance, probabilistic methods are based on a mass collection of data, which is random in nature, to achieve the requisite confidence level. But in large scale the complicated system has the massive fuzzy uncertainty due to which it is difficult to get the exact probability of the events. Thus, results based on probability theory do not always provide useful information to the practitioners due to the limitation of being able to handle only quantitative information. Moreover, in real world applications, sometimes there is insufficient data to accurately handle the statistics of parameters, as these cost parameters are not always fixed i.e., these parameters are non-randomly uncertain (fuzziness) rather than randomly uncertain (probability theory). Due to these limitations, the results based on probability theory aren't always available or reliable and their values aren't enough to reflect the fluctuation of the inventory related costs and hence probabilistic approach to the conventional analysis is inadequate to account for such built-in uncertainties in the data. To overcome these difficulties, methodologies based on fuzzy set theory (Zadeh 1965) are being used in the risk analysis for propagating the basic event uncertainty. The probabilistic approaches deal with uncertainty, which is random in nature, while the fuzzy approach deals with the uncertainty, which is due to imprecision associated with the complexity of the system as well as vagueness of human judgement.

The first inventory model was developed by F. Harris in 1915 (Harris 1915) and was modified and extended later on by several researchers, changing the assumptions, with the objective to make it more realistic. Later in 1965, the concept of fuzzy set was introduced by Zadeh (1965) and then some researchers started to apply the fuzzy set theory in inventory management problems also. Kacpryzk and Staniewski (1982) proposed a model on long-term inventory policy-making through fuzzy—decision making models. Later on, Tinarelli (1983) proposed the inventory control models of problems. Park (1987) proposed a model on fuzzy set theoretical interpretation of economic order quantity inventory problem. Vujosevic et al. (1996) developed an EOQ formula when inventory cost is a fuzzy number. Yao and

Lee (1999) proposed a fuzzy inventory with or without backorder for fuzzy order quantity with a trapezoidal fuzzy number.

With the help of fuzzy extension principle, an EOQ in a fuzzy sense for inventory without backorder model was developed by Lee and Yao (1999). Kao and Hsu (2002) investigated a lot size reorder point inventory model with fuzzy demands applying the α-cuts and the ranking index method. Various researchers Park (1987), Vujosevic et al. (1996), Chung (2003), Liu and Yao (2000) are proposed the EOQ model in the fuzzy sense where inventory parameters are triangular fuzzy concept in decision. Hsieh (2002) proposed an approach for the optimization of fuzzy production inventory models. Yao and Chiang (2003) introduced an inventory without back order with fuzzy total cost and fuzzy storing cost defuzzified by centroid and signed distance. Paknejad et al. (1995) presented a quality adjusted lot-sizing model with stochastic demand and constant lead time and studied the benefits of lower setup cost in the model. Ouyang and Chang (2000) modified Paknejad et al.'s inventory model by relaxing the assumption that the stochastic demand during lead time follows a specific probability distribution and by considering that the unsatisfied demands are partially backordered. Dutta et al. (2005) were the first to incorporate demand as a fuzzy random variable in a simple newsboy problem with fuzzy random demand. Later on, a fuzzy mixture inventory model involving fuzzy random lead time demand has been developed by Chang et al. (2006).

De and Rawat (2011) proposed a fuzzy inventory model without shortages using the triangular fuzzy number. Jaggi et al. (2012) presented a fuzzy inventory model for deteriorating items with time-varying demand and shortages. Dutta and Kumar (2013) proposed an optimal policy for an inventory model without shortage considering fuzziness in demand, holding and ordering cost. Samadi et al. (2013) discussed the new pricing, marketing and service planning inventory model with shortages in fuzzy environment where demand is a function of price, marketing and services. In it, all of the parameters in the model are assumed to be triangular fuzzy numbers. The corresponding model is formulated as a geometric programming problem and the membership functions of the fuzzy profit and the decision variables are derived numerically using fuzzy optimization techniques and generalized geometric programming approach. Chakraborty et al. (2013) considered an inventory model of deteriorating seasonal products with a maximum retail price for a wholesaler having showrooms at different places under random business periods with fuzzy resource constraints. Guchhait et al. (2013) presented an EPQ model with fuzzy production rate and fuzzy demand in an imperfect production process. Dutta and Kumar (2014) developed the fuzzy inventory model for fuzzy deteriorating items with fuzzy demand rate under fully backlogging and by considering the trapezoidal fuzzy numbers. De and Sana (2014) considered the per unit cost parameters and the predicted demand quantity for a multi-periodic and multi-machine of a production plant as fuzzy as well as intuitionistic fuzzy set. In this production system, a cost function is formulated by trading off regular-production cost, overtime production cost, inventory cost, hiring and lay off cost for multi-periods and multi-machines. Naserabadi et al. (2014) developed an inventory model for items with the uncertain deterioration rate, time-dependent demand rate with nonincreasing function, and allowable shortage under fuzzy inflationary situation. Roy (2014) implement the fuzzy set theory in the inventory control of deteriorating items, where holding cost and deterioration rate are considered as linearly increasing function of time. In it, an uncertain cycle time is considered and described by a (symmetric) triangular fuzzy number while the demand rate as a function of selling price.

11.2 Critical Comments on Reviewing Literature

11.2.1 Shortcoming of the Existing Literature

The following shortcomings are observed after critically reviewing the literature.

- Probability theory does not always provide useful information to the practitioners due to the limitation of being able to handle only quantitative information.
- The subjective information is not captured during inventory analysis.
- Almost all the researchers have assumed that demand of the different customers is identical and it follows the normal distribution.
- Most of the literature on inventory control and production planning has dealt with the assumption that the demand for a product will continue infinitely in the future either in a deterministic or in a stochastic fashion. This assumption does not always hold true.
- A basic assumption in the inventory management system is that the set-up cost of production is fixed. In addition, the models also implicitly assume that items produced are of perfect quality. However, in reality, products are not always perfect, but are directly affected by the reliability of the production process employed to manufacture the product.
- No sensitivity analysis has been conducted for analyzing the effect of holding, ordering, set up etc., cost on the performance of the system.

11.2.2 Objective of the Work

The objective of this chapter is to consider the stochastic continuous review inventory model with variable lead time and partial backorders to capture the reality of uncertain backorders (lost sales). In this chapter, we propose an inventory model with fuzzy inventory costs and triangular fuzzy variables are used to model the several inventory parameters. Our objective is to determine the optimal purchase (order) quantity as well as optimal reorder point which minimizes the relevant expected total cost for the period, when demand during that period follows the uniform, the exponential and the Laplace distribution. Sensitivity analysis on system annual cost has been examined by varying the parameters of inventory model. In a nutshell, the following tools are adopted to overcome the above shortcomings, which may give better results (close to real condition):

- It is known that, given the past data, a retailer may estimate that the demand of a commodity may follow a particular distribution. However, it is very difficult to estimate the exact value of the parameters of the distribution. In this case, these parameters are vaguely defined and these can be estimated as fuzzy numbers. Consequently, the distribution is a fuzzy random distribution and we say the demand is fuzzy random.
- In crisp inventory models, all the parameters in the total cost are known and have definite values without ambiguity; in addition the real variable of the total cost is positive. But, in reality, it is not so certain. Hence there is a need to consider the fuzzy inventory models.
- An inventory model for deteriorating items with shortages is considered where demand, holding cost, unit cost, shortage cost and deterioration rate are assumed as a triangular fuzzy number.
- In the lead time, the demand of the different customers are not identical. Therefore, we cannot use only a normal distribution to describe the demand of the lead time. So, in this chapter, we extend it by considering the different types of distribution, namely, exponential, uniform and normal. In addition, the total amount of stock-out is considered a mixture of backorders and lost sales during the stock-out period.
- Sensitivity analysis on the performance of the annual cost has been investigated by varying the parameters of inventory model.

The rest of the chapter is organized as follows. Some basic preliminaries related to fuzzy set theory which are used to develop the model are given in Sect. 11.3 while assumptions and notations used are provided in Sect. 11.4. The mathematical model which describes the annual inventory cost are discussed in Sect. 11.5. Section 11.6 describes the analysis of the result by taking the parameters of the model as crisp as well as fuzzy number. The model considers for several fuzzy costs and numerical values for uniform, exponential, and Laplace lead-time demand is compared. Sensitivity analysis has also been done by varying the values of various parameters. Finally, a concrete conclusion has been presented in Sect. 11.7.

11.3 Basic Features of Fuzzy Set Theory

11.3.1 Fuzzy Set Theory

Basically, a set is defined as a collection of objects, which share certain characteristics. A classic set is a collection of distinct objects. The classical set is defined in such a way that the universe of discourse is split into two groups: members and nonmembers. Consider an object x in a crisp set A. This object x is either a member or a nonmember of the given set A. In case of crisp set, no partial membership exists. This binary issue of membership can be represented mathematically by the indicator function,

$$\chi_A = \begin{cases} 1 \ ; & if \ x \in A \\ 0 \ ; & if \ x \notin A \end{cases} \tag{11.1}$$

where χ_A is the membership in set A for element x in the universe. The membership concept representational mapping from an element x in universe X to one of the two elements in universe Y (either to element 0 or 1). There exist a function-theoretic set called value set for any set A defined on the universe, based on the mapping of characteristic functions, The whole set is assigned a membership value 1, and the null set is assigned a membership value 0. In other words, fuzzy sets (Zadeh 1965) may be viewed as an extension and generalization of the basic concepts of crisp sets. An important property of fuzzy set is that it allows partial membership, i.e., between 0 and 1. Zadeh extended the notion of valuation set {1, 0} (definitely in/definitely out) to the interval of real values (degree of membership) between 1 and 0, denoted as [0, 1], where 0.0 represents the absolutely false and 1.0 represents absolutely truth. The fuzzy set $\tilde{A}$ in the universe of discourse U is defined as a set of ordered pairs $(x, \mu_{\tilde{A}}(x))$, i.e.

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \,|\, x \in U\} \tag{11.2}$$

where $\mu_{\tilde{A}}(x)$ is the degree of membership of x in fuzzy set $\tilde{A}$ and it indicates the degree that x belongs to $\tilde{A}$. Clearly $\mu_{\tilde{A}}(x) \in [0,\ 1]$.

11.3.2 Fuzzy Numbers

A fuzzy set $\tilde{A} = \{(x, \mu_{\tilde{A}}(x))\} \subseteq U$ is called convex fuzzy set if the following relation between the elements x_1, x_2 and x_3 of $\tilde{A}$ holds

$$\mu_{\tilde{A}}(x_2) \geq \min[\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_3)] \tag{11.3}$$

Otherwise the fuzzy set is called non-convex fuzzy set. A fuzzy set whose membership function has at least one element x in the universe whose membership value is unity is called a normal fuzzy set.

A fuzzy number is an extension of a regular number in which the value corresponding to element has its own weight between 0 and 1, called membership functions, instead of single values. Thus, a fuzzy number is a convex and normal fuzzy set of the real line R such that

- $\exists$ exactly one $x_0 \in R$ with $\mu_{\tilde{A}}(x_0) = 1$.
- $\mu_{\tilde{A}}$ is piecewise continuous.

and its membership function is defined as

$$\mu_{\tilde{A}}(x) = \begin{cases} f_A(x) & ;\ if\ a_1 \le x \le a_2 \\ 1 & ;\ if\ x = a_2 \\ g_A(x) & ;\ if\ a_2 \le x \le a_3 \\ 0 & ;\ otherwise \end{cases} \tag{11.4}$$

where $0 \le \mu_{\tilde{A}}(x) \le 1$ and $a_1, a_2, a_3 \in R$ such that $a_1 \le a_2 \le a_3$ and the two functions $f_A,\ g_A : R \to [0,\ 1]$ are called the sides of the fuzzy numbers. The function f_A and g_A are nondecreasing and nonincreasing continuous functions respectively. We denote this fuzzy number as $\tilde{A} = (a_1, a_2, a_3)$ where $\tilde{A}$ represents the fuzzy set of A.

11.3.3 α-Cuts

α-cut is one of the most significant and extensively used the concept in fuzzy set theory which was introduced by Zadeh (1971). When we want to exhibit an element $x \in U$ that typically belongs to a fuzzy set $\tilde{A}$, we may demand that its membership value be greater than some threshold $\alpha \in [0, 1]$.

For a fuzzy set $\tilde{A}$,

$$A_\alpha = \{x | \mu_{\tilde{A}}(x) > \alpha\} \quad ; \quad \alpha \in [0, 1)$$
$$A_\alpha = \{x | \mu_{\tilde{A}}(x) \ge \alpha\} \quad ; \quad \alpha \in [0, 1)$$

are called strong α-cut and weak α-cut respectively.

11.3.4 Fuzzy Arithmetic Operations

The basic arithmetic operations, i.e., addition, subtraction, multiplication and division, of fuzzy numbers depend upon the arithmetic of the interval of confidence. The four main arithmetic operations on two triangular fuzzy sets $\tilde{A}$ and $\tilde{B}$ described by the α-cuts are given below for the following intervals:

$$A^{(\alpha)} = [A_1^{(\alpha)}, A_3^{(\alpha)}] \text{ and } B^{(\alpha)} = [B_1^{(\alpha)},\ B_3^{(\alpha)}] \quad ; \quad \alpha \in [0, 1]$$

- Addition: $\tilde{A} + \tilde{B} = [A_1^{(\alpha)} + B_1^{(\alpha)}, A_3^{(\alpha)} + B_3^{(\alpha)}]$
- Subtraction: $\tilde{A} - \tilde{B} = [A_1^{(\alpha)} - B_3^{(\alpha)}, A_3^{(\alpha)} - B_1^{(\alpha)}]$

- Multiplication: $\tilde{A} \cdot \tilde{B} = [P^{(\alpha)}, Q^{(\alpha)}]$ where $P^{(\alpha)} = \min(A_1^{(\alpha)} \cdot B_1^{(\alpha)}, A_1^{(\alpha)} \cdot B_3^{(\alpha)}, A_3^{(\alpha)} \cdot B_1^{(\alpha)}, A_3^{(\alpha)} \cdot B_3^{(\alpha)})$ and $Q^{(\alpha)} = \max(A_1^{(\alpha)} \cdot B_1^{(\alpha)}, A_1^{(\alpha)} \cdot B_3^{(\alpha)}, A_3^{(\alpha)} \cdot B_1^{(\alpha)}, A_3^{(\alpha)} \cdot B_3^{(\alpha)})$
- Division: $\tilde{A} \div \tilde{B} = \tilde{A} \cdot \frac{1}{\tilde{B}}, \quad if \quad 0 \notin \tilde{B}$

It is clear that the multiplication and division of two TFNs is not again a TFN with linear sides, but it is a new fuzzy number with parabolic sides.

11.4 Assumptions and Notations

11.4.1 Assumption

The following assumptions have been used in developing the model.

- Demand rate is deterministic.
- The replenishment is instantaneous.
- Shortages are allowed and fully backlogged except for the final cycle.
- A fraction $\beta\,(0 \le \beta \le 1)$ of the demand during the stockout period can be backordered, and the remaining fraction $1 - \beta$ is lost.

11.4.2 Notations

D	expected demand per year
Q	lot size
R	reorder point
K	setup cost
θ	proportion of defective items in a lot size $Q, 0 < Q < 1$
$(1 - \theta)Q$	number of non-defective items in a lot.
β	backorder ratio, $0 \le \beta \le 1$
h	nondefective holding cost per unit unit per year.
π	shortage cost per unit short
μ	expected demand during the lead time.
$\bar{b}(R)$	expected demand short at the end of the cycle.
$\bar{b}(R) = \int_R^\infty (x - R) f(x) dx$	where $f(x)$ is the density function of the lead-time demand
$EC(Q, R)$	expected annual cost

11.5 Mathematical Model

11.5.1 Crisp Mathematical Model

Consider a basic economic order quantity model that allows stockouts and back-ordering with shortage. The main objective of the inventory problem is to minimize the total inventory cost derived from the sum of ordering cost (OC), holding cost (HC), shortage cost (SC). So therefore the total inventory cost becomes

$$EC(Q, R) = OC + HC + SC$$

where EC(Q, R) represent the annual expecting cost of the model.

The annual expected ordering cost can be expressed as

$$OC = \frac{DK}{Q} \tag{11.5}$$

The backorder ratio β, the expected inventory at the end of cycle is $\beta\,\bar{b}(R)$ and the expected lost sale is $(1-\beta)\bar{b}(R)$. Hence, the expected annual holding cost is

$$HC = h\left(\frac{1}{2}\{Q(1-\theta)+\theta\} + R - \mu + (1-\beta)\bar{b}(R)\right) \tag{11.6}$$

The backorder price discount of a cycle is $\beta\,\pi\,\bar{b}(R)$ and the expected lost sale is $(1-\beta)\,\pi\,\bar{b}(R)$, so that profit lost due to shortage is $\pi_0(1-\beta)\bar{b}(R)$ and the expected annual shortage cost can be expressed as

$$SC = \frac{D(\pi\beta + (1-\beta)\pi_0)\bar{b}(R)}{Q(1-\theta)} \tag{11.7}$$

Therefore, the annual cost function of this model is

$$\begin{aligned} EC(Q, R) = {} & \frac{DK}{Q(1-\theta)} + h\left(\frac{1}{2}\{Q(1-\theta)+\theta\} + R - \mu + (1-\beta)\bar{b}(R)\right) \\ & + \frac{D(\pi\beta + (1-\beta)\pi_0)\bar{b}(R)}{Q(1-\theta)}, \quad Q, R > 0 \end{aligned} \tag{11.8}$$

where D is the average demand per year, K is the fixed ordering cost per order, h is the inventory holding cost per unit per year, π is the fixed penalty cost per unit short, π_0 is the marginal profit per unit, Q is the order quantity, $b(R)$ is the expected demand shortage at the end of cycle, R is the reorder point. The purpose of this model is to find the optimal order quantity and reorder point level of inventory items at each time such that the annual expected cost is minimized. For this, by using calculus, the optimum values of Q and R can be obtained by setting $\frac{\partial EC}{\partial Q} = 0$ and $\frac{\partial EC}{\partial R} = 0$ as

$$-\frac{DK}{Q^2(1-\theta)} + \frac{h(1-\theta)}{2} - \frac{D(\pi\beta + (1-\beta)\pi_0)\bar{b}(R)}{Q^2(1-\theta)} = 0 \qquad (11.9)$$

$$h + h(1-\beta)\bar{b}'(R) + \frac{D(\pi\beta + (! - \beta)\pi_0)\bar{b}'(R)}{Q(1-\theta)} = 0 \qquad (11.10)$$

where $\bar{b}'(R)$ represents the derivatives of the term $\bar{b}(R)$ with R. Rearranging the Eqs. (11.9) and (11.10), we get the following equations

$$Q(1-\theta) = -\frac{D(\pi\beta + (1-\beta)\pi_0)\bar{b}'(R)}{h + h(1-\beta)\bar{b}'(R)}$$

$$Q(1-\theta) = \sqrt{\frac{2D}{h}[K + (\pi\beta + (1-\beta)\pi_0)\bar{b}(R)}$$

Thus, by equating these equations we obtain the value of R and hence from (11.9), we get Q after substituting the value of R. The second derivatives of the function $EC(Q, R)$ becomes

$$\frac{\partial^2 EC}{\partial Q^2} = \frac{2DK}{Q^3(1-\theta)} + \frac{2D(\pi\beta + (1-\beta)\pi_0)\bar{b}(R)}{Q^3(1-\theta)}$$

$$\frac{\partial^2 EC}{\partial R^2} = h(1-\beta)\bar{b}''(R) + \frac{D(\pi\beta + (1-\beta)\pi_0)\bar{b}''(R)}{Q(1-\theta)}$$

$$\frac{\partial^2 EC}{\partial Q \partial R} = -\frac{D(\pi\beta + (1-\beta)\pi_0)\bar{b}'(R)}{Q^2(1-\theta)}$$

Thus, the sufficient condition for the convexity nature of EC is

$$\frac{\partial^2 EC}{\partial Q^2} > 0,\ \frac{\partial^2 EC}{\partial R^2} > 0 \text{ and } \frac{\partial^2 EC}{\partial Q^2 \partial R^2} - \frac{\partial^2 EC}{\partial Q \partial R}\frac{\partial^2 EC}{\partial R \partial Q} > 0$$

11.5.2 Fuzzy Model

Due to uncertainly in the environment, it is not easy to define all the parameters precisely, accordingly we assume these parameters, namely demand rate, holding cost, shortage cost and set up cost is fuzzy numbers. Thus the Eq. (11.8) reduces to

$$E\tilde{C}(Q,R) = \frac{\tilde{D}\tilde{K}}{\tilde{Q}(1-\theta)} + \tilde{h}\left(\frac{1}{2}\{\tilde{Q}(1-\theta)+\theta\} + \tilde{R} - \mu + (1-\beta)\bar{b}(\tilde{R})\right) + \frac{\tilde{D}(\pi\beta + (1-\beta)\pi_0)\bar{b}(\tilde{R})}{\tilde{Q}(1-\theta)} \tag{11.11}$$

Here, in this article the distribution function of the lead-time demand is taken as uniform, exponential and Laplace distribution. Thus, based on these distribution, the corresponding function $\bar{b}(R)$ has been computed as follows

11.5.2.1 When the Lead Time Follows the Uniform Distribution

The density function of the uniform distribution is given by

$$f(x) = \begin{cases} \dfrac{1}{b-a} & ; \ a \le x \le b \\ 0 & ; \ otherwise \end{cases} \tag{11.12}$$

Based on this distribution, the function $\bar{b}(R)$ is given by

$$\bar{b}(R) = \frac{(b-R)^2}{2(b-a)} \ ; \quad \mu = \frac{a+b}{2} \tag{11.13}$$

Thus, expected fuzzy cost (11.11) is given by

$$E\tilde{C}(Q,R) = \frac{\tilde{D}\tilde{K}}{\tilde{Q}(1-\theta)} + \tilde{h}\left(\frac{1}{2}\{\tilde{Q}(1-\theta)+\theta\} + \tilde{R} - \frac{a+b}{2} + (1-\beta)\frac{(b-R)^2}{2(b-a)}\right) + \frac{\tilde{D}(\pi\beta + (1-\beta)\pi_0)\frac{(b-R)^2}{2(b-a)}}{\tilde{Q}(1-\theta)}$$

11.5.2.2 When the Lead Time Follows an Exponential Distribution

The density function of the exponential distribution is given by

$$f(x) = \begin{cases} \lambda e^{-\lambda x} & ; \ x \ge 0 \\ 0 & ; \ otherwise \end{cases} \tag{11.14}$$

Based on this distribution, the function $\bar{b}(R)$ is given by

$$\bar{b}(R) = \frac{e^{-\lambda R}}{\lambda} \text{ and } \mu = \frac{1}{\lambda} \tag{11.15}$$

Thus, expected fuzzy cost is given by

$$E\tilde{C}(Q,R) = \frac{\tilde{D}\tilde{K}}{\tilde{Q}(1-\theta)} + \tilde{h}\left(\frac{1}{2}\{\tilde{Q}(1-\theta)+\theta\} + \tilde{R} - \frac{1}{\lambda} + (1-\beta)\frac{e^{-\lambda R}}{\lambda}\right) + \frac{\tilde{D}(\pi\beta + (1-\beta)\pi_0)\frac{e^{-\lambda R}}{\lambda}}{\tilde{Q}(1-\theta)}$$

11.5.2.3 When the Lead Time Follows the Laplace Distribution

The density function of the Laplace distribution is given by

$$f(x) = \begin{cases} e^{-\frac{1}{2}\frac{(x-\mu)}{\sigma}}; & x \geq 0 \\ 0 & otherwise \end{cases} \tag{11.16}$$

Based on this distribution, the function $\bar{b}(R)$ is given by

$$\bar{b}(R) = \frac{\sigma}{2} e^{-\left(\frac{R-\mu}{\sigma}\right)} \tag{11.17}$$

Thus, expected fuzzy cost is given by

$$E\tilde{C}(Q,R) = \frac{\tilde{D}\tilde{K}}{\tilde{Q}(1-\theta)} + \tilde{h}\left(\frac{1}{2}\{\tilde{Q}(1-\theta)+\theta\} + \tilde{R} - \mu + (1-\beta)\frac{\sigma}{2}e^{-\left(\frac{\tilde{R}-\mu}{\sigma}\right)}\right) + \frac{\tilde{D}(\pi\beta + (1-\beta)\pi_0)\frac{\sigma}{2}e^{-\left(\frac{\tilde{R}-\mu}{\sigma}\right)}}{\tilde{Q}(1-\theta)}$$

In daily life, most of the actions or decisions implemented by human or machines are binary or crisp. So for application purposes, it is necessary to convert the fuzzy output values to crisp values. The process of converting a fuzzy quantity to a crisp quantity is said to be defuzzification. Here, we defuzzify the fuzzy total cost by graded mean representation as

$$EC_{df}(Q,R) = \frac{EC_1(Q_1,R_1) + 4EC_2(Q_2,R_2) + EC_3(Q_3,R_3)}{6} \tag{11.18}$$

where

$$EC_1(Q_1, R_1) = \frac{D_1 K_1}{Q_1(1-\theta)} + h_1\left(\frac{1}{2}\{Q_1(1-\theta)+\theta\} + R_1 - \mu + (1-\beta)\bar{b}(R_1)\right) + \frac{D_1(\pi\beta + (1-\beta)\pi_0)\bar{b}(R_1)}{Q_1(1-\theta)}$$

$$EC_2(Q_2, R_2) = \frac{D_2 K_2}{Q_2(1-\theta)} + h_2\left(\frac{1}{2}\{Q_2(1-\theta)+\theta\} + R_2 - \mu + (1-\beta)\bar{b}(R_2)\right) + \frac{D_2(\pi\beta + (1-\beta)\pi_0)\bar{b}(R_2)}{Q_2(1-\theta)}$$

$$EC_3(Q_3, R_2) = \frac{D_3 K_3}{Q_3(1-\theta)} + h_3\left(\frac{1}{2}\{Q_3(1-\theta)+\theta\} + R_3 - \mu + (1-\beta)\bar{b}(R_3)\right) + \frac{D_3(\pi\beta + (1-\beta)\pi_0)\bar{b}(R_3)}{Q_3(1-\theta)}$$

Similarly, the corresponding values for Q and R have been obtained.

11.6 Computational Analysis

11.6.1 Crisp Data

To illustrate the approach method, let us consider the input data as $h = 0.5$, $D = 1000$, $K = 100$. The solution of the crisp model is given as Q = 634.04262, R = 96.82979, Q = 633.45632, R = 3.45230 and Q = 633.45632, R = 52.75915 for uniform, exponential and Laplace distribution corresponding to $\theta = 0$ and $\beta = 1$. The corresponding value of expected cost $EC(Q, R)$ are 363.85110, 319.18064 and 367.98731. The detail computations of the crisp values corresponding to different values of θ and β are summarized in Table 11.1. In order to show the convexity of the cost function $EC(Q, R)$, we plot a 3D graph among Q and R, corresponding to uniform, exponential and Laplace distribution shown in Fig. 11.1.

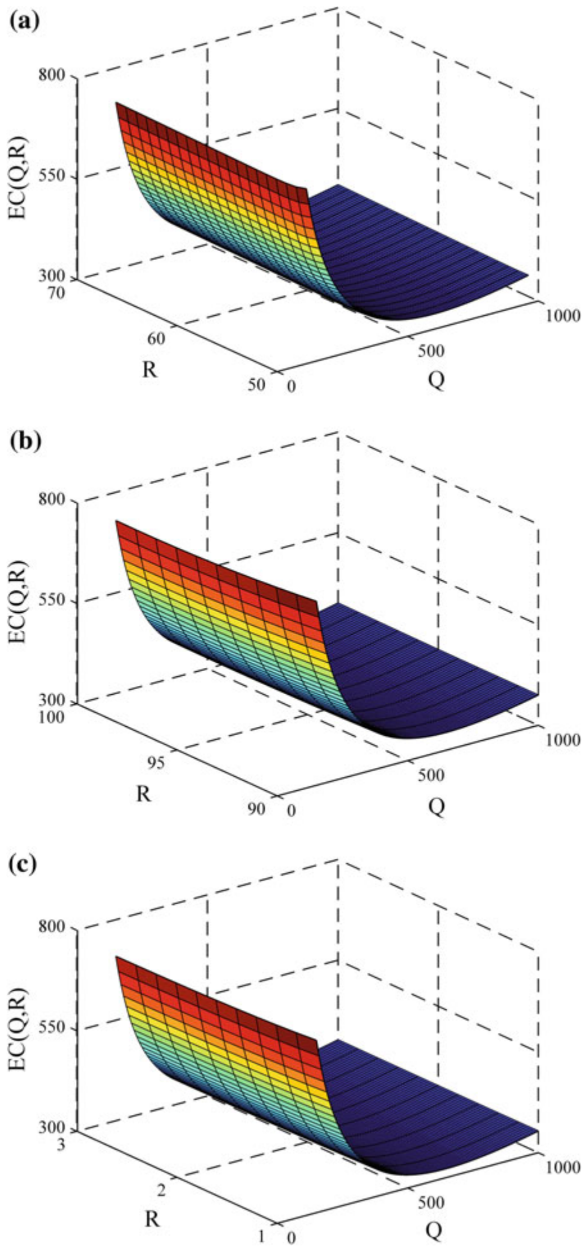
11.6.2 Fuzzy Data

By taking the following fuzzifier data corresponding to the various terms as $\tilde{D} = [950, 1000, 1100]$, $\tilde{K} = [80, 100, 110]$, $\tilde{h} = [0.2, 0.5, 2]$, the expected value of the annual cost is computed corresponding to lead-time follows uniform,

Table 11.1 Inventory problem results: Uniform, Exponential, Laplace distribution

θ	β	Uniform				Exponential				Laplace			
		Crisp (*Q*, *R*, *EC*)	Defuzzified values			Crisp (*Q*, *R*, *EC*)	Defuzzified values			Crisp (*Q*, *R*, *EC*)	Defuzzified values		
			Q	*R*	*EC*		*Q*	*R*	*EC*		*Q*	*R*	*EC*
0	0	(633.302, 98.441, 365.040)	608.134	98.265	406.105	(633.440, 4.161, 319.897)	625.892	4.137	359.668	(633.440, 53.468, 368.696)	625.892	53.444	408.273
	0.5	(633.596, 97.910, 364.644)	612.265	97.670	405.509	(633.445, 3.868, 319.602)	625.898	3.844	359.374	(633.445, 53.175, 368.403)	625.898	53.151	407.979
	1.0	(634.042, 96.829, 363.851)	620.896	96.455	404.472	(633.456, 3.452, 319.180)	625.90961	3.427	358.956	(633.456, 52.759, 367.987)	625.909	52.734	407.562
0.3	0	(904.717, 98.441, 365.115)	868.763	98.265	406.210	(904.915, 4.161, 319.972)	894.132	4.137	359.773	(904.915, 53.468, 368.771)	894.132	53.444	408.378
	0.5	(905.137, 97.910, 364.719)	874.664	97.670	405.614	(904.922, 3.868, 319.676)	894.140	3.844	359.479	(904.922, 53.175, 368.478)	894.140	53.151	408.084
	1.0	(905.775, 96.829, 363.926)	886.995	96.455	404.577	(904.937, 3.452, 319.255)	894.156	3.427	359.061	(904.937, 52.759, 368.062)	894.156	52.734	407.667
0.6	0	(1583.26, 98.441, 365.190)	1520.33	98.265	406.315	(1583.601, 4.161, 320.047)	1564.73	4.137	359.878	(1583.61, 53.468, 368.846)	1564.73	53.444	408.483
	0.5	(1583.99, 97.91, 364.794)	1530.66	97.670	405.719	(1583.61, 3.868, 319.751)	1564.74	3.844	359.584	(1583.61, 53.175, 368.553)	1564.74	53.151	408.189
	1.0	(1585.10, 96.829, 364.001)	1552.24	96.455	404.682	(1583.64, 3.452, 319.330)	1564.77	3.427	359.166	(1583.64, 52.759, 368.137)	1564.77	52.734	407.773
0.9	0	(6333.02, 98.441, 365.265)	6081.34	98.265	406.420	(6334.40, 4.161, 320.122)	6258.92	4.137	359.983	(6334.40, 53.468, 368.921)	6258.92	53.444	408.588
	0.5	(6335.96, 97.910, 364.869)	6122.65	97.670	405.824	(6334.45, 3.868, 319.826)	6258.98	3.844	359.689	(6334.45, 53.175, 368.628)	6258.98	53.151	408.294
	1.0	(6340.42, 96.829, 364.076)	6208.96	96.455	404.787	(6334.56, 3.452, 319.405)	6259.09	3.427	359.271	(6334.56, 52.759, 368.213)	6259.09	52.734	407.87

Fig. 11.1 Convexity of the example for the model. **a** Uniform. **b** Exponential. **c** Laplace



exponential and Laplace distribution. A study of expected annual cost $EC(Q, R)$ with lot size Q and reorder point R is given in Table 11.1 for different defective rate θ and β. From this table it has been concluded that

- If by varying the value of defective rate θ from 0 to 0.9 and simultaneously fixing the β then the corresponding value of lot size Q as well as annual cost $EC(Q, R)$ increases. For instance, in case of uniform distribution, the value of \$EC\$ increases from 406.10527 to 406.21027 to 406.31527 to 406.42027 as θ varies from 0 to 0.3 to 0.6 to 0.9 for a fixed value of $\beta = 0$, while for exponential distribution these values are increased from 359.66800 to 359.77300 to 359.87800 to 359.98300. Similarly, observation has been observed from the other data. Also, it has been observed that the value of reorder point level is independent of θ.
- On the other hand, by varying the value of β from 0 to 1 and by fixing the value of θ, the corresponding value of reorder level R and annual cost $EC(Q, R)$ decreases while the lot size Q increases. Thus, based on this analysis the system analyst may analyze the effect of defective rate θ and β on the performance of the system.
- It has also evident from the Table 11.1 that the variation of the defuzzified values for the annual expected cost from the crisp value follows the same trends i.e., increasing when β has been varying from 0 to 1 for a particular value of θ. For instance, by taking $\theta = 0$ and varying β from 0 to 0.5 and then to 1, the corresponding decreasing value of EC from crisp has been found as 11.249, 11.206, 11.164 % for uniform; 12.432, 12.444, 12.461 % for exponential and 10.734, 10.742, 10.754 % for Laplace distribution respectively. Thus, based on these changes the analyst may have changed their target goals which are now based on defuzzified values rather than crisp values as a safe interval is maintained before reaching the crisp values, i.e., a decision maker should make a decision before reaching the value to the crisp and hence increasing the performance of the system.

11.6.3 Sensitivity Analysis

The effect of the various inventory parameters, namely K, D, h etc., on the annual expected cost is performed in terms of their sensitivity analysis. The results corresponding to uniform, exponential and Laplace are shown in the respective Tables 11.2, 11.3 and 11.4. It has clearly seen from these tables that for a fixed value of θ and by varying the values of β from 0 to 1, the corresponding values of annual cost as well as reorder level points are decreases and lot size Q increases. On the other hand, for a fixing value of β and by varying the value of θ from 0 to 0.9, the corresponding values of lot size Q and annual cost $EC(Q, R)$ are increasing while reorder level point values are independent of it. However, by fixing the value of θ as well asβ and simultaneously increasing the defuzzified of K and D the effect of the same on the annual expected cost is increasing. On the other hand, by increasing the defuzzified value of h, the annual expected cost decreases for a fixed value of θ and β. Thus, based on these analysis system analysts may analyze the

Table 11.2 Sensitivity analysis on parameter K

Fuzzifier value of pararmeter K	θ	β	Uniform			Exponential			Laplace		
			Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$
[60, 80, 100]	0	0	543.52150	98.41711	374.58010	559.21667	4.24227	328.22624	559.21667	53.54912	376.83199
		0.5	547.29017	97.87537	374.03758	559.22179	3.94939	327.93306	559.22179	53.25624	376.53912
		1	555.23071	96.77020	373.09883	559.23222	3.53343	327.51656	559.23222	52.84028	376.12318
	0.5	0	1087.04299	98.41711	374.75510	1118.43334	4.24227	328.40124	1118.43334	53.54912	377.00699
		0.5	1094.58034	97.87537	374.21258	1118.44358	3.94939	328.10806	1118.44358	53.25624	376.71412
		1	1110.46142	96.77020	373.27383	1118.46444	3.53343	327.69156	1118.46444	52.84028	376.29818
	0.9	0	5435.21496	98.41711	374.89510	5592.16668	4.24227	328.54124	5592.16668	53.54912	377.14699
		0.5	5472.90168	97.87537	374.35258	5592.21789	3.94939	328.24806	5592.21789	53.25624	376.85412
		1	5552.30712	96.77020	373.41383	5592.32221	3.53343	327.83156	5592.32221	52.84028	376.43818
[80, 100, 110]	0	0	608.13426	98.26508	406.10527	625.89254	4.13769	359.66800	625.89254	53.44454	408.27328
		0.5	612.26501	97.67030	405.50985	625.89815	3.84430	359.37416	625.89815	53.15115	407.97991
		1	620.89675	96.45560	404.47241	625.90961	3.42731	358.95632	625.90961	52.73416	407.56294
	0.5	0	1216.26853	98.26508	406.28027	1251.78508	4.13769	359.84300	1251.78508	53.44454	408.44828
		0.5	1224.53001	97.67030	405.68485	1251.79631	3.84430	359.54916	1251.79631	53.15115	408.15491
		1	1241.79350	96.45560	404.64741	1251.81921	3.42731	359.13132	1251.81921	52.73416	407.73794
	0.9	0	6081.34263	98.26508	406.42027	6258.92540	4.13769	359.98300	6258.92540	53.44454	408.58828
		0.5	6122.65007	97.67030	405.82485	6258.98154	3.84430	359.68916	6258.98154	53.15115	408.29491
		1	6208.96751	96.45560	404.78741	6259.09605	3.42731	359.27132	6259.09605	52.73416	407.87794

(continued)

Table 11.2 (continued)

Fuzzifier value of pararmeter K	θ	β	Uniform			Exponential			Laplace		
			Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$
[100, 110, 130]	0	0	648.11207	98.15169	430.06678	668.67142	4.07464	383.42561	668.67142	53.38149	432.03093
		0.5	652.91212	97.51694	429.39057	668.67739	3.78088	383.13140	668.67739	53.08773	431.73719
		1	662.97303	96.21900	428.23020	668.68959	3.36313	382.71283	668.68959	52.66998	431.31946
	0.5	0	1296.22414	98.15169	430.24178	1337.34283	4.07464	383.60061	1337.34283	53.38149	432.20593
		0.5	1305.82425	97.51694	429.56557	1337.35478	3.78088	383.30640	1337.35478	53.08773	431.91219
		1	1325.94606	96.21900	428.40520	1337.37918	3.36313	382.88783	1337.37918	52.66998	431.49446
	0.9	0	6481.12070	98.15169	430.38178	6686.71417	4.07464	383.74061	6686.71417	53.38149	432.34593
		0.5	6529.12123	97.51694	429.70557	6686.77388	3.78088	383.44640	6686.77388	53.08773	432.05219
		1	6629.73028	96.21900	428.54520	6686.89588	3.36313	383.02783	6686.89588	52.66998	431.63446

Table 11.3 Sensitivity analysis on parameter D

Fuzzifier value of pararmeter D	θ	β	Uniform			Exponential			Laplace		
			Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$
[800, 950, 1000]	0	0	582.42791	98.18132	393.74015	600.55453	4.09892	346.50253	600.55453	53.40577	395.10782
		0.5	586.17183	97.55707	393.04882	600.56035	3.80531	346.20847	600.56035	53.11217	394.81423
		1	594.01206	96.28111	391.82429	600.57224	3.38788	345.79019	600.57224	52.69473	394.39682
	0.5	0	1164.85582	98.18132	393.91515	1201.10906	4.09892	346.67753	1201.10906	53.40577	395.28282
		0.5	1172.34366	97.55707	393.22382	1201.12071	3.80531	346.38347	1201.12071	53.11217	394.98923
		1	1188.02412	96.28111	391.99929	1201.14449	3.38788	345.96519	1201.14449	52.69473	394.57182
	0.9	0	5824.27909	98.18132	394.05515	6005.54531	4.09892	346.81753	6005.54531	53.40577	395.42282
		0.5	5861.71828	97.55707	393.36382	6005.60354	3.80531	346.52347	6005.60354	53.11217	395.12923
		1	5940.12060	96.28111	392.13929	6005.72243	3.38788	346.10519	6005.72243	52.69473	394.71182
[950, 1000, 1100]	0	0	608.13426	98.26508	406.10527	625.89254	4.13769	359.66800	625.89254	53.44454	408.27328
		0.5	612.26501	97.67030	405.50985	625.89815	3.84430	359.37416	625.89815	53.15115	407.97991
		1	620.89675	96.45560	404.47241	625.90961	3.42731	358.95632	625.90961	52.73416	407.56294
	0.5	0	1216.26853	98.26508	406.28027	1251.78508	4.13769	359.84300	1251.78508	53.44454	408.44828
		0.5	1224.53001	97.67030	405.68485	1251.79631	3.84430	359.54916	1251.79631	53.15115	408.15491
		1	1241.79350	96.45560	404.64741	1251.81921	3.42731	359.13132	1251.81921	52.73416	407.73794
	0.9	0	6081.34263	98.26508	406.42027	6258.92540	4.13769	359.98300	6258.92540	53.44454	408.58828
		0.5	6122.65007	97.67030	405.82485	6258.98154	3.84430	359.68916	6258.98154	53.15115	408.29491
		1	6208.96751	96.45560	404.78741	6259.09605	3.42731	359.27132	6259.09605	52.73416	407.87794

(continued)

Table 11.3 (continued)

Fuzzifier value of pararmeter D	θ	β	Uniform			Exponential			Laplace		
			Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$
[1000, 1100, 1250]	0	0	634.87235	98.33438	425.69631	654.07407	4.18363	378.41179	654.07407	53.49048	427.01703
		0.5	638.63304	97.76432	425.04193	654.07942	3.89051	378.11821	654.07942	53.19737	426.72393
		1	646.46310	96.60169	423.87442	654.09031	3.47409	377.70091	654.09031	52.78094	426.30753
	0.5	0	1269.74469	98.33438	425.87131	1308.14815	4.18363	378.58679	1308.14815	53.49048	427.19203
		0.5	1277.26607	97.76432	425.21693	1308.15884	3.89051	378.29321	1308.15884	53.19737	426.89893
		1	1292.92620	96.60169	424.04942	1308.18062	3.47409	377.87591	1308.18062	52.78094	426.48253
	0.9	0	6348.72346	98.33438	426.01131	6540.74074	4.18363	378.72679	6540.74074	53.49048	427.33203
		0.5	6386.33036	97.76432	425.35693	6540.79419	3.89051	378.43321	6540.79419	53.19737	427.03893
		1	6464.63098	96.60169	424.18942	6540.90312	3.47409	378.01591	6540.90312	52.78094	426.62253

Table 11.4 Sensitivity analysis on parameter h

Fuzzifier value of pararmeter h	θ	β	Uniform			Exponential			Laplace		
			Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$
[0.2, 0.5, 2]	0	0	608.13426	98.26508	406.10527	625.89254	4.13769	359.66800	625.89254	53.44454	408.27328
		0.5	612.26501	97.67030	405.50985	625.89815	3.84430	359.37416	625.89815	53.1511	407.97991
		1	620.89675	96.45560	404.47241	625.90961	3.42731	358.95632	625.90961	52.73416	407.56294
	0.5	0	1216.26853	98.26508	406.28027	1251.78508	4.13769	359.84300	1251.78508	53.44454	408.44828
		0.5	1224.53001	97.67030	405.68485	1251.79631	3.84430	359.54916	1251.79631	53.15115	408.15491
		1	1241.79350	96.45560	404.64741	1251.81921	3.42731	359.13132	1251.81921	52.73416	407.73794
	0.9	0	6081.34263	98.26508	406.42027	6258.92540	4.13769	359.98300	6258.92540	53.44454	408.58828
		0.5	6122.65007	97.67030	405.82485	6258.98154	3.84430	359.68916	6258.98154	53.15115	408.29491
		1	6208.96751	96.45560	404.78741	6259.09605	3.42731	359.27132	6259.09605	52.73416	407.87794
[0.5, 2, 3]	0	0	342.76555	97.04700	661.35006	351.02092	3.57661	614.05829	351.02092	52.88346	661.47957
		0.5	345.26833	96.01502	661.02406	351.03046	3.27914	613.77117	351.03046	52.58599	661.18216
		1	350.31273	93.87868	660.66583	351.05013	2.85379	613.36730	351.05013	52.16064	660.75695
	0.5	0	685.53110	97.04700	661.82923	702.04184	3.57661	614.53745	702.04184	52.88346	661.95873
		0.5	690.53666	96.01502	661.50323	702.06091	3.27914	614.25034	702.06091	52.58599	661.66133
		1	700.62546	93.87868	661.14500	702.10026	2.85379	613.84647	702.10026	52.16064	661.23611
	0.9	0	3427.65550	97.04700	662.21256	3510.20922	3.57661	614.92079	3510.20922	52.88346	662.34207
		0.5	3452.68332	96.01502	661.88656	3510.30455	3.27914	614.63367	3510.30455	52.58599	662.04466
		1	3503.12729	93.87868	661.52833	3510.50131	2.85379	614.22980	3510.50131	52.16064	661.61945

(continued)

Table 11.4 (continued)

Fuzzifier value of parameter h	θ	β	Uniform			Exponential			Laplace		
			Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$	Q	R	$EC(Q, R)$
[2, 3, 5]	0	0	255.24752	96.18756	846.26262	255.71028	3.29127	797.00313	255.71024	52.59812	843.22877
		0.5	256.36765	94.83553	846.73123	255.72255	2.99091	796.73088	255.72255	52.29777	842.92857
		1	258.40357	92.00699	848.18274	255.74806	2.55959	796.35823	255.74806	51.86644	842.49759
	0.5	0	510.49504	96.18756	847.05429	511.42056	3.29127	797.79480	511.42056	52.59812	844.02043
		0.5	512.73529	94.83553	847.52290	511.44509	2.99091	797.52255	511.44509	52.29777	843.72024
		1	516.80714	92.00699	848.97440	511.49612	2.55959	797.14990	511.49612	51.86645	843.28926
	0.9	0	2552.47522	96.18756	847.68762	2557.10282	3.29127	798.42813	2557.10282	52.59812	844.65377
		0.5	2563.67647	94.83553	848.15623	2557.22546	2.99091	798.15588	2557.22546	52.29777	844.35357
		1	2584.03569	92.00699	849.60774	2557.48061	2.55959	797.78323	2557.48061	51.86645	843.92259

effect of inventory parameters on the annual expected cost and hence may plan a suitable step for increasing the performance of the system.

11.7 Conclusion

The main objective of this chapter is to present an effective way to find the optimal solution of the quantity lot size Q and reorder level R which minimize the annual expected cost of the inventory problem. During the formulation of the model, lead time is considered to be zero and reorder level follows the different types of distribution namely uniform, exponential and Laplace distributions. The uncertainties which are obtained in the present data are handled with the help of fuzzy set theory and then reformulate the mixture inventory model involving variable lead-time with partial backorders with varying defective rates θ and β. It is found that the expected annual inventory cost tends to decrease as the backorder ratio increases while increases as the defective rate θ increases by fixing all the other parameters. Also, for our example, at the same inventory parameters we found that the annual cost in the case of the demand exponential distributed is less than the annual cost in the cases when the demand during the period follows the uniform or the Laplace distributions of all different values of θ. A sensitivity analysis is also conducted on the parameters h, D and K to explore the effects of fuzziness. The results corresponding to its' show that change in these parameters will result in the change in fuzzy cost and hence the decision maker, after analyzing the result, can plan for the optimal value for total cost, and for other related parameters. It is highly recommended that if a system analyst or company implements the inventory control model provided in order to reduce stock out and back orders. By doing so, the company could also reduce the total cost associated with their inventory.

References

Balkhi, Z.T.: An optimal solution of a general lot size inventory model with deteriorated and imperfect products, taking into account inflation and time value of money. Int. J. Syst. Sci. **35** (2), 87–96 (2004)

Barbosa, L.C., Friedman, M.: Deterministic inventory lot-size models—a general root law. Manage. Sci. **24**, 819–826 (1978)

Cárdenas-Barrón, L.E.: The economic production quantity (EPQ) with shortage derived algebraically. Int. J. Prod. Econ. **70**, 289–292 (2001)

Cárdenas-Barrón, L.E.: The derivation of EOQ/EPQ inventory models with two backorders costs using analytic geometry and algebra. Appl. Math. Model. **35**(5), 2394–2407 (2011)

Chakraborty, N., Mondal, S., Maiti, M.: A deteriorating multi-item inventory model with price discount and variable demands via fuzzy logic under resource constraints. Comput. Ind. Eng. **66**, 976–987 (2013)

Chang, S.K.J., Chuang, J.P.C., Chen, H.J.: Short comments on technical note—the EOQ and EPQ models with shortages derived without derivatives. Int. J. Prod. Econ. **97**, 241–243 (2005)

Chang, H.C., Yao, J.S., Ouyang, L.Y.: Fuzzy mixture inventory model involving fuzzy random variable lead time demand and fuzzy total demand. Eur. J. Oper. Res. **169**(1), 65–80 (2006)

Chen, J.M.: An inventory model for deteriorating items with time-proportional demand and shortages under inflation and time discounting. Int. J. Prod. Econ. **55**(1), 21–30 (1998)

Chowdhury, R.R., Ghosh, S.K., Chaudhuri, K.S.: An inventory model for perishable items with stock and advertisement sensitive demand. Int. J. Manage. Sci. Eng. Manage. **9**(3), 169–177 (2014)

Chung, K.J.: An algorithm for an inventory model with inventory level dependent demand rate. Comput. Oper. Res. **30**, 1311–1317 (2003)

De, P.K., Rawat, A.: A fuzy inventory model without shortages using triangular fuzzy number. Fuzzy Inf. Eng. **1**, 59–68 (2011)

De, S.K., Sana, S.S.: Fuzzy order quantity inventory model with fuzzy shortage quantity and fuzzy promotional index. Econ. Model. **31**, 351–358 (2013)

De, S.K., Sana, S.S.: A multi-periods production–inventory model with capacity constraints for multi-manufacturers—a global optimality in intuitionistic fuzzy environment. Appl. Math. Comput. **242**, 825–841 (2014)

Dutta, D., Kumar, P.: Optimal policy for an inventory model without shortages considering fuzziness in demand, holding cost and ordering cost. Int. J. Adv. Innov. Res. **2**(3), 320–325 (2013)

Dutta, D., Kumar, P.: Fuzzy inventory model for deteriorating items with shortages under fuzzy backlogged condition. Int. J. Soft Comput. Eng. **3**(2), 393–398 (2014)

Dutta, P., Chakraborty, D., Roy, A.R.: A single period inventory model with fuzzy random variable demand. Math. Comput. Model. **41**, 915–922 (2005)

EL-Sodany, N.H.: Periodic review probabilistic multi-item inventory system with zero lead time under constraint and varying holding cost. J. Math. Stat. **7**, 12–19 (2011)

Fergany, H.A., El-Wakeel, M.F.: Probabilistic single item inventory problem with varying order cost under two linear constraints. J. Egypt. Math. Soc. **12**(1), 71–81 (2004)

Ghasemi, N., Nadjafi, B.A.: EOQ models with varying holding costs. J. Ind. Math. **2013** Article ID 743921, 7 pp. (2013)

Ghosh, S.K., Khanra, S., Chaudhuri, K.S.: Optimal price and lot size determination for a perishable product under conditions of finite production, partial backordering and lost sale. Appl. Math. Comput. **217**(13), 6047–6053 (2011)

Giri, B.C., Goswami, A., Chaudhuri, K.S.: An EOQ model for deteriorating items with time varying demand and costs. J. Oper. Res. Soc. **47**(11), 1398–1405 (1996)

Grubbstrom, R.W.: Modelling production opportunities-an historical overview. Int. J. Prod. Econ. **41**(1–3), 1–14 (1995)

Grubbstrom, R.W., Erdem, A.: The EOQ with backlogging derived without derivatives. Int. J. Prod. Econ. **59**(1–3), 529–530 (1999)

Guchhait, P., Maiti, M.K., Maiti, M.: A production inventory model with fuzzy production and demand using fuzzy differential equation: an interval compared genetic algorithm approach. Eng. Appl. Artif. Intell. **26**, 766–778 (2013)

Hala, A.F., El-Saadani, E.: Constrained single period stochastic uniform inventory model with continuous distributions of demand and varying holding cost. J. Math. Stat. **2**(1), 334–338 (2006)

Harris, F.: Operations and cost (factory management series). A.W. Shaw Co., Chicago (1915)

Harris, F.W.: How many parts to make at once, factory. Mag. Manage. **10**, 135–136 and 152 (1913)

Hsieh, C.H.: Optimization of fuzzy production inventory models. Inf. Sci. **146**(1–4), 29–40 (2002)

Jaggi, C.K., Pareek, S., Sharma, A., Nidhi, : Fuzzy inventory model for deteriorating items with time-varying demand and shortages. Am. J. Oper. Res. **2**(6), 81–92 (2012)

Kacpryzk, J., Staniewski, P.: Long term inventory policy-making through fuzzy-decision making models. Fuzzy Sets Syst. **8**, 117–132 (1982)

Kao, C., Hsu, W.K.: Lot size reorder point inventory model with fuzzy demands. Comput. Math. Appl. **43**, 1291–1302 (2002)

Kotb, K.A.M., Fergany, H.A.: Multi-item EOG model with varying holding cost: a geometric programming approach. Int. Math. Forum **6**, 1135–1144 (2011)
Lee, H.M., Yao, J.S.: Economic order quantity in fuzzy sense for inventory without back-order model. Fuzzy Sets Syst. **105**, 13–31 (1999)
Liu, D.S., Yao, J.S.: Fuzzy economic production for production inventory. Fuzzy Set Syst. **111**, 465–495 (2000)
Mirzazadeh, A.: Inventory management under stochastic conditions with multiple objectives. Artif. Intell. Res. **2**, 16–26 (2013)
Naserabadi, B., Mirzazadeh, A., Nodoust, S.: A new mathematical inventory model with stochastic and fuzzy deterioration rate under inflation. Chin. J. Eng. **2014** Article ID 347857, 10 pp. (2014)
Ouyang, L.Y., Chang, H.C.: Mixture inventory model involving setup cost reduction with a service level constraint. Opsearch **37**(4), 327–339 (2000)
Paknejad, M.J., Nasri, F., Affisco, J.F.: Defective units in a continuous review (s, q) system. Int. J. Prod. Res. **33**(10), 2767–2777 (1995)
Park, K.S.: Fuzzy set theoretic interpretation of economic order quantity. IEEE Trans. Syst. Man Cybern. **17**, 1082–1084 (1987)
Ray, J., Chaudhuri, K.S.: An EOQ model with stock dependent demand, shortage, inflation and time discounting. Int. J. Prod. Econ. **53**(2), 171–180 (1997)
Ronald, R.J., Yang, G.K., Chu, P.: Technical note—the EOQ and EPQ models with shortages derived without derivatives. Int. J. Prod. Econ. **92**(2), 197–200 (2004)
Roy, A.: Fuzzy inventory model for deteriorating items with price dependent demand. Int. J. Manage. Sci. Eng. Manage (2014). doi:10.1080/17509653.2014.959086
Samadi, F., Mirzazadeh, A., Pedram, M.M.: Fuzzy pricing, marketing and service planning in a fuzzy inventory model: a geometric programming approach. Appl. Math. Model. **37**, 6683–6694 (2013)
Sana, S.S.: Optimal selling price and lotsize with time varying deterioration and partial backlogging. Appl. Math. Comput. **217**(1), 185–194 (2010)
Sana, S.S.: The stochastic EOQ modelwith randomsales price. Appl. Math. Comput. **218**(2), 239–248 (2011)
Sarkar, B., Sarkar, S.: An improved inventory model with partial backlogging, time varying deterioration and stock-dependent demand. Econ. Model. **30**, 924–932 (2013)
Singh, T., Pattnayak, H.: Two-warehouse inventory model for deteriorating items with linear demand under conditionally permissible delay in payment. Int. J. Manage. Sci. Eng. Manage. **9** (2), 104–113 (2014)
Sivashankari, C.K., Panayappan, S.: Production inventory model with reworking of imperfect production, scrap and shortages. Int. J. Manage. Sci. Eng. Manage. **9**(1), 9–20 (2014)
Soleimani-Amiri, M., Nodoust, S., Mirzazadeh, A., Mohammadi, M.: The average annual cost and discounted cost mathematical modeling methods in the inflationary inventory systems-a comparison analysis. SOP Trans. Appl. Math. **1**(1), 31–41 (2014)
Sphicas, G.P.: EOQ and EPQ with linear and fixed backorder costs: two cases identified and models analyzed without calculus. Int. J. Prod. Econ. **100**(1), 59–64 (2006)
Tinarelli, G.U.: Inverntory control models and problems. Eur. J. Oper. Res. **14**, 1–12 (1983)
Vujosevic, M., Petrovic, D., Petrovic, R.: Eoq formula when inventory cost is fuzzy. Int. J. Prod. Econ. **45**, 499–504 (1996)
Wang, K.H., Tsung, C.T., Lee, Y.S.: A specific EOQ model for deteriorating items with non-instantaneous re-useable returns. J. Inf. Optim. Sci. **31**(3), 729–748 (2010)
Wee, H.M., Chung, S.L., Yang, P.C.: A modified EOQ model with temporary sale price derived without derivatives. Eng. Econ. **48**(2), 190–195 (2003)
Yao, J.S., Chiang, J.: Inventory without back order with fuzzy total cost and fuzzy storing cost defuzzified by centroid and signed distance. Eur. J. Oper. Res. **148**, 401–409 (2003)

Yao, J.S., Lee, H.M.: Fuzzy inventory with or without backorder for fuzzy order quantity with trapezoidal fuzzy number. Fuzzy Sets Syst. **105**, 13–31 (1999)

You, P.S., Hsieh, Y.C.: An EOQ model with stock and price sensitive demand. Math. Comput. Model. **45**, 933–942 (2007)

Zadeh, L.A.: Fuzzy sets. Inf. Control **8**, 338–353 (1965)

Zadeh, L.A.: Similarity relations and fuzzy orderings. Information Science **32**(2), 177–200 (1971)

Chapter 12
Optimization in Production Management: Economic Load Dispatch of Cyber Physical Power System Using Artificial Bee Colony

Bo Xing

Abstract It is well-known that one of the major application areas of cyber physical system (CPS) concept is in energy control and optimization, i.e., cyber physical power system (CPPS). Within this context, the electricity production management is becoming far more complex than those traditional power systems. Under this circumstance, we pay our attention to economic load dispatch problem (ELDP) in this chapter. The ultimate goal of ELDP is to schedule the output of the committed generating units in a reliable and efficient manner. Artificial bee colony (ABC) algorithm, inspired by the foraging behaviour of honeybee swarms, is employed as an effective approach to optimize the system structure within non-smooth cost functions due to its simple and flexible than most optimization algorithms in terms of algorithm structure. A test example is used to illustrate the flexibility and effectiveness of the proposed algorithm. The results show that the ABC is promising in terms of accuracy and efficiency.

Keywords Cyber physical system (CPS) · Economic load dispatch problem (ELDP) · Computational intelligence (CI) · Artificial bee colony (ABC) · Cyber physical power system (CPPS)

12.1 Introduction

Modern life of the citizens in any country is highly dependent on the availability of a reliable and efficiency supply of power. The conventional approach to power system has been to treat them as predictable and controllable. However, due to

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some reasons such as the scarcity of energy resources, the ever increasing power generation cost, and the continuous growing demand for electrical energy, how to optimize the economic load dispatch is becoming one of the crucial optimization problems in power system operation (Pandi and Panigrahi 2011). The major operational objective of this issue is to provide continuous power at minimum economic cost while meeting environmental, operational and survivability constraints (Liu and Cai 2005). Practical economic load dispatch problem (ELDP) has nonlinear, non-convex type objective function with intense equality and inequality constraints (Mahor et al. 2009). To address this issue, optimization is a priority in solving the cost minimization. In this chapter, the artificial bee colony (ABC) algorithm is applied to solve the ELDP.

The remainder of this chapter is organized as follows. Subsequent to the introduction in Sect. 12.1, the background of cyber physical power system is briefed in Sect. 12.2. Then, the problem statement is presented in Sect. 12.3 which is followed by proposed methodology detailed in Sect. 12.4. Next, Sect. 12.5 conducts an experimental study to demonstrate the feasibility of our proposed approach. The future research directions are highlighted in Sect. 12.6. Finally, the conclusions drawn in Sect. 12.7 close this chapter.

12.2 Background

12.2.1 What is Cyber Physical Power System (CPPS)?

"The people of South Africa are learning to live in the dark." A comment from the recently released "The Economist (Anonymous 2015)" reveals that a South Africa's state-owned power utility is in danger of unable to meet the country's electricity demand. Inevitably, the electricity system disruption from this extreme event will hurt an already stagnant economy. One of the reasons for this incident is due to the struggle with a maintenance backlog and a barrage of technical problems at its aging power stations.

Over decades, system reliability and affordability have been major tenets shaping electric system development. While the most of us focused solely on powering light, electricity systems have become increasingly focusing on critical dispatch. However, it is not an easy job but a somewhat ambiguous task that represents multiple objectives throughout the electric system. To cope with those challenges, in recent years, power systems have begun to take advantage of computer technologies. Generally speaking, the cyber physical power system (CPPS) is a next-generation infrastructure of traditional power system, integrates physical-world devices, cyber-world computing and communication capabilities, so as to make the operation of generation facilities in a more efficient and cost-effective manner (Kim and Kumar 2012). In general, each CPPS contains two types of networks: power and cyber. Similar to other physical networks, the power networks satisfy their own physical laws and limitations, such as the relation between voltage and power through each transmission line. On the other hand, the objective of cyber networks is to integrate information technology into electricity system management, such as monitor, protect and control. Possibilities of developing CPPS have been depicted in Ilić et al. (2010), Rajkumar et al. (2010), Park et al. (2012). The most notable concept is stepping into the "smart grids" environment, which involves a "smarter" change in the existing power grid, such as connecting the global users through advanced metering infrastructure (Mahmood et al. 2015). Overall, the objective of CPPS is to monitor the status of the electric gird in more accurate and fine-grained way.

12.2.2 Economic Load Dispatch Problem (ELDP)

The economic load dispatch problem (ELDP) is considered as a hard optimization problem which cannot be efficiently solved by many traditional algorithms. In general, it is a computational process in which the total generation are divided properly among the generating units available while satisfying all the operating constraints. So far, a number of optimization techniques have been applied to solve ELDP. Some of these techniques use conventional optimization methods, such as Lagrangian relaxation (El-Keib et al. 1994), homogeneous linear programming algorithm (Jabr et al. 2000), quadratic programming (Fan and Zhang 1998), Taguchi method (Liu and Cai 2005); whereas others are based on computational intelligence (CI) methods, such as ant colony optimization (ACO) (Song and Chou 1999), artificial neural networks (ANN) (Yalcinoz and Short 1998), biogeography-based optimization (BBO) (Bhattacharya and Chattopadhyay 2010a, b), clonal algorithm (CA) (Panigrahi et al. 2007), differential evolution (DE) (Nomana and Iba 2008; Yuan et al. 2008), evolutionary programming (EP) (Yang et al. 1996; Sinha et al. 2003), evolutionary strategy (ES) (Pereira-Neto et al. 2005), frog leaping algorithm (FLA) (Roy and Chakrabarti 2011), fuzzy logic (FL) (Attaviriyanupap et al. 2004), genetic algorithm (GA) (Walters and Sheble 1993; Chen and Chang 1995), harmony search (HS) (Coelho and Mariani 2009), Hopfield neural network (HNN) (Abdelaziz et al. 2008), imperialist competitive algorithm (ICA) (Nejad and Jahani 2011), particle swarm optimization (PSO) (Gaing 2003; Park et al. 2005), simulated annealing (SA) (Wong and Fung 1993; Panigrahi et al. 2006), Tabu search (TS) (Lin et al. 2002; Ongsakul et al. 2004), water drop algorithm (WDA) (Rayapudi 2011).

In addition to these methods, hybrid optimization techniques are also applied to the area of ELDP, e.g., the authors of Vaisakh et al. (2012) presented a hybrid optimization methodology which integrates bacterial foraging optimization algorithm (BFOA), PSO and DE, called BPSO-DE for solving non-smooth non-convex ELDP; a hybrid technique combining differential evolution with BBO (DE/BBO) was also proposed in Bhattacharya and Chattopadhyay (2010c) to solve ELDP of thermal power units; later, the same authors used DE/BBO to solve complex economic & emission load dispatch problems (EELDP) (Bhattacharya and Chattopadhyay 2011).

12.3 Problem Statement

Despite to couple with sensor technologies and embedded computing systems which can be used in real time control among the units, another option should lead to consider the balance of real power demand between the two or more on-line generating units at the lowest cost while satisfying the power generators and system constraints. In this regard, strategies for CPPS have to focus on economic load dispatch, which is one of the fundamental optimization problems in CPPS analysis. The objective of ELDP is to minimize the total generation cost of the CPPS within a defined time interval (typically 1 h) while satisfying the equality and inequality operating constraints.

12.4 Proposed Methodology

12.4.1 The Honeybee Swarms Theory

Honeybee exhibits complex social behaviours include bee dance (communication), bee foraging, queen bee, task selection, collective decision making, nest site selection, mating, floral/pheromone laying, and navigation that have long since attracted the attention of human beings (Karaboga and Akay 2009a). Based on those features, many models have been developed for intelligent systems and applied to solve combinatorial optimization problems. For example, inspired by the communication in the hive of honeybees, the authors of Wedde et al. (2004) developed a BeeHive algorithm to deal with routing problem in the networks; Qin et al. (2004) applied queen-bee evolution algorithm to the ELDP which is formulated as a non-linear constrained combinatorial optimization problem; in terms of task allocation, Nakrani and Tovey (2003) proposed a decentralized honeybee algorithm which dynamically allocates servers to satisfy request loads; Yonezawa and Kikuchi (1996) described the principles of collective intelligence generated with the collective cooperative behaviour of honeybees through examining construction of their ecological algorithm; based on the marriage behaviour in honeybees, the authors of Abbass (2001) presented a new optimization algorithm model called marriage in honey-bees optimization (MBO). An interesting survey of the honeybees' behaviour can be found in Karaboga and Akay (2009a), Teodorović (2009).

Among other algorithms inspired by honeybees, probably one of the most noticeable behaviours visible to us is the foraging of each individual bee. Foraging process includes two main modes of behaviour: recruitment of nectar source and abandonment of a source (Tereshko and Lee 2002). It starts with some scout bees leaving the hive in order to search food source to gather nectar. After finding food (i.e., flowers), scout bees return to the hive and inform their hive-mates about the richness of the flower (i.e., quantity and quality) and the distance of the flower to the hive (i.e., location) through a special movements called "dance", such as round dance, waggle dance, and tremble dance depending on the distance information of the source. Typically, she dances on different areas in an attempt to “advertise” food locations (by touching her antennae) and encourage more remaining bees to collect nectar from her source. After the dancing show, more foraging bees will leave the hive to collect nectar follow one of the dancing scout bees. Upon arrive, the foraging bee stores the nectar in her honey stomach and returns to the hive unloading the nectar to empty honeycomb cells. The described process continues repeatedly until the scout bees explore new areas with potential food sources. Since the foraging is the most important task in the hive. Based on this behaviour, researchers investigated various algorithms such as bee colony optimization (BCO) (Lučić and Teodorović 2001, 2002), bees algorithm (Pham et al. 2006; Pham and Ghanbarzadeh 2007), virtual bee algorithm (VBA) (Yang 2005), as well as artificial bee colony (ABC) algorithm (Karaboga and Basturk 2007, 2008), but use different concepts for algorithm development. In this study, we focus on ABC algorithm.

12.4.2 Artificial Bee Colony (ABC) Algorithm

The artificial bee colony (ABC) algorithm is a successful honeybee swarm-based search and meta-heuristic optimization approach that was initially proposed by Karaboga (2005) in 2005. The basic idea of designing ABC is to mimic the foraging behaviour (such as exploration, exploitation, recruitment and abandonment) of honeybees. Typically, ABC algorithm consists of two groups of bees: employed artificial bees (i.e., current exploiting foragers) and unemployed artificial bees (i.e., looking for a food source to exploit). The latter will be classified further in two groups: scouts who are searching the environment surrounding the nest for new food sources, and onlookers that are waiting in the nest and finding a food source through the information shared by employed artificial bees (Karaboga and Basturk 2008).

In ABC, it is assumed that each food source position corresponds to a possible solution and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution. The main steps of the algorithm are as follows (Karaboga and Basturk 2008; Karaboga and Akay 2009b; Omkar et al. 2011):

- Initialization;
  The initial population can be defined as $P(G = 0)$ of SN solutions (food source positions), where SN denotes the size of employed bees or onlooker bees. Moreover, each solution $x_{ij} (i = 1, 2, \ldots, SN; j = 1, 2, \ldots, D)$ is a D-dimensional vector. Here, D is the number of optimization parameters.
- Repeating;
  - Placing the employed bees on the food sources in the memory and updating feasible food source;
    In order to produce a candidate food position from the old one (x_{ij}) in memory, the memory by employed bees is updated by following expression

(Karaboga and Basturk 2008; Karaboga and Akay 2009b; Omkar et al. 2011):

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}), j \in \{1, 2, \ldots, D\}, k \in \{1, 2, \ldots, SN\} \wedge k \neq i. \quad (12.1)$$

where v_{ij} is a new feasible dimension value of the food sources that is modified from its previous food sources value (x_{ij}) based on a comparison with the randomly selected neighbouring food source value (x_{kj}). ϕ_{ij} is a random number between $[-1, 1]$ to adjust the production of neighbour food sources around x_{ij} and represents the comparison of two food positions visually.

– Placing the onlooker bees on the food sources in the memory; she chooses a probability value associated with that food source (p_i) depending on the following expression (Karaboga and Basturk 2008; Karaboga and Akay 2009b; Omkar et al. 2011):

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n}. \quad (12.2)$$

where fit_i is the fitness value of the solution i which is proportional to the nectar amount of the food source in the position; SN denotes the size of employed bees or onlooker bees. Clearly, the higher fit_i is, the greater the probability is of selecting x_{ij}.

– Updating feasible food source, by onlooker bees using Eq. (12.1);
– Adjusting by sending the scout bees in order to discovering new food sources; the operation of scout bees explore a new food source can be defined as following (Karaboga and Basturk 2008; Karaboga and Akay 2009b; Omkar et al. 2011):

$$x_i^j = x_{\min}^j + rand[0, 1](x_{\max}^j - x_{\min}^j). \quad (12.3)$$

where $x_{\min}$ and $x_{\max}$ is the lower and upper limit respectively of the search scope on each dimension. Here the value of each component in every x_i vector should be clamped to the range $[x_{\min}, x_{\max}]$ to reduce the likelihood of scout bees leaving the search space.

– Memorizing the best food source found so far;

- Until (criteria are met)
  In details, each repeated cycle of the search consists of seven steps:

  ① The employed bees will be randomly sent to the food sources and evaluating their nectar amounts. If an employed bee finds a better solution, she will update her memory (see Eq. (12.1)); otherwise, she counts the number of the searches around the source in her memory.

② If all employed bees complete the search process, the nectar and position information of the food sources will be shared with the onlooker bees.
③ An onlooker bee does not have any source in her memory and thus she will evaluate all the information from employed bees and choose a probably profitable food source (recruitment) (see Eq. (12.2)).
④ After arriving at the selected area, the onlooker bee searches the neighbourhood of the source and if she finds a better solution, she will update the food source position just as an employed bee does (see Eq. (12.1)). The criterion for determination of a new food source is based on the comparison process of food source positions visually.
⑤ Stop the exploitation process of the sources abandoned by the employed/onlooker bees if the new solution cannot be further improved through a predetermined number of trials *limit* (see Eq. (12.3)). At this moment, the employed/onlooker bees become scout bees.
⑥ Send the scouts into the search area for discovering new food sources (exploration), randomly.
⑦ Memorize the best food source found so far.

These seven steps are repeated until a termination criterion (i.e., maximum cycle number (MCN)) is satisfied.

So far, the ABC algorithm and its successor has received intensive interest from researchers in a variety of fields, such as adjusting the location of circular failure surface (Kang et al. 2013), bidding strategy (Jain et al. 2012), capacitated vehicle routing (Szeto et al. 2011), clustering (Karaboga and Ozturk 2011), deployment of wireless sensor networks (Ozturk et al. 2011), flow shop scheduling (Pan et al. 2010; Tasgetiren 2011), job shop scheduling (Li et al. 2011; Banharnsakun et al. 2012; Wang et al. 2012, 2013), image processing (Cuevas et al. 2012), inverse analysis (Kang et al. 2009), mechanical optimization (Rao and Patel 2011), neural network training (Karaboga and Ozturk 2009), parametric optimization (Samanta and Chakraborty 2011), portfolio optimization (Hsu 2014), signal processing (Karaboga 2009; Sabat et al. 2010; Karaboğa and Çetinkaya 2011), and structural optimization (Omkar et al. 2011; Sonmez 2011; Apalak et al. 2013).

12.4.3 Problem Formulation

As a critical and fundamental infrastructure, power system's ELDP has received an increasing attention over the years by academic and industrial researchers and practitioners.

12.4.3.1 Objective Function

Several kinds of optimization approaches can be used for the ELDP, the mostly used one of minimizing the total fuel cost of each generating unit is applied here and the objective function of this method is formulated as:

$$\text{Minimize} \sum_{i=1}^{n} F_i(P_i). \tag{12.4}$$

where P_i is the real power output of ith generator; $F_i(P_i)$ is the total fuel cost equation of the ith generator over the whole dispatch period; n is the number of generators. The input of the cost function is the fuel cost in dollars per hour or tons of coal per hour and the output is the electric power output of each unit in MW. Normally it is expressed as continuous quadratic equation:

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i. \tag{12.5}$$

where a_i, b_i and c_i are the cost curve coefficients of ith generator.

12.4.3.2 Constraints

The constraints are discussed in the following:

- First, subject to the real power demand balance constraints:

$$\sum_{i=1}^{n} P_i - P_D - P_L = 0. \tag{12.6}$$

where P_D is the total demand, and P_L is the total real power transmission losses. In addition, P_L can be modelled either by running a complete load flow analysis to the system (Elgerd 1982) or determined by using the loss coefficients method (known as the *β-coefficients*) developed by Kron and undertaken by Kirchmayer and Stagg (Happ et al. 1977). A detailed expression of the loss formula can be defined as follow (Wood and Wollenberg 1996):

$$P_L = \sum_{i}^{n} \sum_{j}^{n} B_{ij} P_i P_j + \sum_{i=1}^{n} B_{oi} P_i + B_{oo}. \tag{12.7}$$

where P_i and P_j are real power injection at ith and jth buses, respectively; B_{ij}, B_{oi} and B_{oo} are the loss coefficients, which under certain assumed operating conditions. The function can be further approximately defined as (Saadat 1999):

$$P_L = \sum_{i}^{n} \sum_{j}^{n} B_{ij} P_i P_j. \tag{12.8}$$

- Second, subject to the generator capacity constraints:

$$P_{i\min} \leq P_i \leq P_{i\max} \; for \; i = 1, 2, 3, \ldots n. \tag{12.9}$$

where $P_{i\min}$ and $P_{i\max}$ are the minimum and maximum active power limits on the loading of the ith generator, respectively.

12.4.4 Matching of Artificial Bee Colony Algorithm for Economic Load Dispatch Problem

The step-by-step procedure for the proposed method is as follows:

- Step 1: Specify the control parameters of the ABC algorithm, such as the generator cost coefficients, generation power limits, and so on;
- Step 2: Initialize the population of the ABC algorithm;
  The initial population can be defined as $M = [P_1, P_2, \ldots, P_m]$ of m solutions (food source positions), where m denotes the size of population (i.e., employed bees or onlooker bees). Moreover, each solution $P_i = \left[P_{i1}, P_{i2}, \ldots, P_{ij}, \ldots, P_{mD}\right]$, $(i = 1, 2, \ldots, m;\ \mathrm{j} = 1, 2, \ldots, D)$ is a D-dimensional vector. For the ELDP, D is equal to the number of generators.
  For example, for each interval in the scheduling horizon and with D generating units, an initial population can be defined as:

$$M = \begin{bmatrix} P_{11} & P_{12} & \ldots & P_{1D} \\ P_{21} & P_{22} & \ldots & P_{2D} \\ \vdots & \vdots & \ddots & \vdots \\ P_{m1} & P_{m2} & \ldots & P_{mD} \end{bmatrix}. \tag{12.10}$$

  where P_{ij} is the real power output of the jth generating unit for the ith individual. The individuals generated should be refined to satisfy the constraint as in Eqs. (12.6) and (12.9).
- Step 3: Updating feasible food sources, by employed bees; For the ELDP, this phase can be represented as:

$$P'_{ij} = P_{ij} + \phi_{ij}\left(P_{ij} - P_{kj}\right). \tag{12.11}$$

- Step 4: Selecting feasible food sources using Eq. (12.2), by onlooker bees;

- Step 5: Updating feasible food sources as in Step 3 using Eq. (12.11), by onlooker bees;
- Step 6: Abandon sources to exploit new sources, by scout bees;

$$P_i^j = P_{\min}^j + rand[0, 1]\left(P_{\max}^j - P_{\min}^j\right). \tag{12.12}$$

- Step 7: Memorize the best solution achieved so far;
- Step 8: Stop the process if the termination criteria is satisfied, otherwise go to the Step 2. By this end, the final solution will be chosen as the optimum output powers of generating units involved in the economic load dispatch process for that time interval.

12.5 Experiments Study

After having our targeted problem formulated and the proposed methodology detailed, we decide to carry out an experimental study to demonstrate the suitability of ABC algorithm. Suppose that we have the following input data (see Eq. 12.13) for our CPPS.

$$\text{Sample Data} = \begin{bmatrix} 0.15247 & 38.53973 & 756.79886 & 10 & 125 \\ 0.10587 & 46.15916 & 451.32513 & 10 & 150 \\ 0.02803 & 40.3965 & 1049.9977 & 35 & 225 \\ 0.03546 & 38.30553 & 1243.5311 & 35 & 210 \\ 0.02111 & 36.32782 & 1658.569 & 130 & 325 \\ 0.01799 & 38.27041 & 1356.6592 & 125 & 315 \end{bmatrix} \tag{12.13}$$

where the number of rows denotes the number of power plants (i.e., 6 power plants in this case); the columns 1–5 represent the fuel cost coefficients, and the power plants generating limits, respectively; and the P_D is set to 700 for now.

The parameters settings for ABC algorithm are as follows: the colony size is 20, the food number is 10, the food source searching trial limit is 100, and the stopping criterion is 1000 cycles, and the runtime is 10.

After running the proposed ABC algorithm, the optimal value for our objective function is 36,912.

12.6 Future Research Directions

Nowadays, the fossil fuel such as coal, natural gas, and oil is used by many power plants as a main resource to drive electrical generators for the purpose of producing electricity. However, the subsequent emission problems caused by these activities raise a lot of debate. With the ever increasing environmental awareness, the practitioners are forced not only to supply electricity to the market at the lowest possible cost, but also with the minimum emissions. Under these circumstances, an alternative approach is to introduce renewable energy resources such as wind and solar into the future CPPS. This movement has been witnessed by a growing trend of wind or solar energy installations all around the world. Nevertheless, the inherent uncertainty of the wind or solar power poses a great challenge to the future CPPS. Therefore, one possible future research direction would be exploring the feasibility of ABC in economic load dispatch by taking the wind or solar power into account.

In addition to employ the ABC algorithm mentioned in this chapter, another potential research direction is to apply other innovative CI methods on the targeted question. Briefly, these novel CI approaches can be classified into the following three categories.

- Biology based CI methods: The approaches fall within this category can be further organized as three groups, namely, animal-, plant-, and human-inspired algorithms. The examples of these algorithms are such as artificial searching swarm algorithm (Chen et al. 2010), bacteria foraging optimization (Acharya et al. 2010; Anandaraman et al. 2012; Cao and Gao 2012; Saber 2012), superbug algorithm (Anandaraman et al. 2012), viral system algorithm (Ituarte-Villarreal and Espiritu 2011), bat algorithm (Damodaram and Valarmathi 2012; Lemma and Hashim 2011; Musikapun and Pongcharoen 2012; Yang and Gandomi 2012), fruit-fly optimization algorithm (Wang et al. 2013), cat swarm optimization (Pradhan and Panda 2012; Tsai et al. 2012; Tsai et al. 2008), cuckoo algorithm (Bacanin 2011; Bacanin 2012; Burnwal and Deb 2013), blind, naked mole-rats (BNMR) algorithm (Taherdangkoo et al. 2012), fish algorithm (Adioui et al. 2003; Ban et al. 2009; Banerjee and Caballé 2011; Bastos-Filho et al. 2008), bean optimization algorithm (Anonymous 2008; Thurston et al. 2008; Wang and Cheng 2010; Zhang et al. 2010), 2012, flower algorithm (Yang et al. 2013), and oriented search algorithm (Taherdangkoo et al. 2012).
- Physics based CI methods: Inspired by some well-studied physical laws, the algorithms within this category include such as artificial physics optimization (APO) (Gorbenko and Popov 2012; Xie et al. 2011), big bang—big crunch (Camp 2007; Erol and Eksin 2006; Genç et al. 2010; Kaveh and Talatahari 2009, 2010a, b; Tabakov 2011; Tang et al. 2010; Yesil and Urbas 2010), central force optimization (Formato 2007, 2009, 2011; Green et al. 2011, 2012; Haghighi and Ramos 2012; Qubati and Dib 2010), electromagnetism-like algorithm (Ali and Golalikhani 2010; Birbil and Fang 2003; Chang et al. 2009), gravitational search algorithm (Bahrololoum et al. 2012; Behrang et al. 2011; Chatterjee et al. 2010), river formation dynamics algorithm (Rabanal et al. 2007, 2008a, b, 2010), particle collision algorithm (Abuhamdah and Ayob 2009a, b; Luz et al. 2008; Luz et al. 2011; Sacco and Oliveira 2005), and charged system search (Kaveh and Behnam 2012; Kaveh and Talatahari 2010c, d).
- Chemistry based CI methods: In this category, the algorithms contain such as artificial chemical reaction (Alatas 2011; Yang et al. 2011), chemical reaction optimization (Lam and Li 2010, 2012; Lam et al. 2012; Xu et al. 2010), and gases Brownian motion optimization (Abdechiri et al. 2013).

The detailed description of each individual technique is out of the scope of the present chapter. Interested readers please refer to Xing et al. (2013a, b, c), Xing and Gao (2014) for more details about their working principles and representative applications.

12.7 Conclusions

In recent years, there have been an increasing number of major power system blackouts worldwide. The causes of blackouts include a wide variety of exogenous and endogenous factors such as line outage or overload. Therefore, how to guarantee the reliability of forthcoming CPPS has received an increasing attention over the years. Among others, the idea of optimizing of operational and planning becomes a topic of overall interest, and especially the adjusting for economic load dispatch. This issue was to require the simultaneous optimization of multiple and often conflicting objective functions with complicated non-linear constraints. In order to arrive at a solution that incorporates all these issues, it is apparent that CI techniques could be of more beneficial and adaptive in nature. In this chapter, we choose ABC algorithm to solve the complex ELDP. ABC is one of the very fast and robust, accurate CI algorithms for global optimization. The operational goal is to minimize the total generation cost of the CPPS within a defined time interval (typically 1 h), while guaranteeing specific constraints on the physical process controlled by the electric loads. Simulation results are promising and show the effectiveness of the proposed approach.

References

Abbass, H.A.: Marriage in honey-bee optimization (MBO): a haplometrosis polygynous swarming approach. In: Proceedings of the Congress on Evolutionary Computation (CEC), Seoul, Korea, pp. 207–214 (2001)

Abdechiri, M., Meybodi, M.R., Bahrami, H.: Gases Brownian motion optimization: an algorithm for optimization (GBMO). Appl. Soft Comput. **13**, 2932–2946 (2013)

Abdelaziz, A.Y., Mekhamer, S.F., Badr, M.A.L., Kamh, M.Z.: Economic dispatch using an enhanced hopfield neural network. Electr. Power Compon. Syst. **36**, 719–732 (2008)

Abuhamdah, A., Ayob, M.: Hybridization multi-neighbourhood particle collision algorithm and great deluge for solving course timetabling problems. In: 2nd Conference on Data Mining and Optimization, Selangor, Malaysia, pp. 108–114, 27–28 Oct 2009

Abuhamdah, A., Ayob, M.: Multi-neighbourhood particle collision algorithm for solving course timetabling problems. In: 2nd Conference on Data Mining and Optimization, Selangor, Malaysia, pp. 21–27, 27–28 Oct 2009

Acharya, D.P., Panda, G., Lakshmi, Y.V.S.: Effects of finite register length on fast ICA, bacterial foraging optimization based ICA and constrained genetic algorithm based ICA algorithm. Digit. Signal Proc. **20**, 964–975 (2010)

Adioui, M., Arino, O., Smith, W.V., Treuil, J.P.: A mathematical analysis of a fish school model. J. Differ. Equ. **188**, 406–446 (2003)

Alatas, B.: ACROA: artificial chemical reaction optimization algorithm for global optimization. Expert Syst. Appl. **38**, 13170–13180 (2011)
Ali, M.M., Golalikhani, M.: An electromagnetism-like method for nonlinearly constrained global optimization. Comput. Math Appl. **60**, 2279–2285 (2010)
Anandaraman, C., Sankar, A.V.M., Natarajan, R.: A new evolutionary algorithm based on bacterial evolution and its applications for scheduling a flexible manufacturing system. Jurnal Teknik Industri **14**, 1–12 (2012)
Anonymous: DHL Solutions Offers Service That is Second to None. Caribbean Business, London, p. B10 (2008)
Anonymous: South Africa's Electricity Crisis: Unplugged. The Economist, London, p. 34 (2015)
Apalak, M.K., Karaboga, D., Akay, B.: The artificial bee colony algorithm in layer optimization for the maximum fundamental frequency of symmetrical laminated composite plates. Eng. Optimiz. **46**, 420–437 (2013)
Attaviriyanupap, P., Kita, H., Tanaka, E., Hasegawa, J.: A fuzzy-optimization approach to dynamic economic dispatch considering uncertainties. IEEE Trans. Power Syst. **19**, 1299–1307 (2004)
Bacanin, N.: Implementation and performance of an object-oriented software system for cuckoo search algorithm. Int. J. Math. Comput. Simul. **6**, 185–193 (2012)
Bacanin, N.: An object-oriented software implementation of a novel cuckoo search algorithm. In: European Computing Conference (ECC' 11), Paris, France, pp. 245–250, 28–30 Apr 2011
Bahrololoum, A., Nezamabadi-pour, H., Bahrololoum, H., Saeed, M.: A prototype classifier based on gravitational search algorithm. Appl. Soft Comput. **12**, 819–825 (2012)
Ban, X., Yang, Y., Ning, S., Lv, X., Qin, J.: A self-adaptive control algorithm of the artificial fish formation. In: IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Korea, pp. 1903–1908, 20–24 Aug 2009
Banerjee, S., Caballé, S.: Exploring fish school algorithm for improving turnaround time: an experience of content retrieval. In: Third International Conference on Intelligent Networking and Collaborative Systems (INCoS), pp. 842–847 (2011)
Banharnsakun, A., Sirinaovakul, B., Achalakul, T.: Job Shop Scheduling with the best-so-far ABC. Eng. Appl. Artif. Intell. **25**, 583–593 (2012)
Bastos-Filho, C.J.A., de Lima-Neto, F.B., Lins, A.J.C.C., Nascimento, A.I.S., Lima, M.P.: A novel search algorithm based on fish school behavior. In: IEEE International Conference on Systems, Man and Cybernetics (SMC), pp. 2646–2651 (2008)
Behrang, M.A., Assareh, E., Ghalambaz, M., Assari, M.R., Noghrehabadi, A.R.: Forecasting future oil demand in Iran using GSA (gravitational search algorithm). Energy **36**, 5649–5654 (2011)
Bhattacharya, A., Chattopadhyay, P.K.: Biogeography-based optimization for different economic load dispatch problems. IEEE Trans. Power Syst. **25**, 1064–1077 (2010a)
Bhattacharya, A., Chattopadhyay, P.K.: Solving complex economic load dispatch problems using biogeography-based optimization. Expert Syst. Appl. **37**, 3605–3615 (2010b)
Bhattacharya, A., Chattopadhyay, P.K.: Hybrid differential evolution with biogeography-based optimization for solution of economic load dispatch. IEEE Trans. Power Syst. **25**, 1955–1964 (2010c)
Bhattacharya, A., Chattopadhyay, P.K.: Hybrid differential evolution with biogeography-based optimization algorithm for solution of economic emission load dispatch problems. Expert Syst. Appl. **38**, 14001–14010 (2011)
Birbil, Şİ., Fang, S.-C.: An electromagnetism-like mechanism for global optimization. J. Global Optim. **25**, 263–282 (2003)
Burnwal, S., Deb, S.: Scheduling optimization of flexible manufacturing system using cuckoo search-based approach. Int. J. Adv. Manuf. Technol. **64**, 951–959 (2013)
Camp, C.V.: Design of space trusses using Big Bang–Big Crunch optimization. J. Struct. Eng. **133**, 999–1008 (2007)

Cao, J., Gao, H.: A quantum-inspired bacterial swarming optimization algorithm for discrete optimization problems. In: Tan, Y., Shi, Y., Ji, Z. (eds.) ICSI 2012, Part I, LNCS 7331, pp. 29–36. Springer, Heidelberg (2012)

Chang, P.-C., Chen, S.-H., Fan, C.-Y.: A hybrid electromagnetism-like algorithm for single machine scheduling problem. Expert Syst. Appl. **36**, 1259–1267 (2009)

Chatterjee, A., Mahanti, G.K., Pathak, N.: Comparative performance of gravitational search algorithm and modified particle swarm optimization algorithm for synthesis of thinned scanned concentric ring array antenna. Prog. Electromagn. Res. B **25**, 331–348 (2010)

Chen, P.H., Chang, H.C.: Large-scale economic dispatch by genetic algorithm. IEEE Trans. Power Syst. **10**, 1919–1926 (1995)

Chen, T., Wang, Y., Pang, L., Liu, Z., Zhang, L.: An improved artificial searching swarm algorithm and its performance analysis. In: Second International Conference on Computer Modeling and Simulation (ICCMS), pp. 260–263 (2010)

Coelho, L.D.S., Mariani, V.C.: An improved harmony search algorithm for power economic load dispatch. Energy Convers. Manage. **50**, 2522–2526 (2009)

Cuevas, E., Sencion-Echauri, F., Zaldivar, D., Perez-Cisneros, M.: Multi-circle detection on images using artificial bee colony (ABC) optimization. Soft. Comput. **16**, 281–296 (2012)

Damodaram, R., Valarmathi, M.L.: Phishing website detection and optimization using modified bat algorithm. Int. J. Eng. Res. Appl. **2**, 870–876 (2012)

Elgerd, O.I.: Electric Energy System Theory: An Introduction, 2nd edn. McGraw Hill Book Company, New York (1982)

El-Keib, A.A., Ma, H., Hart, J.L.: Environmentally constrained economic dispatch using the Lagrangian relaxation method. IEEE Trans. Power Syst. **9**, 1723–1729 (1994)

Erol, O.K., Eksin, I.: A new optimization method: Big Bang-Big Crunch. Adv. Eng. Softw. **37**, 106–111 (2006)

Fan, J.Y., Zhang, L.: Real-time economic dispatch with line flow and emission constraints using quadratic programming. IEEE Trans. Power Syst. **13**, 320–325 (1998)

Formato, R.A.: Central force optimization: a new metaheuristic with applications in applied electromagnetics. Prog. Electromagn. Res. Pier **77**, 425–491 (2007)

Formato, R.A.: Central force optimization: a new deterministic gradient-like optimization metaheuristic. OPSEARCH **46**, 25–51 (2009)

Formato, R.A.: Central force optimization with variable initial probes and adaptive decision space. Appl. Math. Comput. **217**, 8866–8872 (2011)

Gaing, Z.L.: Particle swarm optimization to solving the economic dispatch considering the generator constraints. IEEE Trans. Power Syst. **18**, 1187–1195 (2003)

Genç, H.M., Eksin, İ., Erol, O.K.: Big Bang–Big Crunch optimization algorithm hybridized with local directional moves and application to target motion analysis problem. In: IEEE International Conference on Systems, Man, and Cybernetics (SMC), Istanbul, Turkey, pp. 881–887, 10–13 Oct 2010

Gorbenko, A., Popov, V.: The force law design of artificial physics optimization for robot anticipation of motion. Adv. Stud. Theor. Phys. **6**, 625–628 (2012)

Green, R.C., Wang, L., Alam, M., Formato, R.A.: Central force optimization on a GPU: a case study in high performance metaheuristics using multiple topologies. In: IEEE Congress on Evolutionary Computation (CEC), pp. 550–557 (2011)

Green, R.C., Wang, L., Alam, M.: Training neural networks using central force optimization and particle swarm optimization: insights and comparisons. Expert Syst. Appl. **39**, 555–563 (2012)

Haghighi, A., Ramos, H.M.: Detection of leakage freshwater and friction factor calibration in drinking networks using central force optimization. Water Resour. Manage. **26**, 2347–2363 (2012)

Happ, H.H.: Optimal power dispatch—a comprehensive survey. IEEE T. Power Ap. Syst. **PAS-96**, 841–850 (1977)

Hsu, C.-M.: An integrated portfolio optimisation procedure based on data envelopment analysis, artificial bee colony algorithm and genetic programming. Int. J. Syst. Sci. **45**(12), 2645–2664 (2014). doi:http://dx.doi.org/10.1080/00207721.2013.775388

Ilić, M.D., Xie, L., Khan, U.A., Moura, J.M.F.: Modeling of future cyber-physical energy systems for distributed sensing and control. IEEE Trans. Syst., Man, Cybern. A, Syst., Humans **40**, 825–838 (2010)

Ituarte-Villarreal, C.M., Espiritu, J.F.: Wind turbine placement in a wind farm using a viral based optimization algorithm. In: 41st International Conference on Computers and Industrial Engineering, Los Angeles, CA, USA, pp. 672–677, 23–26 Oct 2011

Jabr, R.A., Coonick, A.H., Cory, B.J.: Homogeneous linear programming algorithm for the security constrained economic dispatch problem. IEEE Trans. Power Syst. **15**, 930–936 (2000)

Jain, A.K., Srivastava, S.C., Singh, S.N., Srivastava, L.: Strategic bidding in transmission constrained electricity markets using artificial bee colony algorithm. Electr. Pow. Compo. Syst. **40**, 1768–1788 (2012)

Kang, F., Li, J., Xu, Q.: Structural inverse analysis by hybrid simplex artificial bee colony algorithms. Comput. Struct. **87**, 861–870 (2009)

Kang, F., Li, J., Ma, Z.: An artificial bee colony algorithm for locating the critical slip surface in slope stability analysis. Eng. Optim. **45**, 207–223 (2013)

Karaboga, N.: A new design method based on artificial bee colony algorithm for digital IIR filters. J. Franklin Inst. **346**, 328–348 (2009)

Karaboga, D., Akay, B.: A survey: algorithms simulating bee swarm intelligence. Artif. Intell. Rev. **31**, 61–85 (2009a)

Karaboga, D., Akay, B.: A comparative study of artificial bee colony algorithm. Appl. Math. Comput. **214**, 108–132 (2009b)

Karaboga, D., Basturk, B.: A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm. J. Global Optim. **39**, 459–471 (2007)

Karaboga, D., Basturk, B.: On the performance of artificial bee colony (ABC) algorithm. Appl. Soft Comput. **8**, 687–697 (2008)

Karaboğa, N., Çetinkaya, M.B.: A novel and efficient algorithm for adaptive filtering: artificial bee colony algorithm. Turk. J. Electr. Eng. Comput. Sci. **19**, 175–190 (2011)

Karaboga, D.: An Idea Based on Honey Bee Swarm for Numerical Optimization, Technical Report TR06, Computer Engineering Department, Engineering Faculty, Erciyes University (2005)

Karaboga, D., Ozturk, C.: Neural networks training by artificial bee colony algorithm on pattern classification. Neural Netw. World **19**, 279–292 (2009)

Karaboga, D., Ozturk, C.: A novel clustering approach: artificial bee colony (ABC) algorithm. Appl. Soft Comput. **11**, 652–657 (2011)

Kaveh, A., Behnam, A.F.: Cost optimization of a composite floor system, one-way waffle slab, and concrete slab formwork using a charged system search algorithm. Sci. Iran. A **19**, 410–416 (2012)

Kaveh, A., Talatahari, S.: Size optimization of space trusses using Big Bang-Big Crunch algorithm. Comput. Struct. **87**, 1129–1140 (2009)

Kaveh, A., Talatahari, S.: A discrete Big Bang-Big Crunch algorithm for optimal design of skeletal structures. Asian J. Civ. Eng. (Build. Hous.) **11**, 103–122 (2010a)

Kaveh, A., Talatahari, S.: Optimal design of Schwedler and ribbed domes via hybrid Big Bang-Big Crunch algorithm. J. Constr. Steel Res. **66**, 412–419 (2010b)

Kaveh, A., Talatahari, S.: A novel heuristic optimization method: charged system search. Acta Mech. **213**, 267–289 (2010c)

Kaveh, A., Talatahari, S.: Optimal design of skeletal structures via the charged system search algorithm. Struct. Multidiscip. Optim. **41**, 893–911 (2010d)

Kim, K.-D., Kumar, P.R.: Cyber-physical systems: a perspective at the centennial. Proc. IEEE **100**, 1287–1308 (2012)

Lam, A.Y.S., Li, V.O.K., Wei, Z.: Chemical reaction optimization for the fuzzy rule learning problem. In: IEEE World Congress on Computational lnteliigence (WCCI), Brisbane, Australia, pp. 1–8, 10–15 June 2012

Lam, A.Y.S., Li, V.O.K.: Chemical reaction optimization for cognitive radio spectrum allocation. In: IEEE Global Communication Conference (IEEE GLOBECOM 2010), Miami, FL, USA, pp. 1–5 (2010)

Lam, A.Y.S., Li, V.O.K.: Chemical reaction optimization: a tutorial. Memetic Comput. **4**, 3–17 (2012)

Lemma, T.A., Hashim, F.B.M.: Use of fuzzy systems and bat algorithm for exergy modeling in a gas turbine generator. In: IEEE Colloquium on Humanities, Science and Engineering Research (CHUSER), Penang, pp. 305-310, 5–6 Dec 2011

Li, J.Q., Pan, Q.K., Gao, K.Z.: Pareto-based discrete artificial bee colony algorithm for multi-objective flexible job shop scheduling problems. Int. J. Adv. Manuf. Technol. **55**, 1159–1169 (2011)

Lin, W.M., Cheng, F.S., Tsay, M.T.: An improved tabu search for economic dispatch with multiple minima. IEEE Trans. Power Syst. **17**, 108–112 (2002)

Liu, D., Cai, Y.: Taguchi method for solving the economic dispatch problem with nonsmooth cost functions. IEEE Trans. Power Syst. **20**, 2006–2014 (2005)

Lučić, P., Teodorović, D.: Bee system: modeling combinatorial optimization transportation engineering problems by swarm intelligence. In: Preprints of the TRISTAN IV triennial symposium on transportation analysis, Sao Miguel, Azores Islands, pp. 441–445 (2001)

Lučić, P., Teodorović, D.: Transportation modeling: an artificial life approach. In 14th IEEE International Conference on Tools with Artificial Intelligence, Washington, D.C., pp. 216–223 (2002)

da Luz, E.F.P., Becceneri, J.C., de Campos Velho, H.F..: A new multi-particle collision algorithm for optimization in a high performance environment. J. Comp. Int. Sci. **1,** 3–10 (2008)

da Luz, E.F.P., Becceneri, J.C., de Campos Velho, H.F.: Multiple particle collision algorithm applied to radiative transference and pollutant localization inverse problems. In: IEEE International Symposium on Parallel and Distributed Processing Workshops and Ph.D. Forum (IPDPSW), pp. 347–351 (2011)

Mahmood, A., Javaid, N., Razzaq, S.: A review of wireless communications for smart grid, Renew. Sustain. Energy Rev. **41**, 248–260 (2015)

Mahor, A., Prasad, V., Rangnekar, S.: Economic dispatch using particle swarm optimization: a review. Renew. Sustain. Energy Rev. **13**, 2134–2141 (2009)

Musikapun, P., Pongcharoen, P.: Solving multi-stage multi-machine multi-product scheduling problem using bat algorithm. In: 2nd International Conference on Management and Artificial Intelligence, vol. 35, pp. 98–102 (2012)

Nakrani, S., Tovey, C.: On honey bees and dynamic allocation in an Internet server colony. In: 2nd International Workshop on the Mathematics and Algorithms of Social Insects, Altanta, Georgia, USA, pp. 1–8 (2003)

Nejad, H.C., Jahani, R.: A new approach to economic load dispatch of power system using imperialist competitive algorithm. Aust. J. Basic Appl. Sci. **5**, 835–843 (2011)

Nomana, N., Iba, H.: Differential evolution for economic load dispatch problems. Electr. Power Syst. Res. **78**, 1322–1331 (2008)

Omkar, S.N., Senthilnath, J., Khandelwal, R., Naik, G.N., Gopalakrishnan, S.: Artificial bee colony (ABC) for multi-objective design optimization of composite structures. Appl. Soft Comput. **11**, 489–499 (2011)

Ongsakul, W., Dechanupaprittha, S., Ngamroo, I.: Parallel tabu search algorithm for constrained economic dispatch. IEE Proc. Gener. Transm. Distrib. **151**, 157–166 (2004)

Ozturk, C., Karaboga, D., Gorkemli, B.: Probabilistic dynamic deployment of wireless sensor networks by artificial bee colony algorithm. Sensor **11**, 6056–6065 (2011)

Pan, Q.K., Tasgetiren, M.F., Suganthan, P.N., Chua, T.J.: A discrete artificial bee colony algorithm for the lot-streaming flow shop scheduling problem. Inf. Sci. **181**, 2455–2468 (2010)

Pandi, V.R., Panigrahi, B.K.: Dynamic economic load dispatch using hybrid swarm intelligence based harmony search algorithm. Expert Syst. Appl. **38**, 8509–8514 (2011)

Panigrahi, C.K., Chattopadhyay, P.K., Chakrabarti, R.N., Basu, M.: Simulated annealing technique for dynamic economic dispatch. Electr. Pow. Compo. Sys. **34**(5), 577–586 (2006)

Panigrahi, B.K., Yadav, S.R., Agrawal, S., Tiwari, M.K.: A clonal algorithm to solve economic load dispatch. Electr. Power Syst. Res. **77**, 1381–1389 (2007)

Park, J.B., Lee, K.S., Shin, J.R., Lee, K.Y.: A particle swarm optimization for economic dispatch with nonsmooth cost functions. IEEE Trans. Power Syst. **20**, 34–42 (2005)
Park, K.-J., Zheng, R., Liu, X.: Cyber-physical systems: milestones and research challenges. Comput. Commun. **36**, 1–7 (2012)
Pereira-Neto, A., Unsihuay, C., Saavedra, O.R.: Efficient evolutionary strategy optimisation procedure to solve the nonconvex economic dispatch problem with generator constraints. IEE Proc. Gener. Transm. Distrib. **152**, 563–660 (2005)
Pham, D.T., Ghanbarzadeh, A., Koç, E., Otri, S., Rahim, S., Zaidi, M.: The bees algorithm—a novel tool for complex optimisation problems. In: Second International Virtual Conference on Intelligent production machines and systems (IPROMS), pp. 454–459 (2006)
Pham, D.T., Ghanbarzadeh, A.: Multi-objective optimisation using the bees algorithm. In: Third International Virtual Conference on Intelligent Production Machines and Systems (IPROMS), Whittles, Dunbeath, Scotland, pp. 1–5 (2007)
Pradhan, P.M., Panda, G.: Solving multiobjective problems using cat swarm optimization. Expert Syst. Appl. **39**, 2956–2964 (2012)
Qin, L., Jiang, Q., Zou, Z., Cao, Y.: A queen-bee evolution based on genetic algorithm for economic power dispatch. In: Proceedings of the 39th International Universities Power Engineering Conference (UPEC), vol. 1, pp. 453–456 (2004)
Qubati, G.M., Dib, N.I.: Microstrip patch antenna optimization using modified central force optimization. Prog. Electromagn. Res. B **21**, 281–298 (2010)
Rabanal, P., Rodríguez, I., Rubio, F.: Using river formation dynamics to design heuristic algorithms. In: Akl, C.S.C.S.G., Dinneen, M.J., Rozenber, G., Wareham, H.T. (eds.) UC 2007, LNCS, vol. 4618, pp. 163–177. Springer, Heidelberg (2007)
Rabanal, P., Rodríguez, I., Rubio, F.: Solving dynamic TSP by using river formation dynamics. In: Fourth International Conference on Natural Computation (ICNC), pp. 246–250 (2008a)
Rabanal, P., Rodríguez, I., Rubio, F.: Finding minimum spanning/distances trees by using river formation dynamics. In: Dorigo, M. (ed.) ANTS 2008, LNCS 5217, pp. 60–71. Springer, Heidelberg (2008b)
Rabanal, P., Rodríguez, I., Rubio, F.: Applying river formation dynamics to the Steiner tree problem. In: 9th IEEE International Conference on Cognitive Informatics (ICCI), pp. 704–711 (2010)
Rajkumar, R.R., Lee, I., Sha, L., Stankovic, J.: Cyber-physical systems: the next computing revolution. In: Proceedings of the Design Automation Conference 2010, Anaheim, California, USA, pp. 1–6 (2010)
Rao, R.V., Patel, V.K.: Optimization of mechanical draft counter flow wet-cooling tower using artificial bee colony algorithm. Energy Convers. Manage. **52**, 2611–2622 (2011)
Rayapudi, S.R.: An intelligent water drop algorithm for solving economic load dispatch problem. Int. J. Electr. Electron. Eng. **5**, 43–49 (2011)
Roy, P., Chakrabarti, A.: Modified shuffled frog leaping algorithm for solving economic load dispatch problem. Energy Power Eng. **3**, 551–556 (2011)
Saadat, H.: Power System Analysis. McGraw Hill WCB, New York (1999)
Sabat, S.L., Udgata, S.K., Abraham, A.: Artificial bee colony algorithm for small signal model parameter extraction of MESFET. Eng. Appl. Artif. Intell. **23**, 689–694 (2010)
Saber, A.Y.: Economic dispatch using particle swarm optimization with bacterial foraging effect. Electr. Power Energy Syst. **34**, 38–46 (2012)
Sacco, W.F., de Oliveira, C.R.E.: A new stochastic optimization algorithm based on a particle collision metaheuristic. In: 6th World Congresses of Structural and Multidisciplinary Optimization, Rio de Janeiro, Brazil, pp. 1–6, 30 May–03 June 2005
Samanta, S., Chakraborty, S.: Parametric optimization of some non-traditional machining processes using artificial bee colony algorithm. Eng. Appl. Artif. Intell. **24**, 946–957 (2011)
Sinha, N., Chakrabarti, R., Chattopadhyay, P.K.: Evolutionary programming techniques for economic load dispatch. IEEE Trans. Evol. Comput. **7**, 83–94 (2003)
Song, Y.H., Chou, C.S.V.: Large-scale economic dispatch by artificial ant colony search algorithms. Electr. Mach. Power Syst. **27**, 679–690 (1999)

Sonmez, M.: Artificial bee colony algorithm for optimization of truss structures. Appl. Soft Comput. **11**, 2406–2418 (2011)
Szeto, W.Y., Wu, Y., Ho, S.C.: An artificial bee colony algorithm for the capacitated vehicle routing problem. Eur. J. Oper. Res. **215**, 126–135 (2011)
Tabakov, P.Y.: Big Bang-Big Crunch optimization method in optimum design of complex composite laminates. World Acad. Sci. Eng. Technol. **77**, 835–839 (2011)
Taherdangkoo, M., Shirzadi, M.H., Bagheri, M.H.: A novel meta-heuristic algorithm for numerical function optimization_blind, naked mole-rats (BNMR) algorithm. Sci. Res. Essays **7**, 3566–3583 (2012)
Tang, H., Zhou, J., Xue, S., Xie, L.: Big Bang-Big Crunch optimization for parameter estimation in structural systems. Mech. Syst. Signal Process. **24**, 2888–2897 (2010)
Tasgetiren, M.F.: A discrete artificial bee colony algorithm for the total flowtime minimization in permutation flow shops. Inf. Sci. **181**, 3459–3475 (2011)
Teodorović, D.: Bee colony optimization (BCO). In: Lim, C.P., Jain, L.C., Dehuri, S. (eds.) Innovations in Swarm Intelligence, pp. 39–60. Springer, Heidelberg (2009)
Tereshko, V., Lee, T.: How information mapping patterns determine foraging behaviour of a honeybee colony. Open. Syst. Inf. Dyn. **9**, 181–193 (2002)
Thurston, L.D.: Jacksonville to Construct First Refrigerated Crossdock, p. 41. Caribbean Business, London (2008)
Tsai, P.-W., Pan, J.-S., Chen, S.-M., Liao, B.-Y, Hao, S.-P.: Parallel cat swarm optimization. In: Seventh International Conference on Machine Learning and Cybernetics, Kunming, China, pp. 3328–3333, 12–15 July 2008
Tsai, P.-W., Pan, J.-S., Chen, S.-M., Liao, B.-Y.: Enhanced parallel cat swarm optimization based on the Taguchi method. Expert Syst. Appl. **39**, 6309–6319 (2012)
Vaisakh, K., Praveena, P., Rao, S.R.M., Meah, K.: Solving dynamic economic dispatch problem with security constraints using bacterial foraging PSO-DE algorithm. Electr. Power Energy Syst. **39**, 56–67 (2012)
Walters, D.C., Sheble, G.B.: Genetic algorithm solution of economic dispatch with valve point loading. IEEE Trans. Power Syst. **8**, 1325–1332 (1993)
Wang, P., Cheng, Y.: Relief supplies scheduling based on bean optimization algorithm. Econ. Res. Guide **8**, 252–253 (2010)
Wang, L., Zhou, G., Xu, Y., Liu, M.: A hybrid artificial bee colony algorithm for the fuzzy flexible job-shop scheduling problem. Int. J. Prod. Res. **51**(12), 3593–3608 (2013). doi:10.1080/00207543.2012.754549
Wang, L., Zhou, G., Xu, Y., Wang, S.Y., Liu, M.: An effective artificial bee colony algorithm for the flexible job-shop scheduling problem. Int. J. Adv. Manuf. Technol. **60**, 303–315 (2012)
Wang, L., Zheng, X.-L., Wang, S.-Y.: A novel binary fruit fly optimization algorithm for solving the multidimensional knapsack problem. Knowl.-Based Syst. **48**, 17–23 (2013)
Wedde, H.F., Farooq, M., Zhang, Y.: BeeHive: an efficient fault-tolerant routing algorithm inspired by honey bee behavior. In Proceedings of the 4th Ant Colony Optimization and Swarm Intelligence (ANTS), Lecture Notes in Computer Science, Brussels, Belgium, vol. 3172, pp. 83–94, 5–8 Sept 2004
Wong, K.P., Fung, C.C.: Simulated annealing based economic dispatch algorithm. IEE Proc. C: Gener. Transm. Distrib. **140**, 509–515 (1993)
Wood, A.J., Wollenberg, B.F.: Power Generation, Operation, and Control. Wiley, New York (1996)
Xie, L., Zeng, J., Formato, R.A.: Convergence analysis and performance of the extended artificial physics optimization algorithm. Appl. Math. Comput. **218**, 4000–4011 (2011)
Xing, B., Gao, W.-J.: Innovative Computational Intelligence: A Rough Guide to 134 Clever Algorithms. Springer, Heidelberg (2014). ISBN 978-3-319-03403-4
Xing, B., Gao, W.-J., Marwala, T.: Intelligent data processing using emerging computational intelligence techniques. Res. Notes Inform. Sci. **12**, 10–15 (2013a)
Xing, B., Gao, W.-J., Marwala, T.: Taking a new look at traveling salesman problem through the lens of innovative computational intelligence. Res. Notes Inform. Sci. **12**, 20–25 (2013b)

Xing, B., Gao, W.-J., Marwala, T.: When vehicle routing problem becomes dynamic: can innovative computational intelligence give us a hand? Res. Notes Inform. Sci. **12**, 26–31 (2013c)

Yang, X.S.: Engineering optimizations via nature-inspired virtual bee algorithms. In: Mira, J., Álvarez, J.R. (eds.) IWINAC 2005, lNCS 3562, vol. 3562/2005, pp. 317–323. Springer, Heidelberg (2005)

Xu, J., Lam, A.Y.S., Li, V.O.K.: Chemical reaction optimization for the grid scheduling problem. In: IEEE International Conference on Communications (ICC), pp. 1–5, May 2010

Yalcinoz, T., Short, M.J.: Neural networks approach for solving economic dispatch problem with transmission capacity constraints. IEEE Trans. Power Syst. **13**, 307–313 (1998)

Yang, X.-S., Gandomi, A.H.: Bat algorithm: a novel approach for global engineering optimization. Eng. Comput. **29**, 464–483 (2012)

Yang, H.T., Yang, P.C., Huang, C.L.: Evolutionary programming based economic dispatch for units with non-smooth fuel cost functions. IEEE Trans. Power Syst. **11**, 112–118 (1996)

Yang, S.-D., Yi, Y.-L., Shan, Z.-Y.: Gbest-guided artificial chemical reaction algorithm for global numerical optimization. Procedia Eng. **24**, 197–201 (2011)

Yang, X.-S., Karamanoglu, M., He, X.: Multi-objective flower algorithm for optimization. Procedia Comput. Sci. **18**, 861–868 (2013)

Yesil, E., Urbas, L.: Big Bang-Big Crunch learning method for fuzzy cognitive maps. World Acad. Sci. Eng. Technol. **71**, 815–824 (2010)

Yonezawa, Y., Kikuchi, T.: Ecological algorithm for optimal ordering used by collective honey bee behavior. In: 7th International Symposium on Micro Machine and Human Science, pp. 249–256 (1996)

Yuan, X., Wang, L., Yuan, Y., Zhang, Y., Cao, B., Yang, B.: A modified differential evolution approach for dynamic economic dispatch with valve-point effects. Energy Convers. Manage. **49**, 3447–3453 (2008)

Zhang, X., Jiang, K., Wang, H., Li, W., Sun, B.: An improved bean optimization algorithm for solving TSP. In: Tan, Y., Shi, Y., Ji, Z. (eds.) ICSI 2012, Part I, LNCS 7331, pp. 261–267. Heidelberg, Springer (2012)

Zhang, X., Sun, B., Mei, T., Wang, R.: Post-disaster restoration based on fuzzy preference relation and bean optimization algorithm. In: IEEE Youth Conference on Information Computing and Telecommunications (YC-ICT), pp. 271–274, 28–30 Nov 2010

Chapter 13
Intelligent Technologies and Systems of Material Management

Gang Xiong, Timo R. Nyberg, Xisong Dong and Xiuqing Shang

Abstract Material Management is the engine that drives its Supply Chain and Logistics of manufacturing enterprise or any other organization. With the economy development and technical progress, many Logistics are transforming from 1PL and 2PL and 3PL to 4PL and 5PL continuously, and many manufacturers are transforming from Mass Production to Mass Customization, and then to new manufacturing modes all the time, like Cloud Manufacturing, Social Manufacturing etc. So, Material Management should continuously apply the latest ICT & intelligent technologies or systems, like Barcode, RFID, IoT (Internet of Things), GPS/BeiDou Navigation Satellite System, Cloud Computing, Big data, Parallel Control and Management, to realize its transformation and upgrade coordinately with its Supply Chain and Logistics.

Keywords Material management · Fifth party logistics · Supply chain management · Enterprise resource planning · Social manufacturing · Internet of things · Cloud computing · Big data · Parallel control and management · Intelligent systems

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13.1 Introduction

Material Management (MM) is one important part of Logistics Management and Supply Chain Management, so to understand logistics and supply chain is helpful to understand the requirements of MM. Information and Communication Technology (ICT) and intelligent technologies or systems are the most important technical supports of the new Material Management System (MMS) to meet the more complex and challenge requirements. So, we organize the Chapter as follows: Sect. 13.2 introduces Logistics and Supply Chain of Material Management: Logistics Upgrade from 1PL to 3PLs; Material Management of Logistics; Material Coding and its Standardization; Material Procedure Management; Key Performance Indicator (KPI) for Materials Management. Section 13.3 introduces Material Management Solution of SAP: Three Important Flows of Material Management in Supply Chain; Material Management Solution of SAP. Section 13.4 is the Material Management Case Study in a Global Chemical Company: "As Is" ERP & shop floor situation; "To be" ERP + MII solution; Business scope; Functional areas; Benefits analysis. Section 13.5 is Material Management Case Study of National Power Group: Technical Solution of Material Management System; Main Functions of Material Management System; Key Performance Indicator of Material Management System; Online Supermarket of National Power Group; Result Analysis and Conclusions. Section 13.6 discusses Development Trend of Material Management: Logistics upgrade to 4PLs; Logistics upgrade to 5PLs. Section 13.7 is Conclusions.

13.2 Material Management of Logistics and Supply Chain

13.2.1 Definitions of Logistics and Supply Chain

Logistics can be defined as the management of business operations, including the acquisition, storage, transportation, and delivery of goods (product, or material) along the supply chain. Supply Chain can be defined as a network of retailers, distributors, transporters, storage facilities, and suppliers that participate in the sale, delivery, and production of a particular product (Murray 2006).

So, logistics is one part of the supply chain process (Fig. 13.1) that plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point of origin to the point of consumption to meet customers' requirements. And, the targets of logistics operation can be summarized as "7R", i.e. transfer right product to client in right time and at right place, with right quantity, right quality, right condition and right cost.

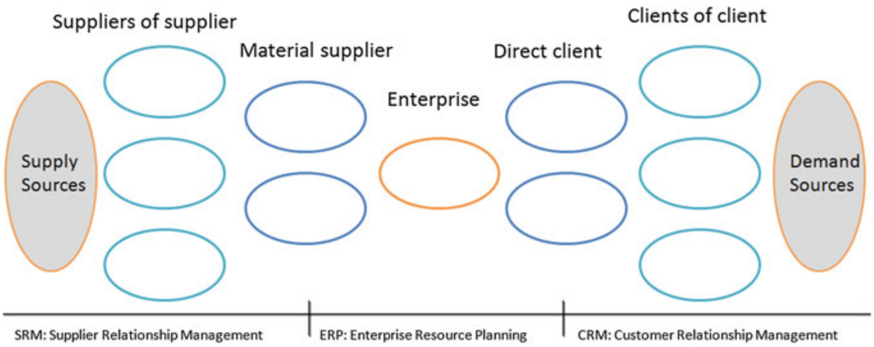

Fig. 13.1 Supply chain management process

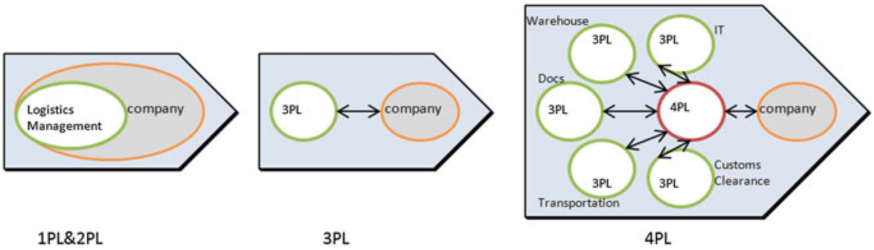

Fig. 13.2 Logistics upgrade from 1PL to 4PL

13.2.2 Logistics Upgrade from 1PL to 3PLs

The concepts of 1PL (First-Party Logistics), 2PL (Second-Party Logistics), 3PL (Third-Party Logistics), and 4PL (Fourth-Party Logistics, discuss later) reflect the evolving demands of supply chain management (Fig. 13.2).

(1) **1PL (First-Party Logistics)**
A 1PL manufacturer essentially owns and handles all logistics functions, such as trucking and warehousing. 1PL is normally the shipper and consignee, who have cargo to send from a point A to B. Most small businesses buying and selling in the same location are 1PLs.

(2) **2PL is capacity provider**
As the business expands geographically, the manufacturer will seek a 2PL provider to share its growing logistics burden. A 2PL provider is generally a commodity capacity provider (Ho 2001), such as a transportation company or a warehouse operator, who physically owns transportation tools (truckers, air freighters or container lines) or storage warehouse. A 2PL provides service for a single or a small number of functions in the supply chain. They face low returns, with high levels of asset intensity but low barriers to entry. Airports and seaports are also categorized

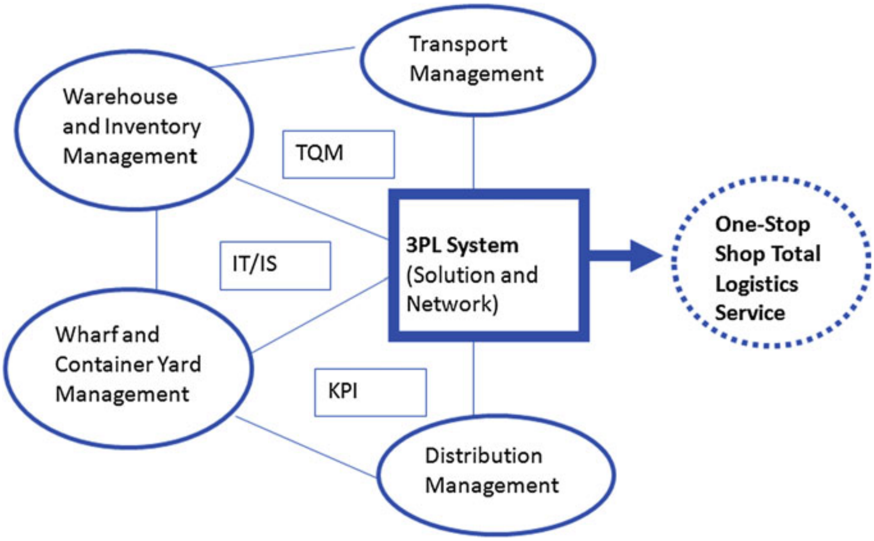

Fig. 13.3 PL example: China resources (Holdings) Co. Ltd (CRC)

as 2PL; their returns are generally better and more stable due to their relative scarcity, natural monopoly geographically. The distributor is another 2PL, who can achieve higher returns through a dense network, legislative protection, and sizeable cost base. For example, the express parcel operators can earn higher margins as they can charge a premium pricing for timely delivery.

(3) **3PL is supply chain manager**

According to the Council of Supply Chain Management Professionals, 3PL (Liu and Sun 2011) is defined as "a firm that provides multiple logistics services for use by customers. Preferably, these services are integrated, or bundled together, by the provider. Among the services, 3PLs provide are transportation, warehousing, cross-docking, inventory management, packaging, and freight forwarding." China Resources (Holdings) Co. Ltd. (Piasecki 2003; John 2003) provides one 3PL example (Fig. 13.3).

While 3PLs do own some assets such as key distribution centers in strategic locations or a small trucking fleet to fill emergency needs, they contract out most of their capacity needs to 2PLs. Hence the terms 3PL and contract logistics are frequently used interchangeably (Ho 2001). 3PL provides such services as EDI information of warehousing and transportation, order fulfillment, automated replenishment, selection of transport, packaging and labeling, distribution, import and export of the product group, etc. 3PL providers focus on logistics solutions and look for the optimal combination of assets available from capacity providers. 3PLs are less assets intensive and are thus nimbler in operation, and therefore have higher returns on assets employed. Their management expertise helps to optimize supply chains for more and more customers. Moreover, the more integrated services of a 3PL, the closer to the customers' operation. This closeness makes 3PL indispensable to the customer, as the 3PL provider becomes more a partner than a supplier. A customer is more reluctant to change its 3PL provider than a 2PL. There is therefore higher customer loyalty and revenue stability. Economies of scale are crucial for 3PLs to be profitable, as they need to support extensive logistics networks.

• Differentiation of 2PL and 3PL
2PL is an outsourced logistics provider with no system integration, 2PL works often on call (e.g. express parcel services); 3PL is always integrated in the customs system, so it is almost every time informed about the workload of the near future. 2PLs only provide standardized services which can't be customized, so they have to face the fluctuating market with hard competition and a price battle on a low level. 3PLs often provide the customized and specialized services to meet the customer's long term cost reduction strategy needs. Normally, a stable and long term contract can be signed between 3PL and its customer, which is cost effective for both sides.

• Advantages and possible disadvantage of 3PL
Advantages of 3PL: Cost and time savings for the customer; Low capital commitment; Ability of customer to focus on core business; 3PLs provide flexibility.

The possible disadvantage of 3PL: The customer has to outsource its own logistics and loss the full control. Actually, this is not big problem in practice.

13.2.3 Material Management of Logistics

MM is an integral part of the logistics function in the supply chain. The goal of MM is to provide an unbroken chain of components for production to manufacture goods on time for the customer base. Materials is generally measured by accomplishing on time delivery to the customer, on time delivery from the supply base, attaining a freight budget, inventory shrink management, and inventory accuracy.

• Three important flows in MM
There exist three important flows in MM (Murray 2006): the material flow; the information flow; and the financial flow. The material flow describes the movement of materials from the vendor to the company and then on to the customer. Today companies are integrating with suppliers and customers, not just interfacing. Therefore any improvements companies can provide to the visibility of their material flow will allow them to be flexible and responsive to their customers. Customers will want to do business with companies who are responsive. Those companies will also be able to gain a competitive advantage and increase market share by being more flexible, quicker, and more dependable. The information flow includes the transmitting of orders (including EDI, fax, etc.) and updating the status of all deliveries. Companies that can show customers and vendors viability by using real-time information have a distinct competitive advantage over others. The financial flow includes the financial documents that are created at each material movement.

• MM in Practice
Redundancy can be reduced and effectiveness is increased when service points are clustered to reduce the amount of redundancy. Effective MM software can also resolve "island" approaches to shipping, receiving, and vehicle movement. Solutions include creating a new central loading location, as well consolidating service areas and docks from separate buildings into one. For example, MM plan may include planning guidelines or full design for the following:

– Truck delivery and service vehicle routes, to reduce vehicle/pedestrian conflict.
– Loading docks and delivery points, to increase accommodation and reduce queuing and vehicle idling.
– Recycling, trash, and hazardous waste collection and removal, to increase waste diversion and reduce costs.
– Service equipment and utility infrastructure relocation or concealment, to improve aesthetics and realize landscaping goals.
– Regulatory and operation planning.

MM are practiced from company to company, there are no standards. Some companies use ERP systems such as SAP, Oracle, BPCS, MAPICS and others to manage material. Some companies design, develop and use their own MMS to meet the specific short term and long term requirements. Some small companies which do not have or cannot afford ERP systems use a form of spreadsheet application to manage material.

• MM's Challenges
MM's major challenge is maintaining a consistent flow of materials for production. There are many factors inhibiting the accuracy of inventory which results in production shortages, premium freight, and often inventory adjustments. MM's major issues are incorrect bills of materials, inaccurate cycle counts, un-reported scrap, shipping errors, receiving errors, and production reporting errors.

MM's another challenge is to provide timely releases to the supply base. On the scale of worst to best practices, sending releases via facsimile or PDF file is the worst practice, and transmitting releases to the supplier based the stable web site is the best practice.

13.2.4 Material Coding and Its Standardization

Materials coding is the process to convert the symbol system that can represent various materials naturally into another standard and uniform symbol system that computers and human can identify and utilize more easily and efficiently (Dong and Lin 2004). It is a technical tool to unify human's recognition, exchange real-time information, and keep the high accuracy of various and complicated information for communication among all kinds of activities.

To improve MM's efficiency, a standard and scientific Materials Classification and Coding (MC&C) should be established to meet the collaboration and communication needs among enterprises. Typically, MC&C is one of indispensable pre-conditions for sharing all kinds of resources and achieving efficient MM. Each material code represents concrete equipment or material uniquely, which can be saved, extracted, modified and retrieved for the application purpose of classification and statistics. MC&C plays an important role in MM (He et al. 2004):

- It could provide the unified and standard identifications for the collaboration of MM.
- Material code is its unique "Identification Number", so can avoid redundant storage of the same material.
- It could avoid manual input and output errors, and improve the quality and efficiency of MM.
- The fixed codes can prevent the fraud activities on MM.

MC&C researches have been done earlier in western developed countries. The United States has invested to study MC&C since 1910s. Germany established the Defense Material Agency in 1956, whose task is military supplies classification and coding. Japan completed "Standard Commodity Classification and Coding" in 1975. The Soviet Union established a unified coding management system with 19 categories in 1979 (Liu et al. 2005). Chinese General Logistics Department completed the standard system of "Logistics Materials Classification and Coding" in 1990 (Zhang and Liang 1995).

In summary, all material coding methods can be classified into two categories: meaningful coding methods, meaningless coding methods. Meaningful coding methods mainly include the classification method, the combined features method and the combined coding method. In contrast, meaningless coding methods mainly include the sequence coding method and the structure coding method, etc. Kraftwerk-Kennzeichen System (KKS) consists of technical identifier, installation location identifier and position identifier. After the long-term practice and improvement, KKS has become mature and complete identification systems for MM.

Currently, the most popular MC&C method is the combination of the property coding method and sequence coding method to identify the materials' properties for the management convenience (Xiong et al. 2010: material code). According to the hierarchical design of MC&C system, the upper catalogs which are formed by the principles of the property coding method and the lower catalogs are designed by the sequence coding method to refine materials classification and improve the utilization percentage of coding space.

13.2.5 Material Procedure Management

Different management procedures come with the building of any new corporation, and become more and more complex with their development and growth. Each corporation and its sub-organizations have their own and specific procedures for different businesses and services, which are made up of various complex sub-procedures. So, those procedures and sub-procedures should be managed reasonably in order to realize the unified management on corporation level. Flexible business process can be realized by suitably connecting different procedures, so efficient procedures management can make many benefits, such as: Time and cost saving; Efficiency and quality improvement; Clear accountability and no duplication, etc. If the procedure management can't be operated effectively, the business process can't track the implementation details of management operations, and these would seriously affect the unified management of the entire system.

Besides saving time and cost, efficient procedures management also help corporations to drastically reduce or even eliminate their faults or damages, which are normally caused by document lost, important information missing, or necessary review process ignoring. On the other hand, a clear procedure helps every employer and employee to know the general status of all involved projects and tasks and the accurate detail and status of his or her duty. And, the manager exactly knows all the information of the project and the duty detail of every participant.

Efficient material procedure management is also the necessary pre-condition for the unified MM. Small adjustments of the procedure structure can only be made in a given mode by specific users, and no adjustment can be made in the most of traditional procedure management. For example, the procedure structure of material warehousing, storage and release is simple procedure structure including material purchase, material warehousing, material back process warehousing, finished product warehousing, material release, product release, and after-sales release, etc. Because of its inflexibility, the traditional procedure managements couldn't meet the unified material procedure management demand.

A complex and flexible procedure management can make the procedure design easier for all kinds of procedures, which become the common communication mechanisms among different projects, different departments, different systems, and different units. The most procedures should be adjusted continuously for their optimization according to the various changing demands. So, the procedure management is not only a simple procedure structure changing, but also a complicated structure adjustment. Not just copying the given procedure structures, the procedure management should be re-designed, and the sub-procedures should be re-structured by using the latest IT, so the complex and flexible procedures of MM can be configured out easily and does not destroy the given procedures structure.

13.2.6 Key Performance Indicator (KPI) for Material Management

Currently, there is less research and discussion on the performance management about the organization of enterprise compared to the performance management about the employees. In fact, the performance management of organization reflects not only the performance of individual employees, but also the management level of leaderships, resource allocation, knowledge, and teamwork, etc. Hence, it is necessary to design and optimize the organization-level KPI system to support healthy and rapid development of enterprises.

KPI is a performance measure tool commonly used to help an organization define and evaluate its performance, typically in terms of making progress towards its long-term goals (Fitz-Gibbon 1990). KPI should be defined objectively to provide quantifiable and measurable indications of the organizations progress towards achieving its goals. KPI can be monitored by using Business Intelligence (BI) techniques to assess the present state of the business and to assist in prescribing a course of improvement action.

It is the key to improve the enterprise performance management efficiently by establishing a clear and reasonable KPI. Furthermore, KPI could be quantifiable, pre-approved and can reflect the realization process of organizational goals. KPI is the effective means of performance management and the driving force to promote the actual business value of an enterprise. From the perspective of functions, KPI can be applied to show the crucial aspects of the business values based on the decomposition of the enterprise's strategic goals, to classify the qualitative and quantitative factors and implement the enterprise's strategy strongly, and to provide an objective basis for communicating between senior managers and lower managers of an enterprise for the evaluation of performance management (Lei 2006).

Figure 13.4 shows the irreplaceable functions of KPI in the performance management of an enterprise. Without the implementation of KPI management, sub-goals are chaotic and can't promote the strategic goal of an enterprise effectively. In contrast, with the help of KPI management, the sub-goals can keep pace to achieve the top goal of an enterprise effectively.

For designing KPI for performance management, it should comply with the principles of SMART where "S", "M", "A", "R", and "T" represent Specific, Measurable, Attainable, Realistic, and Time-bound, respectively.

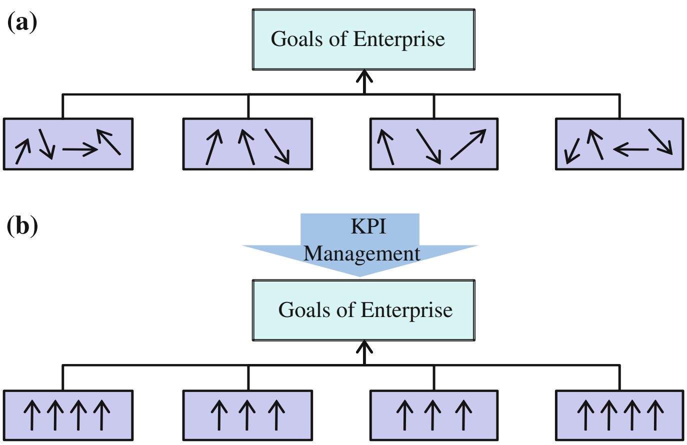

Fig. 13.4 KPI support on the strategic objectives of an enterprise. **a** Before carrying out the KPI management. **b** After carrying out the KPI management

13.3 Material Management Solution of SAP

13.3.1 Three Important Flows of Material Management in Supply Chain

MM is one important module in the logistics functions of ERP, Fig. 13.5 shows a typical MM process. The Logistics function and the flows are defined within the supply chain, and SAP ERP should be developed to manage this supply chain to gain a competitive advantage for the clients (Murray 2006). For example, it can provide a company with the ability to have the correct materials at the correct location at the correct time, with the correct quantity and at the most competitive cost. The competitive advantage is achieved when the company can manage the process. This involves managing the company's relationships with its vendors and customers, controlling their inventory, forecasting customer demand, and receiving timely information with regards to all aspects of the supply-chain transactions.

Although MM is an integral core part of Logistics, it is only one core part of the big picture. The Logistics function in ERP includes the following: MM, Sales and Distribution (SD), Quality Management (QM), Plant Maintenance (PM), Production Planning (PP) (Balla and layer 2006), Project System (PS), Finance (FI), Warehouse Management (WM), and Logistics Information System (LIS). There is additional functionality in the Logistics area, such as Batch Management, Handing Unit Management, Variant Configuration, Engineering Change Management, Environmental, Health, and Safety (EHS). These can be important in the Logistics area, depending on the individual customer requirements.

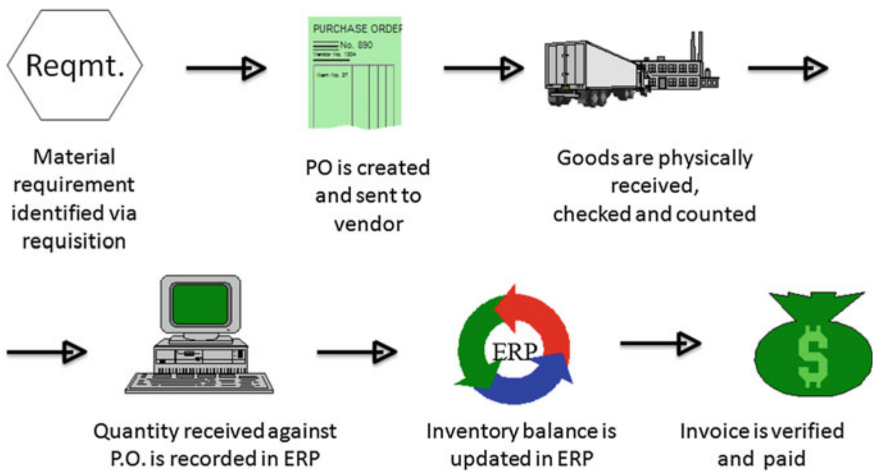

Fig. 13.5 A typical material management process

(1) **Material flow of supply chain**

As defined already, material flow is the material movement from the vendor to the customer (Murray 2006). To instigate a flow, a material need would be have to be created by either PP module via a Materials Requirements Panning (MRP) system or by a sales order created in SD. The need is created, and a Purchase Requirement is sent to the vendor, relating to instructions in delivery date, quantity and price.

The vendor sends the material, and it is received and may be subject to a quality inspection in QM. Once approved, the material can be stored and may be stored in a WM. The material could be required in a Production Order in PP or be part of a larger project defined in PS. Once a final material is available for the customer, it can be picked from the warehouse and shipped to the customer using the SD module. From the description of this simple flow it is easy to see that MM is highly integrated with the other ERP modules.

(2) **Information flow of supply chain**

The information flow can be easily described by using the simple example. Initially, there may be an order from a customer. This order could be transmitted via Electronic Data Interchange (EDI) to the SAP ERP system. The information will communicate whether the item is in stock, and if not, the information is sent to the MRP tool and sent back to the customer to give the delivery date.

The MRP tool takes all information regarding production schedules, capacity of production facility, and the available materials involved in production to create production orders and material requests that appear as information in the procurements system.

The information in procurement system creates orders with required delivery date, which are transmitted to vendors. The return information from the vendor will confirm the delivery date of the material. The vendor can send EDI transmissions informing the company the delivery status. Upon receipt of the material, the information is passed from the receiving documents to WM, in order to store the material correctly. The information is passed to PP to calculate if the production order is ready to commence. Once the material is ready to ship, SAP ERP produce the shipping information and send it to the customer.

At all of the touch points with ERP, information has been recorded available to be reviewed and analyzed. The more information that is shared across the total supply chain, the more cost benefits can be achieved based on the analytical data. The Logistics Information System (LIS) and other standard reports in SAP ERP can give the supply chain management team invaluable insights into how their logistics function operates.

(3) **Financial flow of supply chain**

The typical flow of financial information in the supply chain includes the invoices received by the company from their vendors, the payments to the vendors, the billing of the customers for the materials, and the incoming payments.

The vendor supplies material to the company and sends it an invoice. The company has choices on how to pay the vendor: either pay on receipt of the materials (two-way match), or more often, on receipt on the vendor invoice (three-way match). The accounts payable department carries out this function. The invoice-verification process is an excellent example of the integration between MM and Finance modules.

The financial flow, the information and material flows of the supply chain has not changed in magnitude. However, the SAP R/3 system allows the supply chain users to analyze the financial KPI that are part of the overall supply chain. These can include Inventory Turns, Days of Working Capital, Days of Inventory, Days Sales Outstanding and Days Payables Outstanding. The integration of MM and other key module within the Logistics function combine to provide this important information in an accurate and timely fashion.

Developments in the financial flow of the supply chain have direct impacts on MM module. The imagining of invoices is an important development that allows companies to scan the incoming invoices (either internally or using a third party) and create a Workflow (WF) to speed approval. A message is sent to the purchaser, and approval time is shortened.

Companies now use Procurement cards (P-cards) to reduce costs and speed up the financial flow. Purchasing with a P-card ties purchasers into an approved vendor list and allows companies to focus on obtaining discounts and favorable rates with certain vendors. The other benefit is that the P-card reduces the invoice processing by the accounts payable department. The individual purchases are managed by spending limits associated with each p-card user and payment is made directly to the vendor by the P-card company. The use of P-cards is an example of how the development in the supply chain management outside of ERP influence the integration between ERP modules, in this case FI and MM.

13.3.2 Material Management Solution of SAP

MM is the term applied to all processes and business activities relating to how materials are moved into, stored, used, and moved out of a company. Correctly defining MM organizational structure is the foundation for a successful SAP implementation. It is extremely important to make accurate decisions about entities such as company codes, plants, and storages. The processes of MM are based on various types of Master Data which are stored in Master Records for sharing among all departments access to perform their business activities across Modules (Fig. 13.6). For example, The Material Master and Vendor Master Files are at the core of Procurement, Inventory Management, and Invoice Verification. Material Requirements Planning (MM-MRP) is for Consumption- based Planning: Based on past consumption values, which are used as basis when creating future requirements.

MRP has to meet three objectives simultaneously: to ensure the material availability for production and delivery to customer; to maintain the lowest possible level of inventory; To plan manufacturing activities, delivery schedule, and purchase. Procurement (MM-PUR) is for the acquisition of materials, supplies and services according to the requirements. With its help, purchasing department can negotiate with suppliers for larger saving, better material quality, and more secure supply. Warehouse Management (MM-WM) keeps track of material inventory per storage bin in a warehouse; Processes stock movements into, out of and within a warehouse; Manages stocks within complex warehouse structures; Supports physical stock counting; Controls interfaces between WM and automated warehouse control systems; Provides information to assist with the planning of warehouse space and usage. Inventory Management (MM-IM) involves the receipt, storage, control and disbursement of materials and supplies: Manage the stocks on a quantity and value basis; Planning, entry, and proof of Goods movements; Carrying out the physical inventory. Invoice Verification (MM-IV) is the procedure through which vendors will be paid for the material that delivers to the customer. The procedure can involve a three-way matching process between the customer's purchase order, the good-received note, and the vendor's invoice. SAP MM module also includes Information System (MM-IS), and Electronic Data Interchange (MM-EDI), etc (Fig. 13.6).

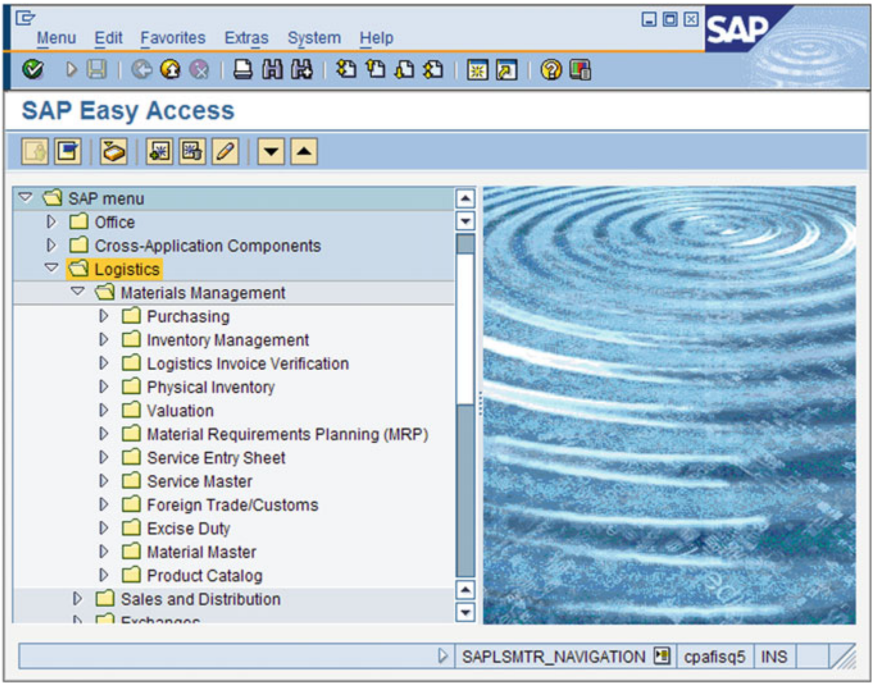

Fig. 13.6 Material management solution of SAP

13.4 Material Management Case Study of Global Chemical Company

13.4.1 The Existing Problems

For manufacturing enterprise, its IT systems' connection among factory level, enterprise level and supply chain level is critical for production personnel to cost-effectively deliver on customer expectations. Unfortunately, the most of existing ERPs are separated from Manufacturing Execution Systems (MES) and Production lines, the situation can be described as in Fig. 13.7. According to the customer survey executed by Managing Automation and AMR Research, "Less than 1 % of respondents indicated that manufacturing data is automatically integrated with ERP with no manual intervention".

In fact, the ERP-MES integration is very important, which main contents include: Production capacity information (What is available for use?); Product definition information (How to make a product?); Production schedule (What to make and use?); Production performance (What was made and used?). Their integration is the key to realize Manufacturing Integration & Intelligence (MII), and then to create more profits, benefits and competences for the chemical enterprises.

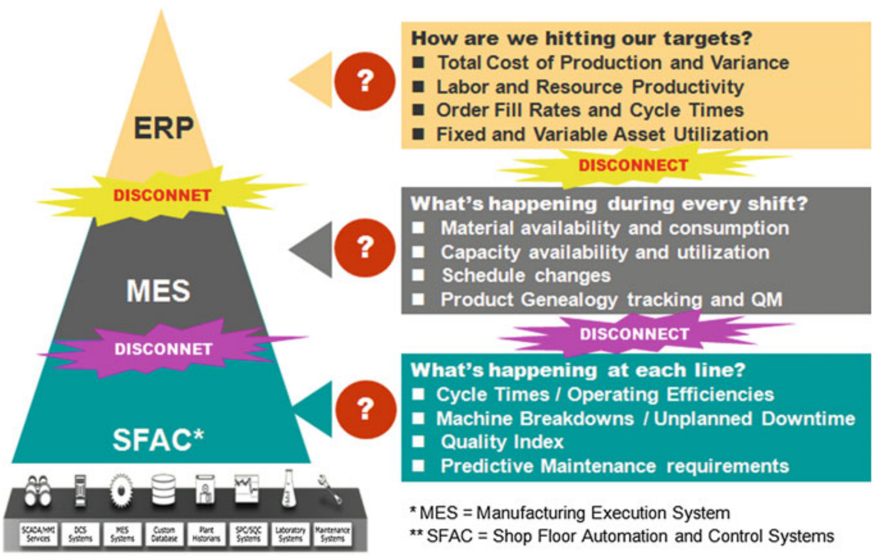

Fig. 13.7 Typical scenario existing in manufacturing enterprise

13.4.2 Manufacturing Integration & Intelligence (MII) Solution

MII solution can solve those existing business and technical challenges described in previous part. It is important that one company becomes adaptive, and then its plants profitably replenish the supply chain, while dynamically responding to unpredictable changes enables the company and their production personnel to deliver superior performance through higher visibility and responsiveness. MII solution owns such capabilities as Manufacturing Operations, Manufacturing Integration, Manufacturing Intelligence and Manufacturing Innovation, where Manufacturing Synchronization and Manufacturing Excellence are two enabling technologies (Fig. 13.8) (Xiong et al. 2012: Real-time Manufacturing).

MII solution automatically synchronizes the orders, materials, maintenance, quality and master data between real-time manufacturing plants and enterprise business processes, to provide a "single version of the truth" and drive manufacturing excellence. MII is composed of a set of integrated tools, like data access, business logic, visualization, KPI's, alerts, metrics, SPC engine and visualization. It aggregates, transforms and visualizes data from multiple sources, like SAP business suite, MES, non-SAP business systems, process control, shop floor, quality, lab systems, PM, and QM, etc. Its visual information for plants can enhance asset reliability, extend PM capability and simplify PM operation for managers, operators, and planners. xMII offers a broad library of pre-built connectors for connecting to shop floor systems. Generally to say, typical benefits of MII solution include the improvement of visibility, responsiveness, and performance.

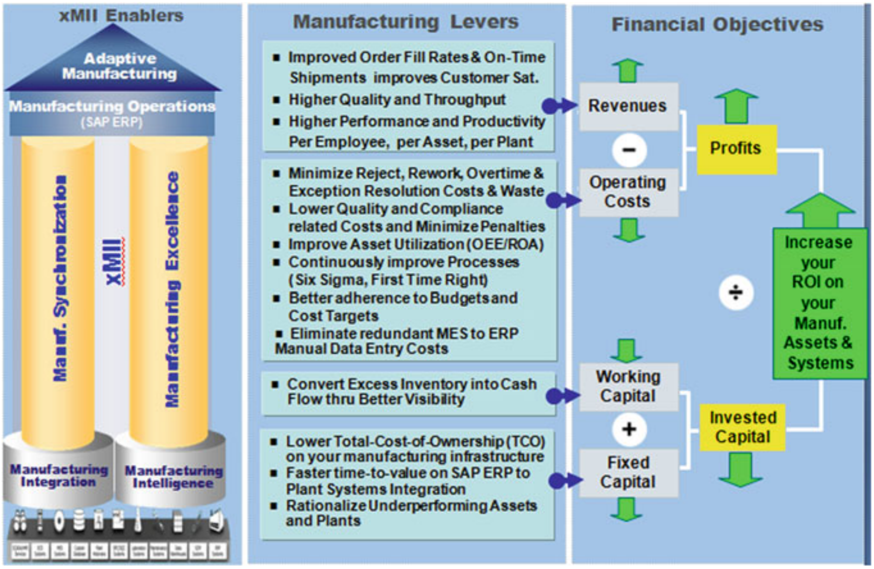

Fig. 13.8 Manufacturing integration and intelligence for the maximum return

13.4.3 *Material Management Case Study in a Global Chemical Company*

We name the global chemical company of our case study as CO Company. CO mainly produces oil additives that improve the performance of fuels and lubricants, such as: viscosity modifiers, industrial engine oil additives, automotive engine oil additives, passenger car and heavy duty diesel marine lubricant additives, and chemicals and components, etc.

(1) **"As Is" ERP & shop floor situation**
Before the project was executed, there are many disparate IT systems running in four plants and many sale offices, seven ERPs running at the same time in the enterprise, MES is not integrated with ERPs. So, learning about the exception too late to address and resolve it losts a huge customer order and thereby lost revenue opportunity. Process Control Systems (PCS) and MES are vastly different among regions in terms of functionalities and integration. Some has functions belong to ERP. Some has only partial functions of typical MES. For example, Asian plant doesn't have existing MES. Some parts of MES are done by Material Movement System Daily Operating Instructions and blend program. North American plant uses Production Tracker (PT) as MES. Europe plant uses GESCOM as MES, which has downloading process (order, recipe and QM) from SAP to PCS, Uploading process (status, material consumption) from PCS to ERP, Optimal blend calculation etc. South American plant doesn't have existing MES system.

(2) **"To be" ERP + MII solution**
The project, a global implementation of ERP, results in a single global system, which provides access to global real time demand, production and cost information no more than 24 h refresh to assure reliably service for customers, provides an improved ability to identify and interpret trends, enables CO company to increasingly differ itself from its competitors by taking full global advantage in the delivery of products and services to customers, enable the capability to cost and price innovative solutions to global customers, and provide a solid IT foundation to support future functionality additions that will support CO's long term strategy.

"TO BE" IT situation in enterprise level can be shown as Fig. 13.9. The objectives are to consolidate older technologies and reduce annual maintenance fees, to keep long-term stability and reusable content throughout ERP systems, and to reduce the hand-off of information and failure points between technologies. The purpose of MII subprojects is to serve as MES of all four manufacturing plants, to provide a front end for shop-floor operators, and integrate ERP and existing shop-floor systems through integration technologies like XI and MII etc. Although MII solution was rolled out first in Asian plant as part of the scope of ERP project, the goal is to create a single global design to cover the business requirements of all four regions. MII connects many IT systems, like SAP R/3, DCS, blend program, MMS, Plant Information Management System (PIMS), Drumming Scheduling System,

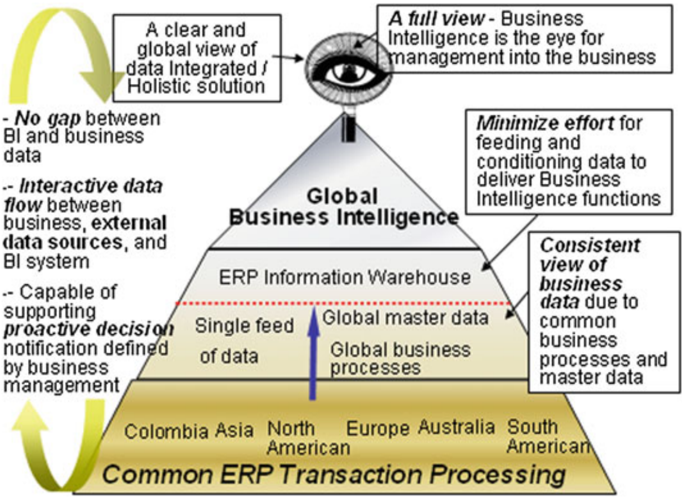

Fig. 13.9 "TO BE" IT situation in CO's enterprise level

and StarLIMS. MII develops those functionalities not covered by ERP and requested by actual business, like optimal blend calculation, component manufacturing system, Weight Bridge, drums field management, drums labeling and bar coding. The business purposes of the ERP + MII Solution are:

- Provide a 360 degree view of manufacturing operations: the production schedules and visibility to the front-line operators can be delivered real-time, then critical events of manufacturing execution can be easily identified, and better planning can be made and executed. Utilization of manufacturing assets (people, machine, etc.) can be monitored to improve operational effectiveness.
- Support cultural and clinical initiatives, like lean production, 6-sigma, OEE, TPM, and Demand Flow, etc.
- Radical user simplification for plants. For example operator front-end is simplified; automated and/or manual production confirmations are simplified.
- Support the disconnected operation, and then improve the limited local survivability.

(3) **Business scope**
Across the globe, all shop floor personnel perform the same basic business functions. Table 13.1 shows a summary of the business functions and activities performed by shop floor personnel at all plants, which then decides MII's technical design.

(4) **Functional areas**
xMII are mainly used to develop those functional areas: Loads (Goods Issue); Unloads; Transfers; DOI (Digital Object Identifier)/Special Instructions; Inventory; Blending; and Dashboard/KPI's. They are described in detail below.

Table 13.1 Business process mapping between ERP and MII

Business function	Activity
Receiving product	Display purchase orders; Create or cancel goods receipt
Manufacturing product	Display process orders; Create process messages
Moving product	Display stock transfer orders; Create or cancel goods movement; Create or cancel goods issue
Shipping product	Display sales orders; Create or display deliveries; Create or cancel Goods issue; Print shipping documents
Plant Maintenance (PM)	Work order; Time tickets; Work assignment; Component consumption
Material Management (MM)	Inventory control; Goods movement; Batch information; Material reservations; Material characteristics; Purchasing
Production Planning (PP)	Production/Process orders; Operations; Time tickets; Production results; Material consumption
Quality Management (QM)	Inspection tasks; Inspection lots; Sample management; Usage decision; Test result recording
Others	Weight; Test results; Recipe information; Status messages; Quantity information

(a) *Loads*

Loads mean Goods Issue. The plant physically loads product into vessels for outbound shipment or return product to a vendor. The loading is based on the Sales orders or Stock issue to third-party sub contractor for storage or stock transport order. Shipping documentation is always required for a load. A load is a separate process from an intra-plant transfer. Product can be loaded on top of product which already exists in the destination vessel.

(b) *Unloads*

All inbound for unloading is scheduled before it can come into plant. If it is also indicated in DOI, MMS Instruction, and then Plant unloads is based on MMS instruction and the Purchase Order. The inbound drive is accompanying with the documentation, e.g. bill of loading or delivery orders documents before plants can accept the inbound shipments. There are four modes of incoming materials: ISO Tank (Tank truck), Lorry Drums, Bulk, and Container (Bags, Bins and Drums). The weigh bridge and warehouse contractor do the good receiving from ERP system, and its variance quantity will then adjusted by the finance. In-house weigh is compared with bridge weight according to its supply documents. All the in-bound data will store in the weight bridge system and upload daily into MMS. Historical data for all in-bound are stored in MMS. For activities payment to contractor, track the truck/ISO tanks demurrage and waste send out to third party for disposal. For bulk vessel in bound: we engaged the surveyor for all the tanks gauging and confirm the actual quantity received. For activities base payments, we pay them by each movement In/Out of the plant.

(c) *Transfers*
The transfer activity is scheduled through the daily activity report (Excel spreadsheet). This document is generated by production planning and control department on the day before. Before the transfer begins, the shift supervisor fills in an "Instruction Sheet", which has relevant information about the transfer, like: product, quantity to be transferred, source tank, and destination tank. This instruction sheet is then sent to the process operator for execution:

- The current quantity on the source tank is ascertained.
- The current quantity on the destination tank is ascertained.
- The new quantity on the source tank is ascertained.
- The new quantity on the destination tank is ascertained.

The quantities are all based on manual gauging, mass flow or tank monitoring systems. After completion, the shift supervisor creates and completes the transfer order (document type "IT") on ERP system.

(d) *DOI/Special Instructions*
All blending (except drum mode) DOI are based on sales order. The DOI is issued for the safe and efficient operation of the blending and shipping unit, drumming, ISO-tank loading and discharging, ship loading and discharging, tanks transfer, process units and other activities, such as equipment preparation for maintenance, special sampling, system flushing for the compatibility, and any non-conformance product or short weigh drum recovery. View the process order list for specific process units and input the list, which needs to be executed, into the DCS system. The batch gets into production once the preceding batches are completed.

(e) *Blending*
The DOI is issued for the safe and efficient operation of the blending unit. Priority of the specific blend products order, destination of the vessel, batch numbers, quantity and date of the requirements before the plant execution, the blend program is downloaded into DCS for production. The process steps and key component modules of the blend program are: (a) ERP imports to blend program; (b) Update product package mode; (c) Blend demand; (d) Upload blend calculation into DCS recipe. There are nine masters maintained by the blend program: Destination such as vessel/blend tank; Key metal; Component; Component source; Component key metal; Product package; Product ERP instructions; Product blend instructions; Product component.

(f) *KPI's Dashboards*
Measurement of the daily, weekly, and monthly production unit performance can be shown on KPI's Dashboards. Planned and unplanned equipment's down times attribute to the production delay, and measure the plants overall equipments availability, performance and quality. Production planner sees the alerts on his dashboard and drills down for the root causes.

(5) **Benefits analysis**
After xMII solution was applied into the global chemical company, the complete value chain integration and visibility is achieved, and value chain agility and customer responsiveness is enhanced.

The tactical benefits has made are:

- Reduce manufacturing costs 3–5 %, through enhancing manufacturing process monitoring and visibility.
- Increase plant efficiencies 15–20 %, through manufacturing processes optimization and its integration with the enterprise.
- Increase production yields 5–8 %, through proactive monitoring of manufacturing events.
- Reduce maintenance costs 8–10 %, through streamlined maintenance processes and alignment with manufacturing metrics.
- Reduce asset capital investments 6–12 %, through the improved asset performance and the greater asset reliability.
- Reduce inventory 8–15 %, through streamlining lean process enablement and reducing execution variability.
- Reduce premium freight costs 10–15 %, through manufacturing events integration with the enterprise and supply chain.

13.5 Material Management Case Study of National Power Group

With the development of Chinese market economy, MM of power plant and power enterprise has changed dramatically. With the help of IT technologies, such as database and Internet, the suitable MMS can then be developed for power enterprises to solve many existing problems and challenges, and to improve their management level and market competitiveness.

Normally, one power enterprise is composed of multiple units in three tiers, i.e. power groups, distribution centers and power plants. For a long time, many power enterprises in China manage their material with very simple and traditional way. Each department of each unit can purchase its material separately, so any kinds of material can be purchased anytime from any vendor at any price and quantity, by anybody according to their own requirements and specification, which has caused many problems, such as the repeated and wasteful purchasing leading to overstocking, material quality and the occupation of funds, etc.

National power group (NPG) is the case study customer. To strengthen and improve MM and fulfill the challenge demands: "Unified management, centralized purchasing, regional distribution". The unified MMS is developed by NPG to support its unified MM procedure on three tiers (Fig. 13.10), and share accurate and real-time material information across NPG.

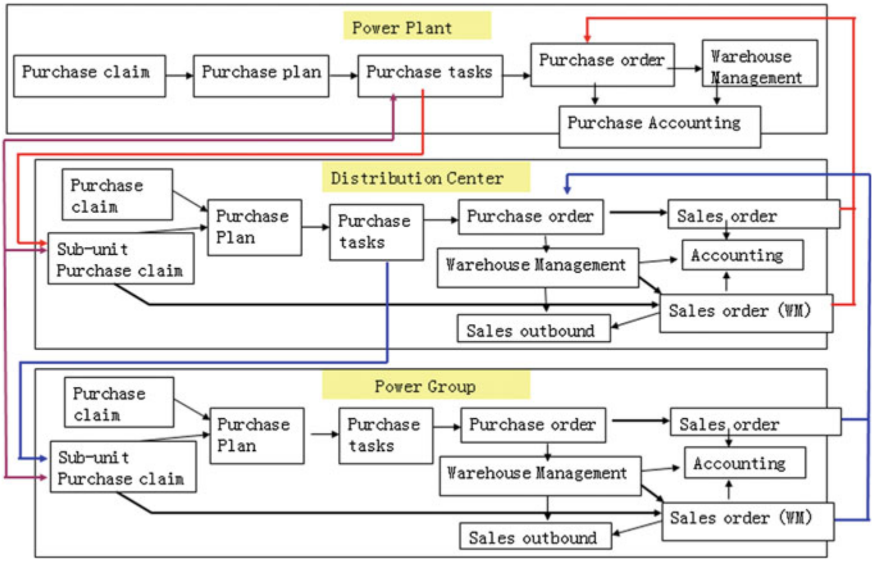

Fig. 13.10 Unified material management procedure on three tiers of NPG

13.5.1 Technical Solution of Material Management System

The technical solution of MMS (Xiong et al. 2012: Design and Development) greatly affects the whole system's availability, scalability security, and portability, so the solution should consider the technical architecture development trend, the future expansion and maintenance of MMS, must be designed and developed to meet the dedicated needs and specifications of MMS. So, the technical solution applies J2EE application server technology (Fig. 13.11), B/S architecture with three tiers. J2EE is a fully functional, stable, reliable, safe and fast enterprise-class computing platform; J2EE can help us quickly build the distributed, scalable, portable, reliable and secure server-side configuration. J2EE is composed of several Java-based technologies: EJB, and Servlet/JSP, and JNDI, JTA, JDBC etc. Concretely, the technical solution uses the following technologies:

- Follow J2EE specification and its B/S multi-tier architecture.
- Object-oriented component design and integration.
- Layer or specific data structure design.
- Standard XML data exchange.
- Visual and flexible control of process engine supports.

The separate procedure management of MMS also chooses the same technical solution to assure MMS's compatibility. Back-end database is Oracle9i Server. And, MMS is designed and developed with component program, standard unified interface for its extensibility. The business process of MMS is quite complex, which

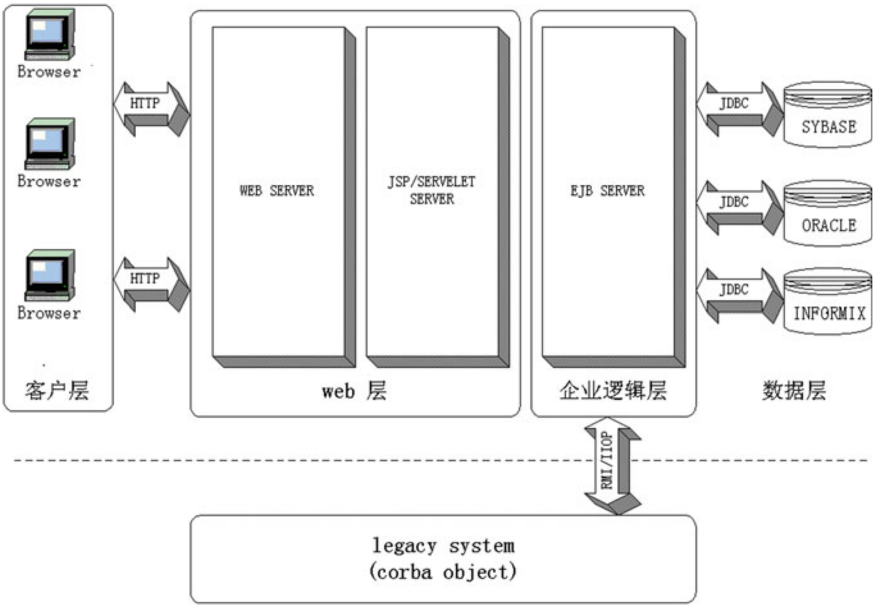

Fig. 13.11 J2EE technical architecture of MMS

can be divided into 3 tiers of management level, i.e. power group, distribution center, and power plant. MM functions of NPG are executed by MMS and online supermarket, which are described separately in detail below.

13.5.2 Main Functions of Material Management System

The main functions of MMS are (Xiong et al. 2012: Design and Development): system architecture, system management, customization management, process management, material code management, purchase plan management, contract management, settlement management, vendor management, bid management, warehouse management, inventory management, and KPI statistics management and interface management, etc.

(1) **Purchase plan management**
Material purchase plan are related with business process and data management, including material purchase claim plan, material supply, material procurement and query support.

- Materials purchase claim plan: to make initially by specific unit members and form plans after the approval of the department leader. Then, the procurement staff collects those plans, accumulates the same material from different members to form one material purchase claim plan of NPG.

- Procurement plan formula: material quantity ordered = material demand claimed + inventory reservation of period end—inventory reservation of period beginning—available resources within NPG.
- Preparation, decomposition and approval function of material purchase plans.
- Preparation and approval function of purchase order: procurement staff prepares purchase order according to procurement task.
- To track purchase order: to query material delivery time, deliver status, and arrive time of purchase order.
- Preparation and approval function of sales orders.
- To track sales orders: to query material arrival time of sales orders and material delivery and shipping information for sales orders.

(2) **Contract management**
Managing all material purchase contracts of NPG is its responsibilities. The function includes basic information, contract information, contract ordering and payment, and contract document. Its purposes are: to realize the standard accounting of contract management and the classified statistics function of procurement contract; to monitor contract implementation status for suitable action; to close the contract after its complete execution; to provide the resource plan staff about the material's expected arrival time, then the extra cash for payment can be prepared in advance to decrease the accounting gaps, and the overdue items can be tracked for the prompt warning.

(3) **Settlement management**
Settlement is divided into three categories: the purchase material settlement; the sales materials settlement; supermarkets material settlement. Settlement management deals with the approval and management for those three settlements, provides the settlement query and statistics function, and tracks the settlement status, etc.

(4) **Vendor management**
The vendor's document is saved digitally in MMS, so the vendors can be evaluated with MMS automatically. The main function of vendor management is to monitor all vendors in their lifecycles, whose targets are like real-time material delivery, and purchase cost reduction, etc.

(5) **Bid management**
The bidding application is extracted from the purchase order of the bidding documents. The bidding application is executed with the purchase order, like determining the bidding way (open, inviting), the material content, the bidding specifications and business specification, and the vendors invitation. The bidding application is submitted to the bidding organization after the internal approval.

(6) **Warehouse management**
Storage management manages the storage detailed information of warehouse material, which is the business process happens most frequently in warehouse management. It mainly manage material quantity and quality check for acceptance, and then insert, delete, modify, approve, book keep, and return the storage record,

print out the storage record, audit the achieved storage documents, and insert the audited material storage record into the inventory account and also material diary.

Material reception includes order goods reception and non-order goods reception. Non-order goods normally are the gift or bonus come with order goods reception. Goods are accepted for storage after passing the check, then to the supplier if the check fails. The accepted goods with order primarily are moved into a temporary storage in warehouse, then into formal storage after its invoice comes; the accepted goods without order is moved into formal storage directly.

• Material usage management
Manage the detailed usage information of warehouse material, which works only within one internal business unit, like power group, distribution center, or power plants. It is another business process occurred most frequently in warehouse management. It mainly insert, delete, modify, approve, book keep, and return the material usage bill, print out the material usage bill, audit the achieved material usage documents, and insert the audited material usage record into the inventory account and material diary.

• Sales management
Manage the detailed sales information of warehouse material. It mainly insert, delete, modify, approve, book keep, and return the material sales record, print out the material sales record, audit the achieved the material sales record, and add those audited the material sales record into the inventory account and material diary.

Sales management also manages the material usage details across one unit. For example, the materials move from power group or distribution center to power plant or external customer; the material move from power plant to another power plant or external customer.

Material sales should be a profitable process, so sales price is generally higher than its inventory cost price. Sale price guide can be generated automatically by MMS according to user-defined pre-conditions. For example, material cost, management cost, shipping cost and other reasonable costs should be taken into consideration.

• Materials transfer management
Material transfer refers to the physical or logical migration of material for the better management.

• Counting management
Normally, inventory counting table is generated according to inventory attributes, like last counting date and cycle, as well as counting stock, booking, engineering projects and other conditions in this time. New inventory counting details can also be added in accordance with actual needs. The counting cycle can 1 year, 1 month, or others. For temporary inventory counting, counting cycle properties is not considered for generating inventory counting table.

• Profit and loss management
Profit and loss account can be updated after importing the updated records of material gain and loss table. After auditing the difference reports, the updated quantity and value record can be inserted into the inventory account and material diary.

• Scarping MM
Focuses on registration management of the scrapped material, the required modifications can be inserted into the corresponding inventory account and material diary.

• Backlog MM
There are many backlog materials existing in every unit of power group. Backlog MM collect the information of backlog materials, power group centrally manages those backlog materials; adjust each backlog material among different units of NPG and external customers for effective usage.

• Central reserves management
For effective usage of all reserve of inventories existing in distribution centers, power group will centrally manage them. After the centralized reserve records are reported to power group and distribution centers, the reasonable transfer plan of each material can be found and executed among internal units and external customers.

(7) **Inventory Management**
The account and diary of inventory management is the concentrated reflection of inventory material balance and its ledger changes within an accounting cycle.

All changes affected by business within inventory system, like stock quantity, unit price, and value amount, etc. which should be reflected in stock ledgers and inventory account accurately. Then, by querying the ledger, users can check the real-time and historic records about material receiving, storing and delivery within inventory system.

• Virtual inventory management
Virtual inventory exists in power group or distribution center, its materials are backlog materials of every unit and central reserves materials. So, virtual inventory can centrally manage and make full use of them.

• Swap management
With the help of virtual inventory stock, internal customer can easily find the materials existing in internal inventories. When internal customer wants to purchase one material, he can firstly apply for the internal transfer from the material owner. If the material owner accepts the transfer agreement, the material purchase process can be executed internally, which means the lower material price and the shorter purchase time.

13.5.3 Key Performance Indicator of Material Management System

With the help of KPI, MMS can execute information management and support the communication, coordination and organizing of the whole material business activities, like inspecting, monitoring, tracking and evaluating process.

MMS should meet the business needs of power plant, distribution center and power group. Its decision-making should be based on statistics, classification and analysis of various data from different IT systems. The major KPI requirements for MM of NPG are as follows:

- To be suitable for statistical reports analysis of collected data, and to display multi-dimensional analysis results.
- To be suitable for the sensitivity analysis of supply chain management, the ultimate satisfaction of customers and the performance evaluation of 3 tier units of NPG.
- The scientific KPI model meets the needs of management and business. To achieve KPI based management target, the overall objective of MM can be divided into quantitative, operational and contrastive sub-objectives.

In particular, MM KPI of NPG is established with data reporting and extracting mechanism. Firstly, all data referring to indicators are centralized. Then, the analyzed results can be obtained with date mining and analyzing mechanism, and are shown as charts, pie charts, histograms, and trend flows, etc. Finally, the 3 tiers managers of NPG can obtain the comprehensive and accurate KPI analysis results of material planning, procurement, contract, storage, distribution and logistics finance in real-time, and then can make their decisions for production and management according to their experiences and KPI data.

The whole KPI of NPG is divided into three different levels (Xiong et al. 2012: Design and Improvement of KPI System):

- Top Level: KPI of power group includes macro management indicators which can be obtained through the specific indicators of distribution center and power plant.
- Middle Level: KPI of distribution center can carry out all kinds of management and performance evaluation based on the data and preliminary analysis from power plant.
- Bottom Level: KPI of power plant is derived from MM functions and its business flows.

According to MM functions, all indicators are divided into four major aspects: administrative indicators, financial indicators, service quality indicators and operating indicators. According to MM business process, all indicators can be classified as planning indicators, purchasing/ordering/contracting indicators, storage indicators and supply chain indicators. So, all KPIs are classified into 16 different zones (Fig. 13.12). Each indicator has its specific meaning, purpose of utilization, computing model, and data sources, etc. The KPIs was included in MMS, which has been applied successfully.

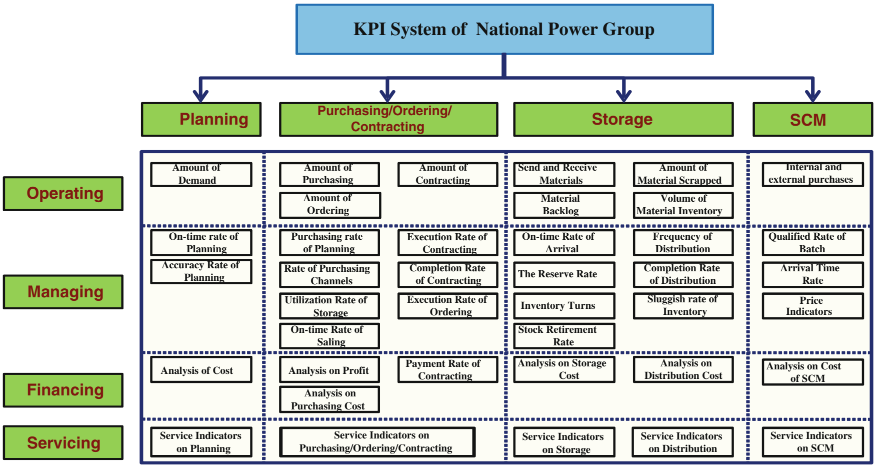

Fig. 13.12 KPIs classification of MMS

13.5.4 Online Supermarket of National Power Group

To become the common e-business platform for Chinese power industry, the online supermarket should have general MM function, efficient inventory control, standard and concise purchasing procedure, and complete analysis and reporting, etc. The main user's requirements of online supermarket are described as below (Hou et al. 2012: A Kind of Online Power):

- Demand side of power materials. By using computer browser or PDA, internal and external users or customers can login online supermarket.
- Suppliers side of power materials. After their qualified certification is checked and approved, an agreement is signed, external material suppliers can login online supermarket, where their advertisements can be released and their products can be found and sold online.
- Management department of online supermarket. To ensure information safety of all trade partners like customer and supplier, to offer the supervision of safe business transaction, and to provide the seamless and safe connection with NPG's internal MMS.
- E-bank (3rd party payment platform). It provides material buyers and sellers with secure and cheap online finance services around the clock, which are different from the traditional banking business. Besides the online payment, there are other payment ways, like COD (cash on delivery), bank transfer, post office remittance, and mobile-phone payment services, etc.
- Certificate authority. It keeps the integrity of transmission information and identify the users with digital certificate, which is a kind of digital files issued by specific authorities and always be individual identity in e-business affairs.

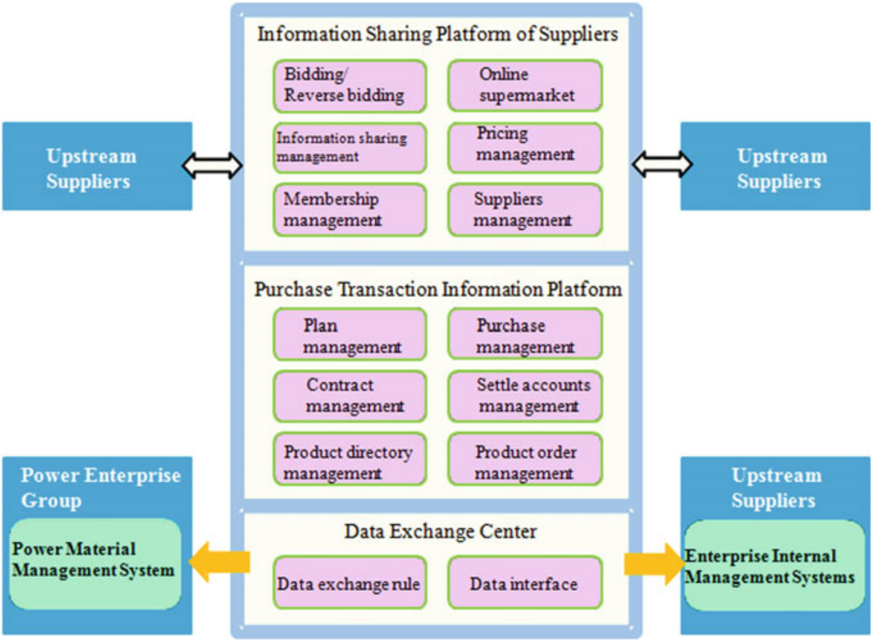

Fig. 13.13 The main functions of online supermarket

The digital certificate includes personal information, public key, certificate serial number and e-signature of certificate authority.

- Distribution center. To accept the delivery application, track the delivery process, and assure its integrity. The deliveries can be divided into domestic distributions and international distributions according to destinations, COD and delivery after online paid by payment ways.

The main functions of online supermarket are shown as Fig. 13.13, which can connect the upstream customer enterprises and downstream supplier enterprises. The internal subsidiaries plants are main customers, so the online supermarket offers the functions like planning, ordering, purchasing and settlement for suppliers and manufacturers. It also offers external users like registered suppliers, the relevant information services, and can connect with their internal IT systems. Online supermarket is composed of three parts:

- Information share platform of suppliers. It provides the member registration and authorization, supplier management, supply and demand information broadcasting, pricing service, online consulting and communication, online sell, and other related services like the integration with the internal MMS.
- Purchase transaction information platform. It provides the integrated online trade services for power enterprise group and its upstream manufacturers, such as purchasing plans, cooperation plans, e-procurements, contract managements,

Fig. 13.14 Online supermarket homepage

order managements, and settlements, etc. After fully developed, it would be used as the comprehensive e-business platform to offer trading servers for power enterprise group and its upstream manufacturers, its upstream manufacturers and their suppliers.

- Data exchange center. It provides data exchange services for e-business participants, including data exchanges between e-business and internal IT system, and data exchanges between e-business and external IT systems.

Now, the online supermarket of NPG (Fig. 13.14) is running on the homepage: (http://www.gdmec.net/phx/bidIndex.action).

13.5.5 Result Analysis and Conclusions

MMS (Fig. 13.15) has been applied to NPG and its subsidiaries, including more than 100 power plants (Fig. 13.16). Application results are summarized as below:

- The "one code refers one material, one material refers one code" accuracy of MM is improved by about 50 %, temporary coding (user codes) is declined by over 80 %. The purchase claims for unclear purpose is cut down by about 80 %. With the help of MMS, the purchase process is shortened by 30 %.
- MMS assures an open, transparent and standardized material procurement process; It acquires the relevant change information of MM, masters

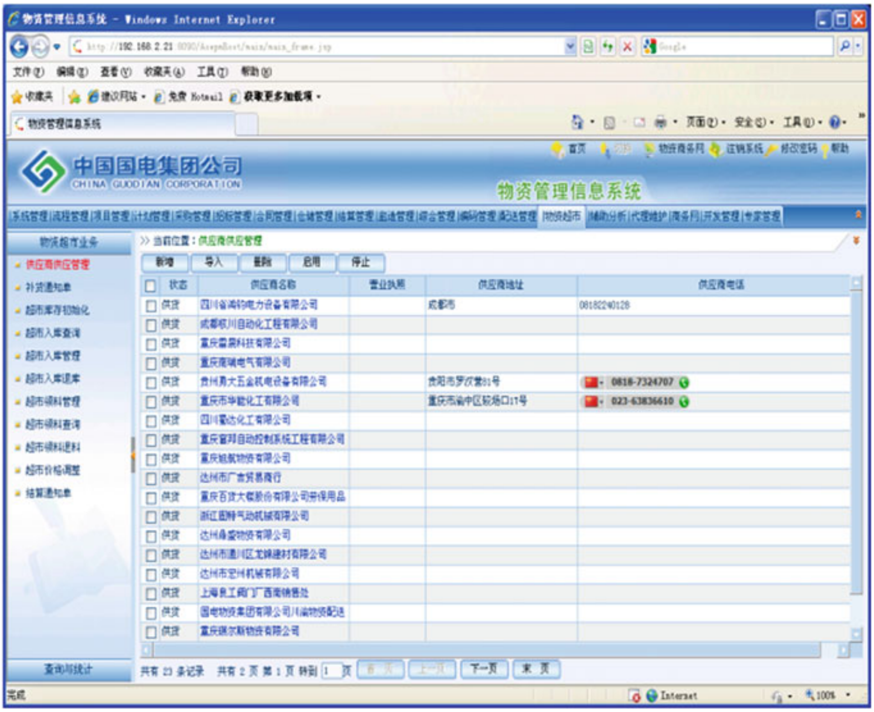

Fig. 13.15 MMS user interface of NPG

comprehensive, accurate and real-time material status understanding, and improves modernization and automation level of NPG's MM.

- MM of NPG is unified to control material purchase cost, project cost and operation cost, and improve the overall efficiency of NPG.
- The usability of MMS is accepted by end users from more than 100 units of NPG. The good results and achievements are praised by SASAC officer: "By referring large commercial chain's operation experience, NPG realizes the online supermarket operation mode and 'Zero inventories' of general materials, saves the reserved capital about 390 million RMB Yuan annually."

13.6 Development Trend of Material Management

MM is the engine that drives its Supply Chain and Logistics of manufacturing enterprises or other organizations. With the economy development and technical progress, Logistics will be transformed from 3PL continuously to 4PL and 5PL, and many manufacturers are transforming from Mass Production to Mass Customization

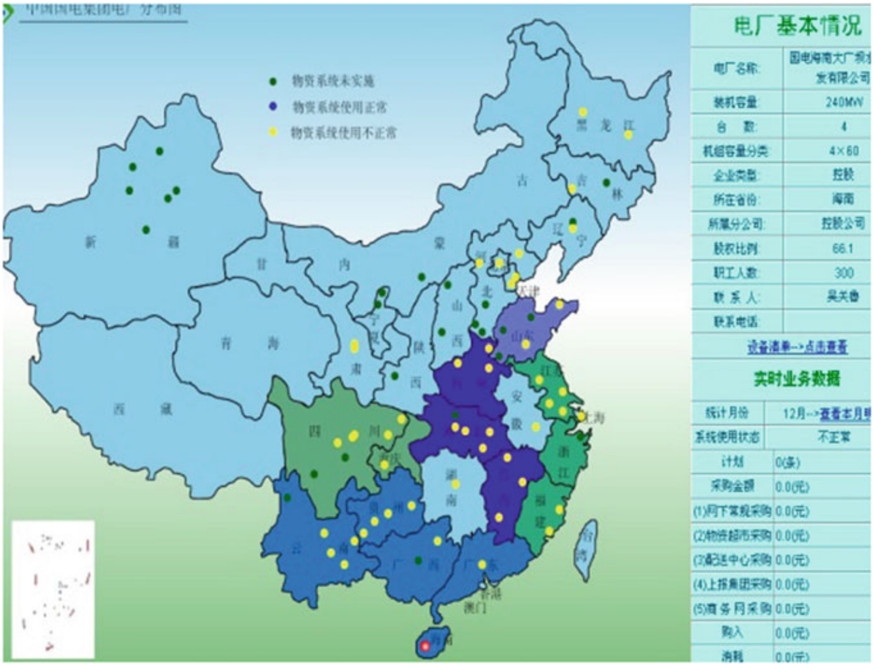

Fig. 13.16 NPG's unit distribution

(Xiong et al. 2010: Mass Customization) and continuously to Social Manufacturing (Wang 2012; Shang et al. 2013, 2014; Xiong et al. 2014; Tuomisaari et al. 2012). So, MM should continuously apply the latest ICT & intelligent technologies or systems, like Barcode, RFID, IoT, GPS, Cloud Computing, Big data, and Parallel Control and Management (Xiong et al. 2010, 2013), etc. Then, MM can realize its transformation and upgrade coordinately with its Supply Chain and Logistics. For examples, artificial system can be developed to improve the safety and reliability of power plants. Complex network can be applied for the vulnerability identification in Smart Power Grid. The latest cloud computing is introduced to enhance power distribution network management.

13.6.1 Logistics Upgrade to 4PLs

Fourth-Party Logistics (4PL) (Yongbin and Qifeng 2010; Tian et al. 2011; Yang et al. 2014) is a modern logistics operation mode, which originally introduced by Accenture in 1998. 4PL is the emerging industry (blue ocean strategy) of advisory firms to design specifically for 1PL, 2PL and 3PL to provide new services, such as: logistics planning, consulting, logistics, information systems, supply chain management and other activities. 4PL will provide an integrated logistics for the logistics industry, including finance, insurance, logistics and distribution arrangements. So, 4PL's main aim is to realize the logistics information sharing and make full use of the social logistics resources and realize the optimism operation of the logistics enterprises.

The main difference between 3PL and 4PL: 3PL is only mere provision of logistics services; 4PL also can assist in import and export tariffs, collection and other functions. 4PL is the logistics system designer, integrator and operator. For example, Accenture consulting company is 4PL operator, who does not actually participate in the specific logistics operations, and mainly provides software and planning, consulting, logistics information systems, supply chain management, and other services for 1PL, 2PL and 3PL companies.

4PL is a SCM provider, who provides the totally integration SCM solution for the customers:

- To manage and direct the activities of multiple 3PLs, serving as an integrator.
- To refinement on the idea of 3PLs.
- 4PLs are not asset based like 3PLs.
- To assemble and manage the resources, capabilities, and technology of its own organization and other organizations to design, build and run comprehensive supply chain solutions.

4PL's basic operating modes (Fig. 13.17; Yang et al. 2014) are: Cooperative operation mode; Integration operation mode; Industry cluster innovation operation mode; and Dynamic alliance operation model. Cooperative operation mode: Customer-oriented supply chain outsourcing, where the strategic capacity, supply chain management, IT and project management of 4PL can be realized through specific 3PL implementations; Integration operation mode: as a leader and hub, 4PL integrates the resources of multiple service providers into the dedicated logistics solution for one important customer; Industry cluster innovation operation mode: according to the specific requirements of specific industry, the mode leads the industry-wide supply chain innovation and upgrade of specific industry, integrates the industry-wide supply chain functions, and makes the best interests and benefits of the entire industry; Dynamic alliance operation mode: with the strong support of

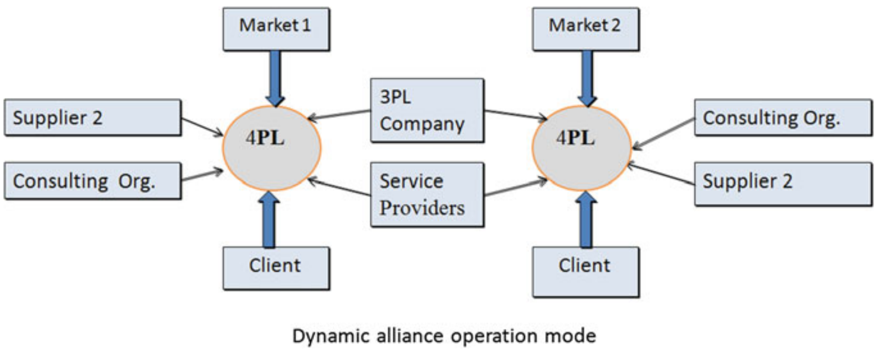

Fig. 13.17 4PL's basic operating mode

powerful 4PL IT platform, those independent service providers can be assembled into the supply chain management strategy alliance at one period for the dedicated purpose. The alliance's composition and dissolution depends on the major market opportunities and disappearances.

13.6.2 Logistics Upgrade to 5PLs

In the beginning of 21st century, United States Morgan Stanley first-ever created 5PL concepts (Wang 2014), and describes the pyramid map from 1PL to 5PL. During the evolution process from 1PL to 5PL, the logistics service providers have less and less physical assets, the capacity of data and information processing and usage increases, so it can realize the collaboration and optimization of the logistics and the supply chain better and better.

In summary, 5PL is logistics service providers, which provide customers with new collaborative supply chain services, system integration and optimization. Logistics organization set up the integrated linkage mechanisms to achieve the optimization of logistics system; By using logistics technologies, like e-commerce, Internet, and IT, an integrated supply chain can be established; By using information system, logistics operation executes the overall coordination, optimization and implementation of the logistics solutions; logistics service assemblies the portfolio members for the logistics optimization of supply chain. 5PL service factors and products are shown as Fig. 13.18 (Wang 2014).

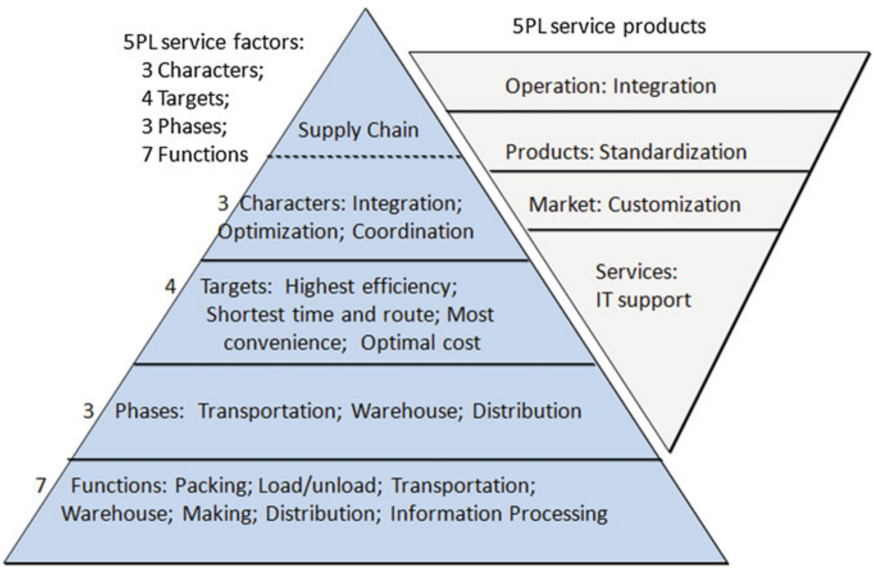

Fig. 13.18 5PL service factors and products

The main difference between 4PL and 5PL: 4PL involves in the actual operation, and the logistics information system can realize the integrated optimization of a single supply chain. The greatest advantages of 5PL are the supply chain logistics information and resources and their integrated management model. 5PL does not actually run the specific activities of the logistics operation, mainly provide value-added service activities, such as logistics information platform, supply chain logistics system optimization, supply chain integration, and supply chain capital operation. For example, the standardized logistics information systems of multiple supply chains help to achieve the integrated optimization. Possibly, 5PL can achieve the characteristics or benefits as below:

- Integrated Operation. To meet customer service needs, IT helps 5PL to link every phases of the supply chain of the customer cluster, to place the platform system into the customer's actual operations, and to collect real-time information by using the tracking, monitoring, assessment and rapid feedback of logistics operational information.
- Standardized Product Categories. The systematic convergence through benchmarking can help the realization.
- Customization market. Accurate market positioning can be found by logistics planning technology and system, through a combination of qualitative and quantitative analysis methods.
- IT supported services. By strategic design, a multi-interface, multi-user and trans-regional logistics service platform can be built up, where the service system can provides a variety of service combinations for every customer anytime.

13.7 Conclusions

The business and functional requirements of MM are from their Logistics and Supply Chain. The most important technical supports of MM are the latest ICT & intelligent technologies or systems. In the future, Logistics will upgrade from 3PL to 4PL and 5PL, and the upgrade of MM and Logistics Management will get support from intelligent technologies and systems, like IoT, GPS, Cloud Computing, Big data, Parallel Control and Management Systems.

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References

Balla, J., Layer, F.: Production Planning with SAP APO—PP/DS. Galileo Press, Boston (2006)

Deqiang, F., Wei, Z.: Integrate virtual logistics with the fourth party logistics. Int. Conf. Manage. Serv. Sci. (MASS). **2011**, 1–3 (2011)

Dong, J.Y., Lin, Z.D.: Material's coding system design and implementation of database [J]. Mech. Electr. Inf. **9**, 15–18 (2004)

Dong, X., Xiong, G., Hou, J., Fan, D.: Artificial power system based on ACP approach. In: IEEE Service Operations and Logistics, and Informatics 2012, pp. 133–137 (2012)

Fitz-Gibbon, C.T.: Performance indicators (BERA Dialogues No. 2, Clevedon, PA), Multilingual Matters Limited (1990)

He, X.D., Xie, F., Zhong, X.M., Mao, P.: Promotion on the establishment of materials coding management system in enterprise [J]. Light Met. **5**, 3–5 (2004)

Ho, h.: China Strategist Industry Overview. 2001

Hou, J., Xiong, G., Liu, X., Fan, D., Liu, S.: A kind of online power materials supermarket system. In: IEEE International Conference on Automation and Logistics, pp. 57–62 (2012)

John, G.: Strategic Supply Chain Alignment, pp. 391–409. Economic Management Press, Beijing (2003)

Lei, H.J.: KPI design methodology and the corresponding cases analysis, Bus Tech. Res.**6**, 54–56 (2006)

Liu, X., Sun, Y.: Information flow model of third-party logistics based on internet of things. In: IEEE International Conference on Computer Science and Automation Engineering (CSAE), pp. 582–586 (2011)

Liu, W., Wang, X.Y., Ji, Y.L.: The thinking about the materials coding management system of Chinese military [J]. Logistics Tech. **4**, 46–47 (2005)

Murray, M.: SAP MM——Functionality and Technical Configuration. Galileo Press, Boston (2006)

Piasecki, D.J.: Inventory Accuracy: People, Processes, and Technology. Ops Publishing, Madsion (2003)

Shang, X., Liu, X., Xiong, G., Cheng, C., Ma, Y., Nyberg, T.R.: Social manufacturing cloud service platform for the mass customization in apparel industry. In: IEEE International Conference on Service Operations and Logistics, and Informatics, pp. 220–224 (2013)

Shang, X., Su, B., Liu, X., Xiong, G., You, Z.: Social manufacture cloud mode in high-end apparel, footwear and hats. In: The 11th World Congress on Intelligent Control and Automation (2014)

Tian, L., Fan, C., Zou, J., Zhang, X.: Analysis and research for fourth party logistics based on internet of things. In: 2011 First International Conference on Instrumentation, Measurement, Computer, Communication and Control, pp. 585–588 (2011)

Tuomisaari, H., Nyberg, T., Mäkelin, M., Xiong, G., Tynjälä, T.: Business model transformation as an explanation of dramatic demand-supply change events. In: IEEE Service Operations and Logistics, and Informatics 2012, pp. 345–349 (2012)

Wang, F.: From social computing to social manufacturing: one coming industrial revolution. Bull. Chinese Acad. Sci. **27**(6), 658–669 (2012)

Wang, S.: The application of "The fifth party logistics theory" in the field of emergency logistics. China Bus. Market. **28**(2), 41–45 (2014)

Xiong, G., Chen, Y., Shang, X., Liu, X., Nyberg, T.R.: AHP fuzzy comprehensive method of supplier evaluation in social manufacturing mode. In: The 11th World Congress on Intelligent Control and Automation (2014)

Xiong, G., Dong, X., Fan, D., Zhu, F., Wang, K., Lv, Y.: Parallel traffic management system and its application to the 2010 Asian games. IEEE Trans. Intell. Transp. Syst. **14**(1), 225–235 (2013)

Xiong, G., Dong,X., Liu X., Nyberg, T.R.: Real-time manufacturing integration and intelligence solution: case study in global chemical company. J. Softw. **7**(8), 1727–1737 (2012)

Xiong, G., Fan, D., Liu, S., Nyberg, T.R., Wang, F.: Mass customization manufacturing solution for cell phone production. In: IEEE International Conference on Automation and Logistics, pp. 518–523 (2010)
Xiong, G., Hou, J., Fan, D., Dong, X.,Yao, Y., Shang, X.: Design and development of material management system for power enterprise group. In: IEEE International Conference on Automation and Logistics, pp. 63–68 (2012)
Xiong, G., Hu, L., Qin, T., Nyberg, T.R., Wang, F., Shi, Q.: Design and improvement of the material coding standardization for power group enterprise. In: IEEE International Conference on Automation and Logistics, pp. 597–602 (2010)
Xiong, G., Liu, S., Dong, X., Zhu, F., Bin, H., Fan, D., Zhang, Z.: Parallel traffic management systems improved the traffic status of the 2010 Asian games in Guangzhou. IEEE Intell. Syst. **27**(3), 74–78 (2012)
Xiong, G., Nyberg, T.R.: Push/pull production plan and schedule used in modern refinery CIMS. Robot. Comput. Integr. Manuf. **16**(6), 397–410 (2000)
Xiong, G., Qin, T., Wang, F., Hu, L., Shi, Q.: Design and improvement of KPI system for materials management in power group enterprise. In: IEEE Service Operations and Logistics, and Informatics 2010, pp. 171–176 (2010)
Xiong, G., Wang, K.F., Zhu, F.H., Cheng, C.: Parallel traffic management for 2010 Asian games. IEEE Intell. Syst. **24**(5), 81–85 (2010)
Xiong, G., Wang, F., Zou, Y., Cheng, C., Li, L., Liao, C.-Y., Cui, F., He, L.: Parallel evaluation method to improve long period ethylene production management. Control Eng. **13**(3), 401–406 (2010)
YanYan, G.: Research on countermeasures to the problems in the development of the fourth party logistics in China. In: International Conference on E-Product E-Service and E-Entertainment (ICEEE), pp. 1–3 (2010)
Yongbin, H., Qifeng, W.: Study on the forth party logistics information service platform based on web services. In: 2010 International Conference on Innovative Computing and Communication and 2010 Asia-Pacific Conference on Information Technology and Ocean Engineering, pp. 330–333 (2010)
Zhang, G.A., Liang, S.: The analysis on the future of materials coding management in military [J]. Reporting Stand. **16**(1), 11–14 (1995)
Zheng, L., Pan, T., Yan, G.: Research of mobile security solution for fourth party logistics. In: 2010 Sixth International Conference on Semantics Knowledge and Grid (SKG), pp. 383–386 (2010)
Yang, Z., Wang, H., Lai, D., LI, B.: Optimization of supply chain integrated management under the fourth party logistics operation mode. Value Eng. **3**, 25–28 (2014)

Part VI
Economical and Financial Management

Chapter 14
Argumentative SOX Compliant and Intelligent Decision Support Systems for the Suppliers Contracting Process

Jesus Angel Fernandez Canelas, Quintin Martin Martin and Juan Manuel Corchado Rodriguez

Abstract More and more our society is linked to the stability of financial markets and this stability depends on key players like private companies, financial markets, investors, analysts, government control agencies and so on. Sarbanes-Oxley Act is a mandatory law in EEUU market and a facto standard in rest of the world and has as main objective to keep the desire financial stability. Within this chapter it will be shown a new decision support intelligent financial model over SOX compatibility based on Artificial Intelligent technology together with Theory of Argumentation. The main aim of this model is to help and support private companies, auditors, executive boards and regulatory bodies to take a SOX compliant decision over an specific process of a typical purchasing financial cycle: **The Contracting Process**. The decision will be supported by the whole argumentation process drive by this model and will be reinforce with quality measures with the final objective to create a very clear argumentative background about the suggested decision. This model directly contributes to both scientific research artificial intelligence area and business sector. From business perspective it empowers the use of intelligent models and techniques to drive decision making over financial statements. From scientific and research area the impact is based on the combination of the following innovative elements: (1) an specific Information Seeking Dialog Protocol, (2) a Facts Valuation based Protocol in which previous gathered facts are analyzed, (3) the already incorporated initial knowledge coming from human expert knowledge, (4) the Intra-Agent Decision Making Protocol based on deductive argumentation

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and (5) the Semi Automated Fuzzy Dynamic Knowledge Learning Protocol giving as a result a novel approach to this kind of problems.

Keywords Multiagent systems (MAS) · Decision support systems (DSS) · Sarbanes-Oxley act (SOX) · Argumentation · Artificial intelligence (AI) · Business intelligence (BI) · Expert systems (ES) · Fuzzy knowledge

14.1 Introduction

Information management is a key topic in today's globalization society and its present in all aspects of our life. From social relationships to business activities. The amount of available information and the amount of information sources are so high that an effective control on such info is really needed to really get benefit on it. It is in this effective control where business intelligence can provide us real added value. Business intelligence can be considered as a combination of methods, techniques, procedures and systems dedicated to help humans in making business decisions. Whatever system designed with the objective to help and support humans in decision making, can be considered a DSS (Decision Support System). The right balance and management of the key complexity variables will determine the performance and success of an specific DSS system and will be key elements in designing such kind of systems. On the other hand, a non proper balance of such kind of elements can generate a DSS system design that will wrongly direct us to take erroneous decisions. It is evident in such environment that a proper goodness fit analysis is needed to properly evaluate and determine the credibility of an specific DSS system.

Decision making is a human process in which a right information management process is the key for making successful decisions. Key questions like what information do we need, why do we need such info, when do we need the info, where do we need the info or how or in which format do we need such info are key questions that should be crystal clear as starting point. A wrong answer in one of those questions will redirect us to take not the best possible decisions. Due to complexity of the topic, business is a field in which decision making is really important. Such complexity is determined by several factors like the questions already presented together with the huge amount of information sources or the amount of such available information (What, Why, When, Where, How, #sources, size_of_info). Such complexity is determined by the right info, in the right moment, in the right place, in the right format, from the right sources and with the right detailed. Not more, not less. There are several levels of information systems in a company. Depending on the complexity and added value. In the basic level there will be pure transactional systems: the objective will be to record each and every transaction of an specific topic like purchases, sales, etc. Next level will be management information systems in which managers can access to transactions information in a summarized way and usually this kind of systems generate periodical monthly reports. There is no intelligence inside such systems.

Another level are those systems able to provide executive reports and dashboards to let top management an helicopter view about ongoing operations of the company. As well those systems are not incorporating any added value intelligence. The next level are those systems helping top management to take decisions based on existing facts and based on an internal artificial intelligence engine those are the DSS systems. Thinking on real financial DSS models it is really important to identify in an early stage the real problem our DSS model is going to be focus with the main objective to solve such problem from and efficient and effective perspective. Based on such idea, our model has born from the reality as it is explained below.

Enron, US multinational company focus on gas and electricity publishes in October 2001 its financial quarterly results with 600 US millions dollars of losses and its stocks decrease from $90 to 30 cents. This is the beginning of its bankruptcy, firing thousands of employees, significant losses on its shareholders, financial markets are collapsed by contagion and social alarm shoots up. Very few months before, on August 2001, Enron reached its historical maximum in the stock exchange market with $90 per share, showing a very healthy financial situation. The social alarm had jumped and the financial irregular practices begin to be visible. After Enron's collapse, other companies like Global Crossing, Worldcom, Tyco or Adelphia show similar financial situation. Principal stock markets worldwide went down showing as well lack of confidence. In July 2002, United States approved the SOX Law (Sarbanes-Oxley Act) in response to all these financial scandals, with the last aim to increase the government control on the economic and financial operations of private sector, control the audits of its accounts, protect the investors, avoid massive dismissals and try to return the calm to the financial markets. This Law is mandatory inside US, but at the same time, turns into a worldwide facto standard due to the high degree of globalization. The present SOX law, in effect nowadays, was created to improve financial government control over US companies. This law is a factor standard out of United States due to several factors like present globalization, expansion of US companies or key influence of US stock exchange markets worldwide (Fernandez et al. 2013a, b, c, d).

Present chapter shows a method to support decisions about the Suppliers Contracting Process and its compliance with this law, using both technologies of Artificial Intelligence and Argumentation Theory. From Artificial Intelligence point of view, there are nowadays several intelligent techniques like expert systems, case base reasoning systems, fuzzy systems, neural networks, genetic algorithms or intelligent agents among others that can be used alone or in a mixed hybrid way like in this paper to implement the desired model. The objective of the present method is on one side to design a decision support intelligent system based on argumentative negotiation technologies to check if Suppliers Contracting Process is compliant with SOX. This helps companies to take corrective actions and helps as well auditors to support their findings and decisions. It provides as well an structured method based on recognized technologies of Artificial Intelligence, Negotiation Techniques and Argumentation Theory. On the other side, as secondary objective, this system will provide a quality measure of the analyzed business case according to a previously defined criteria. This chapter is structure as follows: Sect. 14.2

describes the State of the Art of both relevant areas in which this chapter is based on and states the starting point of this work. Section 14.3 describes the proposed model specifying the key elements as well as the main protocols of the system. Section 14.4 presents a possible integration of the previously proposed system with a higher level multiagent system. Sections 14.5 and 14.6 will provide a clear real example of the use or our proposed model over a real business case. Finally, Sect. 14.7 will remark the conclusions here obtained.

14.2 State of the Art

14.2.1 Artificial Intelligence and Argumentation Theory Relationship

Nowadays Artificial Intelligence has been identified like one of the most important fields of application of the Argumentation Theory (Fernandez et al. 2013a, b; c, d; Fox et al. 1992; Krause et al. 1995; Dimpoulos et al. 1999; Dung 1995; Besnard and Hunter 2008; Bench-Capon and Dunne 2007; Kraus et al. 1998; Moraitis and Spanoudakis 2007; Rahwan and Simari 2009; Amgoud 2012, 2013; Atkinson et al. 2013; Azhar et al. 2013; Gabbriellini and Torroni 2013, 2014; Medellin-Gasque et al. 2013; Zeng et al. 2013). Artificial Intelligence and Argumentation Theory can be seen combined together in many other subjects like: (1) Computational models of argumentation, (2) Argument based decisions making, (3) Deliberation based on argumentation, (4) Persuasion based on argumentation, (5) Search of information for inquiring based on argumentation, (6) Negotiation and resolution of conflicts based on argumentation, (7) Analysis of risks based on argumentation (8) Legal reasoning based on argumentation, (9) Electronic democracy based on argumentation, (10) Cooperation, coordination, and team building based on argumentation, (11) Argumentation and game theory in multiagent systems, (12) Argumentation Human-Agent, (13) Modeling of preferences in argumentation, (14) Strategic behavior in argument based dialogues, (15) Deception, truthfulness and reputation in the interaction based on argumentation, (16) Computational complexity of the dialogues based on argumentation, (17) Properties of dialogues based on argumentation (success, termination, etc.), (18) Hybrid models of argumentation and (19) Implementation of multiagent systems based on argumentation.

There are two difference tendencies about automatic argumentation: (1) Abstract Argumentation and (2) Deductive Argumentation. The Abstract Argumentation is focused in the coexistence of arguments without getting into detail of its meaning. It only takes care about the attack relationships among arguments and their acceptability or not and in which grade. One of the most important studies so far and whose concepts are still valid nowadays are the Abstract Argumentation Systems of Dung (1995). Boella et al. (2006) proposed an extension of Dung's model in which the arguments are dynamic elements not predefined in advance. Deductive Argumentation is another option to the Automatic Argumentation. Deductive models are based on formulas and based on Classical Logic. The arguments, opposite to the Abstract Argumentation, are complex elements that can be subdivided in elements or arguments of more simple structure. Deductive Argumentation is able to manage the complexity of the internal structure of the arguments. The key concept inside this type of argumentation is the logical deduction. The fundamental objective of whatever model of deductive argumentation is to reach a conclusion based on a support formed by arguments and reasoning of deductive logic. In the literature we find a recent study carried out by Besnard and Hunter (2008) which is focused on Deductive Argumentation inside the area of Artificial intelligence. Deductive Argumentation is about how to manage non evident information (information that is not known if it is or not acceptable or truthful) and should generate arguments to support or against this information so that after a process of deductive reasoning, the conclusion about its truthfulness or admissibility is reached.

Argumentation Theory is a key area in Multiagent Systems due to the following two characteristics: (1) On one hand, Argumentation Theory finds in Multiagent Systems a wide field of practical application, allowing Multiagent Systems to get benefits from an entire formal solid theory and with a wide history and where formal existent models in Argumentation Theory offer a wide range of possibilities in the design of this kind of systems (2) On the other hand, Argumentation Theory offers a solid and formal base to Multiagent Systems which allows us to provide those systems with a syntactic and semantic structure which helps to the design of these kind of systems and to reach their own objectives. Multiagent Systems area uses Argumentation Theory and their formal models, for internal reasoning, for their individual agents or in share reasoning among all the agents of the system. About shared reasoning, agents dialog among each other with the final objective to get the common shared previously defined objective. This communication among the agents which conform the Multiagent System, is a key element to reach the objectives of this system. And it is in this communication and in these dialogues where Multiagent Systems area is closed to Argumentation Theory, because those dialogues can be driven by previously well defined dialog models. The success of a Multiagent System consists on achieving its objective for which was designed. The grade of success in getting this objective will depend on the fruitful communication among its agents. And thanks to Argumentation Theory, we can provide a solid formal base to this communication and their corresponding dialogues.

Walton and Krabbe in 1995 made one of the most important initial works about communication in Multiagent Systems based on argumentation techniques (Walton and Krabbe 1995). They defined the most important basic types of dialogues: (1) Dialogues based on information seeking, (2) Dialogues based on questions, (3) Dialogues based on persuasion, (4) Dialogues based on negotiation, (5) Dialogues based on deliberation, (6) Dialogues based on dialectical battles, (7) Dialogues based on commands, (8) Dialogues based on discovery of alternatives, (9) Non cooperative dialogues and (10) Educational dialogues. In 2005, Cogan et al. (2005) made a work in which it is explained a new type of dialogue, the verification dialogues. Tang and Parsons (2006) designed an specific deliberation dialogue model in which the global action plan of the full multiagent system is formed by the union of the sub plans of each agent after a deliberation process with the rest of the agents. There are studies as well that propose modifications to the previously enumerated dialogues (Amgoud et al. 2000; Reed 1998) but always message interchanging between the participant agents is the key idea. This interchange of messages follows several guidelines according to the dialogue type, the initial knowledge of the agents, the reasoning protocol or the mode of argumentation. In the literature we can find as well works suggesting different types of messages to be used depending on the type of dialogue: (1) Messages of Assertion, (2) Messages of Acceptance, (3) Question Messages, (4) Challenged Messages, (5) Testing Messages and (6) Answer Messages. The semantic of those types of messages is specified by preconditions and post conditions.

Nowadays, Multiagent Systems and Argumentation Theory are both areas very much related as we can see in many present scientific researches like: (1) In 2009 Belesiotis et al. (2010) designed a dialogue model based on reasoning, deliberation and tentative knowledge to use Argumentation Theory over calculus of situation plans. (2) Devereux and Reed (2009), proposed an specific model for strategic argumentation in rigorous persuasion dialogues in which it is push the concept of attacking not only the initial knowledge of the agents, but as well this missing knowledge that does not belong to the agent. (3) Matt et al. (2010), designed a model based on dominant decisions on argumentative agents. The idea behind this work is that all possible decisions provided by each agent will be value based on previously indicated preferences looking for maximize the final benefit. This mechanism is as well a procedure to auto explain the winner decision. (4) Wardeh et al. (2010) proposed a multi-party argument model based on the past experience of the agents to classify an specific case. This work promotes the idea that each agent uses data mining techniques and associative rules to solve the case based on its own experience. (5) Morge and Mancarella (2010) proposed an argumentation model based on assumptions to drive the argumentation process between agents with the objective to reach the optimal agreement between all the agents. (6) Thimm (2009) proposed an argumentation model for multiagent systems based on Defeasible Logic Programming in which each agent generates support and opposite arguments to answer the objective question. At the end the most feasible argument is selected to answer the initial question.

14.2.2 Artificial Intelligence Applied to SOX

We can find several studies showing the use of Artificial Intelligence in law financial topics (Chen and Sutchliffe 2012; Ho et al. 2012; Li and Krause 2011; Marghescu et al. 2012; Neri 2012; Peat and Jones 2012; Samakovitis and Kapetanakis 2013; Sarlin and Marghescu 2011; Thakur 2012; Vaez et al. 2013; Gholipour et al. 2014). Some of those works are before SOX Law and show the existing concern about if the financial company reports show the real situation of the company or not (Fernandez et al. 2013a; b, c, d). Changchit et al. (1999), before the SOX Law, remarked the concern about truthful financial reports of companies and remarked the positive impact of using intelligent systems to identify problems on the internal controls of those companies. It constitutes a good example of interaction between Artificial Intelligence and Financial Area. Meservy (1986) designed an expert system to audit companies internal controls. This work is as well before the publication of the SOX Law. O'Callaghan (1994) suggested an artificial Intelligence model based on back propagated neural networks to simulate the revision of fixed actives of a company using an application of internal controls based on the COSO (Committee of Sponsoring Organizations of the Treadway Commission) model. Another work done by Liu et al. (2009) presented an evaluation model of internal controls based on fuzzy knowledge, pattern classification and data mining with the objective to check the effectiveness of company internal controls. Kumar and Liu (2008) is another example that uses techniques of patterns recognition to audit the internal controls and company processes. Alden et al. (2012) is one example more in which genetic algorithms are used with the objective to detect fraudulent situations in financial audits. Changchit and Holsapple (2004) proposed an expert model to evaluate the internal controls by company management with the objective to evaluate the performance of the company internal controls. Korvin et al. (2004) made a work about which internal controls can be used inside an IT system and valuate using fuzzy knowledge techniques, the risk over specific threats.

Deshmukh and Talluru (1998), is another example to value risks on specific threats in company internal controls. This work is based on fuzzy sets theory and lets the management of the company to decide if their internal controls are or not effective and to take appropriate actions. Fanning and Cogger (1998) designed a fraud detection system based on Neural Networks using the data published by the company in its periodical results as input to the system. It is another example in which Artificial Intelligence provides its tools to the Financial Area. Fanning and Cogger based their work on other two previous studies which applied techniques of neural networks to Economy and Finances (Coakley et al. 1995; Fanning and Cogger 1994) and combined them with traditional mathematics techniques to create their model of prediction of financial fraudulent reports. Welch et al. (1998) proposed an specific model to look for financial fraud and support audit decisions based on the use of genetic algorithms. This work is focused on fraud research on government suppliers looking for fraud patterns to identify evidences of these frauds. Srivastava et al. (1998) proposed an specific system to evaluate and plan audits using belief functions based on intelligent expert systems. Sarkar et al. (1998) developed an expert model based on beliefs networks and uses probabilistic models on the inference process.

Nowadays and in relation to the model here design, after revising different international bibliographical sources and up to the best of our knowledge it isn't found any publication that uses Multiagent Systems and Argumentation Theory in the implementation of SOX internal controls with the objective to detect if a Supplier Contracting Process of an specific business case is compliant with SOX Law supporting auditors and companies to take their appropriate decisions about this compliance.

14.3 Proposed Model

The model we present here, is based on the model we proposed on our previous work (Fernandez et al. 2013a, b, c, d) with several added value factors that let us to analyzed an specific business case from a contractual theoretical perspective. The objective of the present work is to design an argumentative SOX compliant intelligent decision support expert system over the Suppliers Contracting Process of the financial Purchasing Cycle using technologies of Artificial Intelligence and Argumentative Negotiation to support companies to identify non SOX compliant situations before it will be too much late and to support financial auditor to decide if the economic and financial periodical results published by those companies are or not compliant with SOX Law. It is as well explained how this system can be incorporated into a higher level multiagent intelligent expert system to cover the full financial Purchasing Cycle. As well the second objective is to provide a quality measure of the contracting process carried out in the analyzed business case. There are seven different key financial typical cycles in whatever company: (1) Purchasing Cycle, (2) Inventory Cycle, (3) Sales Cycle, (4) Employees Payment Cycle, (5) Accounting Cycle, (6) Information Technologies Cycle (as support to other financial cycles) and (7) Cycle of Services Outsourcing. Financial results published by a company will be compatible with SOX Law, if all economic and financial operations that belong to these results are as well SOX compliant. All those economic and financial operations are SOX compliant if all projects or business cases which form those results are SOX compliant too. An specific business case will be SOX compliant if all its financial cycles, are compatible with SOX Law.

The key processes of a typical Purchasing Cycle usually are: (1) Suppliers' Selection, (2) Suppliers' Contracting, (3) Approval of Purchase Orders, (4) Creation of Purchase Orders, (5) Documentary Receipt of Orders, (6) Imports, (7) Check of Invoices, (8) Approval of Invoices without Purchase Order and (9) Suppliers' Maintenance. The Purchasing Cycle of a certain business case will be compatible with SOX regulation if all its processes, including the Suppliers Contracting Process, are SOX compliant. Financial cycles are sets of key processes with clear objectives. They share at the same time a common unique objective as well. This is the best scenario to implement a multiagent intelligent scientific approach providing well founded tools and concepts to the solution of the problem. The agent which is going to model this expert system has being designed with an specific optimized structure to reach the final objective. The elements of this agent are:

1. Agent's Target.
2. Original Starting Know-How
3. Facts Searching Discussion Protocol
4. Facts Scoring Protocol
5. Facts Scoring Matrix
6. Deductive Decision Making Protocol.
7. Dynamic Fuzzy Learning Protocol

14.3.1 Agent's Target

The agent's main objective is to verify if the suppliers contracting process of the business case that is being analyzed is or not compatible with the SOX legislation. As secondary objective, it will provide a measure of the quality of the contracting process carried out in the analyzed business case. For both objectives, it will be check if every belief on the initial beliefs base matches or not with a fact of the facts base of the business case, and in case of matching, how much is this matching (quantitative value of this matching).

14.3.2 Original Starting Know-How

Here it is stored the initial knowledge of the agent as a set of beliefs. It represents the knowledge the agent has on the specific analyzed process without taking in mind any other possible knowledge derived from the experience and from the learning. Those beliefs will be enumerated and their characteristics will be indicated.

14.3.2.1 Contracts Warehousing

This is a key belief of the knowledge base of the Suppliers Contracting Agent. The existence or not of a fact of the analyzed business case that matches to this belief will be a key point for SOX compatibility as well as for the final valuation of the quality of the Suppliers Contracting Process. This is a critical factor from SOX legislation point of view in terms of transparency of whatever financial or economic company operation. Contracts should been stored in a centralized repository to be available to all respective affected company departments: Procurement, Sales, Finance and Control, Support, etc. It is as well a relevant belief from quality point of view as it is the final result of all done negotiations with those suppliers. Existence and store of contracts is very important from SOX and quality point of view, but those contracts should be as well signed. Otherwise it will mean a non SOX compliant and a lack of quality in this contracting process.

14.3.2.2 Pricing, Terms and Conditions Monitorization

This is a key belief of the knowledge base of the Suppliers Contracting Agent. The existence or not of a fact of the analyzed business case that matches to this belief will be a key point for SOX compatibility as well as for the final valuation of the quality of the Suppliers Contracting Process. This is a critical factor from SOX legislation point of view in terms of transparency of whatever financial or economic company operation. Basically, this belief is focused on monitoring pricing, terms and conditions already negotiated with suppliers and reflected on existing contracts over real purchase orders. More in detail, this monitorization is looking for discrepancy on pricing, payment terms (for example, 30, 60 or 90 days) and delivery terms (incoterms) between contract and received invoices from suppliers. Incoterms (there are different versions like 2000 or 2010) are the facto standards from international organizations to specify in which point between manufacturer and purchaser the goods or services are delivered and who pays transport and delivery costs. A simple example on how to monitor those aspects inside the business case could be to compare business case monthly cost with pricing, terms and conditions reflected in already received suppliers invoices.

14.3.2.3 Pricing, Terms and Conditions System Implementation

This is a key belief of the knowledge base of the Suppliers Contracting Agent. The existence or not of a fact of the analyzed business case that matches to this belief will be a key point for SOX compatibility as well as for the final valuation of the quality of the Suppliers Contracting Process. This is a critical factor from SOX legislation point of view in terms of transparency of whatever financial or economic company operation. This belief refers to the registration of the already negotiated pricing, terms and conditions stated in the contract over the internal management system the company uses to create purchase orders towards suppliers. With this approach, all purchase orders will have always right prices, terms and conditions unless manual modification of those conditions.

14.3.2.4 Reselling Agreement

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, reselling agreement details have been taken into consideration. Hardware and software purchases can have two different usages inside a company. It can be an indirect or direct sourcing. Indirect source just in case the final use of the products is for our company and direct sourcing when products have been acquired to be sold later on as standalone or being part of a higher platform or solution. Reselling agreement is needed in direct purchasing activities and its objective is to clearly state that original manufacturer allows the purchaser to resell those goods later on to a third party and in which conditions.

14.3.2.5 Invalid Clauses

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, invalid clause details have been taken into consideration. This is a generic clause that states just in case some clauses are invalid due to several reasons, rest of the clauses remain still valid. Just in case a fact of the analyzed business case matches with this belief, it will denote a good quality of the Suppliers Contracting Process point of view.

14.3.2.6 License Rights

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, license rights details have been taken into consideration. This refers to the fact how seller grants specific rights to buyer over the specific product like for example: right of use, right of copy, right of modification, right of distribution, right of integration, right of adaptation, right of marketing, right of hosting, etc. This belief does not apply to services contracting.

14.3.2.7 Confidentiality

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, confidentiality details have been taken into consideration. Just in case a fact of the facts base of the analyzed business case matches this beliefs, it means that seller and buyer agreed on a confidentiality agreement about how to share information both technical and commercial and that this information will not be share with third parties.

14.3.2.8 Export Control and Applicable Law

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, export details have been taken into consideration. Details like export/import taxes, customs procedures, type of product or the Export Control Classification Number that should be clear and agreed in advanced between seller and buyer.

14.3.2.9 Intellectual Property Rights

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, intellectual property rights details have been taken into consideration. The objective here is to clearly state who is the owner of the ideas (intellectual part) under which the specific product has been designed. In hardware, intellectual property rights belong to the manufacturer who has designed it and during contracting process, seller agree to transfer specific rights different than intellectual ones to the buyer. In software, usually seller sells to buyer a license of use, keeping intellectual property rights on seller side. Usually, intellectual property rights are protected by copyrights, patents and trademarks. In contracting processes about software with source code, it is a must to agree who will be the owner of the intellectual property rights. When contracting hardware or commercial software packages, usually, this intellectual property will remain on manufacturer side.

14.3.2.10 Contract Assignment Right to Third Parties

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, contract assignment right details have been taken into consideration. This means that during contracting process, seller and buyer will clearly state if the rights over the product can be transfer or sell to third parties or not.

14.3.2.11 Product Availability

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, product availability details have been taken into consideration. It is fundamental that product life cycle will be taken into consideration during contracting process thinking on the future use of the product and thinking as well on the combination of this product with other owned products. Unexpected future product availability can have an important economic impact.

14.3.2.12 Documentation

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, documentation details have been taken into consideration. Supplier should provide to buyer all available technical information during or before contracting process.

14.3.2.13 Epidemic Failures

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, epidemic failure details have been taken into consideration. Epidemic failures in an specific product can have a huge economical impact if this product was bought to be part of a higher platform. The impact will depend on the number of units or platforms distributed among end customers. To better handle this situations it is convenient to agree with supplier on an emergency procedure to better mitigate this risk and look for the best possible solution as soon as possible. It is convenient as well to agree who is going to cover collateral costs with origin in this epidemic failure as well as costs to generate a potential solution.

14.3.2.14 Force Majeure

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, force majeure details have been taken into consideration. The final objective of this belief is to assure that the other party takes proper actions to mitigate the negative impact on the other side.

14.3.2.15 Warranty

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, warranty details have been taken into consideration. This guarantee should never be less than local law regulations.

14.3.2.16 Inspection and Testing

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, inspection and testing details have been taken into consideration. The purchased product is according to the specifications of the agreed contract and in case of failure, it will be indicated to the seller to activate as soon as possible the warranty process.

14.3.2.17 Applicable Law and Conflict Resolution

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, applicable law and conflict resolution details have been taken into consideration. In the contracting process, it is about the local country under which whatever law dispute will be handle.

14.3.2.18 Product Liability

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, product liability details have been taken into consideration. It refers to the money buyer can get from seller in case of not proper design or function of the product. This protects the buyer from the seller.

14.3.2.19 Logistics

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, logistics details have been taken into consideration. It refers to packing, labeling, storing and transport details between seller and buyer.

14.3.2.20 Support and Maintenance

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, support and maintenance details have been taken into consideration. When we are buying software and hardware it is very important as well to make a contract to cover support and maintenance as well. There are several types of support and maintenance. The higher the maintenance detail is, the higher the quality of the contracting process is.

Hardware and software generic maintenance	
Network maintenance	Emergencies
	Helpdesk
	Technical queries
Preventive maintenance	Preventive tests
	Preventive regular tests
	Sporadic security controls
	Periodical security controls
Service availability maintenance	Licenses checking and upgrade
Software upgrades	Upgrades planning
	Upgrades installation
	Acceptance tests
	Verification tests

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Expert support	Onsite maintenance
	Tailor made technical support
	Testbed support
	Special events support
Specific hardware maintenance	
Spare part management	Spares supply
	Replacement
	Startup
Repair spares management	Recycling
	Repair

14.3.2.21 Quotations

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, quotation details have been taken into consideration. Seller agrees to deliver the products to buyer under all details indicated on the specific previous quotation and seller accepts as well to deliver those products under all terms and conditions indicated by buyer in the respective purchase order.

14.3.2.22 Business Practices

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, business practices details have been taken into consideration. It refers to make business in accordance with applicable laws and from an ethical point of view too.

14.3.2.23 Pricing

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, pricing details have been taken into consideration. From the beginning, all prices should be reflected by written.

14.3.2.24 Acceptance Procedure

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, acceptance details have been taken into consideration. It is convenient to agree by written between seller and buyer a set of acceptance test to be done at the time to deliver the product. Those tests will be different depending on hardware or software.

14.3.2.25 Purchase Orders Procedure

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, purchase orders details have been taken into consideration. It refers to agree by written in the contract the specific procedure to indicate to the seller the products the buyer wants. The terms and conditions of the purchase order should be the same as the ones indicated in the contract.

14.3.2.26 Products

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, product details have been taken into consideration. It refers to indicate in the contract the products cover under this specific agreement and the terms and conditions that apply to them. In case of services, It should be indicated as well the needed products and tools to deliver those services. If the contract does not clearly indicate covered products and services, the scope of the contract hast not been properly indicated.

14.3.2.27 Buyer Ownership

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, buyer ownership details have been taken into consideration. Whatever document, data, tool or software provided by buyer to seller during contracting process is own by buyer and whatever document, data, tool or software provided by seller to buyer during this contracting process is own as well by buyer unless specifically agree and written the opposite.

14.3.2.28 General Remedies

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, general remedies details have been taken into consideration. This is a buyer security provision just in case seller breaks the warranty or the contract. Basically it states the right the buyer has to claim for monetary compensation just in case the seller breaks the warranty or the contract.

14.3.2.29 Quality Requirements

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, quality requirements details have been taken into consideration. Seller should review supply products to assure the quality of the products and buyer can make inspection tests to assure as well the quality. This should be clearly indicated in the contract.

14.3.2.30 Ethical Requirements

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, ethical requirements details have been taken into consideration. It refers to clearly state by written in the contract the ethical behavior by seller and buyer and that all business practices between both will respect human rights and local law regulations.

14.3.2.31 Environmental Requirements

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, environmental requirements details have been taken into consideration. This refers to accept by written in the contract the applicable law about environmental issues.

14.3.2.32 Termination

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, termination details have been taken into consideration. This refers to clearly state in the contract by written the exact date of contract finalization. It should state as well that purchase orders before this deadline should be accepted by seller.

14.3.2.33 Delivery Terms

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, delivery terms details have been taken into consideration. The objective of this belief is to check with incoterm has been agreed to deliver the product.

14.3.2.34 Payment Terms

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, payment terms details have been taken into consideration. This is about the number of days between the invoice sent by supplier and the payment done by buyer. Frequent examples would be: 30 days, 60 days, 90 days.

14.3.2.35 Delivery Time

This belief is not critical for SOX compatibility, but it will help on quality improvement of the Suppliers Contracting Process. The objective of this belief is to check if during the Suppliers Contracting Process, delivery time details have been taken into consideration. It refers to the time between purchase order sent by buyer and the effective date when supplier delivers the product. If this is not cover by the contract, this would mean a Suppliers Contracting Process lack of quality.

14.3.3 Facts Searching Discussion Protocol

This protocol is designed to let the agent interrogates the analyzed business case looking for relevant information about the Suppliers Contracting Process to be analyzed later on to determine on the basis of the initial knowledge of the agent, the quality degree of the followed process in that business case, as well as to value if the above mentioned process has complied with SOX. The agent inquires the business case according to the beliefs it has in its initial knowledge, and for every question, the agent will gather from the business case an answer with the needed detailed information accordingly to every belief. This protocol is designed taking in mind two ideas: (1) one of the most important elements of an agent is its initial knowledge formed by its beliefs, and (2) a business case (the followed Supplier Contracting Process) can be considered as a set of facts which constitute all the information about how things were done along the life of the above mentioned business case. The aim of this protocol is to capture for every belief of the agent, the correspondent fact of the facts base of the business case which corresponds with the above mentioned belief. Once captured, it will be necessary to see how much it is in line with the specific belief of the agent both from a quality point of view and from SOX compliant point of view. Basically this protocol consists on the idea that the agent asks to the business case (about the Suppliers Contracting Process), “how did you do this?”, and the business case will answer to the agent with the “arguments” or “evidences” of how it did it. Evidences that later on will be analyzed by the agent. It is necessary to keep in mind that the agent has a clear idea of how it is necessary to do things in every stage of the business case based on its initial knowledge, and that what the agent is looking for, is to analyze if inside the business case, things were done as should be.

This Facts Searching Discussion Protocol constitutes a phase in which the agent individually explores the whole documentation of the analyzed Suppliers Contracting Process with the objective to compile as much evidences as possible on how things were done. Those beliefs as already commented, constitute the initial knowledge or original starting know-how of the agent and represent the fundamental characteristics of the process that the agent is analyzing. The Suppliers Contracting Agent analyzes the Suppliers’ Contracting Process and in the above mentioned process there is a series of key characteristics as contract warehousing, pricing terms and conditions monitorization, reselling agreement, …etc. This kind of details are “beliefs” of the agent and more important, inside these beliefs, inside its agent’s initial knowledge, the agent has a clear idea of how things should be done. When the agent analyzes the business case with this protocol, it compiles all the facts of the Suppliers Contracting Process which match with its beliefs. It can happen that for a certain belief a fact does not exist in the facts base of the business case, denoting steps inside the business case that they should have done and have not been like that. For example not inviting different companies to the contest, and assigning without any criteria the contest to a certain company. With this protocol, the agent will take this under consideration for future stages at the time to value the quality of the process and take the appropriate decision about SOX compatibility according to this situation. The inspection of the agent over the business case will be realized across a mediating agent which will facilitate the communication between both. This mediating agent represents the person responsible for the business case in the company, and for each question of the agent who analyzes the case, can seek inside the business case documentation (documentation of the followed Suppliers Contracting Process) to analyze the above mentioned documentation and to provide a response to the formulated question. Here (Fig. 14.1) it is presented the protocol in which the agent inquires the analyzed business case with the objective to gather needed information about its beliefs. This collected information will allow to value the initial beliefs of the Suppliers Contracting Process from SOX compatibility point of view and from quality point of view.

Let’s see in next the next section how to value these collected facts.

Fig. 14.1 Facts searching discussion protocol

14.3.4 Facts Scoring Protocol

This protocol allows the agent to be able to value the facts previously gathered as evidences from the business case (Suppliers Contracting Process) with the Facts Searching Discussion Protocol. The valuation of these evidences will be carried out based on two approaches: (1) quality of the process, and (2) compatibility with SOX legislation. Two weight factors have been assigned to each belief respectively for quality and for SOX compatibility. The weight of quality will denote the relevance of that belief in the global valuation of quality of the whole analyzed process. The weight of SOX compatibility will only denote if this specific belief is relevant or not from SOX compliant point of view. Qualities' weight will be used in a numeric way to calculate the final quality of the specific analyzed process. SOX compatibilities' weight won't be used in a numeric way, it will indicate if that belief is or not relevant for the compatibility with SOX legislation. Regarding valuation of quality, there will be numeric values inside the range [−10, 10], where −10 will denote a penalization in the valuation of quality, and 10 will denote the maximum value of quality. Regarding valuation of SOX compatibility, the possible values will be logical boolean values: true (t) or false (f). True denotes that this belief matches a fact of the facts base of the analyzed business case (about the Suppliers Contracting Process) and therefore the analyzed process by this agent, regarding that belief, is compatible with the SOX legislation. False value will mean the opposite.

This is an example (see Table 14.1):

This agent has ten key beliefs composing the original starting know-how of the agent: (1) Contracts warehousing, (2) Pricing, terms and conditions monitorization, (3) Pricing, terms and conditions system implementation, (4) Reselling agreement,

Table 14.1 Facts scoring protocol

Belief type	Critical or irrelevant for SOX compatibility
	Important or not for the quality of the process
SOX compatibility weight	1 if it is needed and mandatory for SOX compatibility
	0 in rest of cases
Quality weight	X (the agent's beliefs don't have the same relevance in the quality of the process. Critical SOX beliefs will have a total relevance of 50 % over the rest of agent's beliefs although these would be less in number.)
SOX compatibility valuation	Logical boolean valuation: true (t) or false (f) (t) if this belief exists in the facts base of the analyzed business case (f) in rest of cases (NA) in case this belief is irrelevant for SOX compatibility
Quality valuation	Valuation of the fact of the analyzed business case corresponding to this belief inside the range [−10 (penalization), 10]

(5) Invalid clauses, (6) License rights (7) Confidentiality, (8) Export control and applicable law, (9) Intellectual property rights, (10) Contract assignment right to third parties, (11) Product availability, (12) Documentation, (13) Epidemic failures, (14) Force majeure, (15) Warranty, (16) Inspection and testing, (17) Applicable law and conflict resolution, (18) Product liability, (19) Logistics, (20) Support and maintenance, (21) Quotations, (22) Business practices, (23) Pricing, (24) Acceptance procedure, (25) Purchase orders procedure, (26) Products, (27) Buyer ownership, (28) General remedies, (29) Quality requirements, (30) Ethical requirements, (31) Environmental requirements, (32) Termination, (33) Delivery terms, (34) Payment terms and (35) Delivery time.

As an example this is the Scoring Protocol for the first belief (Table 14.2).

14.3.5 Facts Scoring Matrix

In this section, It is showed in table format (Table 14.3) all valuations gathered by the previous Facts Scoring Protocol over each one of the facts of the analyzed business case.

It is needed to highlight, as indicated before, that SOX compatibility weights are indicators of if that belief is or not relevant from SOX compatibility point of view. In

Table 14.2 Contracts warehousing protocol

Belief type	Critical for SOX compatibility. Important for the quality of the process.
SOX compatibility weight	1 (needed and mandatory belief for SOX compatibility)
Quality weight	0.5/3 (The 35 beliefs that compose the base knowledge don't have the same relevance in terms of quality over the Suppliers Contracting Process. The SOX critical beliefs have a total relevance of 50 % over the rest of beliefs. In this case there are 3 SOX critical beliefs and 32 non SOX critical ones)
SOX compatibility valuation	Logical boolean valuation with values true (t) or false (f) (t) if this belief occurs in the facts base of the analyzed business case (f) in rest of cases
Quality valuation	Valuation of the fact of the business case that corresponds to this belief inside the range [−10 (penalization), 10] −10 (penalization) If this belief does not match with any fact or if contracts are not signed 5 if signed contracts are only store in electronic format 10 if signed contracts are stored in electronic format with digital certificates or in paper with original manuscript signatures

Table 3 Facts scoring matrix

Agent's facts scoring matrix over the suppliers contracting process	SOX compatibility valuation	Quality valuation of the suppliers contracting process
	Weight (value)	Weight (value)
1. Fact corresponding to the belief 1	[1 or 0] [T or F or NA]	w12 V12
2. Fact corresponding to the belief 2	[1 or 0] [T or F or NA]	w22 V22
3. Fact corresponding to the belief 3	[1 or 0] [T or F or NA]	w32 V32
…	…	…
N. Fact corresponding to belief N	[1 or 0] [T or F or NA]	wn2 Vn2
	V.SOX_COMP = [T OR F]	V.QUALITY = P12 V12 + P22 V22 + P32 V32 + ⋯ + Pn2 Vn2
	(Intra-agent SOX inference rule)	

the case of being a relevant belief for SOX compatibility, it will be indicated with an unitary weight (1), and its value according to the previous protocol, will be true (t) meaning that it is SOX_COMPLIANT or false (f) meaning NON_SOX_COMPLIANT. In the case of being an irrelevant belief for SOX compatibility, its weight will be null (0), and their value won't be relevant (it doesn't apply, NA). The final valuation of SOX compatibility of the whole agent over the Suppliers Contracting Process, will be calculated by an inference rule describe more in detailed in the next protocol (Deductive Decision Making Protocol). The final valuation of quality of the analyzed process by this agent, will be given by the weighted sum of all the quality values obtained in each one of the analyzed facts of the business case. Table 14.4 describes more in detailed the Facts Scoring Matrix for the Suppliers Contracting Process.

Detailed explanation of SOX weights:
As indicated in Table 14.1, the key beliefs of the agent can be relevant or irrelevant from SOX point of view. Relevant ones will have weight 1 and irrelevant ones will have weight 0.

Detailed explanation of quality weights:
As indicated in Table 14.1, agent's beliefs don't have the same relevance from quality point of view. When we are analyzing the full process among the 35 beliefs of the agent, we have two groups: the SOX important ones (3 beliefs) and the non SOX important ones (32 beliefs). The number of beliefs in both groups is different but from quality point of view, both groups have same relevance (50 %). This is a subjective decision coming from our experience in this field. As we have 3 SOX relevant beliefs, each respective weight will be 50 % divide by 3. (0.5/3). Rest of the non SOX relevance beliefs will have the rest of the relevance: this means the other 50 % divide by 32 non SOX relevance beliefs. (0.5/32).

Table 14.4 Facts scoring matrix of the suppliers contracting process

Suppliers contracting process	SOX compatibility valuation	Quality valuation of the suppliers contracting process
	Weight (value)	Weight (value)
1. Contracts warehousing	1 (v)	0.5/3 (v)
2. Pricing, terms and conditions monitorization	1 (v)	0.5/3 (v)
3. Pricing, terms and conditions system implementation	1 (v)	0.5/3 (v)
4. Reselling agreement	0 (NA)	0.5/32 (v)
5. Invalid clauses	0 (NA)	0.5/32 (v)
6. License rights	0 (NA)	0.5/32 (v)
7. Confidentiality	0 (NA)	0.5/32 (v)
8. Export control and applicable law	0 (NA)	0.5/32 (v)
9. Intellectual property rights	0 (NA)	0.5/32 (v)
10. Contract assignment right to third parties	0 (NA)	0.5/32 (v)
11. Product availability	0 (NA)	0.5/32 (v)
12. Documentation	0 (NA)	0.5/32 (v)
13. Epidemic failures	0 (NA)	0.5/32 (v)
14. Force majeure	0 (NA)	0.5/32 (v)
15. Warranty	0 (NA)	0.5/32 (v)
16. Inspection and testing	0 (NA)	0.5/32 (v)
17. Applicable law and conflict resolution	0 (NA)	0.5/32 (v)
18. Product liability	0 (NA)	0.5/32 (v)
19. Logistics	0 (NA)	0.5/32 (v)
20. Support and maintenance	0 (NA)	0.5/32 (v)
21. Quotations	0 (NA)	0.5/32 (v)
22. Business practices	0 (NA)	0.5/32 (v)
23. Pricing	0 (NA)	0.5/32 (v)
24. Acceptance procedure	0 (NA)	0.5/32 (v)
25. Purchase orders procedure	0 (NA)	0.5/32 (v)
26. Products	0 (NA)	0.5/32 (v)
27. Buyer ownership	0 (NA)	0.5/32 (v)
28. General remedies	0 (NA)	0.5/32 (v)
29. Quality requirements	0 (NA)	0.5/32 (v)
30. Ethical requirements	0 (NA)	0.5/32 (v)
31. Environmental requirements	0 (NA)	0.5/32 (v)
32. Termination	0 (NA)	0.5/32 (v)
33. Delivery terms	0 (NA)	0.5/32 (v)
34. Payment terms	0 (NA)	0.5/32 (v)
35. Delivery time	0 (NA)	0.5/32 (v)

14.3.6 Deductive Decision Making Protocol

In this section it is shown the reasoning side of the Suppliers Contracting Agent which uses a deductive argumentation protocol, makes its own decision about if the Suppliers Contracting Process of the analyzed business case is or not SOX compliant. This protocol is based on Classical Logic Theory or Logic of Predicates and the central base of this protocol is an inference rule which uses as arguments, the result of the valuation of beliefs from the previous phase (Facts Scoring Matrix). Specifically those relevant beliefs for SOX compatibility. The objective of this protocol is to try to demonstrate the truthfulness of a hypothesis that establishes that the process that is being analyzed by this agent is compatible with the SOX legislation (Table 14.5).

To demonstrate the truthfulness of this hypothesis, the agent relies on the following elements:

1. Agent's Target.
2. Original Starting Know-How
3. Facts Searching Discussion Protocol
4. Facts Scoring Protocol
5. Facts Scoring Matrix
6. Deductive Decision Making Protocol.
7. Dynamic Fuzzy Learning Protocol

The Suppliers Contracting Agent will determine the truthfulness or not of the corresponding hypothesis based on an inference rule using the Deductive Decision Making Protocol. This inference rule will come specified in advance by a combination of the agent's beliefs or the agent's initial knowledge with a learning factor that will gather the previous accumulated experience in past business cases, together with the option of new dynamic knowledge collected by a human expert just if needed (Figs. 14.2 and 14.3).

Table 14.5 Agent's hypothesis

	Individual hypothesis
1. Agent of suppliers contracting process	H1: The Suppliers Contracting Process followed in the analyzed business case complies with the SOX regulation

(CONTRACTS_WAREHOUSING (Evidence1) ▲
PRICING_TERMS_AND_CONDITIONS_MONITORING (Evidence2) ▲
PRICING_TERMS_AND_CONDITIONS_SYSTEM_IMPLEMENTATION (Evidence3)) ▼
LEARNING_FACTOR (Evidence1, Evidence2,Evidence3) ⟶

SOX_COMPLIANT(PROCESS_OF_CONTRACTING)

Fig. 14.2 Main rule

(¬ CONTRACTS_WAREHOUSING (Evidence1) ▼
¬ PRICING_TERMS_AND_CONDITIONS_MONITORING (Evidence2) ▼
¬ PRICING_TERMS_AND_CONDITIONS_SYSTEM_IMPLEMENTATION (Evidence3)) ▲
¬ LEARNING_FACTOR (Evidence1, Evidence2, Evidence3) ⟶

NON_SOX_COMPLIANT(PROCESS_OF_CONTRACTING)

Fig. 14.3 Complementary rule

This protocol uses notation of Classical Logic or Predicates Logic with its logical operators: ¬ (negation), ▲(conjunction), ▼(disjunction), → (implication), ↔ (biconditional). The arguments to be used in this protocol are: (1) Contracts Warehousing, (2) Pricing, Terms and Conditions Monitoring, (3) Pricing, Terms and Conditions System Implementation and (4) Learning Factor. First three arguments represent the agent's static knowledge based on their beliefs or base knowledge. The fourth argument represents its experience or dynamic knowledge, it means, the knowledge that this agent has acquired as the time went on in the analysis of other business cases. The arguments that represent the static knowledge are part of the antecedent of the inference rule and are the result of the valuation of their boolean respective functions in the process followed with the Facts Scoring Protocol for SOX compatibility, and therefore they are variables with true (t) or false (f) value. The argument that represents the dynamic knowledge, will also have true (t) or false (f) value depending on the result of the learning protocol. This learning protocol will take into consideration evidences presented by the business case in this contracting process. SOX_COMPLIANT is defined like a boolean function or logical predicate that can take boolean true (t) or false (f) values and its semantic represents the compatibility with the SOX regulation. SOX_COMPLIANT (PROCESS_OF_ CONTRACTING) composes the consequent of the main inference rule and therefore based on its arguments, this rule allows us to obtain its truthfulness or falsehood. The conclusion is represented by the consequent of the previous inference rule and its truthfulness will depend on the truthfulness of the predicates that form the antecedent of the rule. These previous inference rules establish that SOX_COMPLIANT (PROCESS_OF_ CONTRACTING) will be true if their three antecedents belonging to the static knowledge (arguments 1, 2 and 3) are true at the same time, or, if the learning factor (4) that represents the dynamic knowledge indicates this truthfulness. SOX_COMPLIANT (PROCESS_OF_CONTRACTING) will be true (t) if all critical beliefs for SOX compatibility (static knowledge) are true, or, although they weren't, it will be also true (t) if its dynamic knowledge (learning factor) indicates it, based on its past experiences. This means Dynamic Fuzzy Learning Protocol will be taken in use only if the initial static knowledge by itself cannot determine a positive SOX compatibility. The truthfulness or not of SOX_COMPLIANT (PROCESS_OF_CONTRACTING) will allow us to demonstrate or to reject the hypothesis previously outlined. NON_SOX_COMPLIANT (PROCESS_OF_

CONTRACTING) is defined as well as a boolean function or logical predicate which can take true (t) or false (f) values and is the logical complementary predicate of SOX_COMPLIANT.

14.3.7 Dynamic Fuzzy Learning Protocol

This Dynamic Fuzzy Learning Protocol is based on our previous work (Fernandez et al. 2013a, b, c, d) plus specific innovations which improve its performance from contractual point of view perspective. The agent uses its static knowledge or fundamental beliefs to determine the SOX compatibility of the analyzed Suppliers Contracting Process. If the static knowledge cannot determine a positive SOX compatibility, this Dynamic Fuzzy Learning Protocol will be taken in use. There is the possibility that based on the agent's previous experience it can be verified if in similar cases with similar evidences and after consulting to the human expert, it was decided to value this process as compatible with SOX. In other words, to see if this case is an exception to the static knowledge of the agent. There are specific situations that can go beyond the static initially predefined beliefs, and that they will be based on specific court judgments over real cases in which a very specific context after the analysis of the court gives a result of SOX compatibility even although static initial knowledge states a non SOX compatibility. It means we would be under exceptions of real cases that the human expert knows and that belong to court resolutions or decisions of the control organisms on specific business cases where a series of specific evidences, opposite to what it is indicate by the initial knowledge, would have determined a positive SOX compatibility. These exceptions, through the learning protocol, will allow our agent to learn and to evolve beyond the initial knowledge formed by its beliefs. As indicated by Capobianco et al. (2004), the agents should be able to adapt to dynamic and changing environments. In this line, Fukumoto and Sawamura (2006) proposed a model in which the results or conclusions are back propagated to the initial knowledge to enrich future possible argumentations. With this protocol, the agent is able to change its beliefs, improving its knowledge beyond its initial state. As the time goes on, the system should learn from its previous experiences (PE) with previous analyzed business cases as well as from the consultations to an external human expert (HE) representing the knowledge over recent court decisions on exceptional situations so it can define the following learning factor relationship (lf) that represents how the knowledge of the system is evolving with each new business case. Here, it can be seen how the previous experience combines with the opinion of the external human expert and feeds the "future" previous experience term, allowing the system to accumulate the knowledge and learn. In real life, sometimes we can find previous similar experiences but not exactly the same ones. This is model under the SE (similar experiences) term that models some kind of uncertainty or fuzzy knowledge. In this case a certain tuple of evidences (e1′, e2′, e3′) can be considered as (e1, e2, e3) if an only if their respective degree of belonging to those evidences is for example 90 %. This percentage is called, degree of certainty and will be represented by ϕ. If we don't want to take uncertainty of fuzzy knowledge into consideration, we will take this parameter as 100 %.

$$lf : \underset{(pet,het,set)}{PExHExSE} \underset{\rightarrow}{\rightarrow} \underset{lf(pet,het)}{PE} \tag{14.1}$$

Given a state "t" in which the model is analyzing an specific business case, for each specific tuple of evidences e1, e2 and e3, it can be defined the learning factor (lf) as a function of the previous experience (pe) in that moment, similar (but not equal) previous experiences (assuming a certain risk or degree of uncertainty) and the opinion of the human expert (he) taking into consideration the combination of both evidences.

$$lf_t^{e1e2e3} = \alpha_t^{e1e2e3} \cdot pe_t^{e1e2e3} + \beta_t^{e1e2e3} \cdot se_t^{e1e2e3} + \gamma_t^{e1e2e3} \cdot he_t^{e1e2e3} \tag{14.2}$$

α_t^{e1e2e3} is the activation factor of the previous experience (pe) on an specific instant t and for specific evidences e1, e2 and e3. Its value on instant t will be 1 just in case there is previous (equal) experience for those evidences and 0 if no previous experience.

$$\alpha_t^{e1e2e3} = \begin{cases} 1 & \text{if} \exists\, lf_i^{e1e2e3} \in \{0,1\}, \quad i \in \{1,\ldots,t-1\} \\ 0 & \text{otherwise} \end{cases} \tag{14.3}$$

β_t^{e1e2e3} is the activation factor of the similar experiences (se) term on an specific instant t and for specific evidences e1, e2 and e3. Its value on instant t will be 1 just in case we accept a certain risk or degree of uncertainty in our approximation to the evidences e1, e2 and e3.

$$\beta_t^{e1e2e3} = \begin{cases} 1 & \text{if}\, \phi < 100\,\%, \; \phi \in [0\,\%,\ldots,100\,\%] \\ 0 & \text{if}\, \phi = 100\,\% \end{cases} \tag{14.4}$$

ϕ is the degree of certainty we assume. A value of 100 % means no uncertainty. This means 100 % of certainty so we are not assuming any kind of risk at the time to find similar experiences in the past. If ϕ is minor than 100 %, then we are assuming a certain degree of uncertainty when we are approximating the past evidences e1′, e2′ and e3′ like e1, e2 and e3 respectively under specific previously defined criteria. ϕ is the degree of certainty, so it means that (100 %-ϕ) represents the degree of uncertainty or risk we are assuming in our approximations of two past evidences (e1′, e2′, e3′) by (e1, e2, e3).

We defined $\mu_{e1'}^{e1}$ as well, like degree of belonging of e1′ to e1, being e1′ a past evidence and e1 the evidence we are analyzing on instant t.

We defined $\mu_{e2'}^{e2}$ as well, like degree of belonging of e2′ to e2, being e2′ a past evidence and e2 the evidence we are analyzing on instant t.

We defined $\mu_{e3'}^{e3}$ as well, like degree of belonging of e3′ to e3, being e3′ a past evidence and e3 the evidence we are analyzing on instant t.

The condition to consider or approximate a past evidence e1′ to e1 should be that $\mu_{e1'}^{e1} \geq \phi$

The condition to consider or approximate a past evidence e2′ to e2 should be that $\mu_{e2'}^{e2} \geq \phi$

The condition to consider or approximate a past evidence e3′ to e3 should be that $\mu_{e3'}^{e3} \geq \phi$

Taking in mind that evidence e1 (and e1′ too) represent contracts warehousing fact, we correlate $\mu_{e1'}^{e1}$ with the already got quality valuation of this belief according to the Facts Scoring Protocol showed in previous sections. This criteria is subjective and comes from our experience.

$$\mu_{e1'}^{e1} = \frac{\text{quality\_valuation of (contracts\_warehousing for e1}')}{10} * 100 \tag{14.5}$$

The maximum quality valuation according to Facts Scoring Protocol is 10, so previous expression is showing the quality valuation rate of e1′.

Taking in mind that evidence e2 (and e2′ too) represent pricing_terms_and_conditions_monitorization fact, we correlate $\mu_{e2'}^{e2}$ with the already got quality valuation of this belief according to the Facts Scoring Protocol showed in previous sections. This criteria is subjective and comes from our experience.

$$\mu_{e2'}^{e2} = \frac{\text{quality\_valuation of (pricing\_terms\_and\_conditions\_monitorization fore2}')}{10} * 100 \tag{14.6}$$

The maximum quality valuation according to Facts Scoring Protocol is 10, so previous expression is showing the quality valuation rate of e2′.

Taking in mind that evidence e3 (and e3′ too) represent pricing, terms and conditions system implementation fact, we correlate $\mu_{e3'}^{e3}$ with the already got quality valuation of this belief according to the Facts Scoring Protocol showed in previous sections. This criteria is subjective and comes from our experience.

$$\mu_{e3'}^{e3} = \frac{\text{quality\_valuation of (pricing\_terms\_and\_conditions\_system\_implementation for e3}')}{10} * 100 \tag{14.7}$$

The maximum quality valuation according to Facts Scoring Protocol is 10, so previous expression is showing the quality valuation rate of e3′.

γ_t^{e1e2e3} is the activation factor of the human expert (he) on an specific instant t and for specific evidences e1, e2 and e3. Its value on instant t will be 1 just in case there is no previous experience for those evidences (equal or similar) and 0 if previous experience (similar or equal) for those evidences exists.

$$\gamma_t^{e1e2e3} = \begin{cases} 1 \text{ if } \alpha = 0 \text{ and } \beta = 0 \\ 1 \text{ if } \alpha = 0 \text{ and } \beta = 1 \text{ and no } \exists\, se_t^{e1e2e3} \\ 0 \text{ otherwise} \end{cases} \quad (14.8)$$

pe_t^{e1e2e3} represents the previous experience and will exist just in case there is a previous learning factor for those specific evidences e1, e2 and e3 in a previous instant before t. If that is the case, the specific activation factor α_t^{e1e2e3} will be 1.

$$pe_t^{e1e2e3} = \begin{cases} 1 \text{ if } \alpha_t^{e1e2e3} = 1 \text{ and } \exists\, lf_i^{e1e2e3} = 1, i \in \{1,\ldots,t-1\} \\ 0 \text{ if } \alpha_t^{e1e2e3} = 1 \text{ and } \exists\, lf_i^{e1e2e3} = 0, i \in \{1,\ldots,t-1\} \end{cases} \quad (14.9)$$

This factor represents as well the accumulated experience in the past.

$$pe_t^{e1e2e3} = lf_{t-1}^{e1e2e3} \quad (14.10)$$

As we have indicated before, this protocol handles fuzzy knowledge letting us to approximate the evidences (e1, e2, e3) by similar but not equal evidences (e1′, e2′, e3′) from the past. This is manage under the term similar experience (se_t^{e1e2e3}) and let us to approximate e1, e2 and e3 by e1′, e2′ and e3′ only after an specific previously defined threshold ϕ (degree of certainty)

$$se_t^{e1e2e3} = lf_t^{e1'e2'e3'} \; if \; \mu_{e1'}^{e1} > \phi \text{ and } \mu_{e2'}^{e2} > \phi \text{ and } \mu_{e3'}^{e3} > \phi \quad (14.11)$$

Last but not least is the human expert indicator he_t^{e1e2e3} that will be activated by its activation factor just in case there is no previous experience (equal or similar) available for indicated evidences in previous instants of time. This human expert factor will be 1 just in case the human expert indicates a positive SOX compatibility and 0 if negative SOX compatibility is determined.

$$he_t^{e1e2e3} = \begin{cases} 1 \text{ if } \gamma_t^{e1e2e3} = 1 \text{ and} \\ \quad \text{positive SOX compatibility is determined by the human} \\ \quad \text{expert for e1, e2 and e3 evidences.} \\ 0 \text{ if } \gamma_t^{e1e2e3} = 1 \text{ and} \\ \quad \text{negative SOX compatibility is determined by the human} \\ \quad \text{expert for e1, e2 and e3 evidences.} \end{cases} \quad (14.12)$$

Our original learning factor expression, can be shown as well like:

1. $If\ \alpha = 1 \Rightarrow \beta = 0 \text{ and } \gamma = 0 \text{ then } lf_t^{e1e2e3} = \alpha_t^{e1e2e3} \cdot pe_t^{e1e2e3}$ (14.13)

2. $If\ \alpha = 0 \text{ and } \phi = 100\,\%\,(\beta = 0) \Rightarrow \gamma = 1 \text{ then } lf_t^{e1e2e3} = \gamma_t^{e1e2e3} \cdot he_t^{e1e2e3}$ (14.14)

This protocol lets us as well to work with no risk, with no fuzzy knowledge leaving the full responsibility of non crystal clear decisions to the human expert. To do this, we only need to establish our working degree of certainty as 100 %. If we do this, we have the following:

$$\phi = 100\,\% \Rightarrow \beta_t^{e1e2e3} = 0 \tag{14.15}$$

And developing the learning factor initial expression we get the following:

$$lf_t^{e1e2e3} = \alpha_t^{e1e2e3} \cdot pe_t^{e1e2e3} + \beta_t^{e1e2e3} \cdot se_t^{e1e2e3} + \gamma_t^{e1e2e3} \cdot he_t^{e1e2e3} \tag{14.16}$$

$$lf_t^{e1e2e3} = \alpha_t^{e1e2e3} \cdot pe_t^{e1e2e3} + \gamma_t^{e1e2e3} \cdot he_t^{e1e2e3} \tag{14.17}$$

$$lf_t^{e1e2e3} = \alpha_t^{e1e2e3} \cdot lf_{t-1}^{e1e2e3} + \gamma_t^{e1e2e3} \cdot he_t^{e1e2e3} \tag{14.18}$$

$$lf_t^{e1e2e3} = \alpha_t^{e1e2e3} \cdot (\alpha_{t-1}^{e1e2e3} \cdot pe_{t-1}^{e1e2e3} + \gamma_{t-1}^{e1e2e3} \cdot he_{t-1}^{e1e2e3}) + \gamma_t^{e1e2e3} \cdot he_t^{e1e2e3} \tag{14.19}$$

$$lf_t^{e1e2e3} = \alpha_t^{e1e2e3} \cdot (\alpha_{t-1}^{e1e2e3} \cdot lf_{t-2}^{e1e2e3} + \gamma_{t-1}^{e1e2e3} \cdot he_{t-1}^{e1e2e3}) + \gamma_t^{e1e2e3} \cdot he_t^{e1e2e3} \tag{14.20}$$

$$\begin{aligned} lf_t^{e1e2e3} = {} & \alpha_t^{e1e2e3} \cdot (\alpha_{t-1}^{e1e2e3} \cdot (\alpha_{t-2}^{e1e2e3} \cdot pe_{t-2}^{e1e2e3} + \gamma_{t-2}^{e1e2e3} \cdot he_{t-2}^{e1e2e3}) \\ & + \gamma_{t-1}^{e1e2e3} \cdot he_{t-1}^{e1e2e3}) + \gamma_t^{e1e2e3} \cdot he_t^{e1e2e3} \end{aligned} \tag{14.21}$$

And generalizing this development, we get the following expression that represents the accumulated learning experience via propagated past experiences or via consultation to the human expert. The consultation to the human expert in an specific instant of time for a tuple of specific evidences e1, e2 and e3 is propagated to the future via (pe) previous experience factor and will let us to reuse this specific consultation in similar future cases.

$$lf_t^{e1e2e3} = \sum\nolimits_{i=2}^{t} \prod_{j=i}^{t} \alpha_j^{e1e2e3} \cdot \gamma_{i-1}^{e1e2e3} \cdot he_{i-1}^{e1e2e3} \tag{14.22}$$

This expression represents the learning factor model (without fuzzy knowledge, with 100 % of certainty) here proposed and will take value 1 in case of positive SOX compatibility and 0 in case of negative SOX compatibility. This value will come via accumulated past experiences or via consultation to the human expert. The following diagram (see Fig. 14.4) represents this learning process and it will only be used when the static knowledge or the base beliefs establish a negative SOX compatibility. The learning process consists on checking the previously managed business cases by this agent, and based on the evidences provided by the present business case, see if there were cases in which the human expert indicated under a similar situation, a positive SOX compatibility. Otherwise, it will mean that there is no previous experience and the protocol will step to consult to the human

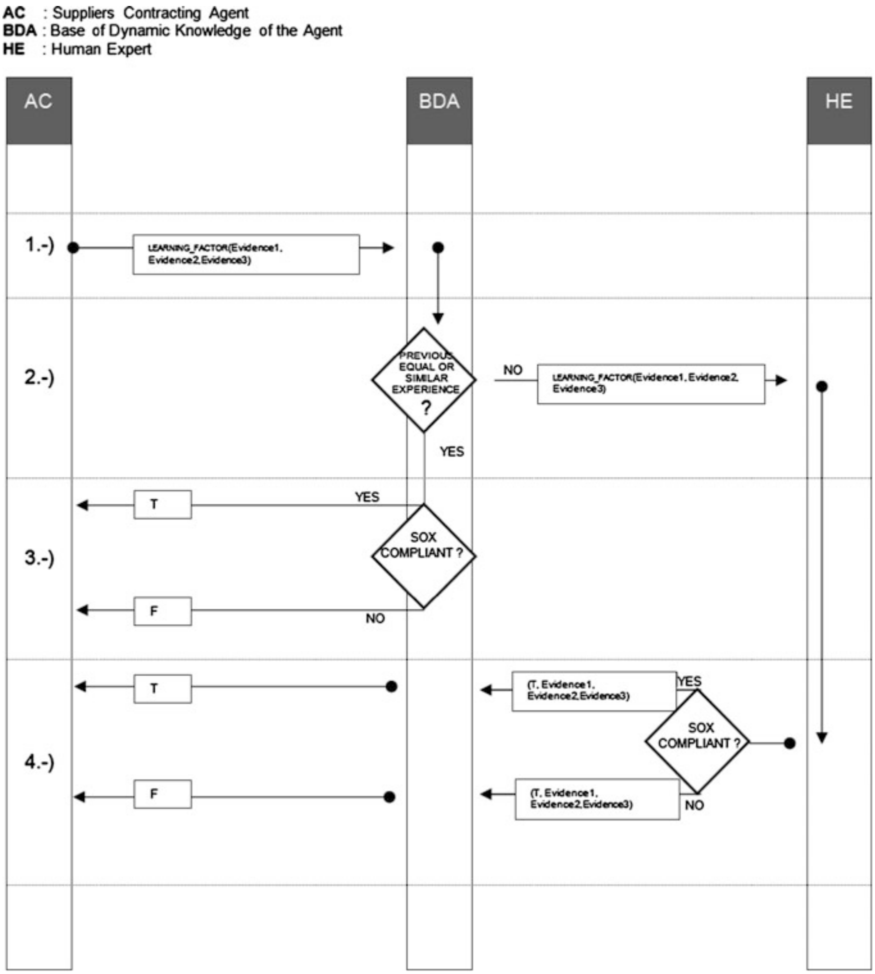

Fig. 14.4 Dynamic fuzzy learning protocol

expert with the evidences provided by this business case. Human expert based on knowledge of this matter and based on knowledge of court specific resolutions will determine if there is or not a positive SOX compatibility. Just in case of a positive SOX compatibility, this compatibility will solve the present process of our business case and at the same time it will increase our agent's knowledge for similar future cases, storing this decision in the dynamic knowledge base. Figure 14.4 describes more in detail this protocol.

The agent by itself and based on its experience over several analyzed business cases will grow up in knowledge and will fine tune its final conclusions. This part of agent learning begins to be useful during a massive use of the system with a big number of business cases and where specific cases show complex situations that comes out the static SOX regulation and where specific control organisms and courts need to take SOX compliant decisions that will be taken into consideration as precedents for future similar cases or situations. These kind of resolutions over exceptional situations not covered by the static SOX regulation will generate a jurisprudence base which experts can consult and apply using the learning protocol here described. At the same time the agent using this protocol is able to assimilate and add those resolutions to its initial knowledge growing in terms of knowledge. There are several recent researches (Capera et al. 2003; Razavi et al. 2005; Weyns et al. 2005; Zambonelli et al. 2003; Ontañon and Plaza 2007; Parsons and Sklar 2006), where it has being shown the need to design multiagent systems able to adapt to the changes happened in their closed environment. With this Learning Protocol our model follows this tendency being able to adapt to legislation changes and to exceptional situations too.

14.4 Integration with a Higher Level Multiagent Intelligent System

As we indicated in our previous work (Fernandez et al. 2013a, b, c, d) for the Suppliers Selection Agent, here, the Contracting Agent is integrated in the same higher level multiagent intelligent system with the final common objective to decide about the SOX compatibility of the full business case. Kakas et al. (2004) stated that the communication protocols between the agents of the systems should be defined in advanced and customized taken in mind the objectives of the agents both infidel and global ones. The idea is to model each key process of the Purchasing Cycle with a dedicated agent which individual objective will be to determine its SOX compatibility and all together in cooperation will discuss about the common objective to determine if the full Purchasing Cycle is or not SOX compliant. To make this possible, it is needed that all agents establish a Mutual Shared Communication Protocol in which they will cooperate together looking for a final decision about the SOX compatibility of the full Purchasing Cycle. After this Mutual Shared Communication Protocol, the agents together as a hole multiagent system will take the final decision with the Conclusive Inter-Agent Cooperative Decision Making Protocol. Rodriguez et al. (2011) reflects the fact that a good coordination is needed to let individual agents to cooperate together to reach the global objective on top of the individual ones. Here, in our model, this coordination is implemented via indicated Mutual Shared Communication Protocol.

14.4.1 Mutual Shared Communication Protocol

Deliberative communication among agents is a key element in multiagent technology to let the full system to evolve towards a common agreed decision or step in

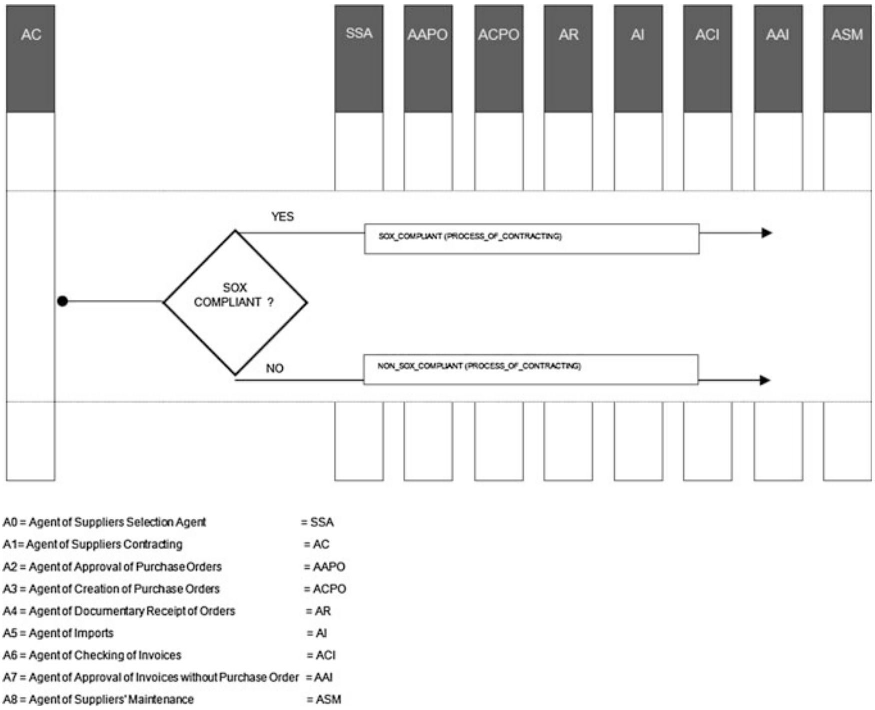

Fig. 14.5 Mutual shared communication protocol

its way to reach the final objective (Corchado and Laza 2003; Corchado et al. 2003). This section is dedicated to the Mutual Shared Communication Protocol, in which the Supplier Contracting Agent will carry out a proposal towards rest of the agents that compose the multiagent system. This proposal will consist on proposing that the Suppliers Contracting Process, based on the data obtained after having interrogated and analyzed the business case, is or not compatible with the SOX regulation (Fig. 14.5).

As answers, each of the other agents will send to this agent during the deliberation process an attack message, contradicting its proposal, or a support message, supporting it. The attack message that an agent will answer to another with the objective of contradicting its initial proposal will consist on sending an opposite message to the one proposed. That is to say, if a SOX_COMPLIANT (compatible with the SOX regulation) was proposed, a NON_SOX_COMPLIANT (not compatible with the SOX regulation) would be answered. If a NON_SOX_COMPLIANT is proposed, a SOX_COMPLIANT would be answered. The support message that an agent will answer to another with the objective of supporting its initial proposal will consist on sending a message that reaffirms and support the agent's proposal. That is to say, if a SOX_COMPLIANT was proposed, a SOX_COMPLIANT would be answer and if a NON_SOX_COMPLIANT was proposed, a NON_SOX_COMPLIANT would be

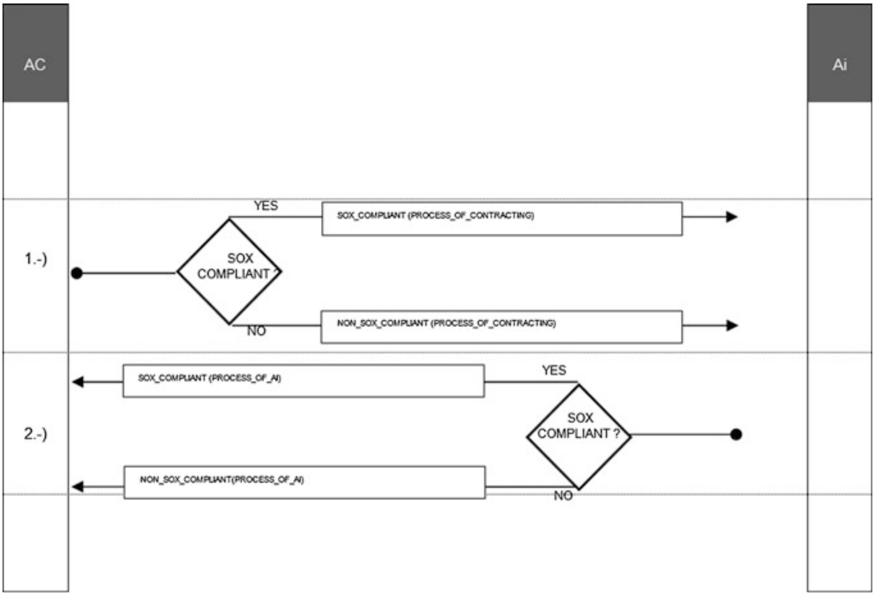

Fig. 14.6 Mutual shared communication protocol (question and answer)

answered (Fig. 14.6). At the end of this protocol, and after all the agents in an individual way have decided about the compatibility or not with the SOX regulation of their process, the system will be in a stage in which all the agents know the results or individual decisions made by the rest of agents.

There are in the literature several studies (Esteva et al. 2001; Hubner et al. 2004; Parunak and Odell 2002) showing the fact that multiagent systems need a higher level of organization to coordinate all the agents of the system. The Mutual Shared Communication Protocol proposes a parallel alternative in which all the agents share its individual findings among the rest of the agents of the system with final idea that in a further phase, all those agents together will use this shared knowledge to find a common agreed decision about the final compatibility over the full Purchasing Cycle.

14.4.2 Inter-agent Cooperative Decision Making Protocol

Here it is described the basic idea of this protocol. The objective is to demonstrate if the analyzed business case is SOX compliant or not. This can be done using classical logic and we determine that just in case all the involved processes of the Purchasing Cycle are SOX compliant, then the full Purchasing Cycle should be as well SOX compliant. With this approach each of the agents involved in the Purchasing Cycle combine its specific initial objective with the common shared objective of the full multiagent system. Morge and Mancarella (2007) proposed an argumentation model in which conflicts are solved based on the arguments that justify each possible action. With this Inter-Agent Cooperative Decision Making Protocol, even although each agent could have a different opinion about the SOX compatibility, a final common share decision is taking among all the agents that conform the full system.

14.5 Case Study

Here it is presented a real business case study in which proposed model was applied during Suppliers Contracting Process. This business case was a real project happened in a European country in 2010 and covered all needed tasks to replace the radio network elements of one specific mobile telecommunications operator in one country for similar equipment of another manufacturer. There were twenty different companies invited to Suppliers Selection Process. All those companies were invited to participate on Suppliers Selection Process to select a group able to implement the project with quality and in reasonable time. Competition was done over four phases of requests for quotations, where it was given detailed information of the project to the invited companies and at the same time some discounts were requested till an acceptable level of pricing. With the information gathered during these four phases, it was carried out the selection process, in which were kept in mind besides the economic approaches, all those aspects and details needed to take the final selection. At the end of the competition between all the initial 20 invited companies, only 5 were selected. And only with these 5 companies it was done the contracting.

14.6 Results

Here it is shown the results obtained after applying the proposed model to the previously explained real business case. The following table summarizes the results of the firsts two protocols: (1) Facts Searching Discussion Protocol and (2) Facts Scoring Protocol (Table 14.6).

According to the Facts Scoring Protocol based on the Agent's Beliefs, between all beliefs of the agent's static knowledge, there are only three that are decisive for the SOX compatibility. These are: (1) Contracts warehousing, (2) Pricing, terms and conditions monitorization and (3) Pricing, terms and conditions implementation. These three together with the other ones, determine the quality of the followed process in the suppliers contracting of the analyzed business case. From quality point of view almost of the key facts of the business case have obtained the maximum value as indicated in previous table, and according to the weight factors, the final punctuation is 9.5. From SOX compliance point of view, all relevant SOX facts have obtained a true value according to the Facts Scoring Protocol. The

Table 14.6 Agent's facts scoring matrix over the business case facts based on its beliefs

Agent's facts scoring matrix over the suppliers contracting process facts	SOX compatibility valuation	Quality valuation of the supplier contracting process
	Weight (value)	Weight (value)
1. Contracts warehousing	1 (T: true)	0.5/3 (10)
2. Pricing, terms and conditions monitorization	1 (T: true)	0.5/3 (10)
3. Pricing, terms and conditions system implementation	1 (T: true)	0.5/3 (10)
4. Reselling agreement	0 (NA)	0.5/32 (10)
5. Invalid clauses	0 (NA)	0.5/32 (0)
6. License rights	0 (NA)	0.5/32 (10)
7. Confidentiality	0 (NA)	0.5/32 (10)
8. Export control and applicable law	0 (NA)	0.5/32 (10)
9. Intellectual property rights	0 (NA)	0.5/32 (10)
10. Contract assignment right to third parties	0 (NA)	0.5/32 (10)
11. Product availability	0 (NA)	0.5/32 (10)
12. Documentation	0 (NA)	0.5/32 (10)
13. Epidemic failures	0 (NA)	0.5/32 (10)
14. Force majeure	0 (NA)	0.5/32 (10)
15. Warranty	0 (NA)	0.5/32 (10)
16. Inspection and testing	0 (NA)	0.5/32 (10)
17. Applicable law and conflict resolution	0 (NA)	0.5/32 (10)
18. Product liability	0 (NA)	0.5/32 (10)
19. Logistics	0 (NA)	0.5/32 (10)
20. Support and maintenance	0 (NA)	0.5/32 (10)
21. Quotations	0 (NA)	0.5/32 (0)
22. Business practices	0 (NA)	0.5/32 (10)
23. Pricing	0 (NA)	0.5/32 (10)
24. Acceptance procedure	0 (NA)	0.5/32 (10)
25. Purchase orders procedure	0 (NA)	0.5/32 (10)
26. Products	0 (NA)	0.5/32 (10)
27. Buyer ownership	0 (NA)	0.5/32 (0)
28. General remedies	0 (NA)	0.5/32 (10)
29. Quality requirements	0 (NA)	0.5/32 (10)
30. Ethical requirements	0 (NA)	0.5/32 (10)
31. Environmental requirements	0 (NA)	0.5/32 (10)
32. Termination	0 (NA)	0.5/32 (10)
33. Delivery terms	0 (NA)	0.5/32 (10)
34. Payment terms	0 (NA)	0.5/32 (10)
35. Delivery time		0.5/32 (10)
	SOX compatibility valuation	Quality valuation of the supplier contracting process
	3	= 9.5

(CONTRACTS_WAREHOUSING (Evidence1) ▲
PRICING_TERMS_AND_CONDITIONS_MONITORING (Evidence2) ▲
PRICING_TERMS_AND_CONDITIONS_SYSTEM_IMPLEMENTATION (Evidence3)) ▼
LEARNING_FACTOR (Evidence1, Evidence2,Evidence3) ⟶

SOX_COMPLIANT(PROCESS_OF_CONTRACTING)

Fig. 14.7 Suppliers contracting process. Deductive decision making protocol, main rule

(┐ CONTRACTS_WAREHOUSING (Evidence1) ▼
┐ PRICING_TERMS_AND_CONDITIONS_MONITORING (Evidence2) ▼
┐ PRICING_TERMS_AND_CONDITIONS_SYSTEM_IMPLEMENTATION (Evidence3)) ▲
┐ LEARNING_FACTOR (Evidence1, Evidence2, Evidence3) ⟶

NON_SOX_COMPLIANT(PROCESS_OF_CONTRACTING)

Fig. 14.8 Suppliers contracting process. Deductive decision making protocol, complementary rule

valuation of all key SOX facts is the inputs for the Deductive Decision Making Protocol during the conclusive individual phase of the agent (Figs. 14.7 and 14.8).

According to the Deductive Decision Making Protocol, the first three antecedents of the main rule, are true and therefore it is not necessary to appeal to the fourth antecedent (LEARNING_FACTOR) to be able to conclude that SOX_COMPLIANT (PROCESS_OF_CONTRACTING) is true. The previous reasoning process, based on the agent's static knowledge, has been able to state that the followed Suppliers Contracting Process is compatible with the SOX regulation, and past experiences and human expert knowledge are not needed to make the decision. In this case the agent and their static knowledge have been enough to reach the conclusion. This fact is positive in the sense that the process has followed the SOX legislation rigorously (Table 14.7) but on the other hand, it has not allowed the agent to be able to learn, to be able to increase its dynamic knowledge. Finally, the present agent concludes that the followed Process of Suppliers Contracting of the analyzed business case is SOX_COMPLIANT. Nowadays and in relation to the model here design, after revising different international bibliographical sources and up to the best of our knowledge it isn't found any publication that uses Multiagent Systems and Argumentation Theory in the implementation of SOX internal controls with the objective of identify if the Supplier Contracting Process of an specific business case is or not compatible with the SOX Law supporting auditors and companies to take their appropriate decisions about this SOX compliance.

Table 14.7 Agent's hypothesis

	Individual hypothesis
1. Agent of suppliers contracting	H1: The Suppliers Contracting Process followed in the analyzed business case complies with the SOX regulation

14.7 Conclusions

As has been shown before, there are several intelligent techniques nowadays (expert systems, case base reasoning systems, fuzzy systems, neural networks, genetic algorithms, intelligent agents, …) that can bring us a lot of help and support at the time to create a model for an specific scientific problem. The key point is how to combine, customize and improve all those intelligent techniques depending on the type of problem we have in front of us and the quality of the solution we are looking for, giving us the final desired model. The problem described before, is a decision making problem with the following main characteristics: (1) Decision making problem: at the end, it is needed to take a decision about the compatibility or not of the specific business case with this law. (2) Decision based on evidences: those evidences will be the support of the decision and will be the probe towards auditors and control organisms. (3) Needed initial expert non standardized knowledge: this law states what should be done but not how should be done. This means that the source of the initial knowledge should be a human expert with enough experience in driving business cases inside a SOX compliant state. (4) Been able to learn from present court resolutions to be able to use this extra knowledge in the future: some kind of learning method is needed to let the initial knowledge evolve and growth far beyond its initial state. This law affects whatever economical or financial major process in a company, like for example purchasing cycle, financial cycle or sales cycle. Those major cycles are divided in different processes. For example, purchasing cycle can be divided in suppliers' selecting process, suppliers contracting process, approval of purchase orders, and so on. This kind of structure can be very well modeled with a Multiagent System (MAS) structure. Taking in mind as well that the final decision should be based on evidences, the Argumentation in combination with MAS is an optimal approach to model this kind of problems. Present existing models using this kind of techniques like MAS and Argumentation show limitations like: (1) They are being designed mainly to solve other type of problems like medical, legal, negotiations, trading, education or ebusiness (COSSAC, CARNEADES, AAC, TAC, INTERLOC, ARGUGRID). (2) They don't have an initial expert based of SOX compliant knowledge. (3) They don't have a learning method able to incorporate court resolutions to the initial knowledge base. Similar to our previous work (Fernandez et al. 2013a, b, c, d) but from contractual framework perspective, the model here presented is a *novel approach* to solve this kind of problems due to the fact that it has an *optimized structure* to solve this specific problem, incorporates an *initial expert knowledge* base coming from the experience of a human expert and incorporates an specific *dynamic fuzzy learning protocol* to add present court resolutions to the initial knowledge base, letting the system to *evolve* far beyond its initial knowledge state, letting the system to increase its efficiency as the times goes on based on its *accumulated experience*.

Conflict of Interest Disclosure The content of this chapter reflects only the opinion of the authors with independence of their affiliations. The authors do not have a direct financial relation with the commercial entities mentioned in this chapter.

References

Alden, M., Bryan, D., Lessley, B., Tripathy, A.: Detection of financial statement fraud using evolutionary algorithms. J. Emerg. Technol. Account. **9**(1), 71–94 (2012)

Amgoud, L., Maudet, N., Parsons, S.: Modelling dialogues using argumentation. In: Proceedings of the 4th International Conference on Multi-Agent Systems (ICMAS'2000), pp. 31–38 (2000)

Amgoud, L.: A Unified setting for inference and decision: an argumentation-based approach. ArXiv Preprint 12071363 (2012)

Amgoud, L.: Postulates for logic-based argumentation systems. Int. J. Approximate Reasoning **55**, 2028–2048 (2013)

Atkinson, K., Bench-Capon, T., Walton, D.: Distinctive features of persuasion and deliberation dialogues. Argument Comput. **4**(2), 105–127 (2013)

Azhar, M., Parsons, S., Sklar, E.: An Argumentation-based dialogue system for human-robot collaboration. In: Proceedings of the 2013 International Conference on Autonomous Agents and Multi-agent Systems, International Foundation for Autonomous Agents and Multiagent Systems, pp. 1353–1354 (2013)

Belesiotis, A., Rovatsos, M., Rahwan, I.: A generative dialogue system for arguing about plans in situation calculus. In: Proceedings of the Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ARGMAS'09), vol. 6057, pp. 23–41. Springer, Berlin, Germany (2010)

Bench-Capon, T.J.M., Dunne, P.E.: Argumentation in artificial intelligence. Artif. Intell. **171** (10–15), 619–641 (2007)

Besnard, P., Hunter, A.: Elements of Argumentation. The MIT Press, Cambridge (2008)

Boella, G., Hulstijn, J., Torre, L.: A logic of abstract argumentation. In: Proceedings of the Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ArgMAS'06), vol. 4049, pp. 29–41. Springer, Berlin, Germany (2006)

Capera, D., Georgé, P.J., Gleizes, M.P., Glize, P.: Emergence of organisations, emergence of functions. In: AISB03 Convention, Symposium on Adaptive Agents and Multi-Agent Systems, pp. 103–108 (2003)

Capobianco, M., Chesñevar, C., Simari, G.: An argument based framework to model an agent's beliefs in a dynamic enviroment. In: Proceedings of the 1st International Workshop, Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ArgMAS'04), vol. 3366, pp. 95–110. Springer, Berlin, Germany (2004)

Changchit, C., Holsapple, C., Madden, D.: Positive impacts of an intelligent system on internal control problem recognition. In: Proceedings of the 32nd Hawaii International Conference on System Sciences (HICSS'99), vol. 6, p. 10 (1999)

Changchit, C., Holsapple, C.W.: The development of an expert system for managerial evaluation of internal controls. Intell. Syst. Account. Fin. Manage. **12**(2), 103–120 (2004)

Chen, F., Sutchliffe, C.: Pricing and Hedging Short Sterling Options using Neural Networks. Intelligent Systems in Accounting, pp. 128–149. Wiley, New York (2012)

Coakley, J., Gammill, L., Brown, C.: Artificial neural networks in accounting and finance: modelling issues. Int. J. Intell. Syst. Account. Fin. Manage. **9**(2), 119–144 (1995)

Cogan, E., Parsons, S., McBurney, P.: New types of interagent dialogues. In: Proceedings of the Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ArgMAS'05), vol. 4049, pp. 154–168. Springer, Berlin, Germany (2005)

Corchado, J.M., Laza, R.: Constructing deliberative agents with case-based reasoning technology. Int. J. Intell. Syst. **18**(12), 1227–1241 (2003)

Corchado, J.M., Laza, R., Borrajo, L., et al.: Increasing the autonomy of deliberative agents with a case-based reasoning system. Int. J. Comput. Intell. Appl. World Sci. **3**(1), 101–118 (2003)

Deshmukh, A., Talluru, L.: A rule-based fuzzy reasoning system for assessing the risk of management fraud. Intell. Syst. Account. Fin. Manage. **7**(4), 223–241 (1998)

Devereux, J., Reed, C.: Strategic argumentation in rigorous persuasion dialogue. In: Proceedings of the Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ARGMAS'09), vol. 6057, pp. 94–113. Springer, Berlin, Germany (2009)

Dimpoulos, Y., Nebel, B., Toni, F.: Preferred arguments are harder to compute than stable extensions. In: Proceedings of the 16th International Joint Conference on Artificial Intelligence (IJCAI'99), vol. 16, pp. 36–43. Lawrence Erlbaum Associated LTD (1999)

Dung, P.M.: On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games. Artif. Intell. **77**(2), 321–357 (1995)

Esteva, M., Rodriguez, J., Sierra, C., Garcia, P., Arcos, J.: On the formal specifications of electronic institutions. Agent Mediated Electron. Commer. **1991**, 126–147 (2001)

Fanning, K.M., Cogger, K.O.: Neural network detection of management fraud using published financial data. Int. J. Intell. Syst. Account. Fin. Manage. **7**(1), 21–41 (1998)

Fanning, K., Cogger, K.: A comparative analysis of artificial neural networks using financial distress prediction. Int. J. Intell. Syst. Account. Fin. Manage. **3,** 241–252 (1994)

Fernandez, J.A., Martin Q., Corchado, J.M.: Argumentative SOX compliance and quality decision support intelligent expert system over the purchase orders approval process, Appl. Math. Comput. Sci. **4**(4), 215–268 (2013a). ISSN 0976-1586

Fernandez, J.A., Martin Q., Corchado, J.M.: Argumentative SOX compliant and quality decision support intelligent expert system over the suppliers selection process. Appl. Comput. Intell. Softw. Comput. **2013**(973704), 23 pp (2013b). doi:10.1155/2013/973704

Fernandez, J.A., Martin, Q., Corchado, J.M.: Business intelligence expert system on SOX compliance over the purchase orders creation process. Intell. Inf. Manage. **5**(3), 49–72 (2013c). doi:10.4236/iim.2013.53007, ISSN 2160-5912, 2160-5920

Fernandez, J.A., Martin, Q., Corchado, J.M.: Decision making intelligent agent on SOX compliance over the goods receipt process. Comput. Eng. Intell. Syst. **4**(10), 1–18 (2013d). ISSN 2222-1719, 2222-2863

Fox, J., Krause, P., Ambler, S.: Arguments, contradictions and practical reasoning. In: Proceedings of the 10th European Conference on Artificial Intelligence (ECAI'92), pp. 623–627. Wiley, New York (1992)

Fukumoto, T., Sawamura, H.: Argumentation-based learning. In: Proceedings of the 3rd International Workshop, Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ArgMAS'06), vol. 4766, pp. 17–35. Springer, Berlin, Germany (2006)

Gabbriellini, S., Torroni, P.: NetArg: an agent-based social simulator with argumentative agents. In: Proceedings of the 2013 International Conference on Autonomous Agents and Multiagent Systems, pp. 1365–1366 (2013)

Gabbriellini, S., Torroni, P.: A New Framework for ABMs based on Argumentative Reasoning. Advances in Social Simulation, pp. 25–36. Springer, Berlin (2014)

Gholipour, R., Jandaghi, G., Rajaei, R.: Contractor selection in MCMD context using fuzzy AHP. Iran. J. Manage. Stud. **7**(1), 151–173 (2014)

Ho, G., Lp, W., Wu, C., Tse, Y.: Using a fuzzy association rule mining approach to identify the financial data association. Expert Syst. Appl. **39**(10), 9054–9063 (2012)

Hubner, J.F., Sichman, J.S., Boissier, O.: Using the Moise+ for a cooperative framework of MAS reorganisation. Lecture Notes in Computer Science, vol. 3171, pp. 506–515 (2004)

Kakas, A., Maudet, N., Moraitis, P.: Layered strategies and protocols for argumentation-based agent interaction. In: Proceedings of the 1st InternationalWorkshop on Argumentation in Multi-Agent Systems (ArgMAS'04), pp. 64–77, July 2004

Korvin, A., Shipley, M., Omer, K.: Assessing risks due to threats to internal control in a computer-based accounting information system: a pragmatic approach based on fuzzy set theory. Intell. Syst. Account. Fin. Manage. **12**(2), 139–152 (2004)

Kraus, S., Sycara, K., Evenchik, A.: Reaching agreements through argumentation: a logical model and Implementation. Artif. Intell. **104**(1–2), 1–69 (1998)
Krause, P., Ambler, S., Elvang-Goransson, M., Fox, J.: A logic of argumentation for reasoning under uncertainty. Comput. Intell. **11**(1), 113–131 (1995)
Kumar, A., Liu, R.: A rule-based framework using role patterns for business process compliance. In: Proceedings of the International Symposium on Rule Representation, Interchange and Reasoning on the Web, Lecture Notes in Computer Science (RuleML'08), vol. 5321, pp. 58–72. Springer, Berlin, Germany (2008)
Li, X., Krause, A.: An Evolutionary Multi-Objective Optimization of Trading Rules in Call Markets. Intelligent Systems in Accounting, pp. 1–14. Wiley, New York (2011)
Liu, F., Tang, R., Song, Y.: Information fusion oriented fuzzy comprehensive evaluation model on enterprises' internal control enviroment. In: Proceedings of the Asia-Pacific Conference on Information (APCIP'09), vol. 1, pp. 32–34 (2009)
Marghescu, D., Sarlin, P., Liu, S.: Early-Warning Analysis for Currency Crises in Emerging Markets: A Revisit with Fuzzy Clustering. Intelligent Systems in Accounting, pp. 143–165. Wiley, New York (2012)
Matt, P., Toni, F., Vaccari, J.: Dominant decisions by argumentation agents. In: Proceedings of the Argumentation inMulti-Agent Systems, Lecture Notes in Computer Science (ARGMAS'10), vol. 6057, pp. 42–59. Springer, Berlin, Germany (2010)
Medellin-Gasque, R., Atkinson, K., Bech-Capon, T., McBurney, P.: Strategies for question selection in argumentative dialogues about plans. Argument Comput. **4**(2), 151–179 (2013)
Meservy, R.: Auditing Internal Controls: A Computational Model of the Review Process (Expert Systems, Cognitive, Knowledge Acquisition, Validation, Simulation), Ohio State University (1986)
Moraitis, P., Spanoudakis, N.: Argumentation-based agent interaction in an ambient-intelligence context. IEEE Intell. Syst. **22**(6), 84–93 (2007)
Morge, M., Mancarella, P.: The hedgehog and the fox. An argumentation-based decision support system. In: Proceedings of the Argumentation in Multi-Agent Systems, Fourth International Workshop, Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ArgMAS'07), vol. 4946, pp. 114–131. Springer, Berlin, Germany (2007)
Morge, M., Mancarella, P.: Assumption-based argumentation for the minimal concession strategy. In: Proceedings of the Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ARGMAS'10), vol. 6057, pp. 114–133. Springer, Berlin, Germany (2010)
Neri, F.: Agent-based modeling under partial and full knowledge learning settings to simulate financial markets. AI Commun. **25**(4), 295–304 (2012)
O'Callaghan, S.: An artificial intelligence application of backpropagation neural networks to simulate accountants' assessments of internal control systems using COSO guidelines. Doctoral dissertation, University of Cincinnati (1994)
Ontañon, S., Plaza, E.: Arguments and counterexamples in case-based joint deliberation. In: Proceedings of the 3rd International Workshop, Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ArgMAS'07), vol. 4766, pp. 36–53. Springer, Berlin, Germany (2007)
Parsons, S., Sklar, E.: How agents alter their beliefs after an argumentation-based dialogue. In: Proceedings of the Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ArgMAS'06), vol. 4049, pp. 297–312. Springer, Berlin, Germany (2006)
Parunak, H.V.D., Odell, J.: Representing social structures in UML. Agent-Oriented Softw. Eng. II **2222**, 1–16 (2002)
Peat, M., Jones, M.: Using Neural Nets to Combine Information Sets in Corporate Bankruptcy Prediction. Intelligent Systems in Accounting, pp. 90–101. Wiley, New York (2012)
Rahwan, I., Simari, G.R.: Argumentation in Artificial Intelligence. Springer, New York (2009)
Razavi, R., Perrot, J., Guelfi, N.: Adaptive modeling: an approach and a method for implementing adaptive agents. In: Massively Multi-Agent Systems I, Lecture Notes in Computer Science, vol. 1, pp. 136–148 (2005)

Reed, C.: Dialogue frames in agent communication. In: Proceedings of the 3rd International Conference on Multiagent Systems (ICMAS'98), pp. 246–253 (1998)
Rodriguez, S., De Paz, Y., Bajo, J., Corchado, J.M.: Socialbased planning model for multiagent systems. Expert Syst. Appl. **38**(10), 13005–13023 (2011)
Samakovitis, G., Kapetanakis, S.: Computer-aided financial fraud detection: promise and applicability in monitoring financial transaction fraud. In: Proceedings of International Conference on Business Management & IS, vol. 2, no. 1 (2013)
Sarkar, S., Sriram, R.S., Joykutty, S.: Belief networks for expert system development in auditing. Int. J. Intell. Syst. Account. Fin. Manage. **5**(3), 147–163 (1998)
Sarlin, P., Marghescu, D.: Visual Predictions of Currency Crises using Self-Organizing Maps. Intelligent Systems in Accounting, pp 15–38. Wiley, New York (2011)
Srivastava, R.P., Dutta, S.K., Johns, R.W.: An expert system approach to audit planning and evaluation in the belief function framework. Int. J. Intell. Syst. Account. Fin. Manage. **5**, 165–184 (1998)
Tang, Y., Parsons, S.: Argumentation-based multi-agent dialogues for deliberation. In: Proceedings of the Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ArgMAS'06), vol. 4049, pp. 229–244. Springer, Berlin, Germany (2006)
Thakur, J.: Role of artificial intelligence and expert system in: business competitiveness. Gian Jyoti E-J. **1**(2) (2012)
Thimm, M.: Realizing argumentation in multi-agent systems using defeasible logic programming. In: Proceedings of theArgumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ARGMAS'09), vol. 6057, pp. 175–194. Springer, Berlin, Germany (2009)
Vaez, S., Baghi, M., Shiralizadeh, M., Farzadi, S.: Prediction the relation between audit fee and financial variables by using of artificial neural networks. Int. Res. J. Fin. Econ. **107**, 17 (2013)
Walton, D.N., Krabbe, C.W.: Commitment inDialogue: Basic Concepts of Interpersonal Reasoning. Suny Press, Albany (1995)
Wardeh, M., Bech-Capon, T., Coenen, F.: Multi-party argument from experience. In: Proceedings of theArgumentation in Multi-Agent Systems, Lecture Notes in Computer Science (ARGMAS'10), vol. 6057, pp. 216–235. Springer, Berlin, Germany (2010)
Welch, O.J., Reeves, T.E., Welch, S.T.: Using a genetic algorithm-based classifier system for modeling auditor decision behaviour in a fraud setting. Int. J. Intell. Syst. Account. Fin. Manage. **7**(3), 173–186 (1998)
Weyns, D., Schelfthout, K., Holvoet, T., Glorieux, O.: Towards adaptive role selection for behavior-based agents. Lecture Notes in Computer Science, vol. 3394, pp. 295–312 (2005)
Zambonelli, F., Jennings, N.R., Wooldridge, M.: Developing multiagent systems: the Gaia methodology. ACM Trans. Softw. Eng. Methodol. **12**(3), 317–370 (2003)
Zeng, Z., Zhang, H., Zhang, R., Xing, Y.: Combination algorithm of probabilistic argumentation systems based on evidence theory. J. Mod. Internet Things **2**(1), 13–18 (2013)

Chapter 15
Intelligent Systems in Managerial Decision Making

Luca Talarico, Genserik Reniers, Kenneth Sörensen and Johan Springael

Abstract This chapter aims at giving a general overview of the existing intelligent systems that can be used to support decision making in a variety of domains. Intelligent systems comprise both the methods, processes and technologies able to gather, analyse and interpret data with the goal of helping decision makers improve the performance of any organization. Such intelligent systems can be based upon several techniques borrowed from different fields such as operations research, decision theory, data mining and game theory. For each category the ideas behind these methods are explained and the operating principles are summarized. Practical applications and tools used for managerial purposes are also provided.

Keywords Intelligent systems · Operations research · Decision theory · Data mining · Game theory

15.1 Introduction

Managerial economics is a branch of research aimed at applying economic concepts and models to support managerial decision making (Allen et al. 2009). As a matter of fact, managers and above all the decisions that they take have a direct impact on costs, revenues and quality of a product/service, which in turn determine the economic results of any business, non-profit organization and/or administration (Stengel 2012).

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Some of these managerial decisions concern several strategic, tactical and operational problems within different areas such as production planning, pricing analysis, budget/resources allocation, transport planning, etc. The decisional process is typically characterized by high levels of uncertainty, scarce resources, several stakeholders, long term effects of such decisions and the number of internal and external variables that need to be considered (Johnson et al. 2005). Therefore, managerial decisions represent a leverage to influence economic parameters and ratios of any organization. For these reasons, in the remainder of the chapter, several techniques and models (referred to as intelligent systems), which might support and strengthen the decisional process within an organization, are addressed.

"Intelligent systems" is a name given to a set of useful and effective instruments to support decision making especially in the context of managerial economics. They can be used in a variety of disciplines, industries and scientific domains, and for an immense diversity of optimization problems, such as in information technologies, production, scheduling, safety and security, supply chain management, public policy, revenue management, transportation, inventory management, product design, etc.

This chapter intends to present some applications of intelligent systems in different disciplines such as marketing, sales, production/operations management, finance, and business strategy in order to support and improve managerial decisions. All these intelligent systems make use of mathematical models to help managers in evaluating the state of a system and its evolution while making decisions. Such models consider environmental variables and data with the aim of supporting decision makers to interpret and understand complex and uncertain economic situations. As a result, having a better vision of a system and of the economic consequences and the impacts of a choice on a system, decision makers can take appropriate managerial decisions.

It would be an impossible task to discuss all intelligent systems for managerial economics in depth, as well as enumerate and explain the existing theories, models, methods, algorithms and applications. Therefore, in this manuscript, we focus on several aspects of some very important research domains. In addition, for each category of intelligent system we will cover three main aspects: (i) what is the idea behind it, (ii) how does it work, (iii) what are the sub-areas of research, and (iv) what/where are the possibilities for applications.

Some of the most common intelligent systems, borrowed from different research domains, to support the decision making process are presented in this chapter. Operations Research (OR) is treated in Sect. 15.2; Decision Theory (DT) is analysed in Sect. 15. 3, Data Mining (DM) in Sect. 15.4, while Sect. 15.5 is devoted to Game Theory (GT). For each domain, as already mentioned, the main ideas and the operating principles of the tools used as a decision support system are mentioned. Practical applications to specific decisional problems in a wide range of business sectors are also presented.

15.2 Operations Research

Operations Research (OR) is a branch of knowledge that uses advanced mathematical methods and techniques to support decision makers (INFORMS.org 2014). By applying quantitative methods to problems, that can be described by using mathematical models, it is possible to understand the (economic) systems behind these problems and take the appropriate decisions to efficiently manage them. Therefore, OR aims at improving the performance of these systems by applying algorithms to solve the mathematical models which are used to describe them (de Keyser and Springael 2010).

In general OR techniques follow a structured approach starting from the problem definition. The problem is then modeled and represented as a set of mathematical constraints in the form of equations and/or inequalities and at least one objective function (See Sect. 1.2 in case of multiple objectives) which represents the goals that the decision maker intends to achieve. The model is then subjected to a computer analysis to determine the optimal solutions associated to benchmark instances or real life cases. When the optimal solution cannot be easily obtained, due to the complexity of the problem, the decision maker can be satisfied with a near optimal and feasible solution.

OR as a formal discipline was developed during World War II for military applications to support planning military logistics operations. Nowadays OR techniques are applied in a wide range of problems in business, industry and civil areas. Decision support systems based on OR can be used to support strategic, tactical and operative decisions within scheduling problems (e.g. production scheduling, staff scheduling, vehicle scheduling), location problems (e.g. definition of the best location for industrial plants, shops, warehouses or strategic facilities), logistic and supply chain problems, forecasting, revenue/price management.

The majority of the OR techniques embedded in the intelligent systems to solve such a variety of complex problems are based on (Lancaster University Management School 2014):

(a) *Simulation*: used to test ideas and models using some predefined real world scenarios. In this way, different decisions can be virtually "tried out" before they are implemented;
(b) *Optimization:* used when the number of possible scenarios is so large that it would be impossible to test and compare them one by one. These approaches are suitable for complex combinatorial problems such as allocation, routing and scheduling problems;
(c) *Probability and statistics:* used to analyse data and make reliable forecasts also in cases of high uncertainty;
(d) *Problem structuring:* used when complex decisions, involving many stakeholders with competing interests, are needed.

With regard to optimization techniques, OR applies different algorithms to solve problems that can be divided in two main categories:

- *Exact approaches*: that attempt to exhaustively explore the solution space, reporting the optimal solution. The most famous exact approaches are represented by the simplex algorithm, the branch-and-bound method and the column generation algorithm. Commercial solvers such as IBM CPLEX and GUROBI Optimizer embed these exact approaches to solve complex problems. The advantage of these methods is that they guarantee the quality of the obtained solution, that is always the optimal one, to the detriment of a long computation time. In fact, depending on the complexity of the decision problem, exact approaches are subject to a combinatorial explosion as the size of the problem increases. For this reason exact approaches are not suitable for large and complex decision problems;
- *Heuristics*: with this term non exact approaches are denoted. Heuristics are widely employed to solve complex optimization problems. Despite they don't guarantee the optimality of the obtained solution, heuristics are able to deliver near optimal solutions in shorter time than exact approaches. Moreover, heuristics are quite useful to deliver approximate solutions when classic methods fail to find any feasible solution. Heuristics can also be used in combination with exact approaches (hybrid heuristic) to exploit the advantages of both the approaches and improve the solution quality. Beside specific heuristic algorithms, metaheuristics are used to cope with complex decision problems. A metaheuristic is a high-level problem-independent algorithmic framework that provides a set of guidelines or strategies to develop heuristic optimization algorithms. The term is also used to refer to a problem-specific implementation of a heuristic optimization algorithm according to the guidelines expressed in such a framework (Sörensen 2015). Some examples of metaheuristic approaches are represented by genetic algorithm, iterated local search, ant colony optimization, GRASP, variable neighbourhood search, tabu search etc.

Intelligent systems based on optimization methods have been efficiently applied to several decisional domains. Practical applications can be found in a wide range of sectors such as supply chain, transportation, workforce management, portfolio optimization, network optimization, project management, etc. Many other sectors (e.g. education, emergency management, energy, health care, defense and security, telecommunications and Information technology), can also benefit from the application of OR techniques (Wagner 1969; Taha 2007). In the following paragraphs some of the main applications of OR optimization methods are discussed.

15.2.1 Supply Chain and Logistic

Several tools have been developed to solve the well-known shortest path problem, the vehicle routing problem and their variants. The shortest path problem consists in finding the "best" (the shortest, the safest etc.) shortest path from an origin to a destination point. Several applications can be found in the modern navigator systems where the "best" path, according to the user's preferences, needs to be found.

OR can efficiently tackle several real-life shortest path applications in which, due to criticalities on the road network (road work, security issues etc.), some paths are not available (Di Puglia Pugliese and Guerriero 2013) or congestion makes the time needed to traverse the road link longer (Vanhove 2012). Other applications can be found in production processes where the use of OR optimization techniques allows to save precious time and thus reduce the production cost. Some examples concern the automated production of integrated circuits, electronic or metal components by means of robots. All these processes have in common the solution of a shortest path problem that is followed by a robot to assemble or build a product.

Vehicle routing problems are generally more complex than the traditional shortest path problems. In this kind of problems several destination points (e.g. customers that need to be visited for delivery or pick up of goods) need to be visited by using a fleet of vehicles that are located to one or several origin points (such as depots from which the vehicles begin/end their routes). The vehicle routing problem has been introduced in the literature by Dantzig et al. (1959) to model the distribution of goods to a set of customers with a given fleet of vehicles having a limited capacity. The model can include several real-life constraints such as predefined time windows in which the customers need to be visited, capacity of the vehicle, maximum route length/duration, maximum driving hours. The main goal of the problem consists in the minimization of the travel time (and/or the minimization of the distribution costs, the minimization of the risk of accidents etc.). This problem can be employed to cope with strategic (number and type of fleet) tactical (type and number of customers to be served), and operational (design of the routes and drivers to allocate to the vehicles) decisions that are typical of the transportation sector. Some recent examples concern the route planning for the collection of diary products (Caramia and Guerriero 2010) the creation of balanced routes for courier companies (Janssens et al. 2014), the definition of safe routes for the collection of valuables (Shangyao et al. 2012, Talarico et al. 2015a), and for waste collection management (Angelelli and Speranza 2002). Other possible applications concern the optimization of public transport systems (Schittekat et al. 2013). It is obvious that the operational economic results of any firm could be improved by optimizing transportation routes. Moreover, a better transportation plan can also allow the service improvement during the transportation activities (pick-up and/or delivery of goods, public transportation, etc.) resulting in an enhanced customer satisfaction.

15.2.2 Workforce Management

This problem concerns the optimal allocation of workforce to workload in order to reduce the cost of personnel and guarantee appropriate service levels and employees' satisfaction. Several applications of OR can be found in several domains ranging from call centers, shops, banks etc. In Jones and Nolde (2013) the employee scheduling for direct-sales retail outlets is addressed taking into account the employees well-being. A scheduling tool based on an exact solution approach is proposed and applied to a chain store in the Swiss market. The proposed tool optimizes the shifts assigned to staff based on a mixed-integer and linear optimization programming model. In Aksin et al. (2007) an optimization exact approach based on a cutting plane method is proposed and applied to a scheduling problem in a call center. The goal is to minimize staffing costs under the constraint that an acceptable service level needs to be offered to customers over multiple time periods. In Kohl and Karisch (2004) an interesting crew scheduling problem in the airline sector has been presented and described as an important part of airline operational decisions. Several types of crew scheduling problems within different airline companies are presented an mathematically modeled. An efficient solution tool based on OR techniques is also developed and applied to these real-life problems. A detailed review of OR applications to real-life staff scheduling problems in several business sectors can be found in Ernst et al. (2004).

15.2.3 Network Optimization

Under this category it is possible to classify all the strategic, tactical and operational decision problems related to the construction of a digital/physical network infrastructure, its use, maintenance and security.

A detailed review about the most relevant OR studies dealing with the transportation of natural gas via pipelines is presented in Rios-Mercado and Borraz-Sánchez (2014). In Janssens et al. (2014) a decision model is presented to support decision makers to select security strategies and allocate a limited security budget on utility networks such as smart grid, water network, pipelines. In Erkut and Neuman (1989) several models and solution approaches are presented to locate special facilities such as garbage dumps, chemical plants or nuclear reactors where closeness to a neighboring population is undesirable. In Baldacci et al. (2007) a mathematical model and a solution approach to design an urban optical telecommunication network are presented. The solution algorithm is implemented and tested on real-world instances. In Tafteh et al. (2014) a mathematical model and a solution approach is presented and applied to a water distribution problem. In particular the model is aimed at optimizing the distribution of irrigation water as well as at defining optimal cultivation patterns to maximize the net profit on the one side and the water productivity on the other.

15.2.4 Portfolio Management

In this category the problems dealing with the selection of goods/services (e.g. assets, ingredients, resources) given a limited budget, to reach certain goals (e.g. minimization of the financial risk, maximization of the expected rate of return etc.)

are grouped. Applications of such decision models can be found in finance, diet problems, budget allocation problems and all the decision problems where a limited number of options need to be selected given a fixed budget. Each good usually presents a cost/weight and certain characteristics (e.g. profit, utility) that can be more or less desirable given the user preferences and goals. OR is widely used to solve such a type of problems determining the optimal mix (in terms of quantity and type) of goods that need to be included in the portfolio (sometimes also named knapsack) to maximize (or minimize) the decision maker objectives given a limited amount of available resources.

In Köksalan and Şakar (2014) a portfolio optimization model is developed for financial applications considering stochastic market movements. A method based on a multiple-scenario optimization is developed and representative solutions are presented to the decision maker. The model is tested on real stocks traded on the Istanbul Stock Exchange market. The attitude to risk of the investors is also considered in Pendaraki et al. (2014) where a tool named POTRAIT is developed to define a set of different investment policy scenarios and support the investor/portfolio manager in composing efficient portfolios that meet her/his profile. The decision model is tested on data from the Greek domestic equity mutual funds over the period from January 2006 to December 2011.

A similar model for a diet decision problem is presented in Garille and Gass (2001). A linear programming method is developed to determine the minimum cost diet by selecting appropriate foods each one presenting different nutritional and cost data. The model can be efficiently applied to the medical sector and the proposed solution method can support dieticians and nutritionists in defining cost-effective diets in line with the patient needs.

15.2.5 Inventory and Warehousing

This type of problems refers to critical decisions that firms need to face on a daily basis. In fact companies have to decide when and how much raw material needs to be ordered to meet the demand of finished products. These decisions depend on a series of factors such as the lead time needed to have the material ready to be used, the demand of the final products, uncertainty and other consumption elements. The problem can be modeled using OR mathematical techniques aimed at optimizing the lot size considering the minimization of the inventory cost due to warehouses costs, obsolescence costs, capital investment in inventory etc. (Maloni and Benton 1997).

In Lu (1995) an integrated inventory model that considers the interaction of buyers and suppliers is proposed. A model and a heuristic approach are developed to determine the optimal solution looking both at the lot price and the lot size which is transferred from suppliers to buyers, given their contrasting interests.

Several methods based on OR techniques are suggested by Malakooti et al. (2013) to create partnerships in the supply chain overcoming and mitigating the traditional barriers that exist between stakeholders (e.g. due to the contrasting interests of suppliers, buyers, vendors and clients). Qualitative and quantitative conceptual and analytical OR decision models are proposed to build mutually beneficial relationships, increasing the information flows, reducing the uncertainty, designing thus a more profitable supply chain.

15.2.6 Project Management

Modern organizations can be considered as complex systems that interact with their environment (competitors, suppliers, shareholders etc.) to achieve objectives according to their mission (Ackoff 1970). Project management deals with the process that leads to the achievement of such goals under the most convenient conditions (e.g. budget, time, quality). Projects in OR are usually represented by a network where nodes represent the milestones and arcs represent the activities that need to be performed to reach the milestones. Methodologies to find the critical path (the sequence of connected activities which take the longest time to complete) can be effectively used by project managers to control the whole project and intervene in case of deviations from the predefined plans.

Several real-life constraints can be included in the OR models to better represent existing projects that are subjected to time constraints and uncertainty. In Guerriero and Talarico (2010) a methodology is proposed to support project managers in planning and controlling a project where the activities are subjected to several types of time constraints. A realistic tool is used to model real-life activities that could be subject to time window constraints, which impose that an activity can start only in a predefined time interval, time schedule constraints, which assume that an activity can start its execution at one of the pre-specified instants of time, and time-switch constraints, which imposes a specified starting time on the project activities and forces them to be inactive during specified time periods.

In Bruni et al. (2009) a decision model is presented considering random factors which may occur during the project execution. In particular, the uncertainty concerning the activities duration is modeled and a solution method to find the critical path is proposed. In Tavares (2002) a review of the OR methods and approaches that can be effectively used for project management applications to support project managers is presented.

15.3 Decision Theory

Decision Theory (DT) refers to the process of selecting the most desirable alternative from a set of feasible options. DT can be considered as a subdomain of OR aimed at supporting decision makers to understand how decisions are made and to guide them in making decisions whitin complex and dynamic economic systems.

It was developed starting from the 1970s and it uses concepts and theory borrowed from many disciplines such as Mathematics, Behavioral decision theory, Economics and Computer science.

Depending on the complexity of the problem several methods can be used. For instance, models based on decision trees are suitable for simple decision problems, while for problems where several variables need to be considered and hundreds of alternative solutions are available, more sophisticated decision support systems need to be used. In general, the decision process involve several stakeholders and at least one decision maker. Depending on the number of decision makers, DT models can be classified as single or group decision making methods. Two approaches are highlighted in Zeleny (1982) to simulate the human decision making: (1) *outcome oriented* approaches that are centered on the outcome of the decisional process and; (2) *process oriented* that includes methods focused on the decisional process. In de Keyser and Springael (2010) two fields of decision making are considered: *normative decision theory* and *descriptive decision theory*. The former deals with what decision maker should do (in theory), while the latter deals with what decision makers do in practice. Normative and prescriptive decision theories can be combined together generating *prescriptive decision theory* that deals with what decision makers should (in theory) and can (in practice) do.

When facing decision problems that need to be solved by using DT, it is necessary to build a mathematical model that simulate the rational behaviour of the decision maker. This model should include parameters that reflect the decision maker's preferences, the objectives of the decision process and some constraints which limit the solution space. If the model contains a single objective there is no decision involved and the model can be solved by using OR techniques aimed at finding the optimal solution that in general maximizes the benefits or minimizes the costs. However, when facing multiple objectives (or criteria) DT is needed. Since the alternative solutions are characterized by multiple attributes as well as multiple objectives, it is more difficult and impractical to combine these various aspects in a single measure of utility. Therefore multi-criteria and multi-objective decision making approaches are needed to support the decision maker in the selection of the "best" alternative among a huge set of solutions.

According to Pohekar and Ramachandran (2004) multi-objective and multi-criteria methods provide better understanding of inherent features of decision problem, promote the role of participants in decision making processes, facilitate compromise and collective decisions. In general multi-objective decision making deals with the generation of multiple and well differentiated alternative solutions in case at least two objective functions are considered in the decision model. Multi-criteria decision making methods deal with the choice of the "best" alternative that suits better the decision making preferences from a set of alternative solutions. Multi-objective and multi-criteria decision making methods can also be embedded into an integrated approach aimed at generating several alternative solutions from which the "best" solution, in line with the criteria defined by the decision makers, is returned. An application of this integrated approach is suggested in Sörensen

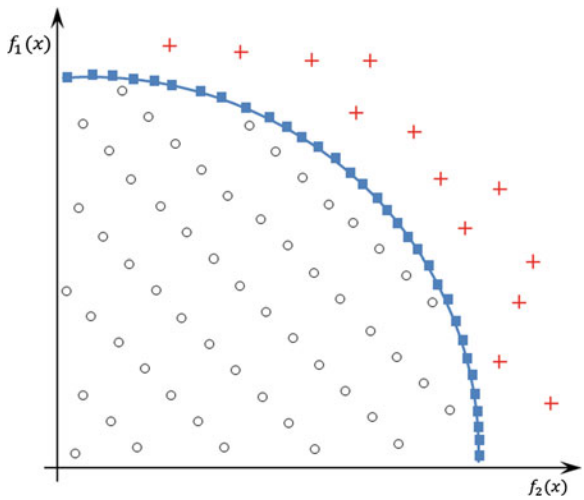
(2015). In Padhye and Kalyanmoy (2011) an integrated approach is applied to a manufacturing process to minimize time surface roughness and processing time.

15.3.1 Multi-objective Decision Making

Multi-objective optimization can be considered an extension of classical OR optimization techniques with several practical applications in different domains. In fact, most of the real-life decision problems can be modelled using multiple (and sometimes conflicting) objectives.

In multiple objective optimization the notion of optimality is replaced by the concept of domination. A solution x dominates another solution y, if x is at least as good as y with respect to all objectives and better with respect to at least one. The complexity of multi-objective problems relies thus in a set of trade-off optimal solutions instead of a single optimal solution. Therefore the goal of a multi-objective decision making approach is to find a set of non-dominated solutions that form as a whole the so called Pareto frontier as shown in Fig. 15.1. Given a problem with two objective functions ($f_1(x)$ and $f_2(x)$) both to be maximized, points denoted in Fig. 15.1 by circles represent feasible but dominated solutions, the squares indicate non dominated solutions that lie on the Pareto frontier while the red crosses are infeasible solutions. Differently from a single objective optimization, in the multi-objective optimization problem a set of Pareto optimal solutions (lying on the Pareto frontier denoted with a blue line in Fig. 15.1) need to be found. The Pareto frontier, made by as many Pareto-optimal solutions as possible, can help and support the decision maker making a choice by comparing and analysing the trade-

Fig. 15.1 Pareto frontier



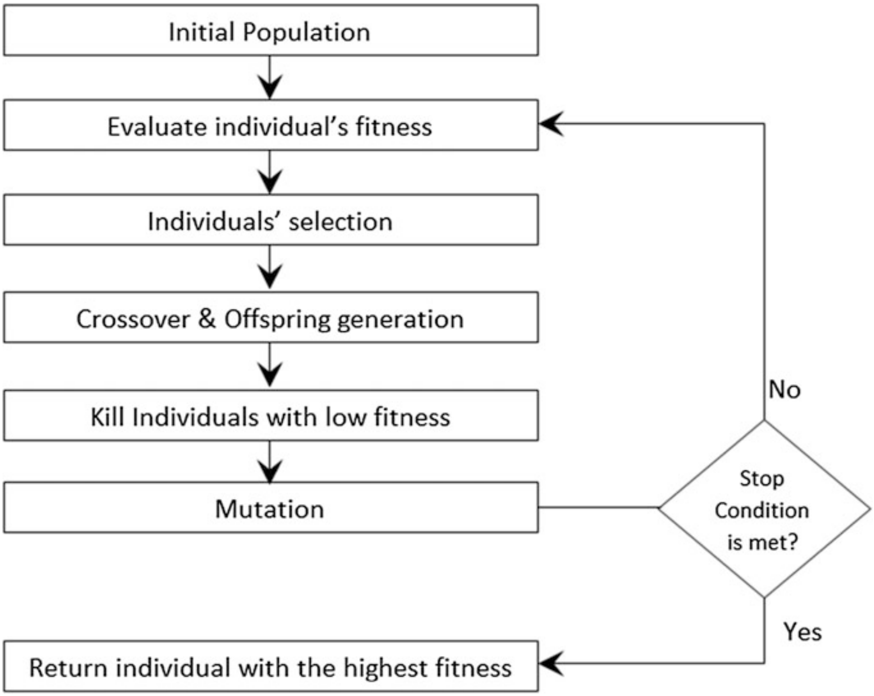


Fig. 15.2 Scheme of the genetic metaheuristic

offs between alternative solutions. For a comparison between single objective and multiple-objective optimization problems the reader is referred to Deb (2014).

Classical approaches to solve multi-objective problems and generate an approximation of the Pareto frontier consist in scaling the problem into a single objective problem by using weighted sum functions which combine the conflicting objectives. Other approaches, such as the evolutionary algorithms, solve multi-objective problems as they are, treating all the objectives independently.

In both cases classical metaheuristic algorithms can be used to solve such multi-objective problems by applying local search or population based heuristics such as the genetic algorithm. For more details about multi-objective optimization methods the reader is referred to Marler and Jasbir (2004).

In the genetic algorithm (see Fig. 15.2), the solution approach mimics the natural evolution of a biological species by means of a natural selection process. An initial population, where each individual represents a solution of the problem, evolves over time. All individuals are evaluated by using a fitness function which measures the quality of the solution. At each iteration of the algorithm a new offspring is generated improving the features of the whole population. Individuals with a higher fitness value have higher chances to reproduce and spread their features to the new generation. These new solutions are added in the initial population set and the individuals with the lowest fitness values are removed from the set. Moreover, to add diversity in the population, a mutation operator can be applied to partially modify the characteristic of some individuals in the set. The process is repeated starting from the new population until a maximum number of iteration is reached or when the population converges towards satisfactory fitness levels.

In Sörensen and Vanovermeire (2013) a bi-objective decision support tool is proposed to locate the logistic terminals which are used within a multimodal logistic network for freight transport in order to minimize the transportation costs sustained by the users of the terminal network, as well as the location costs sustained by the terminal operators. A OR metaheuristic approach, based on a local search, is used to generate, in a relatively short time, a Pareto set approximation, made by a set of non-dominated alternative solutions (containing the number and the location of the logistic terminals) which need to be evaluated by decision makers. Several optimization methods, including also a genetic algorithm, are proposed in Bhaskar et al. (2000) to solve different multi-objective transportation and security problems in the chemical sector. Other interesting fields of application include automotive design (Dandurand et al. 2014), water distribution (Mortazavi-Naeini et al. 2014), portfolio optimization (Yang et al. 2014) or any other sectors in which complex decisions with conflicting objectives need to be adopted.

15.3.2 Multi-criteria Decision Making

Once a set of feasible and non-dominated alternative solutions has been determined a critical issue in the decision making process concerns the selection of the "best" alternative that suits better the customer needs or the company expectations. Sometimes alternatives need to be compared on the basis of various (often conflicting) criteria (objectives). A robust methodology that can be used to classify, score and evaluate alternative decisions is represented by the multi-criteria decision making. Considering the Pareto frontier in Fig. 15.1, the decision maker is left to choose the "best" alternative according to his/her preferences.

Several methods have been developed to classify, compare and rank the alternative solutions on the basis on the criteria that are important for the decision maker. The most common techniques used within the multi-criteria decision making are known as: compromise programming, ELECTRE, PROMETHEE, multi-attribute utility theory, analytic hierarchy process (AHP), etc. These methods use different principles to assign a score to each alternative and rank them. In particular, PROMETHEE methods perform a pair-wise comparison of alternatives in order to rank them with respect to a number of criteria. ELECTRE selects alternatives that are preferred over most of the criteria without causing an unacceptable level of discontent for any of the criteria. Concordance, discordance indices and threshold values are used to generate a graph denoting strong and weak relationships that are used to rank the alternatives. Compromise programming defines the "best" solution as the one in the Pareto frontier whose distance from an ideal point is minimized. Methods based on the multi-attribute utility theory consider the decision maker's preferences in the form of a utility function defined over a set of attributes. Finally the AHP allows both qualitative and quantitative approaches to solve complex decision problems by decomposing them into a hierarchy of elements influencing a system. In particular the AHP approach is based on the generation of a hierarchy from the top (e.g. the objective of the problem) through the intermediate levels (e.g. attributes and sub-attributes on which subsequent levels depends) to the lowest level (e.g. the list of alternatives). For a detailed description and comparison of these methods the reader is referred to de Keyser and Springael (2010), Pohekar and Ramachandran (2004) and Figuera et al. (2005).

Multi-criteria tools can also be used when quantitative information about the alternatives are not available and when the decision should be based either on qualitative values or a combination of qualitative and quantitative measures. Multi-criteria decision making can be applied in a broad range of business areas such as finance, project management and energy management. In Gavalas and Syriopoulos (2014) a multi-criteria tool is used to develop an integrated credit rating model based on a series of critical qualitative and quantitative criteria. The proposed method uses both criteria associated to the credit rating and risk factors to support the bank's final decision on a loan approval. In Pohekar and Ramachandran (2004) a review of several multi-criteria decision tools with applications in the energy sector is presented. It is shown that the problems which are mostly solved by using multi-criteria decision methods concern: renewable energy planning, energy resource allocation, energy management, energy transportation, project planning and electric utility planning. In Al-Harbi (2001) a multi-criteria decision-aiding method is proposed for the area of project management. In particular the tool is able to evaluate and rank a list of contractors based on tangible and intangible factors.

15.4 Data Mining

Data Mining (DM) is a branch of science aimed at exploring large and complex data to find implicit, but potentially useful, information to support the decision making process (Rokach 2008). In Turban et al. (2007) DM is defined as "…the process that uses statistical, mathematical, artificial intelligence and machine-learning techniques to extract and identify useful information and subsequently gain knowledge from large databases…". The continuous development of information technologies (e.g. digital data acquisition and storage technology) is leading to a tremendous amount of data stored in databases, data warehouses, or other kinds of data repositories including the World Wide Web. If data collection has become easier, more efforts are required to retrieve relevant knowledge from databases and DM can offer a valid contribution to support this complex task. Although, DM techniques were developed at the beginning of 1960, in the last decades DM has become more attractive due to its capability of facilitating the discovery of useful knowledge from a huge amount of data (Kim and Han 2003).

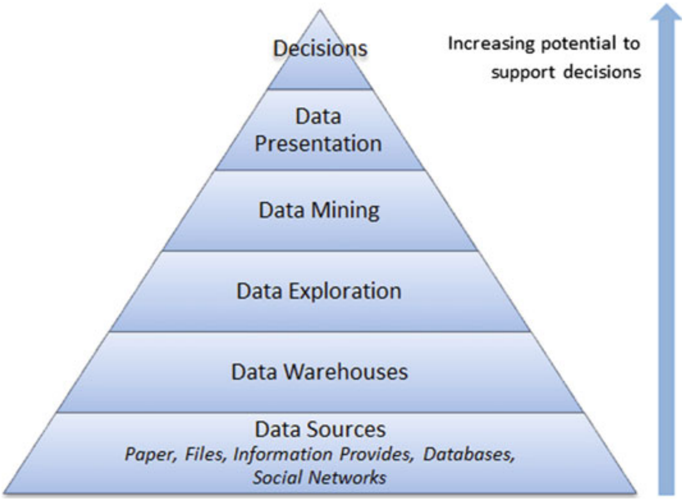


Fig. 15.3 Data mining pyramid

DM can effectively help and support the decision making discovering new unknown knowledge using enormous amount of data from large databases as shown in Fig. 15.3. The availability of large volume of data, made possible by development of information technology, internet and the social networks, has created new opportunities for companies to leverage the data and gain competitive advantage.

The main DM models are summarized in Shaw et al. (2001) based on the goals of the intelligent system beneath the model:

- *Dependency analysis* also known as "market basket analysis" is used to discover relationships between different items (e.g. products seen or purchased by the same customer);
- *Class identification* refers to the generation of homogenous clusters. Similarities among the member of the same class are maximized while similarities between classes are minimized;
- *Concept description* refers to the classification of items based on knowledge domains. The items in such a way described can be used for summarization, discrimination or comparison;
- *Deviation detection* used to discover anomalies (e.g. items that are different from the normal or have changed from previous observations);
- *Data visualization* used to explore the knowledge in a database visualizing data and complex relationships among them in a graphical manner.

More exhaustive classification can be found in Ahmed et al. (2004) including seven different models based on the main DM goals as follows: *Association, Classification, Clustering, Forecasting, Regression, Sequence discovery and Visualization*.

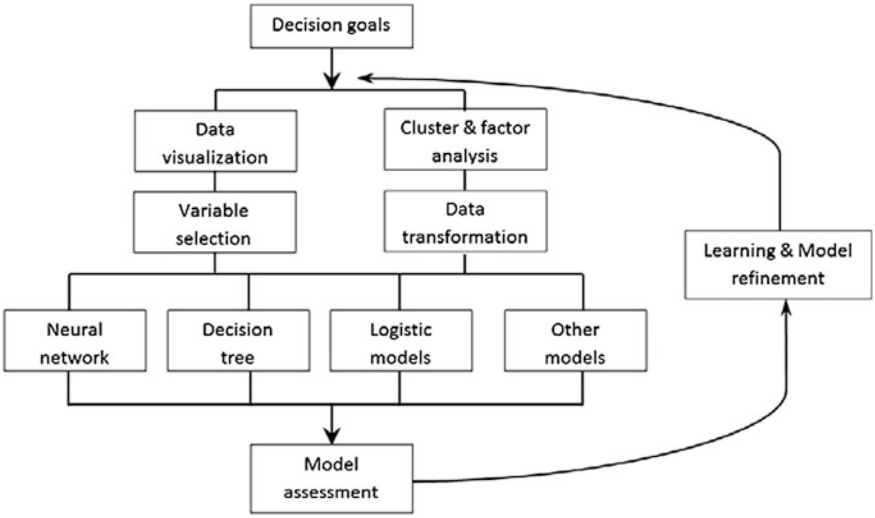


Fig. 15.4 KDD scheme

A DM intelligent system based on a large amount of data is also known as knowledge discovery from data (KDD) that, as defined in Frawley et al. (1991), represents "a nontrivial process of identifying valid, novel, potentially useful, and ultimately understandable information in data". The structure of a KDD model is shown in Fig. 15.4 that has been adapted from Shaw et al. (2001). Here the model is described as an iterative process through which the model, after having been assessed, is refined. The algorithms, which can be used inside a KDD system to analyse and discover relationships between data, are represented by a broad family of computational methods that includes: neural networks, statistical analysis, decision trees, logistic models and other techniques borrowed from statistics (e.g. rule induction). There are many other algorithms available for each type of DM model such as association rules, discriminant analysis, genetic algorithms, Markov chain, K nearest neighbour, Bayesian networks, linear regression etc. Depending on the data and the goal of a DM tool some algorithms are more suitable than others. For a detailed description of these algorithms the reader is referred to Ngai et al. (2009) and Giraud-Carrier and Povel (2003).

DM represents a field of research in constant evolution with several practical applications in different domains such as marketing, finance, banking, manufacturing and telecommunications. Intelligent systems based on DM techniques can be efficiently applied to support strategic decision problems such as credit approval, risk estimation, product selection, corporate bankruptcy, medical diagnosis. However, a greater number of intelligent systems based on DM is used for marketing applications (e.g. customer relationship management, real-time interactive marketing, customer profiling) to increase the sales.

15.4.1 Marketing and Customer Relationship Management

The continuous progress of the ICT allows companies to store in large databases huge amounts of data such as customer characteristics and purchase transactions. The development of DM techniques together with the emphasis on customer relationship management (CRM) make the marketing an ideal application area which can greatly benefit from the use of DM for decision support (Shaw et al. 2001). DM techniques can efficiently be used to detect customer characteristics and profile them in order to formulate customized and effective marketing strategies (e.g. product promotion, selection of the distribution channels, advertising media) with the main goal of increasing the sales. Moreover DM can efficiently speed up the strategic transformation from the mass marketing to the customer relationship marketing by allowing companies to develop specific strategies for each single customer based on his/her profile.

According to Ling and David (2001), CRM concerns the processes and the intelligent systems aimed at supporting a business strategy to establish long term and profitable relationships with customers. CRM can be defined as an "enterprise approach to understanding and influencing customer behaviour through meaningful communications in order to improve customer acquisition, customer retention, customer loyalty, and customer profitability". For this reason customers data and the tools which are used to extract information from such data represent the basis on which a CRM system is built.

The relevance of an effective CRM for marketing decisions is highlighted in Peppers and Rogers (1999). According to them, it is possible to centre the focus of a company back on the customer by using DM techniques. In fact, DM can make a CRM system more effective by: (1) identifying the right customers; (2) differentiating among them; (3) interacting with and learning from existing customers; and (4) customizing the product or service to the needs of every single customer. In Shaw et al. (2001) three possible areas of application are highlighted depending on the needs of extracting hidden knowledge in databases and therefore take the appropriate marketing decisions:

- *customer profiling*: used for strategic marketing decisions aimed at meeting the customer needs. Customized products and marketing campaigns can be defined in line with the customer preferences to increase the sales. Data usually analysed by DM models refer to the frequency, the size and the time of purchases. Some examples of valuable knowledge that can be extracted by these data by DM applications concern: customer groups, customer lifetime values, success/failure of specific marketing programs;
- *deviation analysis*: abnormalities and deviations from normal can be associated either to frauds or a change in the customer behaviour. In the modern society customer preferences are evolving faster than the past. These situations can be easily detected by using specific DM tools allowing companies to take corrective actions. Practical applications of DM include the analysis of changes that occurred as a result of price changes or promotions;

- *trend analysis*: used to analyse and detect short term (e.g. sales following a sales campaign) or long term (e.g. sales of a product over few years) trends, which would have been missed by traditional methods. The trend analysis represents a critical issue for decision makers and can be successfully applied to evaluate the performance of a product, a marketing program or to develop accurate and precise sale forecast.

In Teo et al. (2006) two types of CRM systems are distinguished: operational CRM that refers to the automation of the business processes and analytical CRM where the focus is on the analysis of the customer behaviours and characteristics to support the company strategies aimed at acquire, retain customers and maximize their value.

In Ngai et al. (2009) an extensive review and classification of the relevant DM applications in the field of CRM has been presented. 87 papers have been classified based on the goals of the DM application and the data mining techniques. Four dimensions of an analytical CRM have been proposed in relation to the main activities associated to the customer management. These dimensions include: *customer identification* (e.g. target customer analysis, customer segmentation); *customer attraction* (e.g. direct marketing); *customer retention* (e.g. loyalty program, one-to-one marketing, complaints management) and *customer development* (e.g. customer lifetime value, up/cross selling, basket analysis). Moreover, seven different models of DM, each with a different goal, have been classified and associated to the four dimensions of the CRM (i.e. classification, clustering, forecasting, regression, sequence discovery, visualization, association).

15.4.2 Bankruptcy and Fraud Detection

As mentioned, DM can be used efficiently to make predictions based on data stored in large databases. Interesting applications can be found in the fields of bankruptcy prediction and fraud detection. Corporate bankruptcy represents a critical issue since it might engender economic losses for several types of stakeholders such as partners, public institutions, banks, shareholders, employees, customers that can directly or indirectly be influenced by a firm's failure. Therefore, a DM tool aimed at elaborating accurate bankruptcy predictions can have significant applications in finance.

In Becchetti and Sierra (2003) a DM model based on a stochastic approach is used to predict the risk of bankruptcy in manufacturing firms. The model is tested on a real dataset made by several Italian companies in a period of 9 years. Some predictors such as the firm inefficiency (measured by using specific financial ratios), and the firm characteristics (e.g. the customer's concentration, the strength and the proximity of competitors) are used to execute trend analysis and discover hidden negative trends that will likely lead to corporate failures. A similar approach can also be used to predict the success of small firms in order to develop effective credit analysis and support microcredit decisions (de Moraes Sousa and Figueiredo 2014). In Kim and Han (2003) a DM model based on a genetic algorithm is used to discover experts' decision rules. The model uses both quantitative and qualitative bankruptcy data. In the traditional default risk estimation, experts evaluate the qualitative risk factors through the risk estimation process and assign appropriate levels (e.g. positive, average and negative) to these factors using their experience and knowledge. The model embeds the knowledge of several loan officer experts, having at least 9 year of experience in commercial banks, in the form of rules that are used to estimate and predict firm bankruptcy. A large dataset containing 772 manufacturing and service companies located in South Korea is used to test the accuracy of the predictions.

A similar logic can also be used by DM to detect frauds. Fraud detection is a relatively hard task to be performed by using traditional tools due to the unpredictability of human behaviour. Another factor of complexity concerns the large amount of data that need to be retrieved from different sources and combined together to extract useful information. Since DM can detect relatively unperceivable deviations also in large amount of data, they can be used to effectively detect those anomalous patterns which may discriminate regular from fraudulent behaviours. Data generally used to detect anomalies concern customers profile (either individuals or company) and their financial transactions. These data combined with other predictors may reveal useful rules to predict possible frauds. For example frauds in the usage of credit cards can be efficiently detected by using DM models that relies on discriminant analysis. In practice, a classification problem is solved where transactions are classified either as potentially fraud or non-fraud related. Other applications of DM techniques to discovery frauds on the credit card usage are based on decision trees or neural networks (Donato et al. 1999). In Daskalaki et al. (2003) a decision support system, which uses the knowledge discovered in a vast database, is used to detect customer insolvency. This useful tool is applied to a large telecommunication company, but it can easily be extended to other service-providing companies to detect insolvent customers and take the most appropriate precautions against them reducing thus the loss of revenue for the company.

15.4.3 Medical Applications

Due to the development of modern technologies that make the collection and storage of medical data relatively easy (e.g. patient records collected for diagnosis and prognosis), DM techniques are well suited also for medical applications. In Lavrač (1999) a review of several DM methods that can support intelligent data analysis in medicine is presented. In particular DM tools based on decision trees and rule induction methods can be applied to a variety of medical domains in order to support medical decisions improving thus the quality of the medical services offered to patients, reducing the errors and the medical costs due to diagnosis and the prognosis activities. Some applications include the diagnosis and the prognosis of pathologies in different domains such as oncology, neuropsychology and gynaecology.

Enhanced medical decisions may be achieved by using DM to automatically analyse patient data stored in medical records. DM is also efficiently used to detect abnormalities such as cancers and other lesions by specific algorithm applied to images. In fact DM applied to images can facilitate the extraction of hidden information, not clearly visible from the images and provide valuable information to doctors. An extensive review of DM techniques and tools efficiently used in medical applications for image recognition is presented in Chen et al. (2014).

Other interesting applications of DM can be used to analyse and predict degenerative diseases. By knowing the likelihood of a patient to develop a degenerative disease DM tools can be efficiently employed to support medical staff in defining appropriate preventive treatments improving the quality of life of patients and slow down the progress of the disease. Some practical applications of DM concern the prevention of bone diseases such as Osteoporosis (Li et al. 2014), cerebrovascular diseases (Yeh et al. 2011) and other neurological illnesses such as Alzheimer's disease (Plant et al. 2010).

15.5 Game Theory

Game Theory (GT) is a mathematical tool for investigating strategic behaviour of decision-makers, based on certain assumptions (e.g., rationality). People make decisions all the time. In an organizational setting, these decisions typically are interdependent with decisions made by others. Hence, there is a kind of multi-personal/organizational interaction. A central feature of multi- personal/organizational interaction is the potential for the presence of strategic interdependence, meaning that a person's or an organization's well-being (for example measured as utility or as profit) depends not only on their own actions but also on the actions of other individuals/organizations involved into the situation with strategic interdependence. The actions which are the best for the person/organization may depend on actions which other individuals/organizations have already taken, or are expected to take at the same time, and even on the future actions that other individuals/organizations may take or decide not to take, as a result of the current actions.

The term "game" highlights the theory's central feature: The persons, which are involved in the decisional problems, also called "players", 'decision-makers' or "agents", since persons can also represent entire organizations or nations. These players are concerned with strategy and winning (in the general sense of expected utility maximization). The agent will have some control over the situation, since his/her choice of strategy will influence it in some way. However, the outcome of the game is not determined by the player's choice alone but also depends upon the choices of all other players. This is where conflict and cooperation come into the play. Non-cooperative game theory focuses on how cooperation may emerge from rational objectives of the players, given that rationality is a common knowledge, and in the absence of any possibility to make a binding agreement.

Game theory is thus a logical analysis of situations of conflict and cooperation. More specifically, a game is defined to be any situation in which: (i) there are at least two players. A player may be an individual, but it may also be a more general entity like a company, an institution, a country, etc.; (ii) each player has a number of possible strategies, courses of action which the player may choose to follow; the strategies chosen by each player determine the outcome of the game; (iii) associated to each possible outcome of the game there is a collection of numerical payoffs, one to each player. These payoffs present the value of the outcome to the different players. In real-life applications, these payoffs represent quantifiably gains such as profits, market shares, but also brand recognition and customer's perceptions.

Game theory can generally be divided into non-cooperative game theory and cooperative game theory. Furthermore, a distinction can be made between "static games" and "sequential move games". In a static game a single decision is made by each player, and each player has no knowledge of the decision made by the other players before making their own decision. Sometimes such games are referred to as "simultaneous decision games" because any actual order in which the decisions are made is irrelevant. A sequential game is a game where one player chooses his/her action before the other(s) choose theirs. Importantly, the later players must have some information of the first player's choice, otherwise the difference in time would have no strategic effect. Another distinction that can be made between the game-theoretic models concerns the information available to the players: games of perfect information should be solved differently from games of imperfect information. In many economically important situations the game may begin with some player disposing of private information about a relevant issue with respect to his/her decision making. These are called "games of incomplete information", or "Bayesian games". Incomplete information should not be confused with imperfect information in which players do not perfectly observe the actions of the other players. Although any given player does not know the private information of an opponent, he/she will have some beliefs about what the opponent knows, and the assumption that these beliefs are common knowledge can be made. Traditional applications of game theory aim at finding equilibria in these games. In an equilibrium, each player of the game has adopted a strategy that they are unlikely to change. Many equilibrium concepts have been developed (in particular, the Nash equilibrium) in an attempt to capture this idea. These equilibrium concepts are motivated differently depending on the field of application, although they often overlap or coincide.

It should be noted that game theory is not without criticism, and debates do continue concerning the appropriateness of particular equilibrium concepts, concerning the appropriateness of equilibria altogether, and as regards the usefulness of mathematical models more generally. For instance, game theory should not be considered as a theory that will prescribe the best course of actions in any situation of conflict and cooperation. First of all, the real-world situations are performed in a quite simplified form of a game. In real life it may be hard to say who the players are, to delineate all conceivable strategies and to specify all possible outcomes and it is not easy to assign payoffs. What is typically done is to develop a simple model which incorporates some important features of real-life situations. Thus building such a model and its analysis may give insights into the original situation. The second obstacle is that game theory deals with players which are rational. Each player logically analyses the best way to achieve his/her goals, given that the other players are logically analysing the best way to achieve their goals. In this way, rational play assumes rational opponents. It means that players are able to tell which outcomes are more preferred than others and that they are able to align them in some kind of preference relationship order. However, experiments show that in some cases rationality may fail. Game theory results should thus always be interpreted with caution.

What game theory offers is a variety of interesting examples, analysis, suggestions and partial prescriptions for certain situations in many economic applications (Kelly 2003; Straffin 1993; Carmichael 2005). Some interesting applications of GT can be found in a wide spectrum of business areas such as:

- Actions, procurement, patent licensing and public finance. These processes are all characterized by buyers and sellers having conflicting interests whose behaviours in presence or absence of complete information can easily be modelled by GT (Levitt and List 2009; Easley 2010);
- pricing problems in which an adequate price needs to be defined and paid by a firm in order to purchase a target company during mergers and acquisitions (Agarwal and Zeephongsekul 2011);
- behavioral economics during e.g. negotiations (Fudenberg 2006);
- Political economy and voting systems that can be used not only for political purposes, but also to elect board members and reach consensus within companies of cluster of companies (Brams 1994);
- agent-based computational economics that results from an intricate system of interdependent feedback loops connecting micro behaviours, interaction patterns, and global regularities of players in a complex dynamic systems (Tesfatsion 2006).

Additional applications of GT in specific business fields can be found in Kalyan and Samuelson (2001) and in Feryal and Keskinocak (2003). In the next paragraphs some applications of GT to increase security and mitigate costs (Sect. 15.5.1) and to select appropriate R&D strategies (Sect. 15.5.1) are mentioned.

15.5.1 Counterterrorism and Security

As explained in Bier (2005), game theory has a long history of being applied in fields related to security, starting from military applications, over political science, to cyber-crime. Managerial economists have also published extensively on applications of game theory to security, especially to provide policy insights (Sandler et al. 2003). Since 9/11, there has been a movement towards using game theory to guide decision-support of operational-level actions, for example, which countermeasures to take, which assets to defend, how much to charge for terrorism insurance, etc.

In Talarico et al. (2015) and interesting model based on GT is proposed to optimally allocate security resources in a multi-modal chemical transportation network, considering possible external attacks by criminals. The interests of two categories of adaptive opponents are considered. On one side there is the government (or a public-private institution) who intends to protect a given critical infrastructure on both the inter-modal and intra-modal transportation levels, and on the other side there is the attacker whose goal is to destroy a targeted supply chain. A linear model programming is also used to test the game theoretical model simulating realistic scenarios in the presence of budget limitations both for the attacker and the defender.

In Salani et al. (2010) GT is used to increase security and define optimal route planning in an urban environment. While transporting cash or valuables, by ground vehicles, the risk of being robbed by criminal is relatively high. For this reason game theory is used to model the opposite interests of both a possible attacker and a transportation company. The model attempts to minimize the criminal payoffs, to reduce the overall risk of successful ambush and to lower the travel cost incurred by the transportation firm.

As security science is evolving towards dealing with complex and systemic risks, protecting such complex and systemic systems against intentional malicious acts requires a combination of game theoretical models and risk assessment methods (Bier 2005). Security risk assessment by itself does not account for the attacker's responses to security countermeasures, while game theory often deals with individual assets in isolation, rather than with complex systems.

15.5.2 Macro-economics and R&D Investments

Games are everywhere in economic life. A general application of GT in economics always uses a game as an abstraction of a particular economic situation. Besides obvious game theoretical applications in economics, such as studying macro-economic investment policies by using game theory (e.g., central bank performance, strategic trade policies, oligopolic game theory models, auction modelling, predatory pricing, stockholder well-being, strategic bargaining, cartel enforcement, etc.), the coordination of R&D activities so as to maximise industry profit, is also a (relatively recent) field of application (Bierman and Fernandez 1998). The question of R&D cooperation by using game-theoretical modelling started somewhere in the 1980s and has been growing ever since.

A study proposed by Smit and Ankum (1993) uses a game theoretic approach to evaluate R&D investments instead of the traditional discounted cash flow method that presents some lacks when analysing projects for which information concerning future investment decisions is not yet known.

In Cellini and Lambertini (2002) GT is employed for decisions concerning the product differentiation within a dynamic oligopoly. Recently, in Pauwels et al. (2014), an approach based on GT is proposed and applied to a semi-collusive, differentiated duopoly. The goal of the model is to reduce the R&D cost and support firms to cooperate on the output market. The sharing of the joint profit on the output market is modeled as a Nash bargaining game.

15.6 Conclusions

A lot of progress has been made during the last decades in the scientific field of intelligent systems to support managerial decision making. The overview given in this chapter shows that OR, DT, DM and GT can provide effective, robust and scientific tools to simplify difficult problems within managerial economics and help decision makers in a wide variety of real-life applications. In this chapter several applications of these intelligent systems have been described within supply chain and logistics, workforce management, network optimization, project management, marketing and customer relationship management, bankruptcy and fraud detection, medical applications, counterterrorism and security, macroeconomic and R&D investments decision making. Other fields that we did not expressly treat include emergency management, healthcare, telecommunication problems, water distribution, design energy, resources allocation, electric utility planning, evolutionary biology etc.

The continuous development of ICT technology, the progress in computation power as well as computational performance will further enhance the solution of complex problems, e.g. computation time, more real-time information, more variables to be included into the models, etc. This evolution will ever more allow the decision-maker to have a perception of reality that matches everyday life closer and closer.

Further research can be aimed at closing the chasm that exists between academic works and real-life applications. One of the main factors that limits the use of techniques based on OR, DM and GT consists in applying the solution approach as a black box, delivering only the final solution to decision makers. Such problem can be mitigated by using a transparent design of the algorithm. In this way, the decision maker can interact with the tool to increase his knowledge about how both the problem's and algorithm's parameters and settings are positively or negatively correlated with the solution quality.

A recent trend within the field of OR is to develop heuristics and solution approaches based on metaphors of some natural or man-made processes (e.g. simulating annealing, ant colony optimization, genetic algorithms). Sometimes the true elements of novelty, in many of these approaches, rely more in the analogy that is used as inspiration to make them more appealing to a wider non-expert public. In fact in many cases, these “novel” approaches follow standard optimization procedures, having very little to offer, besides an exotic terminology used to sell existing ideas. However, we believe that the future direction of research in intelligent systems is to find applications in real-life business, optimizing and improving decisional process allowing the decision maker to save precious time that can be dedicated to other added value activities. With reference to the solution approaches, future research might be focused at developing more flexible and robust hybrid intelligent systems obtained by combining different methods and techniques borrowed from several research areas. In the domain of OR these techniques are known as hybrid heuristics and mateuristics. A matheuristic lies on the general idea of exploiting the strength of both metaheuristic algorithms and exact methods, leading to a hybrid approach. Other research direction can be aimed at combining techniques borrowed from DT, OR, GT and DT to solve complex problems in the domain of managerial economics.

References

Ackoff, R.: A concept of corporate planning. Long Range Plan. **3**(1), 2–8 (1970)

Agarwal, N., Zeephongsekul, P.: Psychological pricing in mergers and acquisitions using game theory. In: 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December (2011)

Ahmed, S.R.: Applications of data mining in retail business. In: Proceedings of International Conference on Information Technology: Coding and Computing, ITCC 2004, vol. 2. IEEE (2004)

Aksin, Z., Mor, A., Vijay, M.: The modern call center: a multi-disciplinary perspective on operations management research. Prod. Oper. Manage. **16**(6), 665–688 (2007)

Al-Harbi, K.M.: Application of the AHP in project management. Int. J. Project Manage. **19**(1), 19–27 (2001)

Allen, W.B., Weigelt, K., Doherty, N., Mansfield, E.: Managerial Economics Theory, Applications, and Cases, 7th edn. Norton, London (2009)

Angelelli, E., Speranza, M.G.: The application of a vehicle routing model to a waste collection problem: two case studies. In: Quantitative Approaches to Distribution Logistics and Supply Chain Management pp. 269–286. Springer, Heidelberg (2002)

Baldacci, R., Dell’Amico, M., Salazar González, J.: The capacitated m-ring-star problem. Oper. Res. **55**(6), 1147–1162 (2007)

Becchetti, L., Sierra, J.: Bankruptcy risk and productive efficiency in manufacturing firms. J. Bank. Finan. **27**(11), 2099–2120 (2003)

Bhaskar, V., Gupta, S.K., Ray, A.K.: Applications of multiobjective optimization in chemical engineering. Rev. Chem. Eng. **16**(1), 1–54 (2000)

Bier, V.M.: Game-theoretic methods in counter terrorism and security. In: Wiley Encyclopedia of Operations Research and Management Science (2005)

Bierman, H.S., Fernandez, L.: Game theory with economic applications. Addison-Wesley Publishing Company, Reading (1998)

Brams, S.J.: Voting procedures. In: Aumann, R., Hart, S. (eds.) Handbook of Game Theory with Economic Applications, Elsevier, vol. 2, pp. 1055–1089 (1994)

Bruni, M.E., Guerriero, F., Pinto, E.: Evaluating project completion time in project networks with discrete random activity durations. Comput. Oper. Res. **36**(10), 2716–2722 (2009)

Caramia, M., Guerriero, F.: A milk collection problem with incompatibility constraints. Interfaces **40**(2), 130–143 (2010)

Carmichael, F.: A Guide to Game Theory. Prentice Hall, Harlow (2005)

Cellini, R., Lambertini, L.: A differential game approach to investment in product differentiation. J. Econ. Dyn. Control **27**(1), 51–62 (2002)

Chen, R., Wang, Z., Zheng, Y.: Advanced Medical Image Analysis. Comput. Math. Methods Med. **2014** (2014)

Dandurand, B., Guarneri, P., Fadel, G.M., Wiecek, M.M.: Bilevel multiobjective packaging optimization for automotive design. Struct. Multi. Optim. **50**(4), 663–682 (2014)

Dantzig, G., Ramser, B., Hubert, J.: The Truck Dispatching Problem. Manage. Sci. **6**(1), 80–91 (1959)

Daskalaki, S., Kopanas, I., Goudara, M., Avouris, N.: Data mining for decision support on customer insolvency in telecommunications business. Eur. J. Oper. Res. **145**(2), 239–255 (2003)

de Keyser, W., Springael, J.: Why Don't We Kiss!?: A Contribution to Close the Gap Between Real-world Decision Makers and Theoretical Decision-model Builders, ASP/VUBPRESS/UPA (2010)

de Moraes Sousa, M., Figueiredo, R.S.: Credit analysis using data mining application in the case of a credit union. JISTEM-J. Inf. Syst.Technol. Manage. (Online) **11**(2), 379–396 (2014)

Deb, K.: Multi-objective Optimization, Search Methodologies pp. 403–449. Springer, New York (2014)

Di Puglia Pugliese, L., Guerriero, F.: Dynamic programming approaches to solve the shortest path problem with forbidden paths. Optim. Methods and Softw. **28**(2), 221–255 (2013)

Donato, J., Schryver, J., Hinkel, G., Schmoyer, Jr.R., Leuze, M., Grandy, N.: Mining multi-dimensional data for decision support. Future Gener. Comput. Syst. **15** 433–441 (1999)

Easley, D., Kleinberg, J.: Networks, Crowds, and Markets: Reasoning about a Highly Connected World. Cambridge University Press, Cambridge (2010)

Erkut, E., Neuman, S.: Analytical models for locating undesirable facilities. Eur. J. Oper. Res. **40** (3), 275–291 (1989)

Ernst, A.T., Jiang, H., Krishnamoorthy, M., Sier, D.: Staff scheduling and rostering: A review of applications, methods and models. Eur. J. Oper. Res. **153**(1), 3–27 (2004)

Feryal, E., Keskinocak, P.: Game theory in business applications. Working paper. Department of Management Science and Engineering. Stanford University, Stanford and School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, (2003)

Figuera, J., Greco, S., Ehrgott, M.: Multiple Criteria Decision Analysis, State of the Art Surveys. Springer, New York (2005)

Frawley, W.J., Christopher, J., Matheus, J.: Knowledge discovery in databases. In: Piatetsky-Shapiro, G (ed.). AAAI Press, Cambridge (1991)

Fudenberg, D.: Advancing Beyond Advances in Behavioral Economics. J. Econ. Lit. **4**(3):694–711 (2006)

Garille, S.G., Gass, S.I.: Stigler's diet problem revisited. Oper. Res. **49**(1), 1–13 (2001)

Gavalas, D., Syriopoulos, T.: An integrated credit rating and loan quality model: application to bank shipping finance. Marit. Policy Manage. ahead-of-print 1–22 (2014)

Giraud-Carrier, C., Povel, O.: Characterising data mining software. Intell. Data Anal. **7**(3), 181–192 (2003)

Guerriero, F., Talarico, L.: A solution approach to find the critical path in a time-constrained activity network. Comput. Oper. Res. **37**(9), 1557–1569 (2010)

INFORMS.org: About Operations Research, Retrieved 15 Oct (2014)

Jones, C.N., Nolde, K.: Demand Driven Employee Scheduling for the Swiss Market (2013)

Janssens, J., Talarico, L., Sörensen, K.: A decision model to increase security in a utility network. In: Proceedings 11th International Multidisciplinary Modelling Simulation Multiconference, Bordeaux, France (2014)

Janssens, J., Van Den Bergh, J. J., Sörensen, K., Cattrysse, D.: Multi-objective microzone-based vehicle routing for courier companies: From tactical to operational planning. Eur. J. Oper. Res. (2014)

Johnson, G., Scholes, K., Whittington, R.: Exploring Corporate Strategy: Text and Cases, 7th edn. Prentice Hall, London (2005)

Kalyan, C., Samuelson, W. (eds.): Game Theory and Business Applications. Kluwer Academic Publishers, Norwell (2001)

Kelly, A.: Decision-Making Using Game Theory. Cambridge University Press, Cambridge (2003)

Kim, M.J., Han, I.: The discovery of experts' decision rules from qualitative bankruptcy data using genetic algorithms. Expert Syst. Appl. **25**(4), 637–646 (2003)

Kohl, N., Karisch, S.E.: Airline crew rostering: Problem types, modeling, and optimization. Ann. Oper. Res. **127**(1–4), 223–257 (2004)

Köksalan, M., Şakar, C.T.: An interactive approach to stochastic programming-based portfolio optimization. Annals of Operations Research 1–20 http://dx.doi.org/10.1007/s10479-014-1719-y (2014)

Lancaster University Management School: What is Operational Research, Retrieved 15 Oct (2014)

Lavrač, N.: Selected techniques for data mining in medicine. Artif. Intell. Med. **16**(1), 3–23 (1999)

Levitt, S.D., List, J.A.: Field experiments in economics: the past, the present, and the future. Eur. Econ. Rev. **53**(1), 1–18 (2009)

Li, H., Li, X., Ramanathan, M., Zhang, A.: Identifying informative risk factors and predicting bone disease progression via deep belief networks. Methods **69**(3) (2014)

Ling, R., David, C.Y.: Customer relationship management: An analysis framework and implementation strategies. J. Comput. Inf. Syst. **41**(3), 82–97 (2001)

Lu, L.: A one-vendor multi-buyer integrated inventory model. Eur. J. Oper. Res. **81**(2), 312–323 (1995)

Malakooti, B.: Operations and Production Systems with Multiple Objectives. Wiley, Hoboken (2013)

Maloni, M.J., Benton, W.C.: Supply chain partnerships: opportunities for operations research. Eur. J. Oper. Res. **101**(3), 419–429 (1997)

Marler, R.T., Jasbir, S.A.: Survey of multi-objective optimization methods for engineering. Struct. Multi. Optim. **26**(6), 369–395 (2004)

Mortazavi-Naeini, M., Kuczera, G., Cui, L.: Application of multiobjective optimization to scheduling capacity expansion of urban water resource systems. Water Resour. Res. **50**(6), 4624–4642 (2014)

Ngai, E.W.T., Xiu, L., Dorothy, C.K.C.: Application of data mining techniques in customer relationship management: A literature review and classification. Expert Syst. Appl. **36**(2), 2592–2602 (2009)

Padhye, N., Kalyanmoy, D.: Multi-objective optimisation and multi-criteria decision making in SLS using evolutionary approaches. Rapid Prototyping J. **17**(6), 458–478 (2011)

Pauwels, W., Kort, P.M., Vanhaecht, E.: R&D investments as prebargaining Strategies. Int. Game Theory Rev. **16**(3) (2014)

Pendaraki, K., Spanoudakis, N.: Portfolio performance and risk-based assessment of the PORTRAIT tool. Operational Research 1–20 http://dx.doi.org/10.1007/s12351-014-0162-9 (2014)

Peppers, D., Rogers, M.: Is your company ready for one-to-one marketing? Harv. Bus. Rev. **77**(1), 151–160 (1999)

Plant, C., Teipel, S.J., Oswald, A., Böhm, C., Meindl, T., Mourao-Miranda, J., Bokde, A.W., Hampel, H., Ewers, M.: Automated detection of brain atrophy patterns based on MRI for the prediction of Alzheimer's disease. Neuroimage **50**(1), 162–174 (2010)

Pohekar, S.D., Ramachandran, M.: Application of multi-criteria decision making to sustainable energy planning-a review. Renew. Sustain. Energy Rev. **8**(4), 365–381 (2004)

Rios-Mercado, R.Z., Borraz-Sánchez, C.: Optimization Problems in Natural Gas Transportation Systems: A State-of-the-Art Review, Technical Report PISIS-2014-04, Graduate Program in Systems Engineering, UANL, San Nicolás de los Garza, México, Sept 2014

Rokach, L.: Data Mining with Decision Trees: Theory And Applications, vol. 69. World scientific, Singapore (2008)

Salani, M., Duyckaerts, G., Swartz, P.G.: Ambush avoidance in vehicle routing for valuable delivery. J. Transp. Secur. **3**(1), 41–55 (2010)

Sandler, T. Daniel, G., Arce, M.: Terrorism and game theory. Simul Gaming **34**(3), 319–337 (2003)

Schittekat, P., Kinable, J., Sörensen, K., Sevaux, M., Spieksma, F., Springael, J.: A metaheuristic for the school bus routing problem with bus stop selection. Eur. J. Oper. Res. **229**(2), 518–528 (2013)

Shangyao, Y., Wang, S.-S., Wu, M.-W.: A model with a solution algorithm for the cash transportation vehicle routing and scheduling problem. Comput. Ind. Eng. **63**(2), 464–473 (2012)

Shaw, M.J., Subramaniam, C., Tan, G.W., Welge, M.E.: Knowledge management and data mining for marketing. Decis. Support Syst. **31**(1), 127–137 (2001)

Smit, H.T.J., Ankum, L.A.: A real options and game-theoretic approach to corporate investment strategy under competition. Financ. Manage. **22**(3), 241–250 (1993)

Sörensen, K.: Metaheuristics-the metaphor exposed. International Transactions in Operational Research **22**(1) (2015)

Sörensen, K., Springael, J.: Progressive multi-objective optimization. Int. J. Inf. Technol. Decis. Making **13**(5), 917–936 (2014)

Sörensen, K., Vanovermeire, C.: Bi-objective optimization of the intermodal terminal location problem as a policy-support tool. Comput. Ind. **64**(2), 128–135 (2013)

Stengel, D.N.: Principles of Managerial Economics. Flat World Knowledge, New York (2012)

Straffin, P.D.: Game Theory and Strategy. The Mathematical Association of America, Washington (1993)

Tafteh, A., Babazadeh, H., Ebrahimipak, N.A., Kaveh, F.: Optimization of irrigation water distribution using the MGA method and comparison with a linear programming method. Irrigation and Drainage **63**(5) 590–598 (2014)

Taha, H.A.: Operations Research: An Introduction. Pearson/Prentice Hall, Englewood Cliffs (2007)

Talarico, L., Reniers, G., Sörensen, K., Springael, J.: MISTRAL: A game-theoretical model to allocate security measures in a multi-modal chemical transportation network with adaptive adversaries. Reliability Engineering & System Safety, **138**, 105–114 (2015)

Talarico L., Sörensen K., Springael J.: Metaheuristics for the risk-constrained cash-in-transit vehicle routing problem. Eur. J. Oper. Res. **224**(2), 457–470 (2015a)

Tavares, L.V.: A review of the contribution of operational research to project management. Eur. J. Oper. Res. **136**(1), 1–18 (2002)

Teo, T.S.H., Devadoss, P., Pan, S.L.: Towards a holistic perspective of customer relationship management (CRM) implementation: a case study of the housing and development board, Singapore. Decis. Support Syst. **42**(3), 1613–1627 (2006)

Tesfatsion, L.: Agent-based computational economics: A constructive approach to economic theory. Handb. Comput. Econ. **2**, 831–880 (2006)

Turban, E., Sharda, R., Delen, D., Efraim, T.: Decision Support and Business Intelligence Systems. Pearson Education India, Delhi (2007)

Vanhove, S.: Alternative routing algorithms for road networks. Ph.D. thesis, Ghent University, Department of Applied Mathematics and Informatics (2012)

Wagner, H.M.: Principles of Operations Research: With Applications to Managerial Decisions. Prentice-Hall, Englewood Cliffs (1969)

Yang, J., Wang, Z., Liu, X., Tan, S.: Group Identification in Stock Correlation Networks with an application to portfolio selection. J. Comput. Inf. Syst. **10**(7), 2937–2949 (2014)

Yeh, D.Y., Cheng, C.H., Chen, Y.W.: A predictive model for cerebrovascular disease using data mining. Expert Syst. Appl. **38**(7), 8970–8977 (2011)

Zeleny, M.: Multiple criteria decision making. In: James, L. (ed.) Cochrane, vol. 25, McGraw-Hill, New York (1982)

Part VII
Quality Management

Chapter 16
Intelligent Systems in Total Quality Management

Nihal Erginel and Sevil Şentürk

Abstract Total Quality Management (TQM) is a widely known and applied concept by organizations for continuous improvement in the workplace. This philosophy is based on eight main principles: customer focus, leadership, involvement of employee, system approach, continuous improvement, process approach, and facts based decision making, and mutually beneficial supplier relationship. TQM includes statistical analysis of data, implementation of corrective and preventive actions, measurement of performance indicators of process and also advancement on actions for continuous improvement. The aim of Statistical Process Control (SPC) is to detect the variation and nonconforming units for improvement in the quality of process. While manually collecting data, the ambiguity or vagueness exists in the data which are called fuzzy data from measurement system or human experts. Fuzzy data can be analyzed by fuzzy control charts in SPC. Fuzzy control charts are implemented for monitoring and analyzing process, and reducing the variability of process. Also, an intelligent system is developed to eliminate or reduce uncertainty on data by using a fuzzy approach.

Keywords Total quality management · Intelligent systems · Fuzzy control charts

16.1 Introduction to Total Quality Management

Quality is one of the most important concepts to meet customer satisfaction. Customers select among competitive product or services according to satisfaction level that not only meet the specifications and functions, but also offer an attractive quality for the product or services.

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The definitions of quality change with regard to the needs and expectations of customers. While quality is defined as "conformance to requirements" by Crosby and "fitness for use" by Juran in early literature of quality history, nowadays quality is seen as "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs" by ISO 9000 series, moreover "Quality denotes an excellence in goods and services, especially to the degree they conform to requirements and satisfy customers" by ASQC. As seen in the latest definition of quality, customer satisfaction comes to the fore, especially ISO 9001:2000, Quality Management System—Requirements, standard based on the principles of Total Quality Management approach. In the 1980s, it was accepted that quality is a management system and should be applied to every process and activity of a company.

TQM is a management system to reach successful results through customer satisfaction by achieving cultural change in an organization. Any Organization sets out and manages its processes by defining a customer focused policy and strategies, and by considering partnerships and resources with all employee's contributions for continual improvement. Thus, the organization would obtain excellent results on key performance, employee, customer and society by implementing the TQM approach. We can easily argue that engineering management is achieved by implementing TQM principles.

For development and deployment of TQM worldwide, several models are provided and prizes are given to organizations. Deming Model in Japan has been applied since 1951, Malcom Baldrige Model in the USA since 1986, European Foundation for Quality Management (EFQM) for Excellent Model in Europe since 1992 are all applied by companies or non-profit organizations. Also EFQM Model has been applied in Turkey since 1993 by KalDer. KalDer is a Turkish Society that aims to establish and develop the concepts of TQM and to boost the competitiveness of organizations. EFQM Model is described as in Fig. 16.1.

EFQM Model presents the framework to the management to apply TQM philosophy. EFQM Model underlines that "Excellent results of organization associated

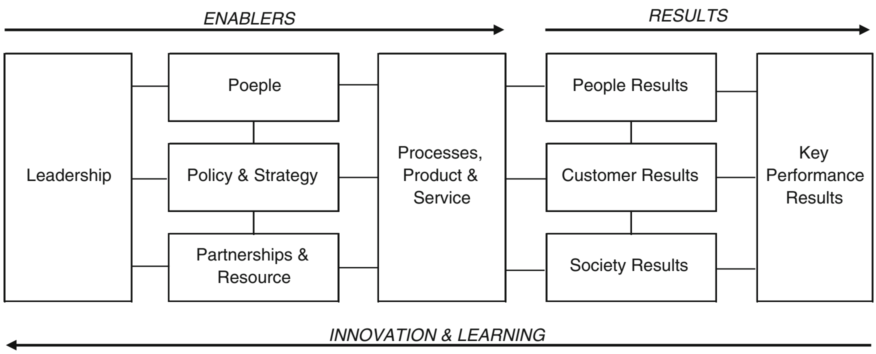

Fig. 16.1 EFQM model (http://www.efqm.org)

with people, customer, society and key performance can be achieved through appropriate leadership managing people, policy and strategy, partnership and resource”. TQM states eight main principles for applying the EFQM model.

16.2 Total Quality Management Principles

Total Quality Management has eight principles and ISO 9000 series are based on these principles (Montgomery 2009). The leaders consider these principles to manage organizations according to the TQM philosophy. The eight principles are defined in ISO 9000:2005, Quality Management System—Fundamentals and vocabulary, and in ISO 9004:2009, managing for the sustained success of an organization—A Quality Management Approach.

16.2.1 Leadership

Leaders understand the whole partnership’s needs which come from customers, owners, employees, suppliers etc., organize and establish the vision, mission and strategies of organization and motivate the people in this direction. Leaders also set the personal goals, provide sources and encourage their employees to achieve these goals to reach the organization’s objectives (Kolarik 1995).

16.2.2 Customer Focus

Organizations make research and understand customer’s current and future needs and expectations by defining and using several tools and ways for collecting and analyzing the customer’s data. Organizational plans and actions are described so that they meet these needs which are reflected on the product or services. In addition, organizations establish a systematic approach to manage customer relations.

16.2.3 Involvement of Employee

People at all levels are motivated and committed to achieve organization’s goals for continual improvement. Reachable and accountable personal goals are evaluated periodically by managers. Moreover, personal goals meet at least one of the organization’s strategies. The leader provides the necessary training and resources to achieve employee’s goal.

16.2.4 Process Approach

When organizations define their process and manage them by defining and monitoring process performance indications, organization's outputs can be seen to be more efficient. Indeed, the process approach is provided to see and manage the activities. A continuation improvement, lower cost and shorter production time lead to efficiency. Process responsible people, process performance indicators, process inputs/outputs, sub-process etc. are identified while establishing processes. Organizations also define the main process, support processes, sub-processes, and detail processes. Moreover they can define the critical processes that support their goals and strategies which need to be improved. The process performance indicators are reviewed periodically by the top management.

16.2.5 System Approach

Documentation, procedures, instructions, forms etc. help to set the organization's system. These documents show the organization's way that performs its work. The System approach contributes to the organization's efficiency and effectiveness by achieving its goals and strategies.

16.2.6 Continuous Improvement

Continuous improvement is provided with planning activities and their resources at all levels for achieving the organization's goals. Monitoring performance indicators, reviewing the organization's results by top management, corrective and preventive actions, and employee's activities result in continual improvement. Continuous improvement can be achieved by employee's contributions.

16.2.7 Facts Based Decision Making

The leader makes decisions based on the analysis of data from process. Therefore, leader can take effective decisions. The accuracy and reliability of data should be also ensured. While collecting data, the information's systems are used both to provide the accuracy of data and to store it. The statistical methods are used for analyzing data, such as, hypothesis tests, variance analysis, regression analysis, and so forth.

16.2.8 Mutually Beneficial Supplier Relationship

Both the organizations and their suppliers set the relationships to create value mutually beneficially. Additionally, organizations set long-term relations with their suppliers. They co-operate on training, continuous improvement, setting open and speed communications and answering responses. Furthermore, they can operate to increase the ability to create value.

16.3 Total Quality Management with Intelligent Systems

Intelligent systems connect the engineering tools with human thinking. Therefore, intelligent systems behave as a human decision mechanism by reflecting human sensitivity. Above all, fuzzy systems consider human linguistic expressions. When we look at this perspective, fuzzy systems are thought as an intelligent systems. Linguistic expressions are used frequently in decision making stages in the real world. Linguistic terms like ‘perfect’, ‘good’, ‘medium’ an etc.; are represented by fuzzy numbers in the fuzzy set theory. Many fuzzy statistical tools or fuzzy quality control techniques are developed for analyzing linguistic terms regarding fuzzy rules. In this manner, fuzzy distributions, fuzzy confidence intervals, fuzzy hypotheses, fuzzy control charts exist in the literature. Statistical process control is the main topic of TQM. In fuzzy statistical process control, fuzzy control charts are used for monitoring and analyzing the process. When data collected from process include ambiguities, the classical control charts are not applicable to evaluate the fuzzy data. Hence, fuzzy control charts are required to examine the fuzzy data. Fuzzy control charts play an important role to represent uncertainty that comes from human subjectivity and measurement systems. In addition, ANFIS (Adaptive Neuro Fuzzy Inference Systems), ANN (Artificial Neural Network), fuzzy QFD (Quality Function Deployment) and fuzzy FMEA (Failure Model and Effect Analysis) are intelligent systems in TQM.

Fuzzy control charts for both fuzzy variable and attribute data are introduced in the literature. While some of them use transformation techniques, few are based on fuzzy rules. In the following section, fuzzy control charts for variable and attribute fuzzy data are given in detail with formulations.

16.4 Fuzzy Statistical Process Control

Statistical process control (SPC) is an approach that uses statistical techniques to monitor the process Control charts proposed by W.A. Shewhart in 1920s. It has a widespread application especially in the production processes. These control charts were designed to monitor a process for both shifts in mean and variance of a single quality characteristic. Data from process may have uncertainty that comes from the measurement system, including operators and gages, and environmental conditions. The fuzzy set theory is a very useful tool to handle this uncertainty. Fuzzy data are analysed by fuzzy control charts because fuzzy data cannot be evaluated by traditional control charts. Published the first papers on fuzzy control charts, Raz and Wang (1990) and Wang and Raz (1990). Whereas Kanagawa et al. (1993) modified Wang and Raz's control charts. The theoretical base of α-cut control chart was firstly introduced by Gülbay et al. (2004). Also, Gülbay and Kahraman (2006a, b) proposed the direct fuzzy approach. Faraz and Moghadam (2007) introduced a fuzzy chart for controlling the process mean. The theoretical structure of fuzzy individual and moving range control charts with α-cuts and fuzzy $\tilde{\bar{\bar{X}}} - \tilde{R}$ and $\tilde{\bar{\bar{X}}} - \tilde{S}$ control charts were developed by Erginel (2008), and Şentürk and Erginel (2008), respectively. In addition, fuzzy regression control charts based on α-cut approximation was introduced by Şentürk (2010) and fuzzy $\tilde{u}$ control charts with applications was presented by Şentürk et al. (2011). Fuzzy $\tilde{\bar{\bar{X}}} - \tilde{S}$ control charts are applied to the packing process of food industry by Erginel et al. (2011). Fuzzy control charts with fuzzy rules were introduced by Kaya and Kahraman (2011) and Erginel (2014). Fuzzy EWMA control chart was introduced by Şentürk et al. (2014).

In fuzzy control charts, control limits can be transformed to fuzzy control limits by using fuzzy numbers and their several types of membership functions. Fuzzy control limits provide a more accurate and flexible evaluation. Some measures of central tendency in descriptive statistics can be used in fuzzy variable control charts and fuzzy attribute control charts for transforming fuzzy data to the crisp data. These measures can be used to convert fuzzy sets into scalars which are fuzzy mode, α-level fuzzy midrange, fuzzy median and fuzzy average. For the selection of these fuzzy measures, there is no theoretical basis. This selection is mainly based on the ease of computation or preference of the user. These fuzzy transformation techniques are introduced by Wang and Raz (1990) and given in the following section.

The fuzzy mode: f_{mode}: The fuzzy mode of a fuzzy set F is the value of the base variable where the membership function equals 1. This is stated as:

$$f_{\text{mode}} = \{x | \mu_F(x) = 1\}, \quad \forall x \in F. \tag{16.1}$$

It is unique if the membership function is unimodal.

The α-level fuzzy midrange: f^{α}_{mr}: The average of the end points of an α-cut. An α-cut, denoted by F_α, is a non fuzzy subset of the base variable x containing all the values with membership function values greater than or equal to α. Thus $f_\alpha = \{x | \mu F(x) \geq \alpha\}$. If a_α and c_α are end points of α-cut F_α such that $a_\alpha = Min\{F_\alpha\}$ and $c_\alpha = Max\{F_\alpha\}$, then,

$$f_{mr}^{\alpha} = \frac{1}{2}(a_{\alpha} + c_{\alpha}) \tag{16.2}$$

The fuzzy median: f_{med}: This is the point that partitions the curve under the membership function of a fuzzy set into two equal regions satisfying the following equation:

$$\int_{a}^{f_{\text{med}}} \mu_F(x)dx = \int_{f_{\text{med}}}^{c} \mu_F(x)dx = \frac{1}{2}\int_{a}^{c} \mu_F(x)dx \tag{16.3}$$

where a and c are the end points in the base variable of the fuzzy set F such that $a < c$.

The fuzzy average: f_{avg}: Based on Zadeh, the fuzzy average is:

$$f_{\text{avg}} = Av(x;F) = \frac{\int_{x=0}^{1} x\mu_F(x)dx}{\int_{x=0}^{1} \mu_F(x)dx} \tag{16.4}$$

In the following section, the theoretical structure of fuzzy control charts for both variable and attribute fuzzy data combined with fuzzy transformation techniques are given.

16.4.1 Fuzzy Variable Control Charts

If fuzzy data are a measurable scale, fuzzy variable control charts are available to use for evaluating the process. For analyzing both the shift in mean and deviation on fuzzy data from process, fuzzy $\tilde{\tilde{\text{X}}}$ and $\tilde{\text{R}}$ control charts, fuzzy $\tilde{\tilde{\text{X}}}$ and $\tilde{\text{S}}$ control charts and fuzzy individual ($\tilde{\text{X}}$) and moving range ($\widetilde{\text{MR}}$) control chart are introduced in the following sections. Also, fuzzy regression control charts is developed to evaluate the tool wearing problem in process, and fuzzy EWMA control charts is implemented to detect the small shifts in fuzzy data.

16.4.1.1 Fuzzy $\tilde{\tilde{\text{X}}}$ and $\tilde{\text{R}}$ Control Charts

The R chart is a very popular control chart used to monitor the dispersion associated with a quality characteristic. Its simplicity of construction and maintenance makes the R chart very commonly used and the range is a good measure of variation for small subgroup sizes (n < 10). Also, fuzzy $\tilde{\text{R}}$ control chart are used for evaluating the deviation of process with fuzzy data by Şentürk and Erginel (2009). In the fuzzy case, triangular fuzzy ranges are represented as $(R_{a_j},\ R_{b_j},\ R_{c_j})$ fuzzy numbers for *j*. fuzzy sample. $R_{a_j},\ R_{b_j},\ R_{c_j}$ are calculated as follows:

$$R_{a_j} = X_{\mathrm{max,a_j}} - X_{\mathrm{min,c_j}} \quad \mathrm{j} = 1, 2, \ldots, \mathrm{m} \tag{16.5}$$

$$R_{b_j} = X_{\mathrm{max,b_j}} - X_{\mathrm{min,b_j}} \quad \mathrm{j} = 1, 2, \ldots, \mathrm{m} \tag{16.6}$$

$$R_{c_j} = X_{\mathrm{max,c_j}} - X_{\mathrm{min,a_j}} \quad \mathrm{j} = 1, 2, \ldots, \mathrm{m} \tag{16.7}$$

where $(X_{\mathrm{max,a_j}}, X_{\mathrm{max,b_j}}, X_{\mathrm{max,c_j}})$ is the maximum fuzzy number in the sample and $(X_{\mathrm{min,a_j}}, X_{\mathrm{min,b_j}}, X_{\mathrm{min,c_j}})$ is the minimum fuzzy number in the sample. Then,

$$\bar{R}_a = \frac{\sum R_{a_j}}{m}\ \bar{R}_b = \frac{\sum R_{b_j}}{m}\ \bar{R}_c = \frac{\sum R_{c_j}}{m} \tag{16.8}$$

Also, $\bar{R}_a$, $\bar{R}_b$, and $\bar{R}_c$ are the arithmetic means of the least possible values, the most possible values, and the largest possible values, respectively. While using $\bar{R}_a$, $\bar{R}_b$ and, fuzzy $\tilde{R}$ control chart limits can be obtained but they are represented by triangular fuzzy numbers as follows:

$$U\tilde{C}L_R = D_4(\bar{R}_a,\ \bar{R}_b,\ \bar{R}_c) \tag{16.9}$$

$$C\tilde{L}_R = (\bar{R}_a,\ \bar{R}_b,\ \bar{R}_c) \tag{16.10}$$

$$L\tilde{C}L_R = D_3(\bar{R}_a,\ \bar{R}_b,\ \bar{R}_c) \tag{16.11}$$

where D_3 and D_4 are control chart coefficients. An α-cut is a nonfuzzy set which comprises of all elements whose membership degrees are greater than or equal to α. Applying α-cuts of fuzzy sets, the values of $\bar{R}_a^\alpha$ and $\bar{R}_c^\alpha$ are determined as follows:

$$\bar{R}_a^\alpha = \bar{R}_a + \alpha(\bar{R}_b - \bar{R}_a) \tag{16.12}$$

$$\bar{R}_c^\alpha = \bar{R}_c - \alpha(\bar{R}_c - \bar{R}_b) \tag{16.13}$$

An α-cut fuzzy $\tilde{R}$ control chart can be calculated as follows:

$$U\tilde{C}L_R^\alpha = D_4\bar{R}^\alpha = D_4(\bar{R}_a^\alpha, \bar{R}_b, \bar{R}_c^\alpha) \tag{16.14}$$

$$C\tilde{L}_R^\alpha = \bar{R}^\alpha = (\bar{R}_a^\alpha, \bar{R}_b, \bar{R}_c^\alpha) \tag{16.15}$$

$$L\tilde{C}R_R^\alpha = D_3\bar{R}^\alpha = D_3(\bar{R}_a^\alpha, \bar{R}_b, \bar{R}_c^\alpha) \tag{16.16}$$

When α-level fuzzy midrange transformation techniques are used to obtain the control limits, α-level fuzzy midrange for α-cut fuzzy $\tilde{R}$ control limits can be calculated as follows:

$$UCL^{\alpha}_{mr-R} = D_3\, f^{\alpha}_{mr-R}(C\tilde{L}) \tag{16.17}$$

$$CL^{\alpha}_{mr-R} = f^{\alpha}_{mr-R}(C\tilde{L}) = \frac{\bar{R}^{\alpha}_a + \bar{R}^{\alpha}_c}{2} \tag{16.18}$$

$$LCL^{\alpha}_{mr-R} = D_4\, f^{\alpha}_{mr-R}(C\tilde{L}) \tag{16.19}$$

These control limits are used to give a decision such as "*in-control*" or "*out-of-control*" for a process. The condition of process control for each sample can be defined as,

$$Process\ control = \left\{ \begin{array}{lll} in\text{-}control & ,for & LCL^{\alpha}_{mr-R} \le S^{\alpha}_{mr-R,j} \le UCL^{\alpha}_{mr-R} \\ out\text{-}of\ control & ,for & otherwise \end{array} \right\} \tag{16.20}$$

where the definition of α-level fuzzy midrange of sample *j* for fuzzy $\tilde{R}$ control chart is calculated as follows:

$$S^{\alpha}_{mr-R,j} = \frac{(R_{a_j} + R_{c_j}) + \alpha[(R_{b_j} - R_{a_j}) - (R_{c_j} - R_{b_j})]}{2} \tag{16.21}$$

The fuzzy $\tilde{\bar{\bar{X}}}$ control chart is used to analyze shifts in mean in fuzzy environment. The triangular fuzzy numbers are represented as $(X_{a_j}, X_{b_j}, X_{c_j})$ for *j*. fuzzy sample. The center line, $C\tilde{L}$ is the arithmetic mean of fuzzy samples, $(\bar{\bar{X}}_a, \bar{\bar{X}}_b, \bar{\bar{X}}_c)$ are called general mean, and calculated as follows:

$$C\tilde{L} = (\bar{\bar{X}}_a, \bar{\bar{X}}_b, \bar{\bar{X}}_c) = (\frac{\sum_{j=1}^{m} \bar{X}_{a_j}}{m}, \frac{\sum_{j=1}^{m} \bar{X}_{b_j}}{m}, \frac{\sum_{j=1}^{m} \bar{X}_{c_j}}{m}) \tag{16.22}$$

The fuzzy $\tilde{\bar{\bar{X}}}$ control limits based on ranges are calculated as following equations:

$$\begin{aligned} U\tilde{C}L_{\bar{\bar{x}}} &= (\bar{\bar{X}}_a, + A_2\bar{R}_a, \bar{\bar{X}}_b + A_2\bar{R}_b, \bar{\bar{X}}_c + A_2\bar{R}_c) \\ &= (L\tilde{C}L_1, LC\tilde{L}_2, L\tilde{C}L_3) \end{aligned} \tag{16.23}$$

$$C\tilde{L}_{\overline{\overline{X}}} = (\bar{\bar{X}}_a, \bar{\bar{X}}_b, \bar{\bar{X}}_c) = (C\tilde{L}_1, C\tilde{L}_2, C\tilde{L}_3) \tag{16.24}$$

$$\begin{aligned} L\tilde{C}L_{\bar{\bar{x}}} &= (\bar{\bar{X}}_a - A_2\bar{R}_c, \bar{\bar{X}}_b - A_2\bar{R}_b, \bar{\bar{X}}_c - A_2\bar{R}_a) \\ &= (L\tilde{C}L_1, LC\tilde{L}_2, L\tilde{C}L_3) \end{aligned} \tag{16.25}$$

where, A_2 is a control chart coefficient and $U\tilde{C}L$ and $L\tilde{C}L$ are the upper and lower control limits, and $C\tilde{L}$ is the center of fuzzy $\tilde{\bar{\bar{X}}}$ control chart. Similarly, α-cut fuzzy $\tilde{\bar{\bar{X}}}$ control chart limits based on ranges can be stated as follows:

$$U\tilde{C}L_{\bar{\bar{x}}}^{\alpha} = (\bar{\bar{X}}_a^{\alpha} + A_2\bar{R}_a^{\alpha}, \bar{\bar{X}}_b + A_2\bar{R}_b, \bar{\bar{X}}_c^{\alpha} + A_2\bar{R}_c^{\alpha}) = (U\tilde{C}L_1^{\alpha}, U\tilde{C}L_2, U\tilde{C}L_3^{\alpha}) \tag{16.26}$$

$$C\tilde{L}_{\bar{\bar{x}}}^{\alpha} = (\bar{\bar{X}}_a^{\alpha}, \bar{\bar{X}}_b, \bar{\bar{X}}_c^{\alpha}) = (C\tilde{L}_1^{\alpha}, C\tilde{L}_2, C\tilde{L}_3^{\alpha}) \tag{16.27}$$

$$L\tilde{C}L_{\bar{\bar{x}}}^{\alpha} = (\bar{\bar{X}}_a^{\alpha} - A_2\bar{R}_c^{\alpha}, \bar{\bar{X}}_b - A_2\bar{R}_b, \bar{\bar{X}}_c^{\alpha} - A_2\bar{R}_a^{\alpha}) = (L\tilde{C}L_1^{\alpha}, L\tilde{C}L_2, L\tilde{C}L_3^{\alpha}) \tag{16.28}$$

For obtained α-level fuzzy midrange for α-cut fuzzy $\tilde{\bar{X}}$ control chart, α-level fuzzy midrange transformation techniques are used as follows:

$$UCL_{mr-\bar{X}}^{\alpha} = CL_{mr-\bar{X}}^{\alpha} + A_2\left(\frac{\bar{R}_a^{\alpha} + \bar{R}_c^{\alpha}}{2}\right) \tag{16.29}$$

$$CL_{mr-\bar{X}}^{\alpha} = f_{mr-\bar{X}}^{\alpha}(C\tilde{L}) = \frac{CL_{(\bar{X})1}^{\alpha} + CL_{(\bar{X})3}^{\alpha}}{2} \tag{16.30}$$

$$LCL_{mr-\bar{X}}^{\alpha} = CL_{mr-\bar{X}}^{\alpha} - A_2\left(\frac{\bar{R}_a^{\alpha} + \bar{R}_c^{\alpha}}{2}\right) \tag{16.31}$$

The condition of process control for each sample can be defined as,

$$Process\ control = \begin{cases} in\text{-}control & ,for \quad LCL_{mr-\bar{X}}^{\alpha} \le S_{mr-\bar{X},j}^{\alpha} \le UCL_{mr-\bar{X}}^{\alpha} \\ out\text{-}of\ control & ,for \quad otherwise \end{cases} \tag{16.32}$$

where the definition of α-level fuzzy midrange of sample j for fuzzy $\tilde{\bar{X}}$ control chart is

$$S_{mr-\bar{x},j}^{\alpha} = \frac{(\bar{X}_{a_j} + \bar{X}_{c_j}) + \alpha[(\bar{X}_{b_j} - \bar{X}_{a_j}) - (\bar{X}_{c_j} - \bar{X}_{b_j})]}{2} \tag{16.33}$$

16.4.1.2 Fuzzy $\tilde{\bar{\bar{X}}}$ and $\tilde{S}$ Control Charts

When the sample size increases (n > 10), the utility of the range measure as a yardstick of dispersion decreases and as a result the standard deviation measure is preferred. Also, for evaluating the deviation of process with fuzzy numbers, fuzzy $\tilde{S}$ control chart is used by Şentürk and Erginel (2009). Fuzzy $\tilde{S}$ control chart limits can be obtained as follows:

$$U\tilde{C}L_S = B_4(\bar{S}_a, \bar{S}_b, \bar{S}_c) \tag{16.34}$$

$$C\tilde{L}_S = (\bar{S}_a, \bar{S}_b, \bar{S}_c) \tag{16.35}$$

$$L\tilde{C}L_s = B_3\bar{S} = B_3(\bar{S}_a, \bar{S}_b, \bar{S}_c) \tag{16.36}$$

where the fuzzy $\tilde{S}_j$ is a standard deviation of sample j and B_3 and B_4 are control chart coefficients. The fuzzy average $\tilde{\bar{S}}$ is calculated as follows:

$$\tilde{S}_j = \sqrt{\frac{\sum_{i=1}^{n}\left[(X_a, X_b, X_c)_{ij} - (\bar{X}_a, \bar{X}_b, \bar{X}_c)_j\right]^2}{n-1}} \tag{16.37}$$

$$\tilde{\bar{S}} = \left(\frac{\sum_{j=1}^{m} S_{aj}}{m}, \frac{\sum_{j=1}^{m} S_{bj}}{m}, \frac{\sum_{j=1}^{m} S_{cj}}{m}\right) = (\bar{S}_a, \bar{S}_b, \bar{S}_c) \tag{16.38}$$

The α-cut fuzzy $\tilde{S}$ control chart limits are managed as follows:

$$U\tilde{C}L_S^{\alpha} = B_4\bar{S}^{\alpha} = B_4(\bar{S}_a^{\alpha}, \bar{S}_b, \bar{S}_c^{\alpha}) \tag{16.39}$$

$$C\tilde{L}_S^{\alpha} = \bar{S}^{\alpha} = (\bar{S}_a^{\alpha}, \bar{S}_b, \bar{S}_c^{\alpha}) \tag{16.40}$$

$$L\tilde{C}R_S^{\alpha} = B_3\bar{S}^{\alpha} = B_3(\bar{S}_a^{\alpha}, \bar{S}_b, \bar{S}_c^{\alpha}) \tag{16.41}$$

where

$$\bar{S}_a^{\alpha} = \bar{S}_a + \alpha(\bar{S}_b - \bar{S}_a) \tag{16.42}$$

$$\bar{S}_c^{\alpha} = \bar{S}_c - \alpha(\bar{S}_c - \bar{S}_b) \tag{16.43}$$

The control limits of α-level fuzzy midrange for α-cut fuzzy $\tilde{S}$ control chart can be obtained in a similar way to α-cut fuzzy $\tilde{R}$ control chart.

$$UCL_{mr-s}^{\alpha} = B_4\, f_{mr-S}^{\alpha}(C\tilde{L}) \tag{16.44}$$

$$CL_{mr-S}^{\alpha} = f_{mr-S}^{\alpha}(C\tilde{L}) = \frac{\bar{S}_a^{\alpha} + \bar{S}_c^{\alpha}}{2} \tag{16.45}$$

$$LCL_{mr-S}^{\alpha} = B_3\, f_{mr-S}^{\alpha}(C\tilde{L}) \tag{16.46}$$

The condition of process control for each sample can be defined as,

$$Process\ control = \left\{ \begin{array}{lll} in\text{-}control & ,for & LCL^{\alpha}_{mr-s} \leq S^{\alpha}_{mr-S,j} \leq UCL^{\alpha}_{mr-S} \\ out\text{-}of\ control & ,for & otherwise \end{array} \right\} \tag{16.47}$$

where the definition of α-level fuzzy midrange of sample j for fuzzy $\tilde{S}$ control chart is

$$S^{\alpha}_{mr-S,j} = \frac{(S_{aj} + S_{cj}) + \alpha[(S_{bj} - S_{aj}) - (S_{cj} - S_{bj})]}{2} \tag{16.48}$$

$(\bar{\bar{X}}_a,\ \bar{\bar{X}}_b,\ \bar{\bar{X}}_c)$ and $(\bar{S}_a,\ \bar{S}_b,\ \bar{S}_c)$ are used for analyzing the shift in mean of fuzzy numbers. The control limits of fuzzy $\tilde{\bar{\bar{X}}}$ Control Chart based on standard deviation are obtained as follows:

$$\begin{aligned} U\tilde{C}L_{\bar{\bar{x}}} &= (\bar{\bar{X}}_a + A_3\bar{S}_a, \bar{\bar{X}}_b + A_3\bar{S}_b, \bar{\bar{X}}_c + A_3\bar{S}_c) \\ &= (L\tilde{C}L_1, LC\tilde{L}_2, L\tilde{C}L_3) \end{aligned} \tag{16.49}$$

$$C\tilde{L}_{\overline{\overline{X}}} = (\bar{\bar{X}}_a,\ \bar{\bar{X}}_b,\ \bar{\bar{X}}_c) = (C\tilde{L}_1,\ C\tilde{L}_2,\ C\tilde{L}_3) \tag{16.50}$$

$$\begin{aligned} L\tilde{C}L_{\bar{\bar{x}}} &= (\bar{\bar{X}}_a - A_3\bar{S}_c, \bar{\bar{X}}_b - A_3\bar{S}_b, \bar{\bar{X}}_c - A_3\bar{S}_a \\ &= (L\tilde{C}L_1, LC\tilde{L}_2, L\tilde{C}L_3) \end{aligned} \tag{16.51}$$

where, A_3 is a control chart coefficient. The α-cut fuzzy $\tilde{\bar{\bar{X}}}$ control chart limits based on standard deviation can be obtained as follows:

$$\begin{aligned} U\tilde{C}L^{\alpha}_{\bar{\bar{x}}} &= (\bar{\bar{X}}^{\alpha}_a + A_3\bar{S}^{\alpha}_a, \bar{\bar{X}}_b + A_3\bar{S}_b, \bar{\bar{X}}^{\alpha}_c + A_3\bar{S}^{\alpha}_c) \\ &= (U\tilde{C}L^{\alpha}_1, U\tilde{C}L_2, U\tilde{C}L^{\alpha}_3) \end{aligned} \tag{16.52}$$

$$C\tilde{L}^{\alpha}_{\bar{\bar{x}}} = (\bar{\bar{X}}^{\alpha}_a, \bar{\bar{X}}_b, \bar{\bar{X}}^{\alpha}_c) = (C\tilde{L}^{\alpha}_1, C\tilde{L}_2, C\tilde{L}^{\alpha}_3) \tag{16.53}$$

$$\begin{aligned} L\tilde{C}L^{\alpha}_{\bar{\bar{x}}} &= (\bar{\bar{X}}^{\alpha}_a - A_3\bar{S}^{\alpha}_c, \bar{\bar{X}}_b - A_3\bar{S}_b, \bar{\bar{X}}^{\alpha}_c - A_3\bar{S}^{\alpha}_a) \\ &= (L\tilde{C}L^{\alpha}_1, L\tilde{C}L_2, L\tilde{C}L^{\alpha}_3) \end{aligned} \tag{16.54}$$

The control limits and center line for α-cut fuzzy $\tilde{\bar{\bar{X}}}$ control chart based on standard deviation using α-level fuzzy midrange are:

$$UCL^{\alpha}_{mr-\bar{X}} = CL^{\alpha}_{mr-\bar{\bar{X}}} + A_3(\frac{\bar{S}^{\alpha}_a + \bar{S}^{\alpha}_c}{2}) \tag{16.55}$$

$$CL^{\alpha}_{mr-\bar{X}} = f^{\alpha}_{mr-\bar{X}}(C\tilde{L}) = \frac{CL^{\alpha}_{(\bar{X})1} + CL^{\alpha}_{(\bar{X})3}}{2} \tag{16.56}$$

$$LCL^{\alpha}_{mr-\bar{X}} = CL^{\alpha}_{mr-\bar{X}} - A_3(\frac{\bar{S}^{\alpha}_a + \bar{S}^{\alpha}_c}{2}) \tag{16.57}$$

The condition of process control for each sample can be defined as,

$$Process\ control = \begin{Bmatrix} in\text{-}control & ,for & LCL^{\alpha}_{mr-\bar{X}} \leq S^{\alpha}_{mr-\bar{X},j} \leq UCL^{\alpha}_{mr-\bar{X}} \\ out\text{-}of\ control & ,for & otherwise \end{Bmatrix} \tag{16.58}$$

16.4.1.3 Fuzzy Individual ($\tilde{X}$) and Moving Range ($M\tilde{R}$) Control Chart

When only one observation is sampled, the individual control chart is used for analyzing the shift in mean of process. In this case, moving ranges are used for evaluating the deviation of process. While using triangular fuzzy numbers, fuzzy moving ranges are calculated by Erginel (2008) with using fuzzy sample observations as follows:

$$MR_{aj} = X_{\mathrm{max,a_j}} - X_{\mathrm{min,c_j}} \tag{16.59}$$

$$MR_{bj} = X_{\mathrm{max,b_j}} - X_{\mathrm{min,b_j}} \tag{16.60}$$

$$MR_{cj} = X_{\mathrm{max,c_j}} - X_{\mathrm{min,a_j}} \tag{16.61}$$

After calculating $(MR_{aj}, MR_{bj}, MR_{cj})$, for $j = 2, 3, \ldots, m-1$, the mean of fuzzy moving range for fuzzy samples is given in the following.

$$\overline{MR}_a = \frac{\sum_{j=2}^{m-1} R_{a_j}}{m-2}\ \overline{MR}_b = \frac{\sum_{j=2}^{m-1} R_{b_j}}{m-2}\ \overline{MR}_c = \frac{\sum_{j=2}^{m-1} R_{c_j}}{m-2} \tag{16.62}$$

Fuzzy moving range control charts limits:

$$U\tilde{C}L_{MR} = D_4(\overline{MR}_a, \overline{MR}_b, \overline{MR}_c) \tag{16.63}$$

$$C\tilde{L}_{MR} = (\overline{MR}_a, \overline{MR}_b, \overline{MR}_c) \tag{16.64}$$

$$L\tilde{C}L_{MR} = D_3(\overline{MR}_a, \overline{MR}_b, \overline{MR}_c) \quad (16.65)$$

α-cut fuzzy moving range control chart:

$$U\tilde{C}L^{\alpha}_{MR} = D_4(\overline{MR}^{\alpha}_a, \overline{MR}_b, \overline{MR}^{\alpha}_c) \quad (16.66)$$

$$C\tilde{L}^{\alpha}_{MR} = (\overline{MR}^{\alpha}_a, \overline{MR}_b, \overline{MR}^{\alpha}_c) \quad (16.67)$$

$$L\tilde{C}L^{\alpha}_{MR} = D_3(\overline{MR}^{\alpha}_a, \overline{MR}_b, \overline{MR}^{\alpha}_c) \quad (16.68)$$

where

$$\overline{MR}^{\alpha}_a = \overline{MR}_a + \alpha(\overline{MR}_b - \overline{MR}_a) \quad (16.69)$$

$$\overline{MR}^{\alpha}_c = \overline{MR}_c - \alpha(\overline{MR}_c - \overline{MR}_b) \quad (16.70)$$

The control limits of α-level fuzzy median for α-cut fuzzy $M\tilde{R}$ control chart are calculated based on α-level fuzzy median transformation techniques as follows:

$$UCL^{\alpha}_{med-MR} = D_4\left[\frac{1}{3}(\overline{MR}^{\alpha}_a + \overline{MR}_b + \overline{MR}^{\alpha}_c)\right] \quad (16.71)$$

$$CL^{\alpha}_{med-MR} = f^{\alpha}_{med-MR}(C\tilde{L}) = \left[\frac{1}{3}(\overline{MR}^{\alpha}_a + \overline{MR}_b + \overline{MR}^{\alpha}_c)\right] \quad (16.72)$$

$$LCL^{\alpha}_{med-MR} = D_3\left[\frac{1}{3}(\overline{MR}^{\alpha}_a + \overline{MR}_b + \overline{MR}^{\alpha}_c)\right] \quad (16.73)$$

The condition of process control for each sample can be defined as in Eq. (16.74).

$$Process\ control = \begin{cases} in\text{-}control & ,for \quad LCL^{\alpha}_{med-MR} \le S^{\alpha}_{med,j-MR} \le UCL^{\alpha}_{med-MR} \\ out\text{-}of\ control & ,for \quad otherwise \end{cases} \quad (16.74)$$

For a sample j, α-level fuzzy median $S^{\alpha}_{med-MR,j}$ can be calculated and provided as follows:

$$S^{\alpha}_{med,j-MR} = \frac{1}{3}(\overline{MR}^{\alpha}_{a,j} + \overline{MR}_{b,j} + \overline{MR}^{\alpha}_{c,j}) \quad (16.75)$$

The fuzzy $\tilde{X}$ control chart with moving ranges is used for evaluating the shifts in mean of process with fuzzy data. Fuzzy center line, fuzzy upper and fuzzy lower limits of fuzzy $\tilde{X}$ control chart are obtained as follows:

$$U\tilde{C}L_x = \left(\bar{X}_a + \frac{3}{d_2}\overline{MR}_a, \bar{X}_b + \frac{3}{d_2}\overline{MR}_b, \bar{X}_c + \frac{3}{d_2}\overline{MR}_c\right) \tag{16.76}$$

$$C\tilde{L}_x = (\bar{X}_a, \bar{X}_b, \bar{X}_c) = \left(C\tilde{L}_1, C\tilde{L}_2, C\tilde{L}_3\right) \tag{16.77}$$

$$L\tilde{C}L_x = \left(\bar{X}_a - \frac{3}{d_2}\overline{MR}_c, \bar{X}_b - \frac{3}{d_2}\overline{MR}_b, \bar{X}_c - \frac{3}{d_2}\overline{MR}_a\right) \tag{16.78}$$

An α-cut fuzzy $\tilde{X}$ control chart is obtained by integrating fuzzy moving range and α-cuts as in the following:

$$U\tilde{C}L_x^\alpha = \left(\bar{X}_a^\alpha, + \frac{3}{d_2}\overline{MR}_a^\alpha, \bar{X}_b + \frac{3}{d_2}\overline{MR}_b, \bar{X}_c^\alpha + \frac{3}{d_2}MR_c^\alpha\right) \tag{16.79}$$

$$C\tilde{L}_x^\alpha = (\bar{X}_a^\alpha, \bar{X}_b, \bar{X}_c^\alpha) = \left(C\tilde{L}_1^\alpha, C\tilde{L}_2, C\tilde{L}_3^\alpha\right) \tag{16.80}$$

$$L\tilde{C}L_x^\alpha = \left(\bar{X}_a^\alpha - \frac{3}{d_2}\overline{MR}_c^\alpha, \bar{X}_b - \frac{3}{d_2}\overline{MR}_b, \bar{X}_c^\alpha - \frac{3}{d_2}\overline{MR}_a^\alpha\right) \tag{16.81}$$

α-level fuzzy median for α-cut fuzzy $\tilde{X}$ control chart can be also calculated as follows:

$$UCL_{med-x}^\alpha = CL_{med-x}^\alpha + \frac{3}{d_2}\left[\frac{1}{3}(\overline{MR}_a^\alpha + \overline{MR}_b + \overline{MR}_c^\alpha)\right] \tag{16.82}$$

$$CL_{med-x}^\alpha = f_{med-x}^\alpha(C\tilde{L}) = \frac{1}{3}\left(CL_{(x)1}^\alpha + CL_{(x)2} + CL_{(x)3}^\alpha\right) \tag{16.83}$$

$$LCL_{med-x}^\alpha = CL_{med-x}^\alpha - \frac{3}{d_2}\left[\frac{1}{3}(\overline{MR}_a^\alpha + \overline{MR}_b + \overline{MR}_c^\alpha)\right] \tag{16.84}$$

where d_2 is the control chart coefficient. The condition of process control for each sample can be defined as,

$$Process\ control = \left\{\begin{array}{lll} in\text{-}control & ,for & LCL_{med-x}^\alpha \le S_{med,j-x}^\alpha \le UCL_{med-x}^\alpha \\ out\text{-}of\ control & ,for & otherwise \end{array}\right\} \tag{16.85}$$

For a sample j, α-level fuzzy median $S_{med-x,j}^\alpha$ can be calculated as follows:

$$S_{med-x,j}^\alpha = \frac{1}{3}(X_{aj}^\alpha + X_{bj} + X_{cj}^\alpha) \tag{16.86}$$

16.4.2 Fuzzy Attribute Control Charts

If the quality characteristics are represented by attributes, fuzzy attribute control charts are used to evaluate the process such as fuzzy p for the fuzzy fraction of nonconforming, fuzzy np for fuzzy nonconforming units, fuzzy c for fuzzy number of nonconformities and fuzzy u control charts for fuzzy nonconformities per unit.

16.4.2.1 Fuzzy $\tilde{p}$ Control Charts

Fuzzy $\tilde{p}$-control chart based on constant sample size:

In the fuzzy case, the fuzzy number of nonconforming units is stated by triangular fuzzy **numbers** $\left(d_{a_j}, d_{b_j}, d_{c_j}\right)$. In this case, the fuzzy fraction nonconforming can be expressed by triangular fuzzy numbers $\left(p_{a_j}, p_{b_j}, p_{c_j}\right)$. $(\bar{p}_a, \bar{p}_b, \bar{p}_c)$ is the fuzzy average of the fractions nonconforming, where $j = 1, 2, \ldots, m$.

$$p_{a_j} = \frac{d_{a_j}}{n}\; p_{b_j} = \frac{d_{b_j}}{n}\; p_{c_j} = \frac{d_{c_j}}{n} \tag{16.87}$$

$$\bar{p}_a = \frac{\sum p_{a_j}}{m}\; \bar{p}_b = \frac{\sum p_{b_j}}{m}\; \bar{p}_c = \frac{\sum p_{c_j}}{m} \tag{16.88}$$

Fuzzy center line, fuzzy upper and fuzzy lower limits of fuzzy $\tilde{p}$-control chart are obtained as follows, that is to say by using fuzzy averages the fraction nonconforming $(\bar{p}_a, \bar{p}_b, \bar{p}_c)$ and the rules of fuzzy arithmetic are described by Kahraman and Yavuz (2010).

$$U\tilde{C}L_p = \left(\bar{p}_a + 3\sqrt{\frac{\bar{p}_a(1-\bar{p}_a)}{n}},\; \bar{p}_b + 3\sqrt{\frac{\bar{p}_b(1-\bar{p}_b)}{n}},\; \bar{p}_c + 3\sqrt{\frac{\bar{p}_c(1-\bar{p}_c)}{n}}\right) \tag{16.89}$$

$$\tilde{C}L_p = (\bar{p}_a, \bar{p}_b, \bar{p}_c) \tag{16.90}$$

$$L\tilde{C}L_p = \left(\bar{p}_a - 3\sqrt{\frac{\bar{p}_a(1-\bar{p}_a)}{n}},\; \bar{p}_b - 3\sqrt{\frac{\bar{p}_b(1-\bar{p}_b)}{n}},\; \bar{p}_c - 3\sqrt{\frac{\bar{p}_c(1-\bar{p}_c)}{n}}\right) \tag{16.91}$$

The α-cut fuzzy $\tilde{p}$-control chart is obtained as follows:

$$U\tilde{C}L_p^{\alpha} = \left(\bar{p}_a^{\alpha} + 3\sqrt{\frac{\bar{p}_a^{\alpha}(1-\bar{p}_a^{\alpha})}{n}},\; \bar{p}_b + 3\sqrt{\frac{\bar{p}_b(1-\bar{p}_b)}{n}},\; \bar{p}_c + 3\sqrt{\frac{\bar{p}_c^{\alpha}(1-\bar{p}_c^{\alpha})}{n}}\right) \tag{16.92}$$

$$\tilde{C}L_p^\alpha = \left(\bar{p}_a^\alpha,\ \bar{p}_b,\ \bar{p}_c^\alpha\right) \tag{16.93}$$

$$L\tilde{C}L_p^\alpha = \left(\bar{p}_a^\alpha - 3\sqrt{\frac{\bar{p}_c^\alpha(1-\bar{p}_c^\alpha)}{n}},\ \bar{p}_b - 3\sqrt{\frac{\bar{p}_b(1-\bar{p}_b)}{n}},\ \bar{p}_c - 3\sqrt{\frac{\bar{p}_a^\alpha(1-\bar{p}_a^\alpha)}{n}}\right) \tag{16.94}$$

where;

$$\bar{p}_a^\alpha = \bar{p}_a + \alpha(\bar{p}_b - \bar{p}_a) \tag{16.95}$$

$$\bar{p}_c^\alpha = \bar{p}_c - \alpha(\bar{p}_c - \bar{p}_b) \tag{16.96}$$

By using these formulations, the fuzzy center line, fuzzy upper and fuzzy lower limits of α-level fuzzy median for α-cut fuzzy $\tilde{p}$-control chart can be calculated as below;

$$UCL_{med-p}^\alpha = CL_{med-p}^\alpha + 3\sqrt{\frac{CL_{med-p}^\alpha(1-CL_{med-p}^\alpha)}{n}} \tag{16.97}$$

$$CL_{med-p}^\alpha = \frac{1}{3}\left(\bar{p}_a^\alpha + \bar{p}_b + \bar{p}_c^\alpha\right) \tag{16.98}$$

$$LCL_{med-p}^\alpha = CL_{med-p}^\alpha - 3\sqrt{\frac{CL_{med-p}^\alpha(1-CL_{med-p}^\alpha)}{n}} \tag{16.99}$$

The condition of process control for each sample can be defined as;

$$Process\ control = \left\{\begin{array}{lll} in\text{-}control & ,for & LCL_{med-p}^\alpha \le S_{med-p,j}^\alpha \le UCL_{med-p}^\alpha \\ out\text{-}of\ control & ,for & otherwise \end{array}\right\} \tag{16.100}$$

Fuzzy p̃*-control chart based on variable sample size:*

When the sample size is not constant, variable sample size should be used in fuzzy *p*-control chart. In this case, control limits are calculated using each individual sample size. The fuzzy fraction nonconforming for each sample and their fuzzy averages are calculated in line with the following equations, respectively;

$$p_{a_j} = \frac{d_{a_j}}{n_j}\ p_{b_j} = \frac{d_{b_j}}{n_j}\ p_{c_j} = \frac{d_{c_j}}{n_j} \tag{16.101}$$

$$\bar{p}_a = \frac{\sum d_{a_j}}{\sum n_j}\ \bar{p}_b = \frac{\sum d_{b_j}}{\sum n_j}\ \bar{p}_c = \frac{\sum d_{c_j}}{\sum n_j} \tag{16.102}$$

The control limits can be calculated in fuzzy $\tilde{p}$-control chart for each n_j by using triangular membership function and fuzzy average of sample fraction nonconforming such as;

$$U\tilde{C}L_{p,j} = \left(\bar{p}_a + 3\sqrt{\frac{\bar{p}_a(1-\bar{p}_a)}{n_j}},\ \bar{p}_b + 3\sqrt{\frac{\bar{p}_b(1-\bar{p}_b)}{n_j}},\ \bar{p}_c + 3\sqrt{\frac{\bar{p}_c(1-\bar{p}_c)}{n_j}}\right) \tag{16.103}$$

$$\tilde{C}L_{p,j} = (\bar{p}_a,\ \bar{p}_b,\ \bar{p}_c) \tag{16.104}$$

$$L\tilde{C}L_{p,j} = \left(\bar{p}_a - 3\sqrt{\frac{\bar{p}_a(1-\bar{p}_a)}{n_j}},\ \bar{p}_b - 3\sqrt{\frac{\bar{p}_b(1-\bar{p}_b)}{n_j}},\ \bar{p}_c - 3\sqrt{\frac{\bar{p}_c(1-\bar{p}_c)}{n_j}}\right) \tag{16.105}$$

α-cut control limits for fuzzy $\tilde{p}$-control chart based on variable sample size is presented in the following equations:

$$U\tilde{C}L^{\alpha}_{p,j} = \left(\bar{p}^{\alpha}_a + 3\sqrt{\frac{\bar{p}^{\alpha}_a(1-\bar{p}^{\alpha}_a)}{n_j}}, \bar{p}_b + 3\sqrt{\frac{\bar{p}_b(1-\bar{p}_b)}{n_j}}, \bar{p}_c + 3\sqrt{\frac{\bar{p}^{\alpha}_c(1-\bar{p}^{\alpha}_c)}{n_j}}\right) \tag{16.106}$$

$$\tilde{C}L^{\alpha}_{p,j} = \left(\bar{p}^{\alpha}_a,\ \bar{p}_b,\ \bar{p}^{\alpha}_c\right) \tag{16.107}$$

$$L\tilde{C}L^{\alpha}_{p,j} = \left(\bar{p}^{\alpha}_a - 3\sqrt{\frac{\bar{p}^{\alpha}_a(1-\bar{p}^{\alpha}_a)}{n_j}},\ \bar{p}_b - 3\sqrt{\frac{\bar{p}_b(1-\bar{p}_b)}{n_j}},\ \bar{p}_c - 3\sqrt{\frac{\bar{p}^{\alpha}_c(1-\bar{p}^{\alpha}_c)}{n_j}}\right) \tag{16.108}$$

Control limits of α-level fuzzy median for α-cut fuzzy $\tilde{p}$-control chart based on variable sample size can be calculated by considering fuzzy median transformation technique as follows;

$$UCL^{\alpha}_{med-p,j} = CL^{\alpha}_{med-p} + 3\sqrt{\frac{CL^{\alpha}_{med-p}(1 - CL^{\alpha}_{med-p})}{n_j}} \tag{16.109}$$

$$CL^{\alpha}_{med-p} = \frac{1}{3}\left(\bar{p}^{\alpha}_a + \bar{p}_b + \bar{p}^{\alpha}_c\right) \tag{16.110}$$

$$LCL^{\alpha}_{med-p,j} = CL^{\alpha}_{med-p} - 3\sqrt{\frac{CL^{\alpha}_{med-p}(1 - CL^{\alpha}_{med-p})}{n_j}} \tag{16.111}$$

The condition of process control for each sample is

$$Process\ control = \left\{ \begin{array}{lll} in\text{-}control & ,for & LCL^{\alpha}_{med-p,j} \leq S^{\alpha}_{med-p,j} \leq UCL^{\alpha}_{med-p,j} \\ out\text{-}of\ control & ,for & otherwise \end{array} \right\} \quad (16.112)$$

α-level fuzzy median value for each sample can be stated as follows;

$$S^{\alpha}_{med-p,j} = \frac{1}{3}\left(p^{\alpha}_{a,j} + p_{b,j} + p^{\alpha}_{c,j}\right) j = 1, 2, \ldots, m \quad (16.113)$$

16.4.2.2 Fuzzy $n\tilde{p}$ Control Charts

When sample size is constant, fuzzy $n\tilde{p}$-control chart is more accessible to deal with *the number of nonconforming units*. In many situations, observation of the number of nonconforming units is easier to interpret than the usual fraction nonconforming control chart. The average of the sample number of nonconforming units can be expressed in triangular fuzzy numbers $(n\bar{p}_a, n\bar{p}_b, n\bar{p}_c)$ as follows;

$$n\bar{p}_a = \frac{\sum_{j=1}^{m} d_{a_j}}{m} \quad n\bar{p}_b = \frac{\sum_{j=1}^{m} d_{b_j}}{m} \quad n\bar{p}_c = \frac{\sum_{j=1}^{m} d_{c_j}}{m} \quad (16.114)$$

The limits of fuzzy $n\tilde{p}$-control chart can be calculated with the following equations:

$$U\tilde{C}L_{np} = \left(n\bar{p}_a + 3\sqrt{n\bar{p}_a(1-\bar{p}_a)}, n\bar{p}_b + 3\sqrt{n\bar{p}_b(1-\bar{p}_b)}, n\bar{p}_c + 3\sqrt{n\bar{p}_c(1-\bar{p}_c)}\right) \quad (16.115)$$

$$\tilde{C}L_{np} = (n\bar{p}_a, n\bar{p}_b, n\bar{p}_c) \quad (16.116)$$

$$L\tilde{C}L_{np} = \left(n\bar{p}_a - 3\sqrt{n\bar{p}_a(1-\bar{p}_a)}, n\bar{p}_b - 3\sqrt{n\bar{p}_b(1-\bar{p}_b)}, n\bar{p}_c - 3\sqrt{n\bar{p}_c(1-\bar{p}_c)}\right) \quad (16.117)$$

When applying α-cut on fuzzy $n\tilde{p}$-control chart, the limits of α-cut fuzzy $n\tilde{p}$-control chart are obtained as follows:

$$U\tilde{C}L^{\alpha}_{np} = \left(n\bar{p}^{\alpha}_a + 3\sqrt{n\bar{p}^{\alpha}_a(1-\bar{p}^{\alpha}_a)}, n\bar{p}_b + 3\sqrt{n\bar{p}_b(1-\bar{p}_b)}, n\bar{p}^{\alpha}_c + 3\sqrt{n\bar{p}^{\alpha}_c(1-\bar{p}^{\alpha}_c)}\right) \quad (16.118)$$

$$\tilde{C}L^{\alpha}_{np} = \left(n\bar{p}^{\alpha}_a,\ n\bar{p}_b,\ n\bar{p}^{\alpha}_c\right) \quad (16.119)$$

$$L\tilde{C}L_{np}^{\alpha} = \left(n\bar{p}_a^{\alpha} - 3\sqrt{n\bar{p}_a^{\alpha}(1-\bar{p}_a^{\alpha})}, n\bar{p}_b + 3\sqrt{n\bar{p}_b(1-\bar{p}_b)}, n\bar{p}_c^{\alpha} - 3\sqrt{n\bar{p}_c^{\alpha}(1-\bar{p}_c^{\alpha})}\right) \tag{16.120}$$

By incorporating fuzzy median transformation technique with α-cut fuzzy $n\tilde{p}$-control chart, the following equations can be expressed for α-level fuzzy median for α-cut fuzzy $n\tilde{p}$-control chart;

$$UCL_{med-np}^{\alpha} = CL_{med-np}^{\alpha} + 3\sqrt{CL_{med-np}^{\alpha}(1 - \frac{CL_{med-np}^{\alpha}}{n})} \tag{16.121}$$

$$CL_{med-np}^{\alpha} = \frac{1}{3}\left(n\bar{p}_a^{\alpha} + n\bar{p}_b^{\alpha} + n\bar{p}_c^{\alpha}\right) \tag{16.122}$$

$$LCL_{med-np}^{\alpha} = CL_{med-np}^{\alpha} - 3\sqrt{CL_{med-np}^{\alpha}(1 - \frac{CL_{med-np}^{\alpha}}{n})} \tag{16.123}$$

The condition of process control for each sample can be defined as;

$$Process\ control = \left\{ \begin{array}{lll} in\text{-}control & ,for & LCL_{med-np}^{\alpha} \le S_{med-np,j}^{\alpha} \le UCL_{med-np}^{\alpha} \\ out\text{-}of\ control & ,for & otherwise \end{array} \right\} \tag{16.124}$$

where

$$S_{med-np,j}^{\alpha} = \frac{1}{3}\left(np_{a,j}^{\alpha} + np_{b,j} + np_{c,j}^{\alpha}\right) \tag{16.125}$$

16.4.2.3 Fuzzy $\tilde{c}$ Control Chart

When we are interested in fuzzy number of nonconformities, fuzzy $\tilde{c}$ control chart is used to evaluate the process. Center line $\tilde{C}L$ is the mean of fuzzy samples and can be represented by triangular fuzzy numbers (Gülbay and Kahraman 2006a, b):

$$\tilde{C}L = \left(\frac{\sum c_{a_j}}{n}, \frac{\sum c_{b_j}}{n}, \frac{\sum c_{c_j}}{n}\right) \tag{16.126}$$

$$U\tilde{C}L_c = \left(\bar{c}_a + 3\sqrt{\bar{c}_a}, \bar{c}_b + 3\sqrt{\bar{c}_b}, \bar{c}_c + 3\sqrt{\bar{c}_c}\right) \tag{16.127}$$

$$\tilde{C}L_c = (\bar{c}_a, \bar{c}_b, \bar{c}_c) \tag{16.128}$$

$$L\tilde{C}L_c = \left(\bar{c}_a - 3\sqrt{\bar{c}_a}, \bar{c}_b - 3\sqrt{\bar{c}_b}, \bar{c}_c - 3\sqrt{\bar{c}_c}\right) \tag{16.129}$$

α-cut control limits for fuzzy c̃-control chart are presented in the following equations:

$$U\tilde{C}L_c^\alpha = \left(\bar{c}_a^\alpha + 3\sqrt{\bar{c}_a^\alpha}, \bar{c}_b^\alpha + 3\sqrt{\bar{c}_b^\alpha}, \bar{c}_c^\alpha + 3\sqrt{\bar{c}_c^\alpha}\right) \tag{16.130}$$

$$\tilde{C}L_c^\alpha = \left(\bar{c}_a^\alpha,\ \bar{c}_b,\ \bar{c}_c^\alpha\right) \tag{16.131}$$

$$L\tilde{C}L_c^\alpha = \left(\bar{c}_a^\alpha - 3\sqrt{\bar{c}_a^\alpha}, \bar{c}_b^\alpha - 3\sqrt{\bar{c}_b^\alpha}, \bar{c}_c^\alpha - 3\sqrt{\bar{c}_c^\alpha}\right) \tag{16.132}$$

α-level fuzzy median for an α-cut fuzzy-c̃ control chart can be calculated by transforming α-level fuzzy median transformation technique as below:

$$UCL_{med-c}^\alpha = CL_{med-c}^\alpha + 3\sqrt{CL_{med-c}^\alpha} \tag{16.133}$$

$$CL_{med-c}^\alpha = \frac{1}{3}\left(\bar{c}_a^\alpha, \bar{c}_b, \bar{c}_c^\alpha\right) \tag{16.134}$$

$$LCL_{med-c}^\alpha = CL_{med-c}^\alpha - 3\sqrt{CL_{med-c}^\alpha} \tag{16.135}$$

The condition of process control for each sample can be defined as,

$$Process\ control = \left\{\begin{array}{lll} in\text{-}control & ,for & LCL_{med-c}^\alpha \le S_{med-cj}^\alpha \le UCL_{med-c}^\alpha \\ out\text{-}of\ control & ,for & otherwise \end{array}\right\} \tag{16.136}$$

where

$$S_{med-c,j}^\alpha = \frac{1}{3}\left(c_{a,j}^\alpha, c_{b,j}, c_{c,j}^\alpha\right) \tag{16.137}$$

16.4.2.4 Fuzzy ũ Control Chart

If we relate to the fuzzy number of nonconformities on one product, fuzzy ũ-control chart is used by Şentürk et al. (2011). In this case, the fuzzy number of nonconforming can be expressed by, triangular fuzzy numbers such as $\left(u_{a_j}, u_{b_j}, u_{c_j}\right)$. Here $(\bar{u}_a, \bar{u}_b, \bar{u}_c)$ are the fuzzy averages of the number of nonconforming $\left(u_{a_j}, u_{b_j}, u_{c_j}\right)$, respectively.

$$\bar{u}_a = \frac{\sum u_{a_j}}{m} \;\; \bar{u}_b = \frac{\sum u_{b_j}}{m} \;\; \bar{u}_c = \frac{\sum u_{c_j}}{m} \tag{16.138}$$

Fuzzy $\tilde{u}$-control chart are obtained by using fuzzy numbers and equations as follows:

$$U\tilde{C}L_u = \left(\bar{u}_a + 3\sqrt{\frac{\bar{u}_a}{n_j}}, \bar{u}_b + 3\sqrt{\frac{\bar{u}_b}{n_j}}, \bar{u}_c + 3\sqrt{\frac{\bar{u}_c}{n_j}}\right) \tag{16.139}$$

$$\tilde{C}L_u = (\bar{u}_a, \bar{u}_b, \bar{u}_c) \tag{16.140}$$

$$L\tilde{C}L_u = \left(\bar{u}_a - 3\sqrt{\frac{\bar{u}_a}{n_j}}, \bar{u}_b - 3\sqrt{\frac{\bar{u}_b}{n_j}}, \bar{u}_c - 3\sqrt{\frac{\bar{u}_c}{n_j}}\right) \tag{16.141}$$

Applying α-cut of a fuzzy set, the values of $\bar{u}_a^\alpha$ and $\bar{u}_c^\alpha$, which are the α-cut representation of average numbers of nonconformities, respectively are determined as follows:

$$\bar{u}_a^\alpha = \bar{u}_a + \alpha(\bar{u}_b - \bar{u}_a) \tag{16.142}$$

$$\bar{u}_c^\alpha = \bar{u}_c - \alpha(\bar{u}_c - \bar{u}_b) \tag{16.143}$$

α-cut fuzzy $\tilde{u}$-control chart is obtained by integrating fuzzy $\tilde{u}$-control chart and α-cut as in the following equations:

$$U\tilde{C}L_u^\alpha = \left(\bar{u}_a^\alpha + 3\sqrt{\frac{\bar{u}_a^\alpha}{n_j}}, \bar{u}_b + 3\sqrt{\frac{\bar{u}_b}{n_j}}, \bar{u}_c + 3\sqrt{\frac{\bar{u}_c^\alpha}{n_j}}\right) \tag{16.144}$$

$$\tilde{C}L_u^\alpha = \left(\bar{u}_a^\alpha, \bar{u}_b, \bar{u}_c^\alpha\right) \tag{16.145}$$

$$L\tilde{C}L_u^\alpha = \left(\bar{u}_a^\alpha - 3\sqrt{\frac{\bar{u}_a^\alpha}{n_j}}, \bar{u}_b - 3\sqrt{\frac{\bar{u}_b}{n_j}}, \bar{u}_c - 3\sqrt{\frac{\bar{u}_c^\alpha}{n_j}}\right) \tag{16.146}$$

α-level fuzzy median for an α-cut fuzzy $\tilde{u}$-control chart can be calculated as follows:

$$UCL_{med-u}^\alpha = CL_{med-u}^\alpha + 3\sqrt{\frac{CL_{med-u}^\alpha}{n_j}} \tag{16.147}$$

$$CL_{med-u}^\alpha = \frac{1}{3}\left(\bar{u}_a^\alpha, \bar{u}_b, \bar{u}_c^\alpha\right) \tag{16.148}$$

$$LCL^{\alpha}_{med-u} = CL^{\alpha}_{med-u} - 3\sqrt{\frac{CL^{\alpha}_{med-u}}{n_j}} \tag{16.149}$$

The condition of process control for each sample can be defined as,

$$Process\ control = \begin{Bmatrix} in\text{-}control & ,for & LCL^{\alpha}_{med-u} \leq S^{\alpha}_{med-uj} \leq UCL^{\alpha}_{med-u} \\ out\text{-}of\ control & ,for & otherwise \end{Bmatrix} \tag{16.150}$$

where

$$S^{\alpha}_{med-u,j} = \frac{1}{3}\left(u^{\alpha}_{a,j}, u_{b,j}, u,^{\alpha}_{c,j}\right) \tag{16.151}$$

16.5 Conclusions

TQM is a philosophy which incorporates an improvement for both management quality and production quality. TQM provides continuous improvement, customer satisfaction and success of key performance results. TQM organizes employees, process, product and services through the policy and strategy with strong leadership by using their resource to achieve their target defining policies and strategies. TQM is a root for engineering management through policies, strategies, and partnerships. TQM considers product and process quality using Statistical Control Charts. When any vagueness in the data collected from the process exists, fuzzy control charts are appropriate to monitor and evaluate the process. In this chapter, theoretical bases of both fuzzy variable and fuzzy attribute control charts are introduced as intelligent techniques to implement TQM principles. For further research, Type 2 fuzzy control charts can be developed and their performance can be compared with our study.

References

Erginel, N.: Fuzzy individual and moving range control charts with α-cuts. J. Intell. Fuzzy Syst. **19**, 373–383 (2008)

Erginel, N.: Fuzzy rule-based $\tilde{p}$ and $n\tilde{p}$ control charts. J. Intell. Fuzzy Syst. **27**(1):159–171 (2014)

Erginel, N., Şentürk, S., Kahraman, C., Kaya, İ.: Evaluating the packing process in food industry using $\tilde{\bar{X}}$ and $\tilde{S}$ control charts. Int. J. Comput. Intell. Syst. **4**(4):509–520 (2011)

Faraz, A., Moghadam, M.B.: Fuzzy control chart a better alternative for Shewhart average chart. Qual. Quant. **41**, 375–385 (2007)

Gülbay, M., Kahraman, C.: Development of fuzzy process control charts and fuzzy unnatural pattern analyses. Comput. Stat. Data Anal. **51**, 434–451 (2006a)

Gülbay, M., Kahraman, C.: An alternative approach to fuzzy control chart: direct fuzzy approach. Inf. Sci. **77**(6), 1463–1480 (2006b)

Gülbay, M., Kahraman, C., Ruan, D.: α-cut fuzzy control chart for linguistic data. Int. J. Intell. Syst. **19**, 1173–1196 (2004)

ISO 9001:2000: Quality management system—requirements

ISO 9000:2005: Quality management system—fundamentals and vocabulary

ISO 9004:2009: Managing for the sustained success of an organization—a quality management approach

Kahraman, C., Yavuz, M.: Production Engineering and Management Under Fuzziness, Studies in Fuzziness and Soft Computing, pp. 431–456. Springer, Berlin (2010)

Kanagawa, A., Tamaki, F., Ohta, H.: Control charts for process average and variability based on linguistic data. Intell. J. Prod. Res. **31**(4), 913–922 (1993)

Kaya, İ., Kahraman, C.: Process capability analysis based on fuzzy measurements and fuzzy control charts. Expert Syst. Appl. **38**, 3172–3184 (2011)

Kolarik, W.J.: Creating Quality—Concepts. Systems. Strategies and Tools. McGraw Hill, New York (1995)

Montgomery, D.C.: An Modern Introduction Statistical Quality Control, 6th edn. Wiley, New York (2009)

Raz, T., Wang, J.H.: Probabilistic and memberships approaches in the construction of control chart for linguistic data. Prod. Plann. Control **1**, 147 (1990)

Şentürk, S.: Fuzzy regression control chart based on α-cut approximation. Int. J. Comput. Intell. Syst. **3**(1), 123–140 (2010)

Şentürk, S., Erginel, N.: Development of fuzzy $\tilde{\bar{\bar{X}}} - \tilde{R}$ and $\tilde{\bar{\bar{X}}} - \tilde{S}$ control charts using α-cuts. Inf. Sci. **179**, 1542–1551 (2009)

Şentürk, S., Erginel, N., Kaya, İ., Kahraman, C.: Design of fuzzy $\tilde{u}$ control chart. J. Multiple Valued Logic Soft Comput. **17**, 459–473 (2011)

Şentürk, S., Erginel, N., Kaya, İ., Kahraman, C.: Fuzzy exponentially weighted moving average control chart for univariate data with a real case application. Appl. Soft Comput. **22**, 1–10 (2014)

Wang, J.H., Raz, T.: On the construction of control charts using linguistic variables. Intell. J. Prod. Res. **28**, 477–487 (1990). http://www.efqm.org

Chapter 17
Testing Fuzzy Quality in Engineering Management

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Abstract Fuzzy process capability indices establish the relationship between the actual performance and the fuzzy specification limits, which are used to determine whether a production process is capable of producing items within fuzzy specification tolerance. In this chapter we test a fuzzy process capability index $\tilde{C}_p$, where instead of precise quality we have two membership functions for specification limits. Also, we develop the operating characteristic (OC) curves for the fuzzy capability index in testing one sided and two sided hypotheses. Numerical examples are given to show the performance of the method.

Keywords Testing hypotheses · Fuzzy process capability index · Probability of type I and II errors · Operating characteristic curve · Fuzzy quality

17.1 Introduction

Capability indices that qualify process potential and process performance are practical tools for successful quality improvement activities and quality program implementation. A process capability index (PCI) is a real number as a summary that compares the behavior of a product or process characteristic with engineering specifications (Kane 1986). More details about C_p, C_{pk}, C_{pm} PCIs and their statistical properties can be found in (Kotz and Johnson 1993; Kotz and Lovelace 1998).

The stages of prove out testing at the machine supplier, initial testing at the manufacturing facility, and pre-production testing all seek to determine whether machinery can produce on an on-going basis production units that meet the required engineering specification limits (SLs) (see Hoffman (1993)). Kane (1986) develops a table, which gives values needed for the determination of critical value in testing

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C_p only for two values of probability errors. In this situation, Hoffman (1993) has derived a generalized approach to testing hypotheses for C_p, which allows testing for any given probability of type I and sample size.

Successful applications of fuzzy set theory in the environmental fields recently shows its great potential for considering some applied techniques in engineering management. For instance, see (Wu 2009) and (Kaya and Kahraman 2011a). There are many efforts by several authors to apply the fuzzy set theory in statistics. For these trends one can see (Taheri 2003; Viertl 2002; 2011). In this regard, statistical quality control recently affected by fuzzy set theory. Lee (2001) investigated a process capability index, C_{pk}, as a fuzzy set when observations are fuzzy. In this situation, but from different point of view, Tsai and Chen (2006) introduced the capability index C_p as a fuzzy number and presented a method to test this introduced fuzzy capability index. As a new point of view, Parchami and Mashinchi (2007) estimated PCIs with fuzzy numbers. In quality control topic, where specification limits are not precise numbers and they are expressed by fuzzy terms, the classical methods could not be applied. For such cases Amirzadeh et al. (2009) constructed p-charts based on the fuzzy quality. Yongting (1996) introduced the process capability index $\tilde{C}_p$ as a real number and it is extended by Sadeghpour-Gildeh (2006). Parchami et al. (2005) introduced fuzzy PCIs as fuzzy numbers and discussed relations among them when SLs are fuzzy rather than crisp. Also, they tested the capability of the process and they obtained fuzzy confidence intervals for these new process capability indices (Parchami et al. 2006; Parchami and Mashinchi 2009; Ramezani et al. 2011). Wu (2009) proposed a three-decision testing rule based on the fuzzy estimation of C_{pk} index. Kaya and Kahraman (2011a) analyzed the capability of process based on fuzzy measurements by fuzzy control charts. Parchami et al.(2011) investigated on the approximate confidence interval for the Taguchi capability index in engineering management (also, see (Parchami and Mashinchi 2011)). Sadeghpour Gildeh and Moradi (2012) worked on monitoring process capability using the process capability plots in engineering management by fuzzy information. Kaya and Kahraman (2011b) investigat on the approximate confidence interval for the Taguchi capability index in fuzzy systems. Moradi and Sadeghpour Gildeh (2013) proposed a general multivariate capability index by considering a fuzzy tolerance region. A fuzzy-based approach is considered in this chapter for testing the quality of a product in engineering management.

The organization of this chapter is as follows. In Sect. 17.2, we review some traditional PCIs and we represent fuzzy PCIs. We review ranking functions in Sect. 17.3. In Sect. 17.4, we present a statistical approach for one sided and two sided testing fuzzy PCI and numerical examples are given to illustrate the method. The final section is the conclusions part with presenting some further works.

17.2 Process Capability Indices

17.2.1 Traditional Process Capability Indices

Several PCIs are introduced in the literature such as C_p, C_{pk}, C_{pm} and etc. (Kotz and Johnson 2002, 1993; Montgomery 2005). For convenience, we will denote the upper and lower specification limits by U and L, respectively, rather than the more customary USL and LSL notations. When univariate measurements are concerned, we will denote the corresponding random variable by X. The expected value and standard deviation of X will be denoted by μ and σ, respectively. We will limit ourselves to the situation where μ is within the specification interval, i.e. $L \le \mu \le U$ Throughout the discussion it is assumed that the measured characteristic is approximately normally distributed and in a state of statistical control.

The commonly recognized PCIs are:

$$C_p = \frac{U - L}{6\sigma}, \tag{17.1}$$

this C_p is used when $\mu = M$ where $M = (U + L)/2$,

$$C_{pk} = \frac{U - L - 2|\mu - M|}{6\sigma} = \frac{min\{U - \mu, \mu - L\}}{3\sigma}, \tag{17.2}$$

and

$$C_{pm} = \frac{U - L}{6\sqrt{\sigma^2 + (\mu - T)^2}} = \frac{U - L}{6\sqrt{E[(X - T)^2]}}, \tag{17.3}$$

where T is the target value and $E[.]$ stands for the expected value. For each of these indices a large value implies a better distribution of the quality characteristic.

Usually $T = M$, if $T \neq M$ the situation is sometimes described as asymmetric tolerances (Boyles 1994, Vännman 1997; 1998). Introduction of C_p is ascribed to Juran (1974); that of C_{pk} to Kane (1986) and that of C_{pm} for the most part to Hsiang and Taguchi (1985). Substituting the sample mean and standard deviation in Eqs. (17.1–17.3) will provides a point estimate for any of these indices.

17.2.2 Fuzzy Process Capability Indices

Let R be the set of real numbers and $F(\mathrm{R}) = \{A|A : \mathrm{R} \to [0, 1]\}$, $F_T(\mathrm{R}) = \{T(a, b, c)|a, b, c \in \mathrm{R}, a < b < c\}$, where

$$T(a,b,c)(x) = \begin{cases} \frac{x-a}{b-a} & if \quad a < x \leq b, \\ \frac{x-c}{b-c} & if \quad b < x \leq c, \\ 0 & \quad elsewhere. \end{cases} \tag{17.4}$$

Any $A \in F(\mathrm{R})$ is called a fuzzy set on R and any $T(a,b,c) \in F_T(\mathrm{R})$ is called a triangular fuzzy number. We suppose that $T(a,a,a) = I_{\{a\}}$, where I is the indicator function and $a \in \mathrm{R}$. The following definition could be given by using the extension principle (Nguyen and Walker 2005).

Definition 1 Let $T(a,b,c), T(a',b',c') \in F_T(\mathrm{R})$, $k \in \mathrm{R}$ and $k \geq 0$. Define the operations $\otimes$, $\oplus$ and $\ominus$ on $F_T(\mathrm{R})$ as follows

$$k \otimes T(a,b,c) = T(a,b,c) \otimes k = T(ka,kb,kc), \tag{17.5}$$

$$T(a,b,c) \oplus T(a',b',c') = T(a+a', b+b', c+c'), \tag{17.6}$$

$$T(a,b,c) \ominus T(a',b',c') = T(a-c', b-b', c-a'), \tag{17.7}$$

called multiplication, summation and subtract on the triangular fuzzy numbers, respectively.

The C_p index based on fuzzy SLs was introduced as a real number by Yongting (1996). But when we have fuzzy SLs, it will be more realistic to have a C_p which is also fuzzy, since a fuzzy capability index could be more informative than a precise number. In this situation, Parchami et al. introduced PCIs as fuzzy numbers. They used fuzzy numbers $U(a_u,b_u,c_u), T(a_u,b_u,c_u) \in F_T(\mathrm{R})$ and $L(a_l,b_l,c_l), T(a_l,b_l,c_l) \in F_T(\mathrm{R})$ for engineering specification limits and they gave the following definitions (Parchami et al. 2005).

Definition 2 A process with fuzzy specification limits, which we call a fuzzy process for short, is one which states the normal distribution condition, that is $X_1, X_2, \ldots, X_n$ are independent, identically distributed random variables with $N(\mu, \sigma^2)$.

Definition 3 In a fuzzy process, let $U(a_u,b_u,c_u), L(a_l,b_l,c_l) \in F_T(\mathrm{R})$ be the engineering fuzzy specification limits, where $a_u \geq c_l$. Then the fuzzy PCIs are defined as follows

$$\tilde{C}_p = T\left(\frac{a_u - c_l}{6\sigma}, \frac{b_u - b_l}{6\sigma}, \frac{c_u - a_l}{6\sigma}\right). \tag{17.8}$$

Note that $\tilde{C}_p$ is useful when $\mu = m$ where $m = (b_u + b_l)/2$. Also

$$\tilde{C}_{pk} = T\left(\frac{a_u - c_l - 2|\mu - m|}{6\sigma}, \frac{b_u - b_l - 2|\mu - m|}{6\sigma}, \frac{c_u - a_l - 2|\mu - m|}{6\sigma}\right), \quad (17.9)$$

and

$$\tilde{C}_p = T\left(\frac{a_u - c_l}{6\sqrt{\sigma^2 + (\mu - t)^2}}, \frac{b_u - b_l}{6\sqrt{\sigma^2 + (\mu - t)^2}}, \frac{c_u - a_l}{6\sqrt{\sigma^2 + (\mu - t)^2}}\right), \quad (17.10)$$

where t is the target value.

Note that, substituting the sample mean and standard deviation in (17.8)–(17.10) will provides a so called point estimate for any of above fuzzy indices. It is obvious that $\tilde{C}_p$, $\tilde{C}_{pk}$ and $\tilde{C}_{pm}$ as fuzzy PCIs, differ in interpretation from traditional C_p, C_{pk}, C_{pm}, since they are triangular functions. More details about their interpretations and comparisons are presented in (Parchami et al. 2005). A generalized version of the above fuzzy PCIs is studied in (Moeti et al. 2006), where the SLs are *L-R* fuzzy intervals.

17.3 Linear Ranking Function

In the sequel section we are going to give an approach to testing PCI, where comparing fuzzy numbers is emergent and so an ordering approach is needed. We need a criterion for comparison of two fuzzy subsets. A simple but efficient approach for the ordering of the elements of $F(\mathrm{R})$ is to define a ranking function $R : F(\mathrm{R}) \to \mathrm{R}$. This R maps each fuzzy number into the real line, where a natural order exists. Maleki (2002) defines the order $\underset{R}{\leq}$ on $F(\mathrm{R})$ as follows

$\tilde{A} \underset{R}{\leq} \tilde{B}$ if and only if $R(\tilde{A}) \leq R(\tilde{B})$,
$\tilde{A} \underset{R}{\geq} \tilde{B}$ if and only if $R(\tilde{A}) \geq R(\tilde{B})$,
$\tilde{A} \underset{R}{=} \tilde{B}$ if and only if $R(\tilde{A}) = R(\tilde{B})$,
$\tilde{A} \underset{R}{\neq} \tilde{B}$ if and only if $R(\tilde{A}) \neq R(\tilde{B})$,

where $\tilde{A}$ and $\tilde{B}$ are in $F(\mathbb{R})$. Several ranking functions R have been proposed by researchers to suit their requirements of the problems under consideration. For more details see (Bortolan and Degani 1985; Wang and Kerre 2001).

Definition 4 Let $T(a, b, c) \in F_T(\mathrm{R})$. According to Roubens's ranking function, $\| \, . \, \|$ as the absolute value operation on $F_T(\mathrm{R})$ is defined as follows

$$\| T(a,b,c) \| = \begin{cases} T(a,b,c) & \textit{if} \quad R(T(a,b,c)) \geq 0, \\ T(-c,-b,-a) & \textit{if} \quad R(T(a,b,c)) < 0. \end{cases}$$

which called the absolute of $T(a, b, c)$.

Throughout this chapter, we restrict our attention to linear ranking functions, satisfying

$$R\big((k \otimes \tilde{A}) \oplus \tilde{B}\big) = kR(\tilde{A}) + R(\tilde{B}) \tag{17.11}$$

for any $\tilde{A}, \tilde{B} \in F_T(\mathrm{R})$ and any $k \in \mathrm{R}$.

Lemma 1 *Let $m, n \in \mathrm{R}$, $T(a,b,c) \in F_T(\mathrm{R})$. For any linear ranking function R such that $R(T(a,b,c)) \geq 0$, we have:*
$m \otimes T(a,b,c) \underset{R}{\leq} n \otimes T(a,b,c)$ if and only if $m \leq n$.

Proof Note that

$$m \otimes T(a,b,c) \underset{R}{\leq} n \otimes T(a,b,c)$$

if and only if, by Eq. (17.5),

$$T(ma, mb, mc) \underset{R}{\leq} T(na, nb, nc)$$

if and only if,

$$R(T(ma, mb, mc)) \leq R(T(na, nb, nc))$$

if and only if, by Eq. (17.11),

$$mR(T(a,b,c)) \leq nR(T(a,b,c))$$

if and only if, by the fact $R(T(a,b,c)) \geq 0$,

$$m \leq n.$$

□

Lemma 2 *Let $k \in \mathrm{R}$ and $T(a,b,c), T(a',b',c') \in F_T(\mathrm{R})$. For any linear ranking function R, we have:*

$$(i) \qquad R(||T(a,b,c)||) = |R(T(a,b,c))|, \tag{17.12}$$

$$(ii) \qquad R(k \otimes T(a,b,c)) = kR(T(a,b,c)), \tag{17.13}$$

$$(iii) \qquad R(T(a,b,c) \ominus T(a',b',c')) = R(T(a,b,c)) - R(T(a',b',c')), \tag{17.14}$$

where $\|\,.\,\|$ is the absolute value operation on $F_T(\mathrm{R})$.

Proof By Definitions 1 and 4, the proof is obvious. □

In particular, as a linear ranking function, the ranking function proposed in (Roubens 1991; Fortemps and Roubens 1996) is defined by

$$R_r(\tilde{A}) = \frac{1}{2}\int_0^1 \left(inf\tilde{A}_\alpha + sup\tilde{A}_\alpha\right)d\alpha \qquad (17.15)$$

Lemma 3 *If* $T(a,b,c) \in F_T(\mathrm{R})$, *then* R_r *for a triangular fuzzy number* $T(a,b,c)$ *reduces to* (Parchami et al. 2006):

$$R_r(T(a,b,c)) = \frac{2b+a+c}{4}.$$

17.4 Testing Hypotheses on Fuzzy Capability Index

The proper decision based on capability indices is very important, since they are commonly used in managerial decisions. In this section, we study the one sided and two sided testing problems based on $\tilde{C}_p$.

17.4.1 One Sided Test

Kane derives the operating characteristic (OC) curve for testing C_p using the fact that $(n-1)S^2/\sigma^2$ has a Chi-square distribution with $n-1$ degree of freedom (Kane 1986; Kotz and Lovelace 1998). In an analogous manner, we are going to compute the OC curve for testing $\tilde{C}_p$ as a fuzzy PCI. Firstly, it must be mentioned that most of the contents of this subsection is reviewed and quoted from (Parchami and Mashinchi 2009).

In this subsection, to test whether a given fuzzy process is capable, we consider the following statistical hypotheses testing:

$$H_0 : \tilde{C}_p \underset{R}{\le} \tilde{c}_0 \quad \text{(fuzzy process is not capable)},$$

$$H_1 : \tilde{C}_p \underset{R}{>} \tilde{c}_0 \quad \text{(fuzzy process is capable)},$$

which we call one sided test for short, where $\tilde{c}_0 \in F_T(\mathrm{R})$ is the standard minimal criteria for $\tilde{C}_p$ as a practical realization with $R(\tilde{c}_0) > 0$. Note that, as a general approach, it is natural to use a fuzzy boundary $\tilde{c}_0$ whenever we have a fuzzy parameter $\tilde{C}_p$. The power function of the test can be computed by the following theorem, which shows the chance of correctly judging a capable fuzzy process as capable (Parchami and Mashinchi 2009).

Theorem 1 *Suppose that* $X_1, X_2, \ldots, X_n$ *are independent, identically distributed random variables with* $N(\mu, \sigma^2)$ *and* $U(a_u, b_u, c_u), L(a_l, b_l, c_l) \in F_T(\mathrm{R})$ *are the engineering fuzzy specification limits, where* $a_u \geq c_l$*. Then using fuzzy critical value* $\tilde{c} \in F_T(\mathrm{R})$*, the power function of the one sided testing* $\tilde{C}_p$ *for any linear ranking function R is*

$$\prod\left(\tilde{C}_p\right) = Pr\left(\chi^2_{n-1} < (n-1)\left(\frac{R(\tilde{C}_p)}{R(\tilde{c})}\right)^2\right), \tag{17.16}$$

where $\tilde{C}_p = T\left(\frac{a_u - c_l}{6\sigma}, \frac{b_u - b_l}{6\sigma}, \frac{c_u - a_l}{6\sigma}\right)$ *and* χ^2_{n-1} *is a Chi-square random variable with degree of freedom* $n-1$ (Parchami and Mashinchi 2009).

Instead of defining the power function Π as a function of $\tilde{C}_p$*, it could have been defined as a function of the* $R(\tilde{C}_p)$*. So, let us denote* $\prod\left(\tilde{C}_p\right)$ *by* $\prod\left(R(\tilde{C}_p)\right)$*. Using Eq.* (17.16)*, we develop the operating characteristic curve for* $\tilde{C}_p$ *index as the following*

$$OC\left(R(\tilde{C}_p)\right) = 1 - \prod\left(R(\tilde{C}_p)\right), \tag{17.17}$$

which plots the true value of $1 - \prod\left(R(\tilde{C}_p)\right)$ *versus* $R(\tilde{C}_p)$*.*

In all examples of this chapter, we will use the linear ranking function R_r*, while one can use any others.*

Example 1 Suppose we wish to evaluate whether a fuzzy process is capable at $\tilde{c}_0 = T(1.2, 1.33, 1.4)$ as the standard minimal lower boundary of $\tilde{C}_p$. We can design the hypotheses as follows

$$H_0 : \tilde{C}_p \underset{R}{\leq} T(1.2, 1.33, 1.4),$$

$$H_1 : \tilde{C}_p \underset{R}{>} T(1.2, 1.33, 1.4),$$

or equivalently testing $H_0 : R(\tilde{C}_p) \leq 1.315$, v.s. $H_1 : R(\tilde{C}_p) > 1.315$. Suppose that the rejection limit (critical value) used for $\hat{\tilde{C}}$ is $\tilde{c} = T(1.2, 1.33, 1.4)$. For sample size $n = 30$, using Eq. (17.17), we draw the OC curve for $\tilde{C}_p$. See curve (a) in Fig. 17.1. This curve indicates that $OC(1.315) = 0.46$, which implies that we have a 46 % risk of concluding that our fuzzy process is not capable.

According to the OC curve (a), to obtain a 5 % risk of concluding that the fuzzy process is not capable, the Roubens's rank of the true value of $\tilde{C}_p$ must be $R_r(\tilde{C}_p) = 1.61$. Accuracy of the estimate is improved by increasing the sample size, which is illustrated by curve (b) in Fig. 17.1. This Figure provides the OC curves for the sampling plan that rejects the fuzzy process capability if $\hat{\tilde{C}}_p \underset{R}{<} \tilde{c}$ for $\tilde{c} = T(1.2, 1.33, 1.4)$, $n = 30$; and also $\tilde{c} = T(1.4, 1.46, 1.5)$, $n = 70$.

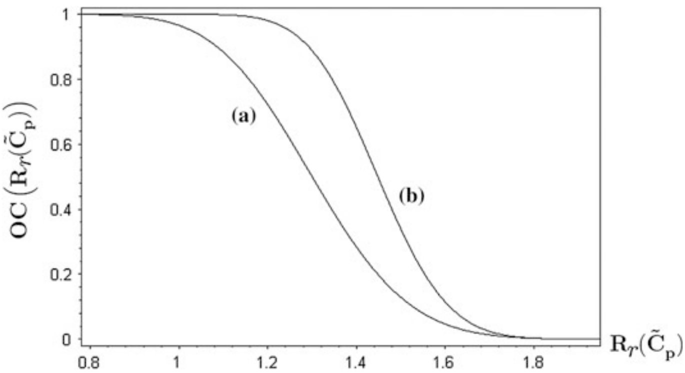

Fig. 17.1 The operating characteristic curve for $\tilde{C}_p$ in Example 1

In testing the capability of a process, selecting an appropriate critical value requires establishing both an acceptable quality level (*AQL*) and a rejectable quality level (*RQL*), see (Burr 1976; Kane 1986). In case of fuzzy process capability, we define the *AQL* to be a sufficiently high qualified fuzzy process capability so that fuzzy processes with capabilities above the *AQL* would be accepted. In contrast, we define the *RQL* to be a sufficiently low qualified fuzzy process capability so that fuzzy processes with capabilities below the *RQL* would be rejected. So, we let $\tilde{C}_p(low) \in F_T(\mathrm{R})$ be the *RQL* and $\tilde{C}_p(high) \in F_T(\mathrm{R})$ be the *AQL* such that $\tilde{C}_p(high) \underset{R}{>} \tilde{C}_p(low)$.

Theorem 2 *Let R be a linear ranking function. In testing one sided hypotheses*

$$H_0 : \tilde{C}_p \underset{R}{\leq} \tilde{C}_p(low) \quad (\textit{fuzzy process is not capable}),$$

$$H_1 : \tilde{C}_p \underset{R}{>} \tilde{C}_p(low) \quad (\textit{fuzzy process is capable}),$$

at the given significance level α, the rank of fuzzy critical value is

$$R(\tilde{c}) = R(\tilde{C}_p(low))\sqrt{\frac{n-1}{\chi^2_{n-1,\alpha}}}, \tag{17.18}$$

in which $\chi^2_{n-1,\alpha}$ *is the α-quantile of Chi-square distribution with* $n-1$ *degree of freedom* (Parchami and Mashinchi 2009).

Theorem 3 *Under the same assumption and testing hypotheses as in Theorem 2, the probability of type I and II errors are*

$$\alpha = Pr\left(\chi^2_{n-1} < (n-1)\left(\frac{R(\tilde{C}_p(low))}{R(\tilde{c})}\right)^2\right) \tag{17.19}$$

and

$$\beta = Pr\left(\chi^2_{n-1} > (n-1)\left(\frac{R(\tilde{C}_p(high))}{R(\tilde{c})}\right)^2\right), \tag{17.20}$$

respectively (Parchami and Mashinchi 2009).

Given α and n, the fuzzy process is capable if $R(\widehat{\tilde{C}}) > R(\tilde{c})$; otherwise it is incapable. By Theorem 3, we are able to calculate the probability that the decision rule will consider the given fuzzy process not to be capable. Also from the practical point of view, one can determine $R(\tilde{c})$ and n, for any given α, β, $\tilde{C}_p(low)$ and $\tilde{C}_p(high)$.

Example 2 For a special product suppose that the specification limits are considered to be "approximately 4" and "approximately 8" which are characterized by $L(2,4,6) \in F_T(\mathrm{R})$ and $U(7,8,9) \in F_T(\mathrm{R})$, respectively, depicted in Fig. 17.2. Assume that the process mean is 6 and the estimated process standard deviation is 2/3 (Parchami and Mashinchi 2009). By Eq. (17.8), we can estimate $\tilde{C}_p$ by $\widehat{\tilde{c}}_p = T(0.25, 1, 1.75)$. In other words, the observed value of $\widehat{\tilde{C}}$ is "approximately one" shown in Fig. 17.3 (see Example 4.1. from Parchami et al. (2005)).

Now, suppose that we want to test

$$H_0 : \tilde{C}_p \underset{R}{\leq} \tilde{C}_p(low),$$

$$H_1 : \tilde{C}_p \underset{R}{>} \tilde{C}_p(low),$$

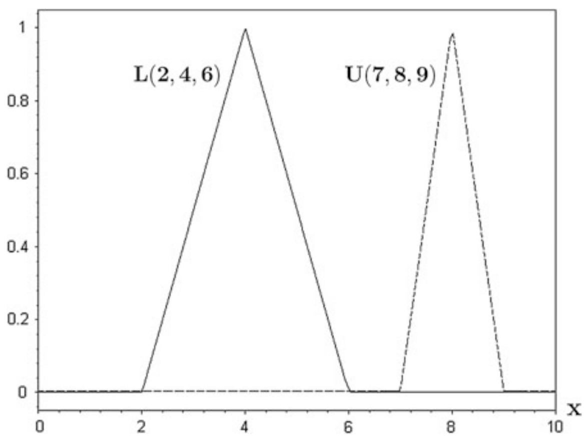

Fig. 17.2 The membership functions of fuzzy specification limits in Example 2

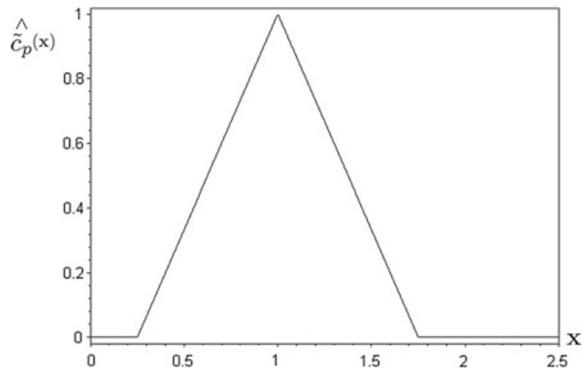

Fig. 17.3 The membership function of the estimate of fuzzy capability index in Example 2

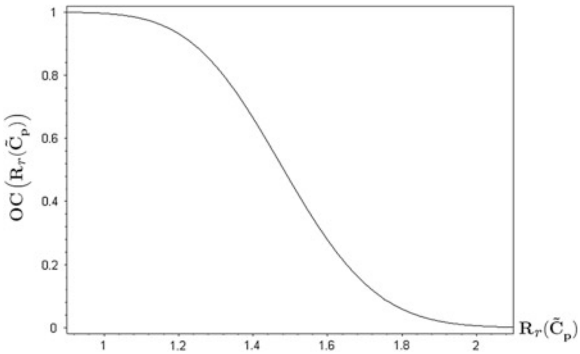

Fig. 17.4 The operating characteristic curve for $\tilde{C}_p$ in Example 2

at significance level $\alpha = 0.05$, where $n = 30$ and $\tilde{C}_p(low) = T(1, 1.2, 1.3)$. Using Eq. (17.18), the critical region is $R_r(\hat{\tilde{C}}_p) > 1.5$. Since $R_r(T(0.25, 1, 1.75)) < 1.5$, we do not reject H_0 at significance level 0.05 (accept H_0). Now by Eq. (17.22), for any determined $\tilde{C}_p(high)$ one can compute probability of type II error. For instance, if $\tilde{C}_p(high) = T(1.6, 1.7, 2)$, then $\beta = 0.096$ which is shown in Fig. 17.4.

Example 3 Under the same assumption as in Example 2, if $\alpha = \beta = 0.10$ and $\tilde{C}_p(high) = T(1.5, 1.55, 1.64)$, then in testing hypotheses

$$H_0 : \tilde{C}_p \underset{R}{\leq} T(1, 1.2, 1.3),$$

$$H_1 : \tilde{C}_p \underset{R}{>} T(1, 1.2, 1.3),$$

one can obtain $n = 50$, and $R_r(\tilde{C}) = 1.356$, using Eqs. (17.19–17.22). For a similar calculation, see Table 1 from (Kane 1986). Thus for $n = 50$, and $R_r(\tilde{C}) = 1.356$, there is a 10 % risk of concluding that a process with $\tilde{C}_p$ below $T(1, 1.2, 1.3)$ is capable and a 10 % risk of concluding that a process with $\tilde{C}_p$ above $T(1.5, 1.55, 1.64)$ is incapable.

17.4.2 Two Sided Test

In this subsection, we are going to extend some statistically concepts for a fuzzy process by considering two sided test on fuzzy capability index $\tilde{C}_p$. Since in manufacturing procedures, we some times need to test the hypotheses

$$H_0 : \tilde{C}_p \underset{R}{=} \tilde{c}_0,$$

$$H_1 : \tilde{C}_p \underset{R}{\neq} \tilde{c}_0,$$

which we call two sided test for short, where $\tilde{c}_0 \in F_T(\mathrm{R})$ is the standard criteria for $\tilde{C}_p$ as a practical realization with $R(\tilde{c}_0) > 0$.

Theorem 4 *Suppose that* $X_1, X_2, \ldots, X_n$ *are independent, identically distributed random variables with* $N(\mu, \sigma^2)$ *and* $U(a_u, b_u, c_u), L(a_l, b_l, c_l) \in F_T(\mathrm{R})$ *are the engineering fuzzy specification limits, where* $a_u \geq c_l$*. Then using critical value c, the power function of the two sided testing* $\tilde{C}_p$ *for any linear ranking function R is* $\prod(\tilde{C}_p) =$

$$1 - Pr\left(\chi^2_{n-1} > (n-1)\left(\frac{R(\tilde{C}_p)}{R(\tilde{c}_0) + c}\right)^2\right) + Pr\left(\chi^2_{n-1} > (n-1)\left(\frac{R(\tilde{C}_p)}{R(\tilde{c}_0) - c}\right)^2\right), \tag{17.21}$$

where $\tilde{C}_p = T\left(\frac{a_u - c_l}{6\sigma}, \frac{b_u - b_l}{6\sigma}, \frac{c_u - a_l}{6\sigma}\right)$ *and* χ^2_{n-1} *is a Chi-square random variable with* $n-1$ *degree of freedom.*

Proof Let $\widehat{\tilde{C}_p} = T\left(\frac{a_u - c_l}{6s}, \frac{b_u - b_l}{6s}, \frac{c_u - a_l}{6s}\right)$. By Lemmas 1 and 2, normality assumption and using a critical region of form $\| \widehat{\tilde{C}_p} \ominus c_0 \| \underset{R}{>} T(c, c, c)$, where $c \geq 0$, the power function of the above test is obtained directly from the Chi-square distribution of the random sample variance as follows

$$\begin{aligned}
\prod\left(R(\tilde{C}_p)\right) &= Pr\left(\parallel \widehat{\tilde{C}_p} \ominus \tilde{c}_0 \parallel \underset{R}{>} T(c,c,c)\right) \\
&= Pr\left(R\left(\parallel \widehat{\tilde{C}_p} \ominus \tilde{c}_0 \parallel\right) > R(T(c,c,c))\right) \\
&= Pr\left(\left|R\left(\widehat{\tilde{C}_p} \ominus \tilde{c}_0\right)\right| > c\right) \\
&= 1 - Pr\left(R\left(\widehat{\tilde{C}_p} \ominus \tilde{c}_0\right) < c\right) + Pr\left(R\left(\widehat{\tilde{C}_p} \ominus \tilde{c}_0\right) < -c\right) \\
&= 1 - Pr\left(R\left(\widehat{\tilde{C}_p}\right) < R(\tilde{c}_0) + c\right) + Pr\left(R\left(\widehat{\tilde{C}_p}\right) < R(\tilde{c}_0) - c\right) \\
&= 1 - Pr\left(R\left(\frac{\sigma}{S} \otimes \tilde{C}_p\right) < R(\tilde{c}_0) + c\right) \\
&\quad + Pr\left(R\left(\frac{\sigma}{S} \otimes \tilde{C}_p\right) < R(\tilde{c}_0) - c\right) \\
&= 1 - Pr\left(\frac{\sigma}{S} R\left(\tilde{C}_p\right) < R(\tilde{c}_0) + c\right) + Pr\left(\frac{\sigma}{S} R\left(\tilde{C}_p\right) < R(\tilde{c}_0) - c\right) \\
&= 1 - Pr\left((n-1)\frac{S^2}{\sigma^2} > (n-1)\left(\frac{R(\tilde{C}_p)}{R(\tilde{c}_0) + c}\right)^2\right) \\
&\quad + Pr\left((n-1)\frac{S^2}{\sigma^2} > (n-1)\left(\frac{R(\tilde{C}_p)}{R(\tilde{c}_0) - c}\right)^2\right) \\
&= 1 - Pr\left(\chi^2_{n-1} > (n-1)\left(\frac{R(\tilde{C}_p)}{R(\tilde{c}_0) + c}\right)^2\right) \\
&\quad + Pr\left(\chi^2_{n-1} > (n-1)\left(\frac{R(\tilde{C}_p)}{R(\tilde{c}_0) - c}\right)^2\right).
\end{aligned}$$

□

Theorem 5 *Under the same assumption and testing hypotheses as in Theorem 4, for any linear ranking function R, the probability of type I and II errors are*

$$\alpha = \prod\left(R(\tilde{c}_0)\right) \tag{17.22}$$

and

$$\beta = \sup_{R(\tilde{C}_p) > 0}\left[1 - \prod\left(R(\tilde{C}_p)\right)\right], \tag{17.23}$$

respectively, in which Π is given in (17.21).

Proof The probability of type I error is

$$\alpha = \sup_{\tilde{C}_p \underset{R}{=} \tilde{c}_0} \prod \left(R(\tilde{C}_p)\right)$$
$$= \prod \left(R(\tilde{c}_0)\right).$$

Also, the probability of type II error is

$$\beta = \sup_{\tilde{C}_p \underset{R}{\neq} \tilde{c}_0} \left[1 - \prod \left(R(\tilde{C}_p)\right)\right]$$
$$= \sup_{R(\tilde{C}_p) \neq R(\tilde{c}_0)} \left[1 - \prod \left(R(\tilde{C}_p)\right)\right], \quad (17.24)$$

To obtain the supremum on $R(\tilde{C}_p) \neq R(\tilde{c}_0)$ in (17.24), one can obtain the supremum on the set of non-negative real numbers, because $R(\tilde{C}_p)$ can continuously change on the set of non-negative real numbers. So regarding supremum properties we can omit one point from this continues real line and therefore we have Eq. (17.23). □

Remark 1 In a process, when $U(a_u, b_u, c_u), L(a_l, b_l, c_l)$ and $\tilde{c}_0$ are all precise numbers, in other words when they are indicator functions, then the introduced power functions coincide with the traditional power functions in one sided and two sided tests.

Example 4 Suppose we wish to test

$$H_0 : \tilde{C}_p \underset{R}{=} T(1.25, 1.33, 1.5),$$

$$H_1 : \tilde{C}_p \underset{R}{\neq} T(1.25, 1.33, 1.5),$$

or equivalently test $H_0 : R(\tilde{C}_p) = 1.3525$, v.s. $H_1 : R(\tilde{C}_p) \neq 1.3525$. In this situation, the critical region is of form $\| \widehat{\tilde{C}_p} \ominus T(1.25, 1.33, 1.5) \| \underset{R}{>} T(c, c, c)$ which is

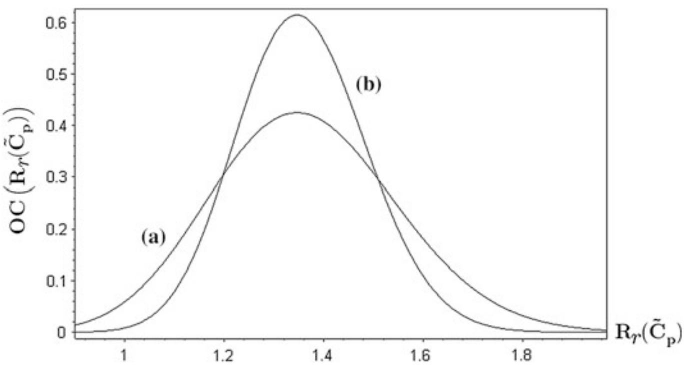

Fig. 17.5 The operating characteristic curve for $\tilde{C}_p$ in Example 4, where $\tilde{c} = T(1.25, 1.33, 1.5)$, $c = 0.1$ and **a** $n = 30$, **b** $n = 70$

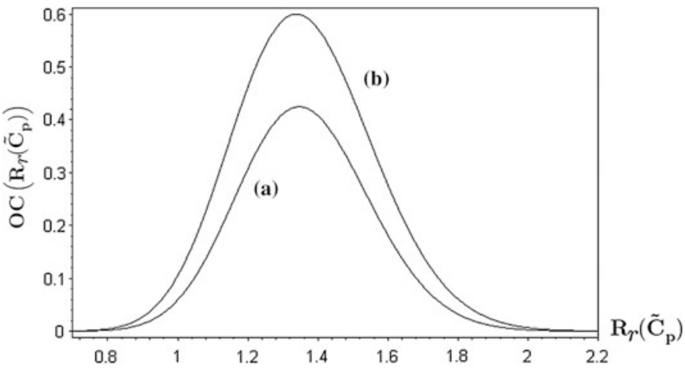

Fig. 17.6 The operating characteristic curve for $\tilde{C}_p$ in Example 4, where $\tilde{c} = T(1.25, 1.33, 1.5)$, $n = 30$ and **a** $c = 0.10$, **b** $c = 0.15$

equivalent to $\left|R_r\left(\widehat{\tilde{C}_p}\right) - 1.3525\right| > 0.1$ for $c = 0.1$. Let $n = 30$, the OC curve (a) in Fig. 17.5 indicates that $OC(1.43) = 0.39$, which implies that we have a 39 % chance of incorrectly concluding that the fuzzy capability index is equal to $T(1.25, 1.33, 1.5)$. According to the OC curve (a), the Roubens's rank of the fuzzy capability index would have to be about $R_r\left(\tilde{C}_p\right) = 0.99$ (or 1.76) before the chance of incorrectly concluding "the fuzzy capability index is equal to $T(1.25, 1.33, 1.5)$" drops below 5 %. Accuracy of the estimate is improved by increasing the sample size, which is illustrated by curve (b) in Fig. 17.5. Also, for comparing two OC curves with $c = 0.10$ and $c = 0.15$ see Fig. 17.6, where $n = 30$.

17.5 Conclusions and Further Works

In recent years, process capability analysis has become an important integrated part in engineering management and in statistical process control to the continuous improvement of quality and productivity. If the specification limits are fuzzy quantities, it is more appropriate to define the process capability indices as fuzzy numbers. In this chapter we introduced an approach to testing one sided and two sided hypotheses for fuzzy process capability indices $\tilde{C}_p$, when the engineering specification limits are triangular fuzzy numbers. Also, we developed the operating characteristic (OC) curves for the fuzzy capability index in each case. Numerical examples are given to illustrate the performance of the method.

As a potential subject for further research, one can investigate on statistical testing fuzzy quality based on Bayes, Minimax, Neyman–Pearson, Likelihood ratio, sequential and p-value approaches. Study on alternative approaches for point and interval estimation of the extended capability indices is another potential subject for further works.

References

Amirzadeh, V., Mashinchi, M., Parchami, A.: Construction of p-charts using degree of nonconformity. Inf. Sci. **179**(1), 150–160 (2009)

Bortolan, G., Degani, R.: A review of some methods for ranking fuzzy numbers. Fuzzy Sets Syst. **15**, 1–19 (1985)

Boyles, R.A.: Process capability with asymmetric tolerances. Commun. Stat. Simul. Comput. **23**, 613–643 (1994)

Burr, I.R.: Statistical Quality Control Methods. Marcel Dekker, New York (1976)

Fortemps, P., Roubens, M.: Ranking and defuzzification methods based on area compensation. Fuzzy Sets Syst. **82**, 319–330 (1996)

Hoffman, L.L.: A general approach for testing the process capability index. Qual. Reliab. Eng. Int. **9**, 445–449 (1993)

Hsiang, T.C., Taguchi, G.: Tutorial on quality control and assurance—the Taguchi methods. In: Joint Meeting of the American Statistical Association, Las Vegas, Nevada, pp. 188 (1985)

Juran, J.M.: Jurans Quality Control Handbook, 3rd edn. McGraw-Hill, New York (1974)

Kane, V.E.: Process capability indices. J. Qual. Technol. **18**, 41–52 (1986)

Kaya, I., Kahraman, C.: Process capability analyses based on fuzzy measurements and fuzzy control charts. Expert Syst. Appl. **38**, 3172–3184 (2011a)

Kaya, I., Kahraman, C.: Process capability analyses with fuzzy parameters. Expert Syst. Appl. **38** (9), 11918–11927 (2011b)

Kotz, S., Johnson, N.L.: Process Capability Indices. Chapman and Hall, New York (1993)

Kotz, S., Johnson, N.L.: Process capability indices—a review, 1992–2000. J. Qual. Technol. **34** (1), 2–19 (2002)

Kotz, S., Lovelace, C.R.: Process Capability Indices in Theory and Practice. Oxford University Press Inc., New York (1998)

Lee, H.T.: C_{pk} index estimation using fuzzy numbers. Eur. J. Oper. Res. **129**, 683–688 (2001)

Maleki, H.R.: Ranking functions and their applications to fuzzy linear programming. Far East J. Math. Sci. **4**, 283–301 (2002)

Moeti, M.T., Parchami, A., Mashinchi, M.: A note on fuzzy process capability indices. Scientia Iranica **13**(4), 379–385 (2006)

Montgomery, D.C.: Introduction to Statistical Quality Control, 5th edn. Wiley, New York (2005)

Moradi, V., Sadeghpour Gildeh, B.: Fuzzy process capability plots for families of one-sided specification limits. Adv. Manuf. Technol. **64**, 357–367 (2013)

Nguyen, H.T., Walker, E.A.: A First Course in Fuzzy Logic, 3rd edn. Chapman and Hall/CRC, London (2005)

Parchami, A., Mashinchi, M.: Fuzzy estimation for process capability indices. Inf. Sci. **177**(6), 1452–1462 (2007)

Parchami, A., Mashinchi, M.: Testing the capability of fuzzy processes. Qual. Technol. Quant. Manage. **6**(2), 125–136 (2009)

Parchami, A., Mashinchi, M.: Interval estimation of an extended capability index with application in educational systems. Turk. J. Fuzzy Syst. **2**(2), 64–76 (2011)

Parchami, A., Mashinchi, M., Maleki, H.R.: Fuzzy confidence interval for fuzzy process capability index. J. Intell. Fuzzy Syst. **17**(3), 287–295 (2006)

Parchami, A., Mashinchi, M., Mashinchi, M.H.: Approximate confidence interval for generalized Taguchi process capability index. In: IEEE International Conference on Fuzzy Systems, Taipei, Taiwan, pp. 2968–2971, July 27–30 (2011)

Parchami, A., Mashinchi, M., Yavari, A.R., Maleki, H.R.: Process capability indices as fuzzy numbers. Austrian J. Stat. **34**(4), 391–402 (2005)

Ramezani, Z., Parchami, A., Mashinchi, M.: Fuzzy confidence regions for the Taguchi capability index. Int. J. Syst. Sci. **42**(6), 977–987 (2011)

Roubens, M.: Inequality Constraints Between Fuzzy Numbers and Their Use in Mathematical Programming. Stochastic Versus Fuzzy Approaches to Multiobjective Mathematical Programming Under Uncertainty, pp. 321–330. Kluwer Academic Publishers, London (1991)

Sadeghpour Gildeh, B., Moradi, V.: Fuzzy tolerance region and process capability analysis. Adv. Intell. Soft Comput. **147**, 183–193 (2012)

Sadeghpour-Gildeh, B.: Multivariate process capability index based on fuzzy tolerance region. In: 37-th Annual Iranian Mathematics Conference, pp. 607–610 (2006)

Taheri, S.M.: Trends in fuzzy statistics. Austrian J. Stat. **32**, 239–257 (2003)

Tsai, C.C., Chen, C.C.: Making decision to evaluate process capability index C_p with fuzzy numbers. Int. J. Adv. Manuf. Technol. **30**, 334–339 (2006)

Vännman, K.: A general class of capability indices in the case of tolerances. Commun. Stat. Theory Methods **26**, 2049–2072 (1997)

Vännman, K.: Families of capability indices for one-side specification limits. Statistics **31**, 43–66 (1998)

Viertl, R.: On the future of data analysis. Austrian J. Stat. **31**, 241–244 (2002)

Viertl, R.: Statistical Methods for Fuzzy Data. Wiley, New York (2011)

Wang, X., Kerre, E.E.: Reasonable properties for the ordering of fuzzy quantities (II). Fuzzy Sets Syst. **118**, 387–405 (2001)

Wu, C.W.: Decision-making in testing process performance with fuzzy data. Eur. J. Oper. Res. **193** (2), 499–509 (2009)

Yongting, C.: Fuzzy quality and analysis on fuzzy probability. Fuzzy Sets Syst. **83**, 283–290 (1996)

Chapter 18
Advanced Quality Control Systems Using Intelligent Modeling and Simulation Methods

Salah Bouhouche

Abstract Quality management and control is a basic and important activity needed along the production process. From raw material to the final product, quality control and testing need an online measurement, control, evaluation and management. Generally, the management system is based on continuous measurements and improvement which is affected by several factors such as environmental perturbations and physical constraints. Methods and techniques of modeling and identification based on the first principle, black and gray box models are widely used. Because the systems are complex such as the mechanical testing where complex effects and interactions take place, it is strongly recommended to use a data driven empirical model. Such a model is based on the analysis of interactions between variables, data exploration, and modeling. The quality management of engineering process is a complex system defined by multivariate interactions between products and processes, where several factors such as the structure and others parameters must be processed to obtain a reliable model for online prediction of the quality behavior of the considered elements. In this work, new methods and techniques will be considered, essentially based on the intelligent approach such as the monitoring of the quality indexes—based model. These approaches are applied to quality monitoring and management of iron and steel products and processes. To give an optimal and a certified or accredited system, intelligent methods and techniques are strongly recommended. The objective of this chapter is to give the main principles of the management of engineering system—based intelligent methods.

Keywords Quality control · Management processes · Intelligent methods and models · Continuous casting process · Rolling process · Measurement process

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18.1 Introduction

One of the main common principles characterizing the quality management system is the continuous improvement which is based on the data collection and processing. The quality management system given by Fig. 18.1 gives the highlights of the continuous improvement: The quality policy is transformed to operational objectives which are applied on the engineering system by different actions. Such actions can be defined as changes of set points of the production processes, modification of planning etc. Measurement and control methods are an important tools used to improve different processes by analysis of different data collected from processes.

Data collection and processing is a basic action required by all quality management systems in different fields of engineering. Methods and techniques remain not clearly specified, in practice, a reference to statistical methods is given. The domain of such methods is wide, they change from simplest (descriptive statistics) to complex (Advanced tools—based Models). Figure 18.2 shows some standards of quality management system where the data processing is required.

There are many related works in the field of data processing for quality management system with applications for different systems and processes, the following are some of them:

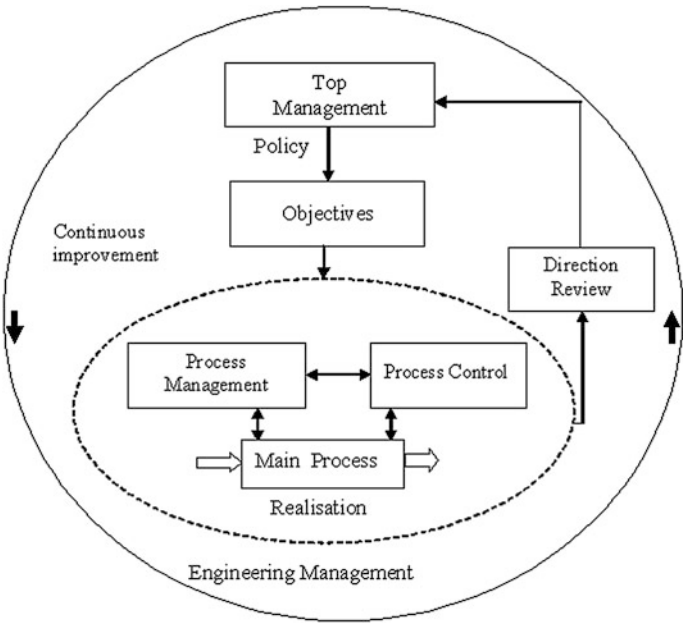

Fig. 18.1 Principle of management of engineering system

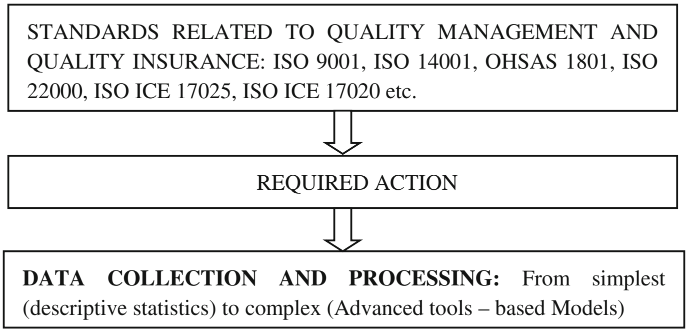

Fig. 18.2 Principle of data—based quality management

- The prediction and evaluation of the key factors characterizing the product quality in various processes using soft sensing based Multivariate Statistical Process Control, Fuzzy means and multivariate identification (Kadlec et al. 2009; Kadlec 2011; Si et al. 2011; Zhang and ShuaiLi 2012; Sun et al. 2012; Bouhouche et al. 2011),
- Soft Sensing methods including Support Vector Machine, data driven and data mining (Bouhouche et al. 2010; Bouhouche et al. 2012; Jin et al. 2012; Li and Wen 2014; Godoy et al. 2014; Fan et al. 2013; Gharavian and Almas 2013; Khatibi et al. 2010; Kahlen et al. 2010),
- Mechanistic modeling based energy and mass balance (Alexander et al. 2010). This aspect is very complex to model, particularly in a dynamic way.

Soft Sensing based Principal Component Analysis (PCA), and Partial Least Squares (PLS), including its adaptive form have been widely considered as a promising approach for quality monitoring and data-based analysis and control from process history data. Its successful applications have been reported in numerous process industries (Fan et al. 2013). Traditionally, the PCA as a part of the MSPC takes an important place in monitoring methods. Moreover, in some works, it was extended to quality prediction-based models (Peng and Li 2014; Changa et al. 2013).

18.2 Basic of Quality Control Methods

The principle of quality control methods is shown in Fig. 18.3, according to the nature of the considered product or process measurement or sampling is made to acquire data. Globally, there are two situations, the first is based on the product and the second is related to the process. The evaluation can be simple or complex; in this situation advanced models are then used. To assume the impartiality, the control quality services must be independent from the production services: This situation is shown in the following flowchart given by Fig. 18.4. The management policy is defined by the top management and affected to local management as

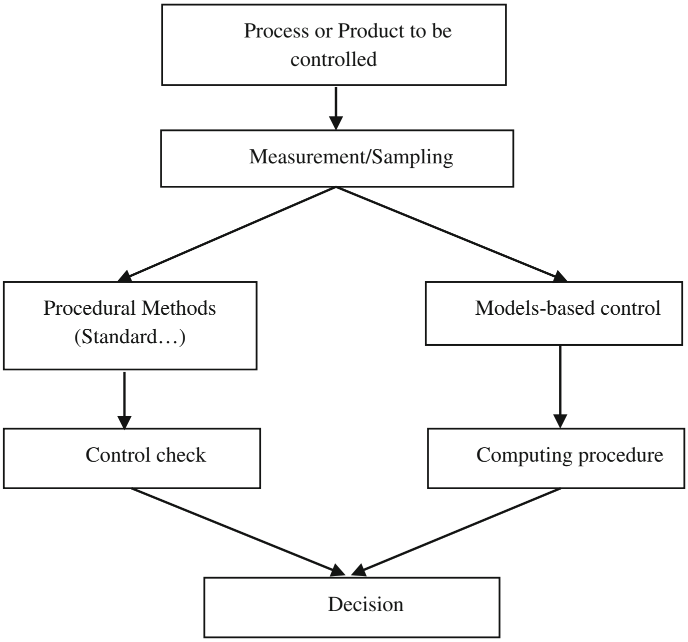

Fig. 18.3 Principle of quality control

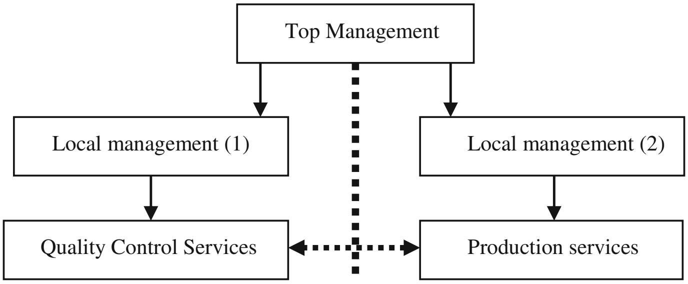

Fig. 18.4 Typical quality management organization flowchart

objectives and actions. All data are recorded on the documentation of the quality management system.

The documentation (keeping records) of the management system is a basic element, it permits to have written procedures to achieve the target objectives, also the documentation assumes the traceability and saving information provided from different sub systems. The decision-making is made by an intelligent processing of input/output information coming from subsystems.

The overall management system needs continuous improvement—based data analysis, processing and control to achieve optimal decision according to the system policy and objectives.

One of the most important and interesting methods is the one which is based on the intelligent modeling and optimization. Such methods are based on the development and application of required techniques according to the properties of the applications (engineering, service …); a particular attention will be reserved to ISO 17025. The information recording is one of the important tasks that must be accomplished. The ISO 17025 management system uses the certified measurement capability (CMC) as a perusable condition to achieve a good measurement management system.

A management system is generally composed of different sub-systems that act interactively, such system operates by:

- Definition of the quality policy,
- Objectives are affected as set points of different sub-systems,
- Each objective is declined to actions for different processes.

A management system acts as a decentralized system, all processes are monitored using the generated data, and the management is controlled via different steps such as:

- Processing of data generated by different processes,
- Audit results,
- Reclamations processing.

The required actions are taken in the direction review, decisions can be formulated by:

- Changes of policy and objectives,
- Means allocation or development,
- Changes of methods and techniques.

Modeling and simulation tools are recommended to assume the following tasks:

- Predict quality properties from process behavior,
- Assume an accurate assessment for conformity declaration,
- Compute an accurate uncertainties quantification and evaluation.

The modeling of the quality index is obtained using the system generated data. These data are generally obtained in the repeatability and reproducibility conditions of the 5 M tool (Fig. 18.5).

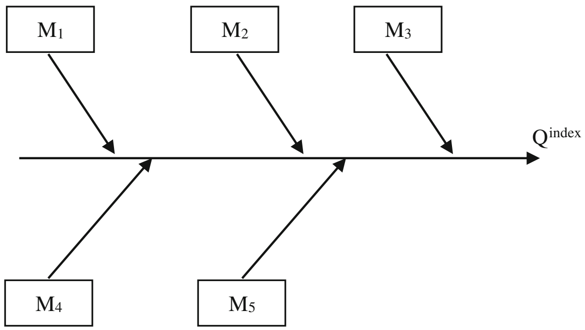

Fig. 18.5 Modeling using 5 M tool

18.3 Modeling and Simulation—Based Quality Control: Application to Breakout in Continuous Casting

Generally, industrial systems in real working environment suffer parameters deviations; hence it becomes necessary to detect these parameters variations to make a robust system. The first task to do is the identification of the parameters of which deviation induces process defects. Under the operating conditions, either the parameters vary slowly or in case of defect, these parameters make a fast transition from their nominal values to their defect values. Hence, continuous supervision of these parameters by the measurement of system, available variables become absolutely essential to ensure a sturdy performance of process control. There are many conventional approaches to perform supervision and control: the geometric approach, the factorization approach, the parity space approach, principal component analysis approach (PCA), Partial least square approach (PLS) and multivariate statistical process control (MSPC) (Godoy et al. 2014)

Model output-based conditions monitoring uses residual connected to multivariate statistical process control (MSPC) as an indicator for process monitoring.

A significant step forward in recent years in multivariate statistical process control (MSPC) for operational condition monitoring and fault diagnosis such as the introduction of principal component analysis for compression of process data. Published works have shown that in some applications of statistical process monitoring, PCA based methods exhibited advantages comparing to those based on other data compression techniques. However it is more appropriate to use PCA characterized by Hotelling's T^2 and SPE charts, because the independent components are separated through maximizing their non-Gaussianity, while satisfying Gaussian distribution is the basis of T^2 and SPE monitoring charts, as well as univariate SPC charts.

PCA algorithm operates with the whole process data defined by an observation matrix X, this work consists in exploratory methods for finding and explaining structure of data describing behavior of complex industrial process.

We propose a new method for deriving statistical process control charts. Which is based on the model sensitivity of the observation matrix X. Sensitivity of the process data matrix is obtained by a derivative formulation of Jacobean or Hessian matrix; which also consider the sensitivity of process parameters. A combined use of process data and its first variations improve considerably the detection, diagnosis and takes into account small and nonlinear variations of process parameters, the principle is given in Fig. 18.6. This approach improves the supervision ability of process variability and reduces the false alarm. Applications to breakouts in continuous casting show an improvement of conditions monitoring by earlier fault detection.

This work is organized as follows: in the Sect. 18.3.1, we developed the monitoring—based data analysis with a brief description of conventional PCA method, in the sub Sect. 18.3.1.1; we consider a new PCA model based sensitivity. In the Sect. 18.3.1.2, a derivative form of the PCA is then obtained and a monitoring

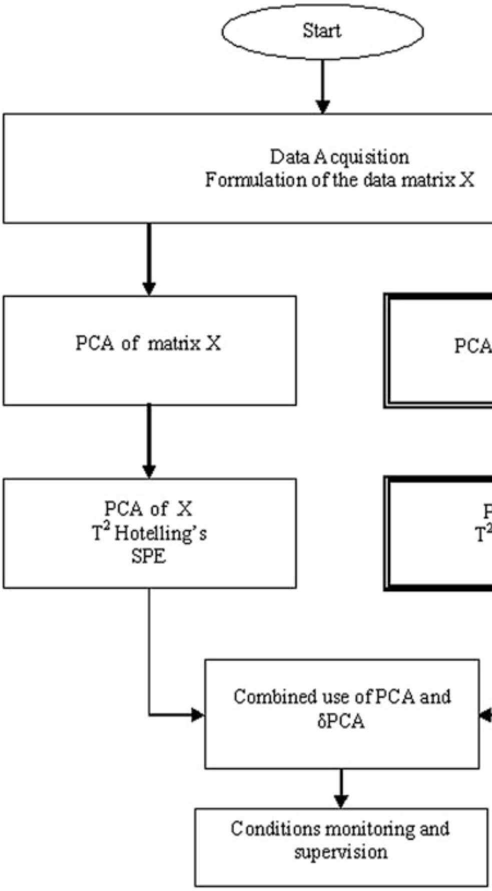

Fig. 18.6 Principle of use of PCA and δPCA

scheme is given by combined form of PCA and its sensitive form (δPCA). In the Sect. 18.3.2, we give an application of this new approach in continuous casting. A comparative study between PCA and δPCA is given.

18.3.1 Monitoring—Based Measurement Data Analysis

18.3.1.1 Brief Description of Principal Component Analysis (PCA)

By projecting the data into a low-dimensional space that accurately characterizes the state of the system, dimensional reduction techniques, such as PCA method, can greatly simplify and improve process monitoring procedures. It produces a lower-dimensional representation in a way that it preserves the correlation structure between the process variables, and it is optimal in terms of capturing the data variability. This technique is an optimal linear method of system reduction in the sense of the capturing of the process variability which is important in process fault detection. More details of PCA methods are given in different works (Zhang and ShuaiLi 2012; Godoy et al. 2014)

18.3.1.2 Model Sensitivity of Dynamic Principal Component Analysis (δPCA)

Figure 18.7 shows the diagnosis scheme based on PCA and its sensitive form δPCA. Model sensitivity is generally obtained by a derivative form of the initial observations.

Let $X(t)$ be an observation matrix including the dynamic variations of the model input—output for a time moving windows.

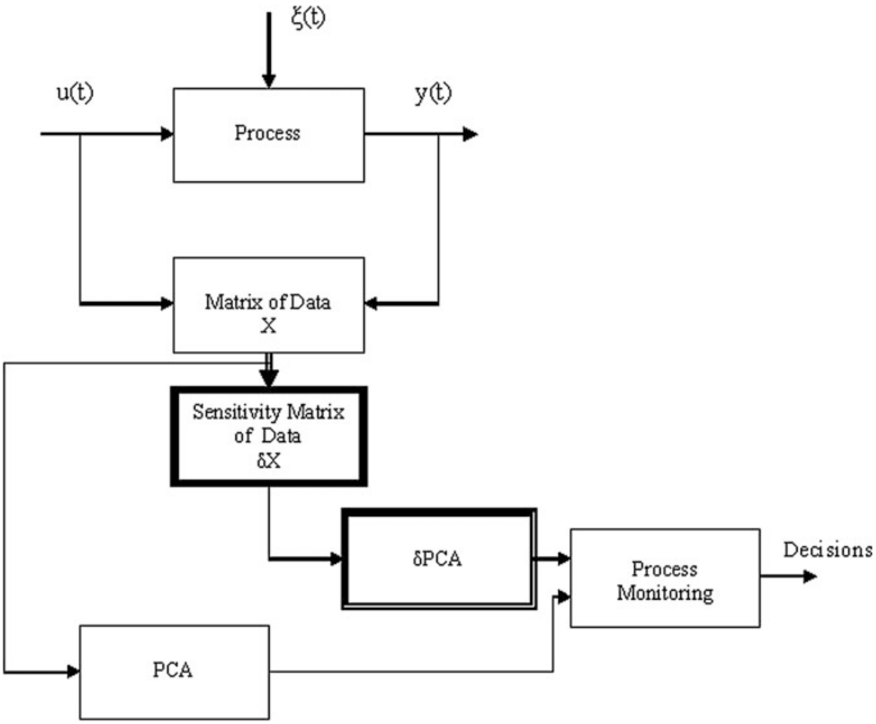

Fig. 18.7 Hybrid supervision scheme based PCA and δPCA

$$X(t) = \begin{bmatrix} u(t-n:t) \\ y(t-n:t) \end{bmatrix} \tag{18.1}$$

n is the length of the moving window, $X(t) \in R^{(2n)}$

The time sensitivity model of $X(t)$ is given by:

$$dX(t) = \left(\frac{\partial X(t)}{\partial t}\right)_0 \Delta t + \left(\frac{\partial^2 X(t)}{\partial t^2}\right)_0 \Delta t^2 + \cdots + \Delta X^n(0) \tag{18.2}$$

$$\frac{\partial X(t)}{\partial t} \approx \frac{X(t) - X(t-1)}{\Delta t} \approx \frac{\Delta X}{\Delta t} \tag{18.3}$$

$$dX(t) = F(\Delta X, \Delta^2 X, \ldots, \Delta^n X) \tag{18.4}$$

$dX(t)$ can be approximated by a first finite difference:

$$dX(t) \approx \Delta X(t) \tag{18.5}$$

With

$$\Delta X(t) \approx X(t) - X(t-1) \tag{18.6}$$

$\Delta X(t)$ is a small variation of the system model around the operating point defining the actual operating conditions of the system.

As shown in Fig. 18.7, the diagnosis scheme is composed of two parts:

- The first part is formed by the conventional PCA that uses the observation matrix X(t) as input. PCA algorithm is then used to compute the corresponding indexes (T^2 Hotelling's and *SPE*) as given in different works (Zhang and ShuaiLi 2012; Godoy et al. 2014; Issam et al. 2011)
- The second part is formed by a sensitive form of the observation matrix X(t) as given by the Eq. 18.6, this part takes into account the first variation of the process data.

18.3.2 Application to Breakout in Continuous Casting

18.3.2.1 Process Description

Continuous casting is a process by which molten metal is poured into a water cooled mould and exits in solid form. Metal billets or slabs are created with this process using a topless and bottomless mold in a rectangular shape. The molten metal is continuously poured into the top of the mold while the sides of the mold are cooled, typically with cold water flowing towards the side of the mold, absorbing heat, and then flowing away from the mold. These cooled sides of the cast allow the molten metal to quickly cool and solidify, and the metal in solid form is continuously removed from the bottom of the cast as more liquid metal is added at the top, typically from a nozzle. From the description of the casting procedure, it is easy to see that there are many complicated conduction and convection processes that govern this system of phase change.

In this process, temperature variations during cooling cause quality problems such as cracks, breakouts, especially under transient conditions. Due to high casting speeds and short response times, setting the control operations to maintain optimal temperature profiles during process changes becomes for operators increasingly difficult.

Generally, conventional breakout detection system generates a high rate of false breakout, to overcome this inconvenient, diagnostic based on the analysis of SPE and T^2 Hotelling's is used to an accurate prediction.

This work has led to improved fundamental insights into the process monitoring. The next steps, proposed in this work, are (1) to simulate different normal and faulty situations that can be appear in the practice, i.e. some scenario of process parameters changes and their influence on the breakouts (2) to implement the corresponding supervision strategy for earlier breakout detection and to improve the diagnostic of the false alarm in basis of T^2 Hotelling's and SPE.

A new δPCA method based is used in the mould temperatures variability analysis, Fig. 18.8 shows the principle of breakout supervision using PCA and its sensitive form δPCA. The δPCA computing formalism is given in the Sect. (18.3.1.2), the breakout conditions monitoring are based on the analysis of the dynamical importance of SPE and T^2 Hotelling's.

As shown in Fig. 18.8, a mixed form of thresholds limits of the computed indexes (*SPE* and T^2 Hotelling's) respectively for PCA and δPCA are used. According to operating conditions of breakout, the indexes are computed and analyzed to classify the process capability and diagnostic.

Breakout temperatures (T_U and T_L) are acquired from thermocouples located on the copper mould (Kahlen et al. 2010), v(t) is the measured casting speed. $T_U(t)$ and $T_L(t)$ and their recurrent past values constitute the observation matrix X(t), this matrix is the key of the process variability analysis using PCA and δPCA.

18.3.2.2 Conditions Monitoring

To qualify the proposed approach, three (03) operating conditions are considered:

- The first series of data given by Fig. 18.9 shown a normal thermal profile of a real breakout, this situation is characterized by a correlation between the upper (T_U) and the lower (T_L) temperatures variations. This real breakout is used as a reference to determine the PCA and δPCA models defined by the V and D matrices resulting from the decomposition of the observation matrix X(t). The

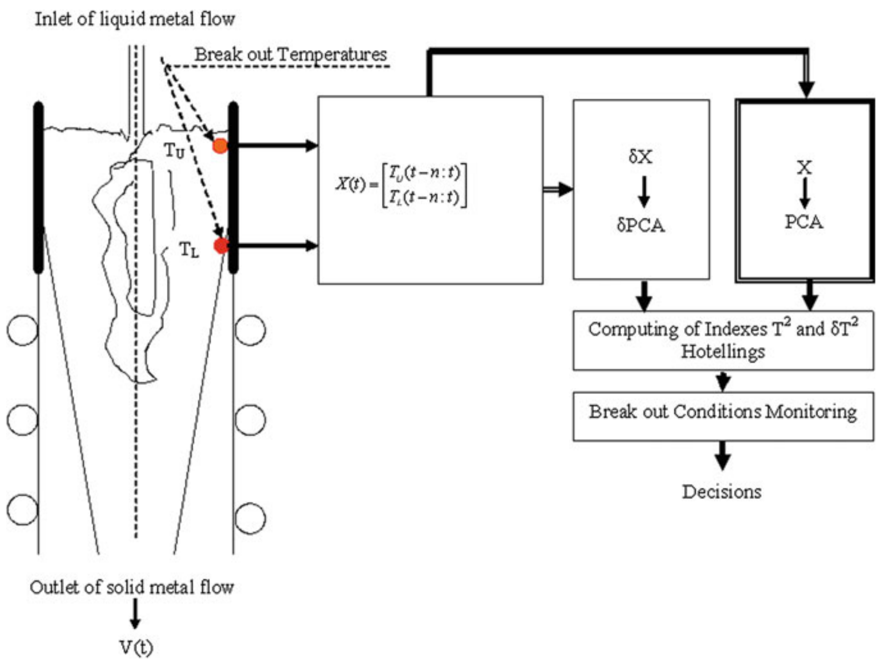

Fig. 18.8 Principle of breakout monitoring in continuous casting process

variation of SPE and T^2 Hoteling's indexes are presented in Figs. 18.9a and 18.11b,

- The second series of data given by Fig. 18.10, shown a new typical breakout, this situation is characterized by different changes of (T_U) and (T_L). Using the PCA and δPCA models obtained in the first series of data (see, Fig. 18.9), the corresponding SPE and T^2 Hoteling's indexes are computed and presented in Figs. 18.10b, and 18.10,
- The third series of data given by Fig. 18.11, shown a false breakout, this situation is characterized by abnormal typical changes in measured breakouts temperatures. The corresponding computed indexes (SPE and T^2 Hoteling's) are completely different from normal breakout by its ranges of mean and standard deviation (see, Fig. 18.11b–e). There is a good separation level between real and false breakout as shown in the next Table 18.1.

For each situation of breakout, SPE and T^2 Hoteling's indexes are computed using δPCA and PCA. As shown in (Figs. 18.9, 18.10 and 18.11), the combined use of PCA and δPCA algorithms improve the detect ability and the diagnostic. The δPCA algorithm gives an earlier detection comparatively to the PCA algorithm (see, Fig. 18.9b, c as example), in the case of false breakout, PCA algorithm assumes a good diagnostic by a clear separation level of SPE and T^2 Hoteling's indexes in normal and faulty situation as shown in Fig. 18.11 and Table 18.1.

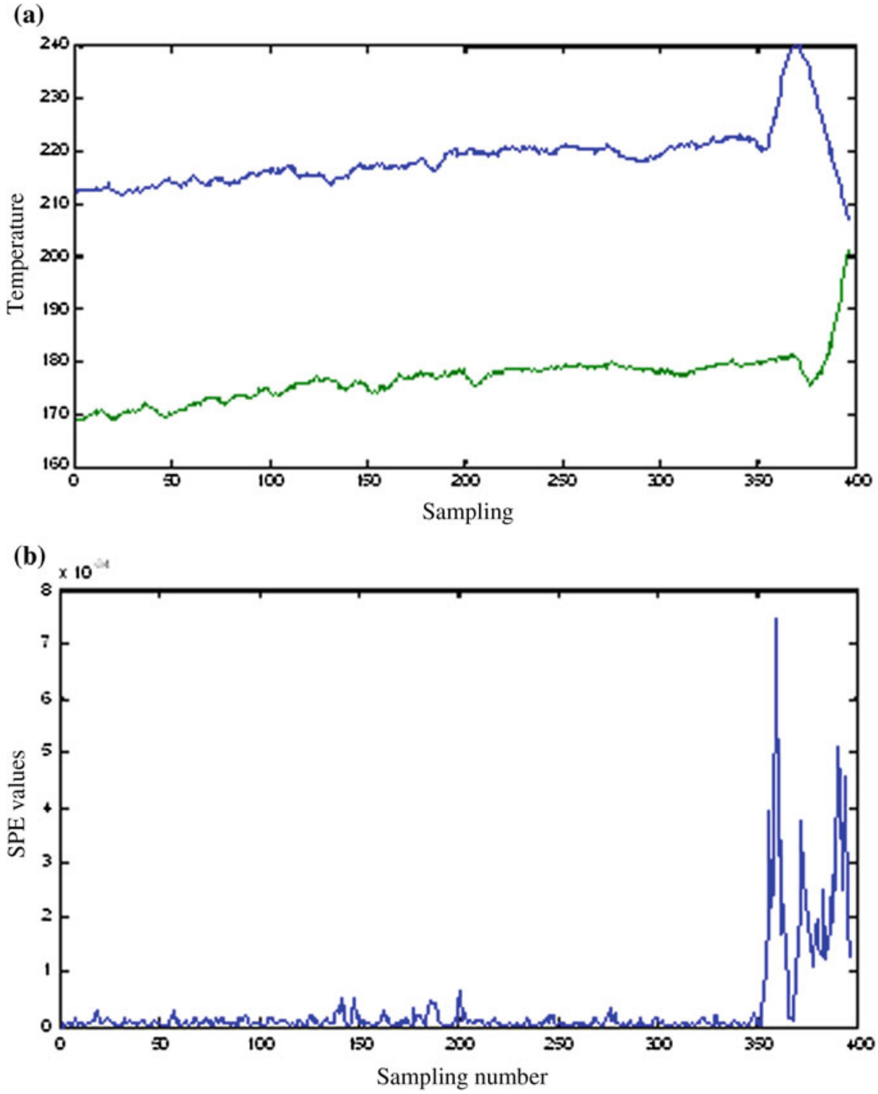

Fig. 18.9 **a** Dynamic changes of breakout measured temperatures. **b** Computed SPE base δPCA. **c** Computed SPE based PCA. **d** Detailled dynamic changes of Fig. 18.9b. **e** Detailled dynamic changes of Fig. 18.9c. **f** Computed T2 Hotelling's based δPCA. **g** Computed T2 Hoteling's based PCA

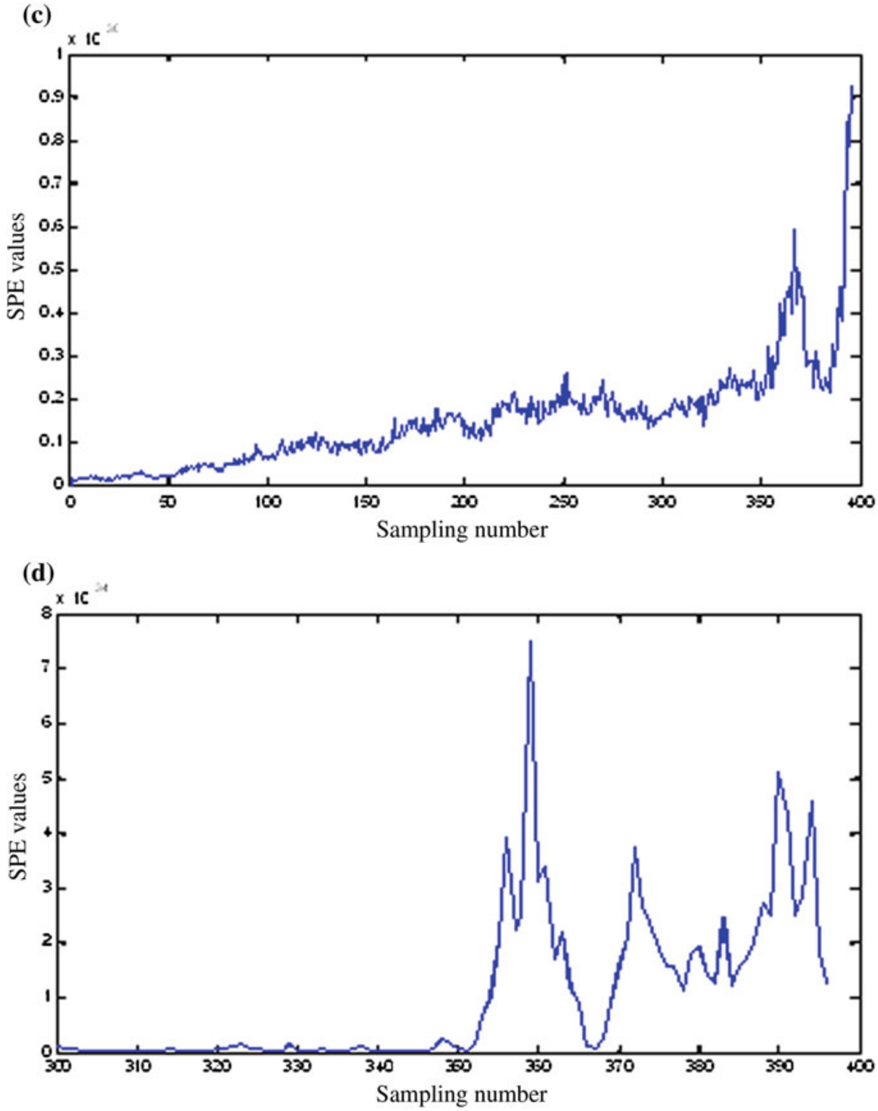

Fig. 18.9 (continued)

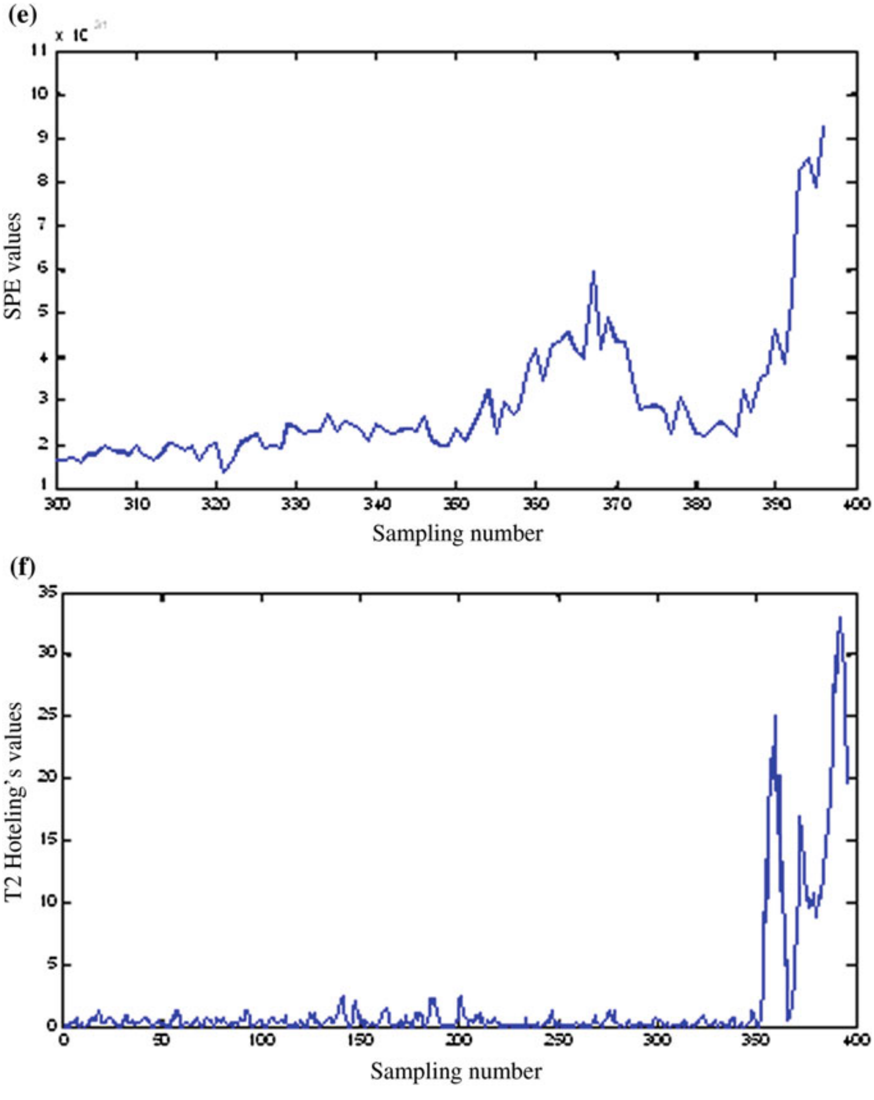

Fig. 18.9 (continued)

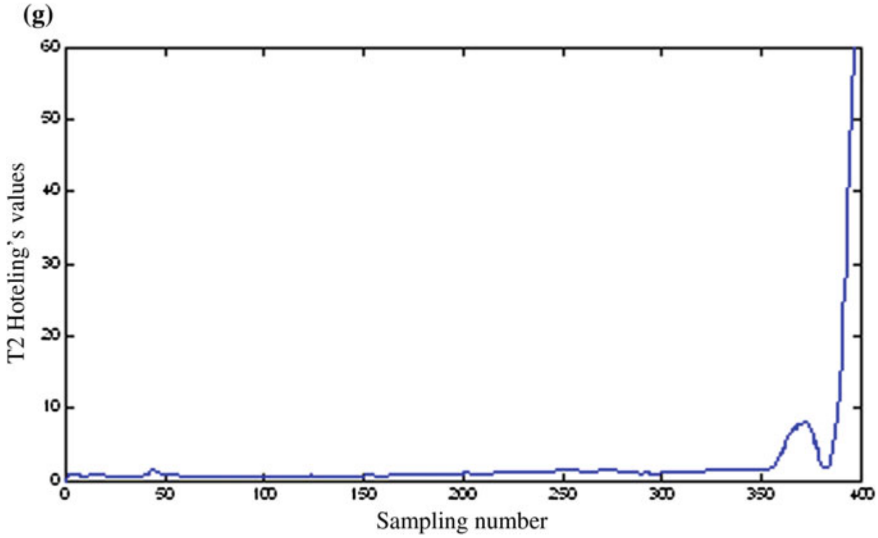

Fig. 18.9 (continued)

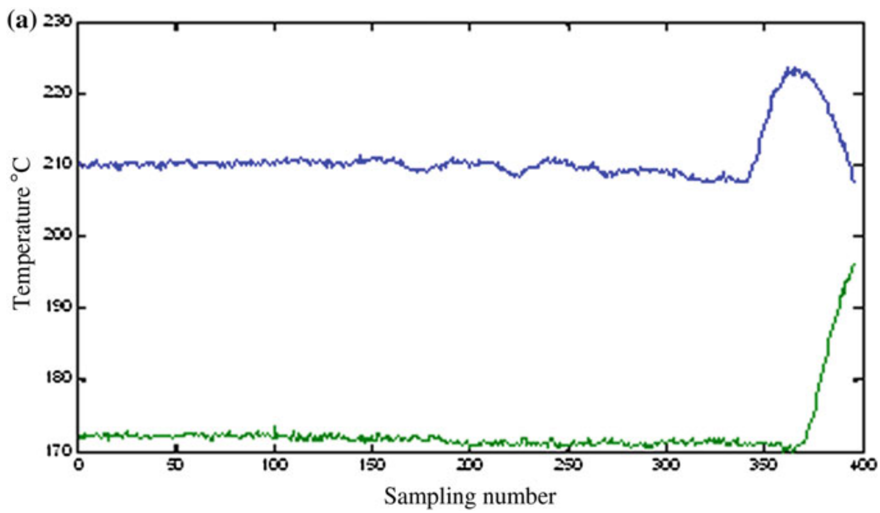

Fig. 18.10 **a** Dynamic changes of breakout measured temperature. **b** Computed SPE based δPCA. **c** Computed SPE based PCA. **d** Detailled dynamic changes of Fig. 18.10b. **e** Detailled dynmaic changes of Fig. 18.10c. **f** Computed T2 Hoteling's based δPCA. **g** Computed T2 Hoteling's based PCA

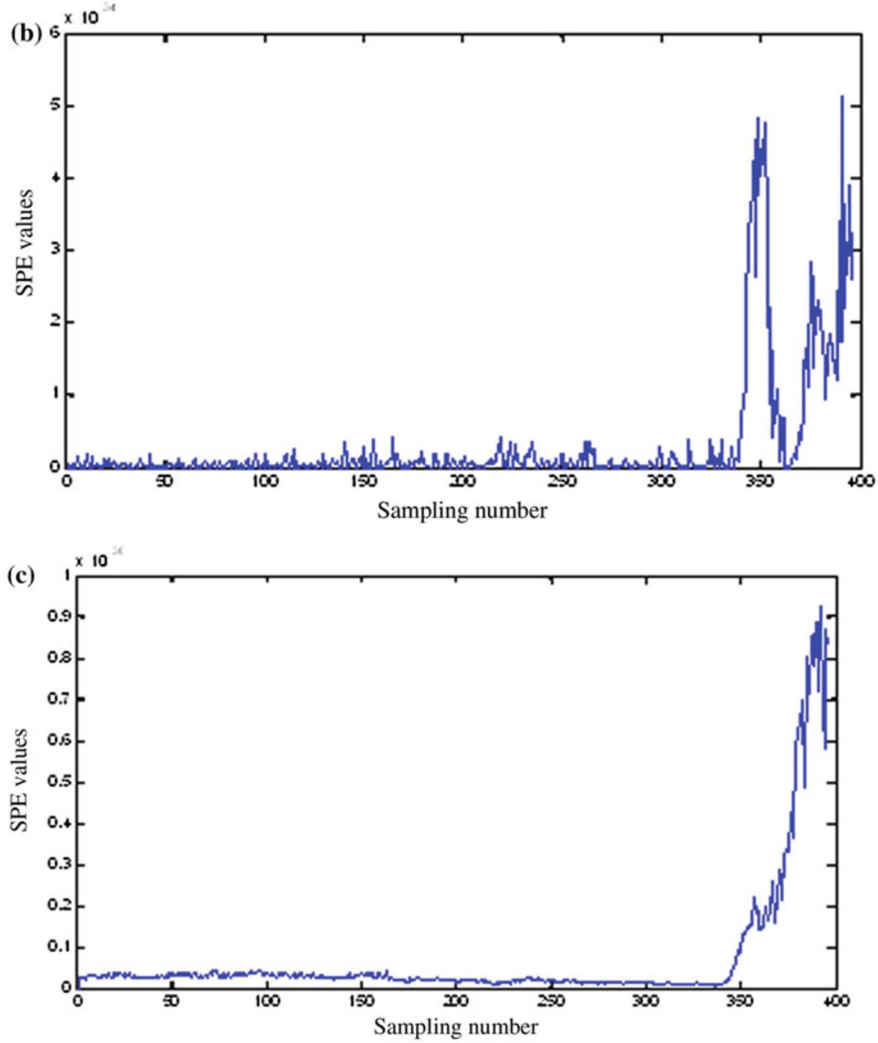

Fig. 18.10 (continued)

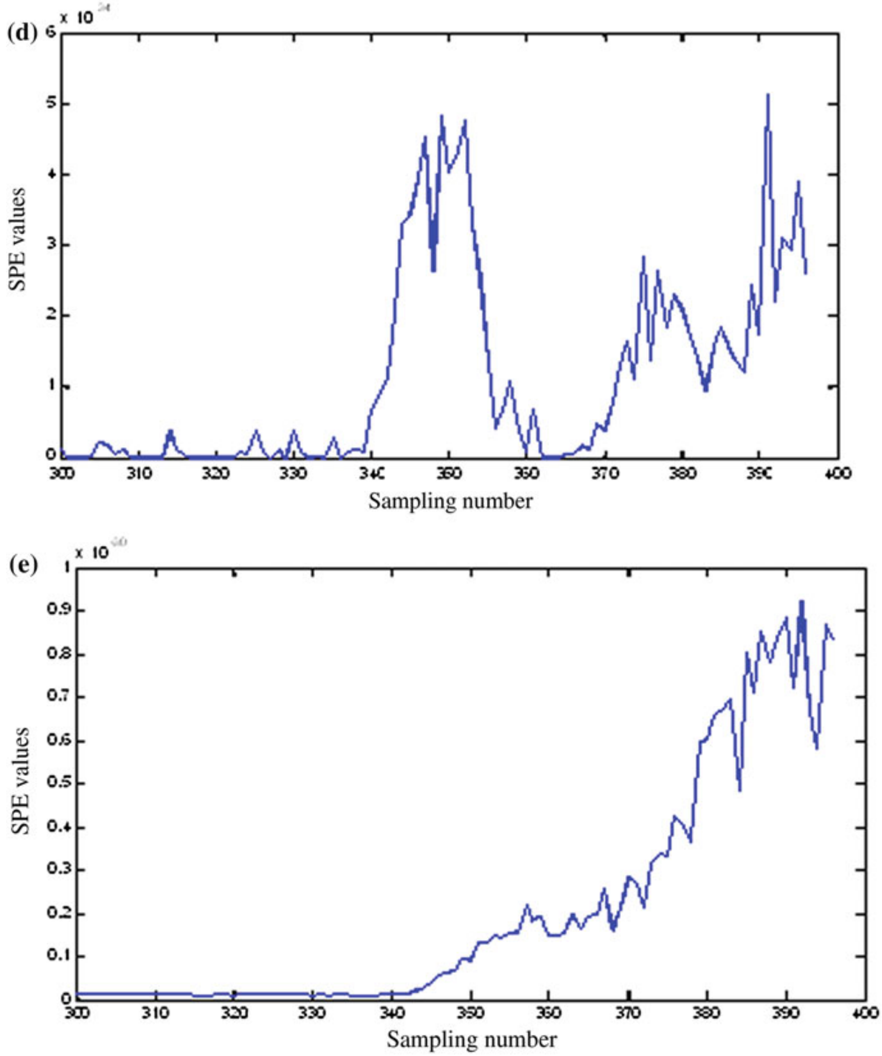

Fig. 18.10 (continued)

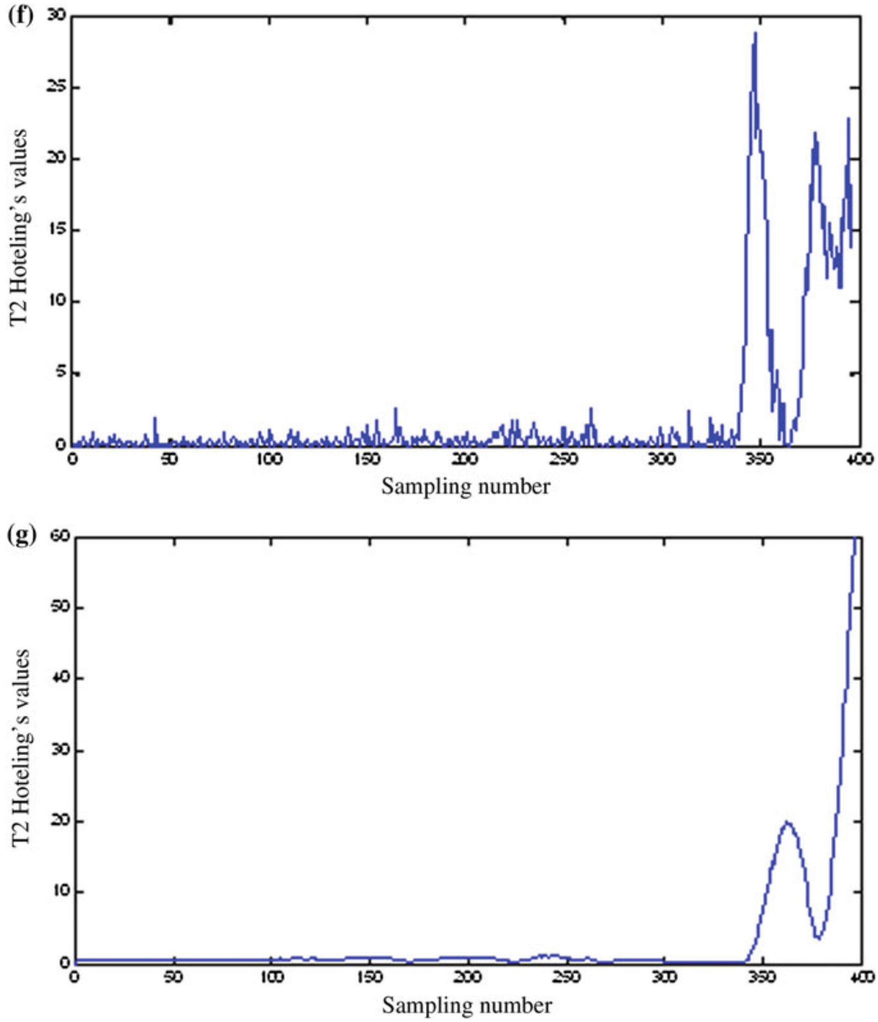

Fig. 18.10 (continued)

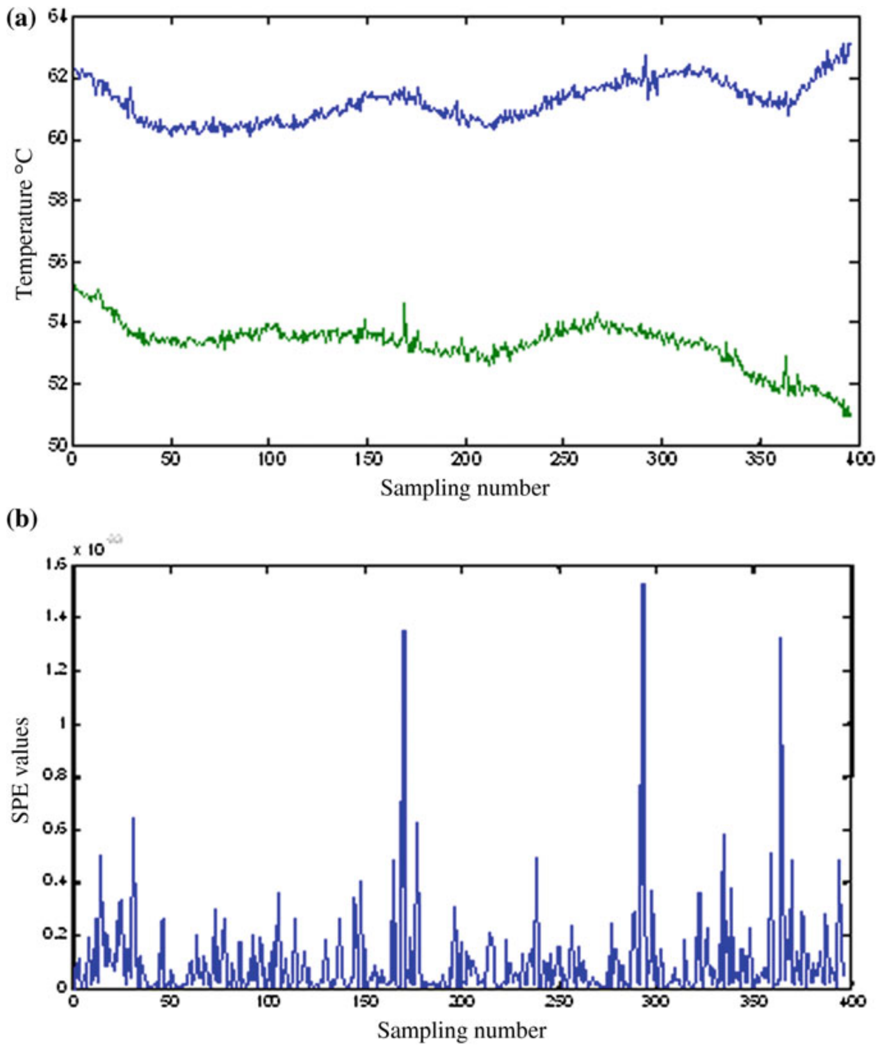

Fig. 18.11 **a** Dynamic changes of false breakout measured temperature. **b** Computed SPE based δPCA. **c** Computed SPE based PCA. **d** Computed T2 Hoteling's based PCA. **e** Computed T2 Hoteling's based δPCA

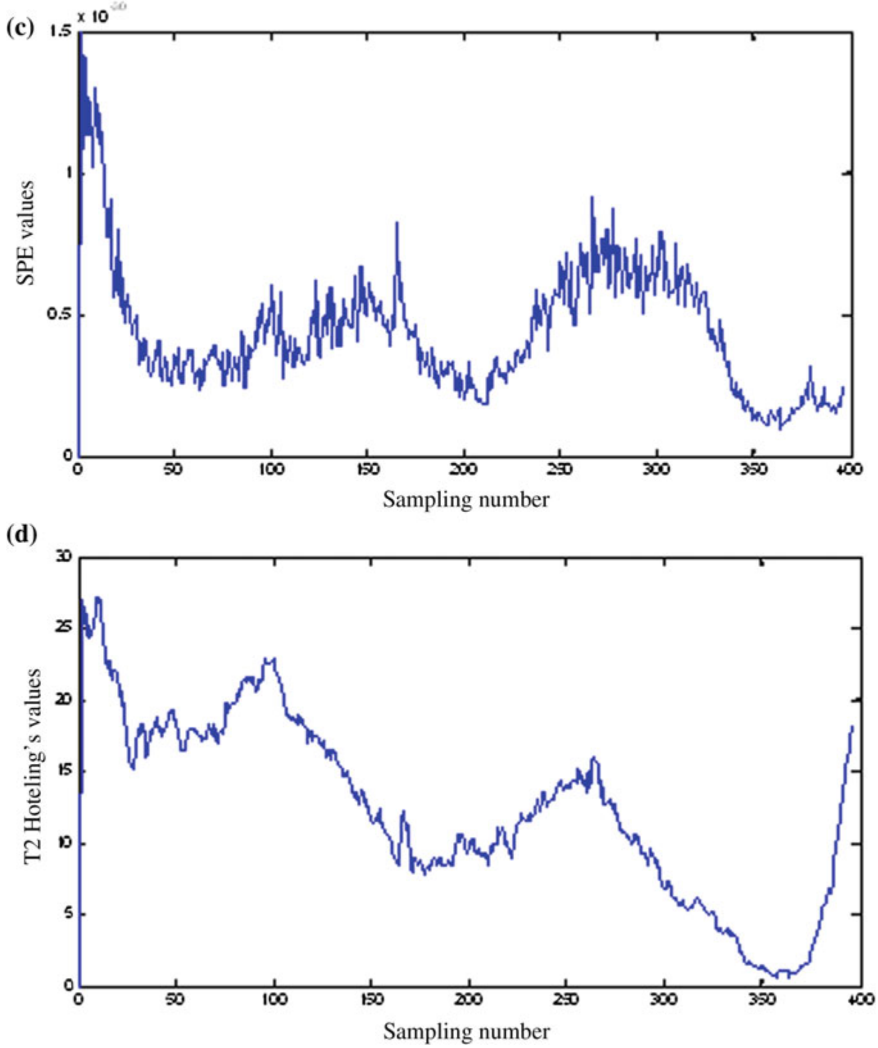

Fig. 18.11 (continued)

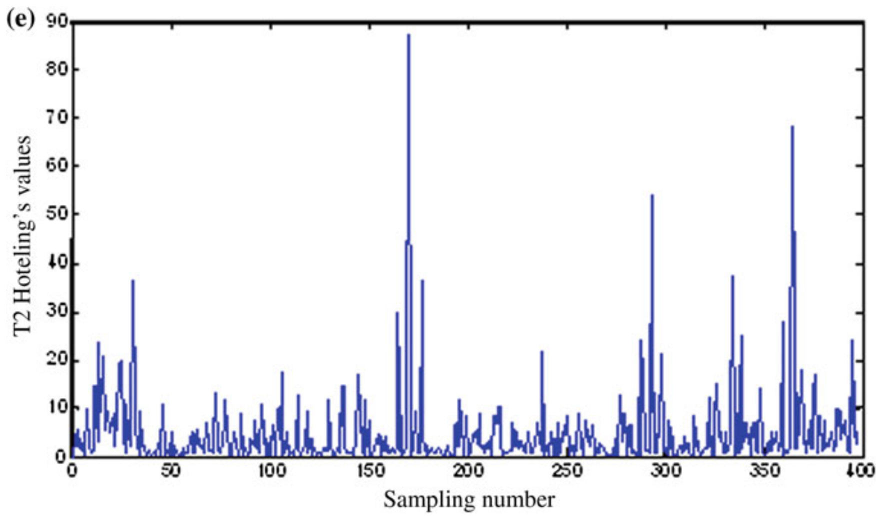

Fig. 18.11 (continued)

Table 18.1 Detection and diagnostic results

ITEMS	Detection time using PCA	Detection time using δPCA	Diagnostic using PCA + δPCA	Conclusion
Breakout (Fig. 18.9)	SPE curve: detection of 30 % of variation at sampling number 355	SPE curve: detection of 30 % of variation at sampling number 360	Means of SPE and T^2 Hoteling's in the acceptable range of fault	Diagnostic: Real breakout and Earlier detection using δPCA
Breakout (Fig. 18.10)	SPE curve: detection of 50 % of variation at sampling number 345	SPE curve: detection of 20 % of variation at sampling number 360	Means of SPE and T^2 Hoteling's in the acceptable range of fault	Diagnostic: Real breakout and Earlier detection using δPCA
Breakout (Fig. 18.11)	Random	Random	Means of SPE and T^2 Hoteling's out of acceptable range of fault	Diagnostic: False breakout and random detection using PCA and δPCA

An accurate method for breakout detection and evaluation has been developed and implemented using a new form of the derivative PCA. When the measured signal is much noised, the derivative PCA is not recommended to use, in this case PCA algorithm operates alone. The developed method can be used as a part of the quality management system in continuous casting processes, without such approach the productivity objectives cannot be attained

18.4 Quality Control and Evaluation of Cooling Bed of Bar Rolling Using Temperature Monitoring and Fuzzy Methods

A method for process quality evaluation and temperature monitoring of bar rolling is considered, this method extracts residual as a difference between the measured temperature and a reference values. Temperature field measured by an infrared camera is affected by several factors. Fault detection and its allied methods such as the combined use of residual analysis and fuzzy reasoning are used for a global evaluation of the monitored area of the rolling bar. This approach is applied in rolling bar process for constructing a complementary condition monitoring system which permits an online quality and process evaluation. Simulation results based on the measured surface temperature and the analysis of generated residuals show that the new approach is easily implementable and give good results when implemented online.

The aim of the present work is to develop a soft sensing approach to evaluate the process capability using temperature measurement and soft sensing method; this is carried out by an analysis of the bar surface temperature measured by an infrared camera. The evaluation method is based on the residual generation and analysis, residuals are obtained as a difference between an optimal temperature profile and a real temperature measured by an infrared camera. Figure 18.12 shows the principle of the temperature monitoring and process evaluation system in rolling bar process, the calamine and other perturbations are considered as a noise that disturbs the measurement, in this work a method is developed to evaluate the process using intelligent approach and measurement repeatability. There are many developed general works in the field of quality control and evaluation, the most commonly cited are:

- The evaluation—based computer vision and signal processing methods, which allow non-destructive on-line real-time processing. The input of the system in this case is information of one or two dimensions signal (image). The used algorithms are based on simple or complex analysis such as the comparative thresholds or other complex techniques,

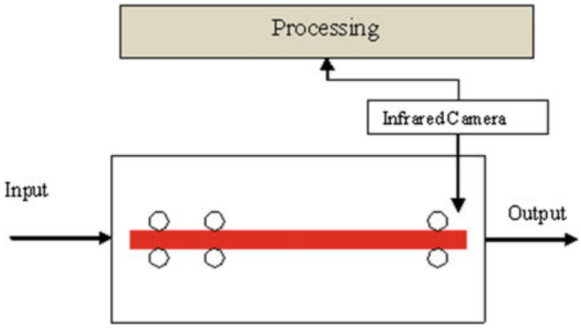

Fig. 18.12 Principle of bar rolling surface temperature monitoring

- Intelligent methods including fuzzy methods and expert systems have also been considered in several works (Kadlec et al. 2009; Kadlec 2011; Si et al. 2011; Zhang and ShuaiLi 2012; Sun et al. 2012; Bouhouche et al. 2011). The system uses fuzzy rules and membership functions of linguistic variables, conducts inference and defuzzification, and gives a global quality evaluation of welding.

Fault detection and isolation (FDI) methods based on Multivariate statistical process control (MSPC) techniques, including the residual generation, have been widely considered as a promising approach for mining monitoring and control—relevant information from process history data, its successful applications have been reported in numerous process industries. Traditionally, the FDI method as a part of the MSPC technique takes an important place in monitoring methods, some works are extended to process and quality evaluation (Godoy et al. 2014; Fan et al. 2013). Quality evaluation of calamine in continuous casting using FDI based residual analysis remains relatively new, it will be developed in this work.

In this work, an extension of FDI methods using the combined approach based on the fuzzy reasoning of generated residual is considered. This approach combines the following two steps:

- The first step is a modeling and residual generation part: residual is generated by the difference between the real thermal distribution (y^t) measured by an infrared camera and an optimal thermal distribution (y_r^t),
- The second step is a fuzzy evaluation of the generated residual for condition monitoring and process capability evaluation rolling bar.

This approach gives a global evaluation of the process according to the residual evolutions, the main motivations of using such approach based on residual generation and fuzzy reasoning are:

- The nature of the process application, characterized by a contactless temperature measurement using infrared camera,
- The evaluation technique requires a soft sensing approach,
- Usually, a combined approach between residual generation and evaluation is strongly recommended for an automatic evaluation. Generally, the residual is used in fault detection and diagnosis without an analysis of its impacts on the product quality (Godoy et al. 2014; Fan et al. 2013; Gharavian et al. 2013),
- The quality evaluation of continuous and batch processes is naturally a fuzzy form: it uses a comparison of the quality level between different repeated steps.

This chapter is organized as follows: In Sect. 18.4.1, a brief description of the bar rolling scheme characterized by the heat transfer in cooling zones and its impact on the calamine appearance. Section 18.4.2 gives the principle of thermographic measurements of surface bar. In Sect. 18.4.3, the condition monitoring of rolling bar temperature based on residual generation and fuzzy reasoning is developed, and a computing scheme is proposed. It is given results analysis and evaluation of the quality on the basis of the residual importance. The fuzzy system is tested; a good

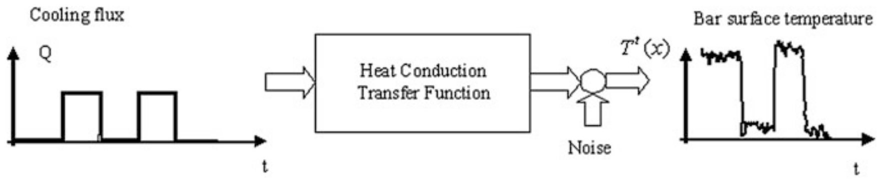

Fig. 18.13 Principle of Measurement Model

agreement between the quality evaluated by expert and the measured surface temperature in the considered area are obtained.

18.4.1 Surface Temperature Monitoring in Rolling Bar Process

It is considered in this part the dynamic behaviour of rolling bar surface temperature as a noised system. On the measurement point, we suppose that the measured surface temperature is affected by a random noise characterized by its statistical and distribution properties. The principle of surface quality evaluation is given by the following (Fig. 18.12).

As shown in Fig. 18.13, the surface temperature is controlled by the process variable such as the air flow rate; the presence of the calamine is modeled by a random noise. Extracting this noise permits an evaluation of the cooling bed quality according to the temperature repeatability.

18.4.2 Thermographic Measurements of Surface Billet

Surface rolling bar temperature measurement is affected by different disturbances; the commonly known is the calamine. Calamine is a result of the surface billet oxidation; its intensity depends of the steel grade, cooling conditions and other process parameters. In the past decade, some works in this field have been developed and the majority is based on the use of the infrared pyrometer equipped by a mechanical system to clean the surface measured point. In this chapter, a soft sensing approach for quality evaluation is developed. The vision system elaborated within the framework of the research described in the work has been assigned to such processes. The system has included hardware and software parts. The hardware part has consisted of a camera and a portable PC to make recordings in real time, the main task of this part was to observe the process by means of IR camera. The device used was a FLIR ThermaCAM A40 imaging system. It has a 240 × 320 pixels focal-plane-array uncooled microbolometer detector, with a sensitive range of 7.5–13 mm. Imaging and storage was made at a frequency rate of 50.

18.4.3 Condition Monitoring and Evaluation

In the last decade, quality control methods have proved to be a powerful tool in the area of product and process engineering for solving low cost quality control and inspection using classification and evaluation methods. However, their online application needs data acquisition, training, validation and testing using new algorithms, which are time-consuming in the case of large data sets. In rolling bar process, generally, an optimal thermal profile of the strand machine guaranteed an optimal quality of the cooled product (rebar), the set point temperature at each point of the strand is generally constant. Any deviation between the optimal thermal distribution (y_r^t) and the real thermal distribution (y^t) is considered as a source of a possible defect in process repeatability. In recent years, many works based on conventional and advanced methods have been considered; however, FDI theory and methods are not yet fully tested and applied.

The quality evaluation and monitoring scheme proposed in this work uses the FDI principle which is divided into two parts: the first part is a residual generator and the second is a fuzzy reasoning approach. Evaluation is naturally a fuzzy expert-system because it generally uses rules and word evaluation such as “good”, “poor”, “medium” etc.

18.4.4 Residual Generation

The proposed scheme for calamine intensity evaluation is based on the residual fuzzy sets analysis and it is illustrated in Fig. 18.14. First, it considers a residual $e(t)$ obtained as the difference between the optimal and real thermal distributions (y^t) and (y_r^t) respectively, then fuzzy rules for $e(t)$ and $\Delta e(t)$ are used to evaluate changes.

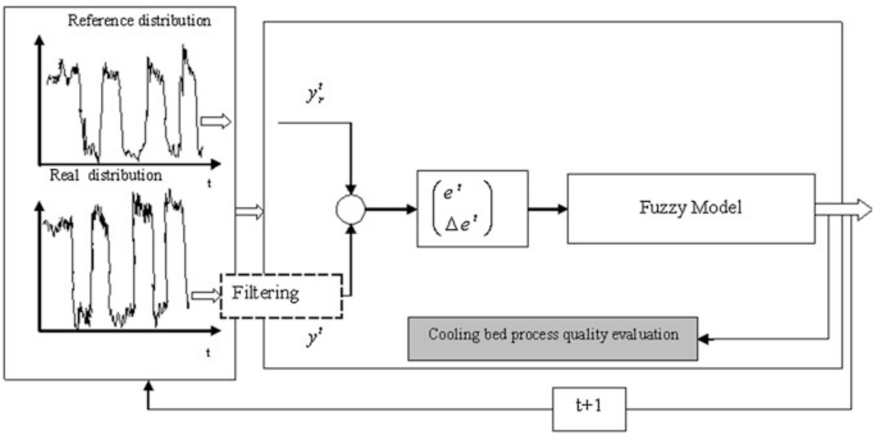

Fig. 18.14 Principle of welding quality evaluation by residual fuzzy reasoning

Now, we can describe the scheme in details:

Let the optimal thermal profile (y_r^t) and the real measured thermal profile (y^t), the optimal thermal profile is defined as the quadratic form of the considered area. It is computed by the following formula:

$$y_r^t = \|T_r(i,j)\| \tag{18.7}$$

the value of the real thermal profile is defined by

$$y^t = \|T(i,j)\| \tag{18.8}$$

this temperature is filtered via a low frequency filter defined by

$$y_f^t = (1-\alpha)y_f^{t-1} + \alpha y^t \tag{18.9}$$

the residual is defined as

$$e(t) = y_f^t - y_r^t \tag{18.10}$$

the residual change can be computed as

$$\Delta e(t) = e(t) - e(t-1) \tag{18.11}$$

Figure 18.15 shows a typical thermal distribution, using such reference profile, residuals have been generated and plotted in different graphs of Fig. 18.16.

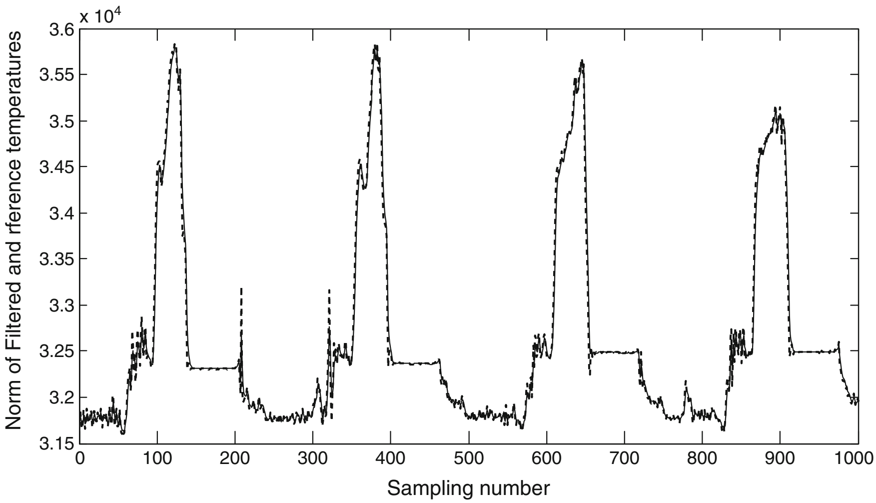

Fig. 18.15 Typical real and filtered thermal profile

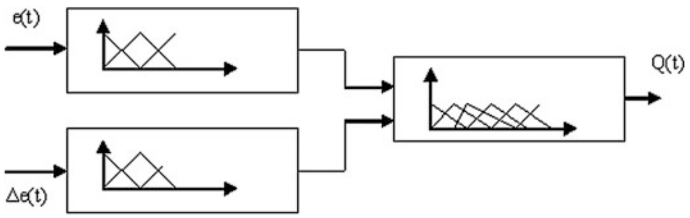

Fig. 18.16 Principle of Fuzzy evaluation of quality index

18.4.5 Evaluation Using Fuzzy Sets

Fuzzy rule-based systems have been successfully applied to various applications in different areas such as control and classification (Khatibi et al. 2010; Kahlen et al. 2010). While the main objective in the design of fuzzy rule-based systems has been to maximize performance, their comprehensibility has also been taken into account in some recent studies. The comprehensibility of fuzzy rule-based systems is related to various factors:

- Comprehensibility of fuzzy partitions (e.g., linguistic interpretability of each fuzzy set, separation of neighboring fuzzy sets, the number of fuzzy sets for each variable),
- Simplicity of fuzzy rule-based systems (e.g., the number of input variables, the number of fuzzy if-then rules),
- Simplicity of fuzzy if-then rules (e.g., type of fuzzy if-then rules, the number of antecedent conditions in each fuzzy if-then rule),
- Simplicity of fuzzy reasoning (e.g., selection of a single winner rule, voting by multiple rules).

This work shows how a small number of simple fuzzy if-then rules based on the residual and its variations can be selected for designing a comprehensible fuzzy rule-based system for condition monitoring and evaluation. As shown in Fig. 18.16, fuzzy reasoning operates on the residual.

To evaluate the welding quality, we use in this scheme the residual value Q_i and its variation ΔQ_i. Theoretically, it is possible to extend the residual variations to a higher derivative form such as $\Delta^2 Q_i$, $\Delta^3 Q_i$, …, $\Delta^n Q_i$. This extension is useful for systems that have high dynamic variations, but generally a Jacobean or/and Hessian form of dynamic residual $e(t)$ is sufficient.

Using if-then rules of the following form of n-dimensional pattern classification problem is defined as:

Rule R_q: If x_1 is A_{q1} and….and x_n is A_{qn} then Class C_q with CF_q
where R_q is the label of the qth-fuzzy if-then rule, $x = (x_1, \ldots x_n)$ is an n-dimensional pattern vector, A_{qi} is a fuzzy set, C_q is a consequent class, and CF_q is a weight rule or membership value in the unit interval [0, 1].

The precision of correlated relation between the different HAZ distribution is given by the residual. The quality of welding from a pass to another is evaluated according to the importance of the residual Q_i and its change ΔQ_i, its fuzzy reasoning based rules are used as a tool for qualifying the quality of welding on the basis of the quality evaluation connected to the residual importance. It uses linear membership's functions as shown in Fig. 18.17.

The following fuzzy rules associated to the linear membership functions are applied:

1. If ΔQ_i is Minimum AND Q_i is Minimum THEN the quality is Very Good (VG),
2. If ΔQ_i is Minimum AND Q_i is Medium THEN the quality is Good (G),
3. If ΔQ_i is Minimum AND Q_i is Maximum THEN the quality is Medium (M),
4. If ΔQ_i is Medium AND Q_i is Minimum THEN the quality is Good (G),
5. If ΔQ_i is Medium AND Q_i is Medium THEN the quality is Medium (M),
6. If ΔQ_i is Medium AND Q_i is Maximum THEN the quality is Poor (P),
7. If ΔQ_i is Maximum AND Q_i is Minimum THEN the quality is Poor (P),
8. If ΔQ_i is Maximum AND Q_i is Medium THEN the quality is Poor (P),
9. If ΔQ_i is Maximum AND Q_i is Maximum THEN the quality is Very Poor (VP).

According the above rules, the quality index can be written as:

$$quality = fuzzy[Q_i, \Delta Q_i] \tag{18.12}$$

System evaluation is given by a fuzzy system defined by its membership functions of inputs (Fig. 18.17a, b), the membership function of output is given by Fig. 18.17c. Figure 18.18 shows the residual and its variations. Final quality evaluation illustrated by Fig. 18.19 is obtained using the above membership function and fuzzy rules. It is considered a fuzzification and rules based on the Q_i and its changes ΔQ_i, this permits to take into account of the dynamic behavior of the residual. Output of the fuzzy system is an evaluation of the quality using an index in the range of $[0 - 1]$ (see, Fig. 18.19).

18.4.6 Conclusion

Advanced and intelligent methods and models have been considered for an optimal quality management and control. As shown in different part of this chapter, without the developed methods and models the considered iron and steel processes cannot be good achieved. Computing procedures presented in this chapter are the basic elements of the management of such complex system.

Breakouts detection and evaluation using data mining—based PCA are obtained. A new version of the PCA called derivative PCA (δPCA) is developed and tested, an improvement of the detection-evaluation is then obtained.

On line quality evaluation of rolling process is carried out by residual processing, fuzzy system based membership functions and fuzzy rules is applied and a

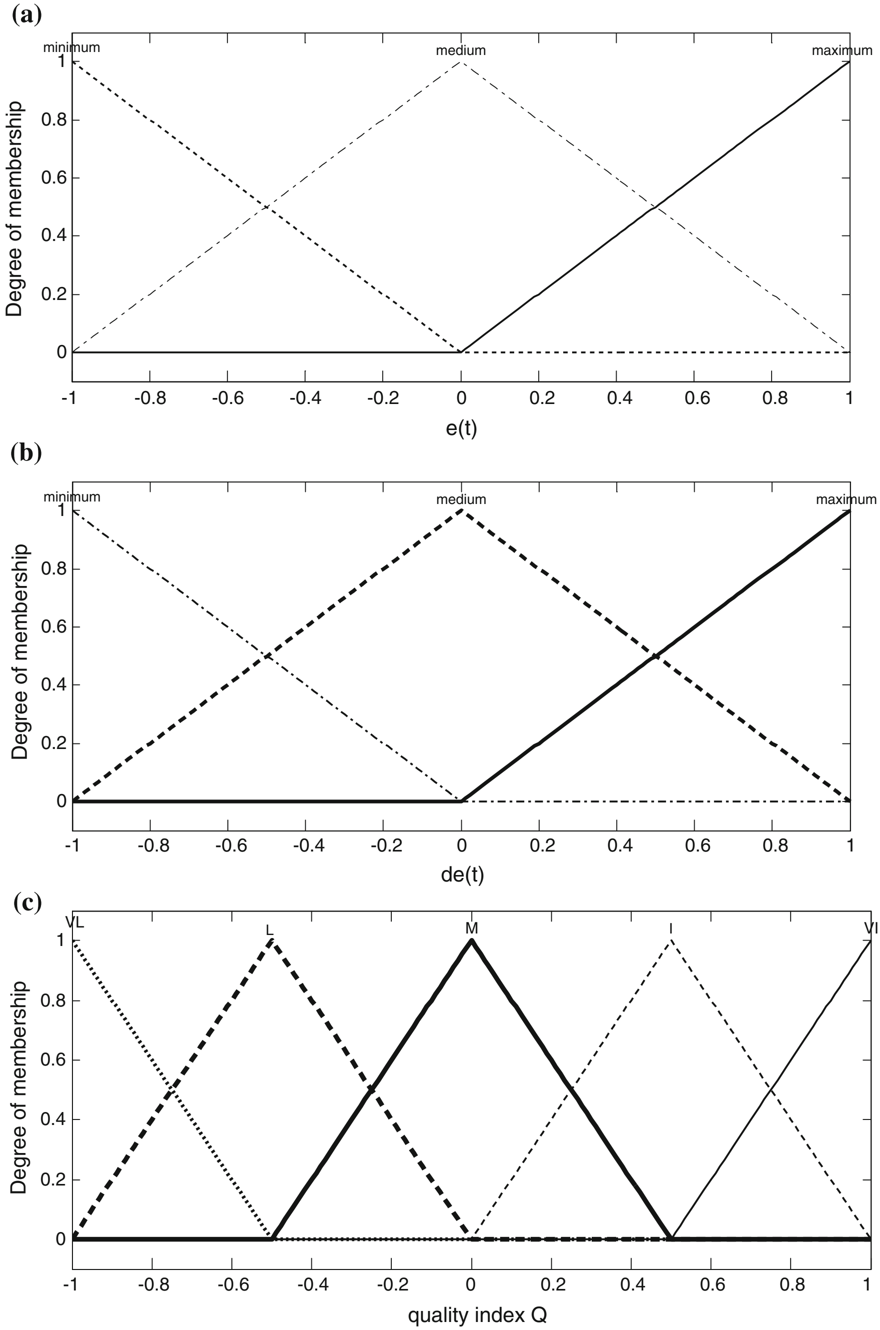

Fig. 18.17 **a** Membership function of $e(t)$. **b** Membership function of $\Delta e(t)$. **c** Membership function of output Q (quality index)

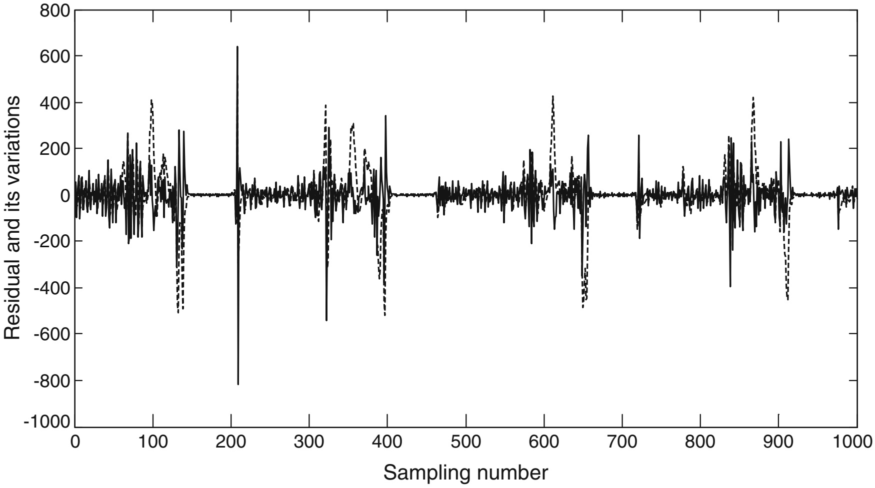

Fig. 18.18 Evolution of residual [e(t) and Δe(t)]

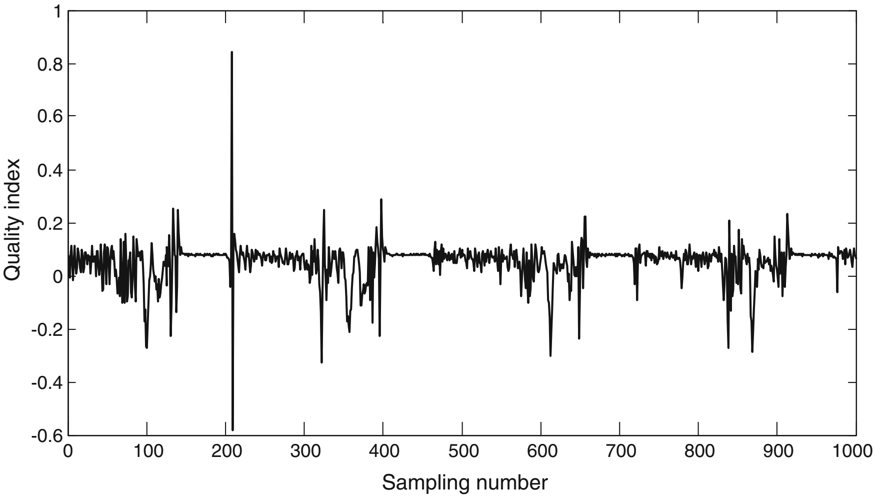

Fig. 18.19 Evolution of quality index (Q)

global quality evaluation is obtained according to the temperature changes from their usual values, this temperature is measured using IR camera. The application of such method is made using typical and real temperature distribution in hot rolling bar process. A global quality evaluation and a reduction of the quality control cost are obtained.

References

Alexander, E., Philip, B., Bradford, D.: Carbon nanotube yarn and 3-D braid composites. Part I: Tensile testing and mechanical properties analysis, Composites: Part A **41**, 230–237 (2010)

Bouhouche, S., Yazid, L.L., Jurgen, B.: Evaluation—Based online support vector machine and fuzzy reasoning. Application to condition monitoring of speeds rolling. Control Eng. Pract. **18**, 1060–1068 (2010)

Bouhouche, S., Mostepha, Y., Jürgen, B.: Combined use of principal component analysis and self organization map for condition monitoring in pickling process. Appl. Soft Comput. **11**, 3075–3082 (2011)

Bouhouche,S., Zoheir, M., Hazem, M., Yazid, L.L.: Combined use of support vector regression and monte carlo simulation in quality and process control calibration. In: Proceedings of the 2012 international conference on industrial engineering and operations management, pp. 3–6 (2012)

Changa, Chuan-Yu., Chang, Chuan-Wang, Zheng, Jun-Ying, Chung, Pau-Choo: Physiological emotion analysis using support vector regression. Neurocomputing **122**, 79–87 (2013)

Fan, J., Joe Qin, S., Wang, Y.: Online monitoring of nonlinear multivariate industrial processes using filtering KICA–PCA. Control Engineering Practice, In Press, Available online 6 Aug 2013

Gharavian, M.H., Almas, F.: Ganj, A.R. Ohadi, H. Heidari Bafroui, Comparison of FDA-based and PCA-based features in fault diagnosis of automobile gearboxes. Neurocomputing **121**(9), 150–159 (2013)

Godoy, José L., Vega, Jorge R., Marchetti, Jacinto L.: Relationships between PCA and PLS-regression. Chemometr. Intell. Lab. Syst. **130**, 182–191 (2014)

Issam, B.K., Mohamed, L., Weihs, C.: Variable window adaptive Kernel Principal Component Analysis for nonlinear non stationary process monitoring. Comput. Ind. Eng. **61**, 437–446 (2011)

Jin, X., Wang, S., Huang, B., Forbes, F.: Multiple model based LPV soft sensor development with irregular/missing process output measurement. Control Eng. Pract. **20**, 165–172 (2012)

Kadlec, P.: Review of adaptation mechanisms for data-driven soft sensors. Comput. Chem. Eng. **35**, 1–24 (2011)

Kadlec, P., Gabrys, B., Strandt, S.: Data—driven soft sensors in the process industry. Comput. Chem. Eng. **33**, 795–814 (2009)

Kahlen, S., Jerabek, M., Wallner, G.M., Lang, R.W.: Characterization of physical and chemical aging of polymeric solar materials by mechanical testing. Polym. Test. **29**, 72–81 (2010)

Khatibi, G., Lederer, M., Weiss, B., Licht, T., Bernardi, J., Danninger, H.: Accelerated mechanical fatigue testing and lifetime of interconnects in microelectronics. Procedia Eng. **2**, 511–519 (2010)

Li, S. Wen, J.: A model-based fault detection and diagnostic methodology based on PCA method and wavelet transform. Energy Buildings **68**(Part A), 63–71 (2014)

Livieris, I.E., Pintelas, P.: A new conjugate gradient algorithm for training neural networks based on a modified secant equation. Appl. Math. Comput. **221**, 491–502 (2013)

Peng, Jiangtao, Li, Luoqing: Support vector regression in sum space for multivariate calibration. Chemometr. Intell. Lab. Syst. **130**, 14–19 (2014)

Si, X.S., Wang, W., Hu, C.H., Zhou, D.H.: Remaining useful life estimation—A review on the statistical data driven approaches. Eur. J. Oper. Res. **213**, 1–14 (2011)

Sun, J., MaoyunGuo, Y.C., Li, H.F.: On-line adaptive principal component extraction algorithms using iteration approach. Sig. Process. **92**, 1044–1068 (2012)

Vuković, N., Miljković, Z.: A growing and pruning sequential learning algorithm of hyper basis function neural network for function approximation. Neural Networks **46**, 210–226 (2013)

Wang, Y.N., Bao, Y.P., Cui, H., Chen, B., Ji, C.X.: Final temperature prediction model of molten Steel in RH-TOP refining process for IF steel production. J. Iron. Steel Res. Int. **19**(3), 01–05 (2012)

Zhang, Y., ShuaiLi, Y.T.: Dynamic processes monitoring using recursive kernel principal component analysis. Chem. Eng. Sci. **72**, 78–86 (2012)

Part VIII
Marketing and Sales Management

Chapter 19
Market Analysis Using Computational Intelligence: An Application for GSM Operators Based on Twitter Comments

Basar Oztaysi, Ceren Öner and Dilek H. Beyhan

Abstract Users all around the world widely publish contents and leave comments about products/services they experienced in social networking sites. With the emerging computational intelligence approaches, the data can be processed and transformed to valuable knowledge. In this study, we propose a methodology based on computational intelligence techniques for market analysis. In the proposed approach, first customers' comments are collected automatically, then sentiment analysis is applied to each message using artificial neural networks. At the third phase, themes of messages are determined using text mining and clustering techniques. In order to represent the outcomes of the computational intelligence, a real world example from GSM operators in Turkey is given.

Keywords Text mining · GSM operator · Sentiment analysis · Social network · Artificial neural networks

19.1 Introduction

Thanks to the improvements in Internet technologies, social networks usage covered a ground in both reflecting social life and business transactions. Because of the increasing potential of online marketing and sales operations, social networks have become an essential tool for the extending communications with the customers. Thus, diversified types of online meetings, firms, blogs and forums focus on the

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development of their social network attraction. Accordingly, business firms have more emphasize on improving their sales potential with online operations using social networks.

Computational intelligence could be defined as a set of nature-inspired computational methodologies and approaches to address complex real-world problems. Main techniques of computational intelligence can be identified as artificial neural networks, evolutionary computation, fuzzy logic, natural language processing, image processing and data mining. With the immense attention of users to social media resulted huge amount of data both structured and unstructured, to be stored in social networking sites. Today, with the help of emerging data storage and processing technologies the data collected in social networking sites can be analyzed using computational intelligence applications which empower engineering management working areas such as, product development, design, risk management, financial management, marketing and sales management, project management, and supply chain management can be developed.

The data collected in social networks has been attracted both academic and professional studies. One of the most important analysis area has been on marketing operations. Some of the studies identified different applications of social networks on text classification and clustering of users based on usage frequency and personality. On the other hand, these research areas are mainly based on social sciences that assist managerial science. Additionally, by accurate processing of the text data, management strategies, options and practical solutions for satisfying customer needs could be provided which could lead sales growth and more profit in taking the advantage in global competition (Murray and Weiss 1988).

In traditional approach, gathering user comments and reflections which are the major indicators of customer satisfaction, requires direct contacts with customers and takes waste of time, money and manpower in the process of making surveys. A novel approach is to use social media as a source. In order to extract and analyze the related information from social networks, computational intelligence methods such as data mining, text mining, and machine learning, are required. Text mining is defined as a semi-automated process of extracting pattern from large amounts of unstructured data sources. Specifically, text mining has a widespread practice in law, academic research, finance, medicine, biology, technology and marketing. Another technique used in the analysis of user comments is sentiment analysis (or opinion mining). Sentiment analysis deal with investigating the subjective information in the source text. The emotions and evaluations have expressed under the name of “attitude” in texts. The attitude could be even positive, negative or neutral. In the literature, techniques such as support vector machine, bag of words, latent semantic analysis and artificial neural networks are used for sentiment analysis.

In this study, an approach for competitive market analysis via Twitter is represented. The approach proposes a three-stage analysis based on sentiment analysis and text mining. First of all, tweets which include GSM firms’ names were gathered from Twitter for a specific date interval. After that, sentiment analysis was applied in order to determine customer opinions. Using the same tweets, clustering was carried out to obtain the theme of the content. Finally, sentiment analysis results were evaluated with respect to clusters and companies. The significance of these results were evaluated taking in the consideration of both sales data and advertisement- marketing strategies.

The rest of this chapter is organized as follows. In Sect. 19.2, literature review about Text mining and sentiment analysis is provided. In Sect. 19.3, details of Artificial Neural Networks and the steps of the methodology is introduced. In Sect. 19.4, a real world application for market analysis via Twitter is presented. Finally the conclusions are given in the final section.

19.2 Sentiment Analysis and Computational Intelligence

Text mining is defined as the semi-automated process of extracting patterns and useful information from large amount of unstructured data sources (Turban et al. 2011). There are many application areas of text mining both in academic and professional world. Some of the recent text mining studies from the literature is given in Table 19.1.

Sentiment analysis, in other words, opinion mining, is one of the attractive field in text mining due to the rapid developments in social networking. In general, sentiment analysis is a computational tool that investigates people's opinions, attitudes and emotions in order to extract valuable information for the usage of business decisions (Medhat et al. 2014). In the literature, sentiment analysis is generally considered as applying sentiments to the documents or focused on seeking sentiments of words, subjective explanations, subjective clauses and topics stored in web sites or databases (Prabowo and Thelwall 2009; Li and Wu 2010).

Table 19.1 Recent studies on text mining

Topic	Studies
Demographic analysis	Ikeda et al. (2013)
e-commerce	Zheng et al. (2013), Eirinaki et al. (2012), Marrese-Taylora et al. (2014), Thorleuchter and Van den Poel (2012), Vinodhini and Chandrasekaran (2014), Zhang et al. (2013)
Security	Fuller et al. (2011), Al-Zaidy et al. (2012), Kancherla et al. (2012), Suarez-Tangil et al. (2014), Keyvanpour et al. (2011), Tseng et al. (2012)
Decision making	Ghazinoory et al. (2013)
New product development	Yoon et al. (2014), No et al. (2014), Seol et al. (2011)
Health/Biomedical	Zhu et al. (2013), Pereira et al. (2013), Anholt et al. (2014), Piedra et al. (2014), Seoud and Mabrouk (2013), Zhou et al. (2010)
Market analysis	Yu et al. (2013)
Automotive	Rajpathak (2013), Khare and Chougule (2012), Chougule et al. (2011), Buddhakulsomsiri and Zakarian (2009)

Additionally, sentiment analysis could be also utilized on the purpose of different real world applications and business intelligence areas (Ortigosa-Hernandez et al. 2012). Earlier studies mostly dealt with customer segmentation (Kamakura and Gessner (1986); Huth et al. 1994), finance (Ising et al. 2006) and social text summarization (Hijikata et al. 2007). Besides, most of the studies have been searched in additional numerous areas in recent years such as social and conventional media (Yu et al. 2013), social reviews (Xianghua et al. 2013), e-learning (Ortigosa et al. 2014), stock market predictions and financial evaluations (Bollen et al. 2011; Kearney and Liu 2014), market evaluations via social networks (Qui et al. 2013), determination of users' sentiments (Costa et al. 2012), early detection of emerging political topics on Twitter (Rill et al. 2014).

In recent years, the data collected and stored in social networking sites has become an important research topic for text mining applications since social media phenomenon took attention of many users all around the world. At that point, computational intelligence which implies the methods that could solve complex real world problems have come into play and has been used in various studies (Eberhart and Shi 2011). For example, Olsher (2014) proposed machine learning, big data, and natural language processing combined data mining tool to provide social artificial intelligence. Sun et al. (2014) established a social media based recommendation system which is depended on sentiment analysis. Wang et al. (2013a, b) tried to summarize customer opinions via sequential extreme learning and intuitionistic fuzzy sets. Table 19.2 summarizes some of the studies on social media data mining and text mining via computational intelligence and sentiment analysis.

Sentiment analysis and computational intelligence techniques are beneficial for marketing applications that can be used to determination of further marketing strategies and making improved analysis about customer using customer reviews. Sentiments which could be classified as positive, negative and neutral could provide insight to business users. Theoretically, in the literature, sentiment analysis was divided into two subgroups as lexicon based and machine learning methods. According to this classification, supervised algorithms for learning procedure is provided to decision tree classifiers, linear classifiers, rule based classifiers and probabilistic classifiers. Specifically, linear and probabilistic classifiers were supported by computational intelligence tools such as support vector machine (SVM), neural networks, Naïve Bayes, Bayesian networks and maximum entropy.

When examining literature, SVM have been widely used in sentiment analysis studies. On the other hand, Artificial Neural Networks (ANN) have seldomly been taken into account in the sentiment analysis. For instance, Ng et al. (1997), Ruiz et al. (1999) and Zhu et al. (2010) suggested ANN based sentiment clustering method. Chen et al. (2011) offered semantic orientation indexes as inputs an ANN model for commercial blog comment analysis. Generally, ANN was combined with other computational intelligence tools such as SVM (Ghiassi et al. 2013; Poria et al. 2014), NLP (Danesh et al. 2011; Moraes et al. 2013). Therefore, there is a lack of studies related to ANN applications (Moraes et al. 2013). Although it is a hot topic

Table 19.2 An overview of studies in social media data and text mining with computational intelligence

Problem domain	Author(s)	Methodology	Specific point
Literature review	Medhat et al. (2014), Montoyo et al. (2012)	Methodology classification, Research paper evaluation	Sentiment analysis algorithms and applications
Movie review with sentiment analysis	Basari et al. (2013)	SVM and particle swarm optimization combination	Movie classification with Twitter data
Ontology-based sentiment analysis	Kontopoulos et al. (2013)	Machine learning based classification	Character limit of text-based sentiment analysis of tweets issue
Conversation analysis	Wang et al. (2013a, b)	Iterative matrix factorization	Summarizing opinions
Sentiment-aware social media data analysis	Sun et al. (2014)	Collaborative filtering	Recommendation systems via sentiment analysis
	Olsher (2014)	Machine learning, Big Data, natural language understanding/processing, and social AI	Social Big Data analysis via COGBASE
Text classification	Wang et al. (2014)	Ensemble learning	Social media data analysis for text classification
	Li and Tsai (2013)	Fuzzy formal concept analysis	
	Aue and Gamon (2005), Beneike et al. (2004), Lin et al. (2006)	SVM –Native Bayes combined method	Document sentiment analysis with training classifiers
	Tan et al. (2007)	Natural language Processing under AI	Domain transfer problem in document sentiment analysis
Predicting customer sentiments	Wang et al. (2013a, b)	Sequential extreme learning and intuitionistic fuzzy sets	Potential customer detection

among computational intelligence- oriented researches in other fields, there is a lack of analyzing the findings of ANN to extract business value for maintaining competitiveness. Overall studies related with ANN for text mining and sentiment analysis is shown in Table 19.3.

This study tries to demonstrate the methodology of making substantial comments from the findings proposed in the ANN based sentiment analysis in order to sustain constructive and long-lived relations with customers.

Table 19.3 An overview of computational intelligence studies in social media data and text mining with ANN

Problem domain	Author(s)	Methodology	Specific point
Brand sentiment analysis	Ghiassi et al. (2013)	ANN and SVM-hybrid model	Dynamic artificial neural network supported with SVM
Text sentiment classification	Zhu et al. (2010)	Individual model (i model) with ANN	ANN with polarity judgment of human sentiment
	Ng et al. (1997), Ruiz et al. (1999)	ANN	Perceptive learning for text categorization
Commercial blog comment analysis	Chen et al. (2011)	Recognizing emotion with NN	Semantic orientation indexes are used as inputs of NN model
Market prediction	Khadjeh Nassirtoussi et al. (2015)	News mining with ANN	Matching market-type and the textual data of news
Customer review sentiment analysis	Zhang et al. (2014)	Labeling sentiment data with NN	Analyzing human interaction affects
Sentiment aware social media analysis	Poria et al. (2014)	SVM, ANN-based clustering technique	Concept level sentiment analysis
Literature evaluation	Koppel and Schler (2005)	NN applications	Comparison of earlier applications
	Moraes et al. (2013)	SVM-ANN comparison	Evaluation of ANN and SVM with classification accuracy rate

19.3 Methodology

In this section, the methodology used for market analysis of GSM operator in Turkey is introduced. Initially, Artificial Neural Networks are introduced then the steps of the applied methodology is given (Fig. 19.1).

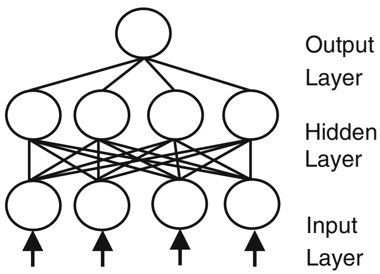

Fig. 19.1 A Typical Neural Network with four inputs and one output

19.3.1 Artificial Neural Networks

Artificial Neural Network (ANN) is a mathematical invention that inspired by observations made in the study of biological systems, though loosely based on the actual biology (Priddy and Keller 2005). The aim of a neural network is to map input to a desired output using interconnected units called neurons. In the literature, there are various types of networks. While the network type used in modeling depends on the problem to be solved, backpropagation network is reported as the most frequently used one (Kosko 1992). Backpropagation network generally contains at least three neuron layers: one input layer, one output layer and at least one hidden layer (Fig. 19.2). Generally, a network with only one hidden layer is preferred to reduce calculation time. All the neurons of the network are connected by an axon to each neuron of the next layer except the output layer.

The input layer consists of neurons, each independent variable of the model is represented as a neuron in the network. The next layer, hidden layer, contains a specific number of neurons which is predetermined by the system user before systems starts working. The output layer represents the dependent variables of the model. Figure 19.2 represents an ANN network with a single output, four inputs and four neurons in the hidden layer.

Each connection between two neurons, which is represented with a line, is given a random weight value at the beginning of the process, these weights are modified by during the training of the network. Each neuron except the ones in input layer evaluates the state of the signal from the previous layer as shown in Fig. 19.3 using Eq. (19.1).

$$a_j = X_i W_{ji} \tag{19.1}$$

In the equation, a_j represents the net input of neuron j; X_i denotes the output value of neuron i of the previous layer; and finally W_{ji} shows the weight factor of the connection between neuron i and neuron j.

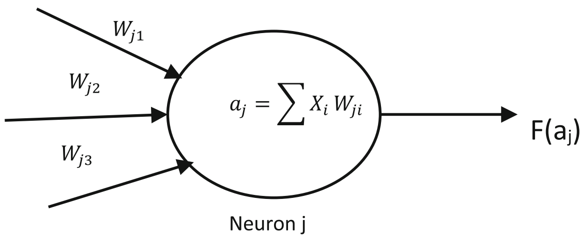

Fig. 19.2 A sample neuron with three inputs and an output

Fig. 19.3 A sample TDM matrix

Documents \ Terms	blog	artist	social	student	editor
Text1	1		1		
Text2		1			
Text3				2	
Text4					1
Text5			1	1	
Text6		3			1

In artificial neural networks, the output of that node given an input or set of inputs is defined as activity of neurons and generally determined by using a sigmoid function given in Eq. (19.2):

$$f(a) = \frac{1}{1 + exp^{-a_j}} \tag{19.2}$$

For a classification problem, back propagation technique is used in which, the network is trained with a set of inputs and output. At the end of each iteration, the connection weights of between neurons are modified so as to minimize the error of the reply. Starting from output layer towards input layer, the adjustments of weights are calculated using Eq. (19.3).

$$\Delta W_{ji} = \eta \delta_j f(a_i) \tag{19.3}$$

In which ΔW_{ji} represents the adjustment of weight between neuron j and neuron i from the previous layer; $f(a_i)$ denotes the output of neuron i, η denotes the learning rate, and δ_j shows a parameter calculated depending on the existing layer. For the output layer δ_j is determined using Eq. (19.4) and for other layers it is determined by using Eq. (19.5).

$$\delta_j = \left(Y_j - \widehat{Y}_J\right) f_i(a_j) \tag{19.4}$$

$$\delta_j = f_i(a_j) \sum\nolimits_{k=1}^{K} \delta_k W_{kj} \tag{19.5}$$

In Eq. (19.4), Y_j denotes the observed value of neuron j and $\widehat{Y}_j$ represents the estimated value of neuron j. In Eq. (19.5) K shows the number of neurons in the next layer.

The learning rate plays an important role in training. Gallant (1993) reported that when the learning rate is determined as a low value, the convergence of the weight to an optimum will be very slow. On the other hand, if the rate is set to a too high value, the network can oscillate, or it can get stuck in a local minimum. In order to deal with this problem, Eq. (19.3) is added a momentum term and ΔW_{ji} is determined by using Eq. (19.6).

$$\Delta W_{ji} = \eta \delta_j f(a_i) + \alpha \Delta W_{ji}^{Prev} \tag{19.6}$$

In Eq. (19.6). ΔW_{ji}^{Prev} denotes the correction in the previous iteration. In the application of ANN, α and η parameters are selected by the user then they are modified during the iterations. The training of the network is performed until the sum squared of errors is minimized (Reby et al. 1997).

As the training of the network is finished, the performance of the network is tested. For testing, the existing data set is divided into two groups: one group for training, one group for testing. The training data is fed into the system and the network is trained, then test dataset which is not used for training is given to the network. For classification problems, the percentage of correct classifications gives the performance of the trained set.

19.3.2 Steps of the Methodology

The methodology applied in this study is adopted from the general text mining methodology given by Turban et al. (2011). The steps of the methodology can be summarized as follows:

Step 1: *Establishing the corpus*:

Corpus is a large and structured set of texts that are prepared for further analysis. The purpose of this phase is to collect all of the text files that are relevant to the problem being addressed. The quality and quantity of the documents considered in the corpus is one of the most important elements in text mining projects. Also, the corpus should be identified and collected using manual or automated techniques such as software programs that periodically collects data from different blogs or searches for relevant news extracts from several websites. The source of data may include HTML files, emails, web blogs or textual documents. As these various types of documents are collected, they should be organized for the computer processing. In this study, user tweets constitute the corpus.

Step 2: *Sentiment Analysis*:

Sentiment analysis refers to the use of natural language processing, text analysis and computational linguistics to identify and extract subjective information in source materials. The term opinion mining is also used instead of sensitivity analysis. The aim of sentiment analysis is to determine the attitude of a speaker or a writer with respect to some topic or the overall contextual polarity of a document. The attitude may be his or her judgment, affective state or the intended emotional communication. (ANNs) that are introduced in the previous subsection are used for sentiment analysis.

Step 3: *Formation of Term Document Matrix*:

The next step of the process aims to convert the unstructured data into term-document matrix (TDM) which is a structured representation of the corpus. The TDM is a matrix form in which the documents represented by the rows and terms represented by the columns. In Fig. 19.3, a sample TDM matrix is presented.

The values in the TDM matrix show the relationships between the terms and the documents such as how frequently a given term occurs in a document. The relationship between terms and documents can be illustrated with various measures. In this study TF-IDF (term frequency—inverse document frequency) function, given in Eq. 19.7 is used.

$$TF-IDF(i,j) = \begin{cases} 0, & if\ wf_{ij} = 0 \\ \left(1 + \log\left(wf_{ij}\right)\right) * \log\dfrac{N}{df_i}, & if\ wf_{ij} = 0 \end{cases} \tag{19.7}$$

Converting unstructured data to a TDM matrix, there is an underlying assumption that the meaning of the documents can be represented within the matrix using the measures in the cells. However, not all the terms are equally important for characterizing a document, articles and auxiliary verbs have distinguishing power between the documents and thus, they should be excluded from the process. This kind of terms is called “stop terms” and they should be identified before or during this phase. On the other hand, there are other specific types of terms that can be identified, the “include terms” defines the predefined terms that are chosen to build the TDM. For the sake of the study the “synonyms”, the pairs of terms that are to be treated the same, should be defined. Finally, specific phrases can be defined so that the phrase is included as a whole instead of separate words. Since the success of the text mining process depends on the accuracy of the TDM, the phase includes feedbacks that the miner can turn back to previous tasks and renew them for better outcome.

Step 4: *Determining the Themes*:

After the creation of the TDM and dealing with the dimensionality problem, the next task is to extract novel and beneficial patterns from this matrix. In order to determine the themes of tweets, k-means clustering is used.

K-means clustering is an unsupervised learning algorithm that follows a simple and easy way to classify a given data set through a certain number of clusters which is determined before the analysis. The main idea is to define k centroids randomly. The next step is to take each point belonging to a given data set and associate it to the nearest centroid. When no point is pending, the first step is completed. At that point, k new centroids are recalculated. After these k new centroids are determined, a new binding has to be done between the same data set points and the nearest new centroid. Sequentially, the application steps are repeated until a stopping condition, such as no change in clusters, is reached.

K-means algorithm aims at minimizing an objective function in which squared error function is used (Eq. 19.8)

$$J = \sum\nolimits_{j=1}^{k} \sum\nolimits_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\|^2 \tag{19.8}$$

where k is the number of clusters, n is the number of data points, c_j is the center of jth cluster, and x_{ij} is the ith data point in jth clusters. In the equation $\left\| x_i^{(j)} - c_j \right\|^2$ is used as a distance measure to be minimized.

Step 5: *Analysis of the results*:

The results of sentiment analysis are integrated with determined themes in order to analyze the performance of each company in each theme.

19.4 Real World Application for Market Analysis via Twitter

In this chapter, we provide a market analysis using Twitter in Turkey. The companies are chosen from GSM providers. The main players of this sector are Turkcell (50.77 % subscriber, 49.21 % market share), Vodafone (28.75 % subscriber, 30.56 % market share) and Avea (20.48 % subscriber, 20.24 % market share) which have entries in social media. For the understanding of huge amount of entries appeared in social media, sentiment analysis and text mining methods are both applied. The first part of the analysis includes extracting data from Twitter for the sentiment analysis. For extracting the data and establishing the sentiment analysis, a software developed by Botego is utilized. As a result, tweets are classified as positive, negative and neutral. The data that was used in the analysis is composed of tweet messages which include "Turkcell", "Avea" and "Vodafone" words and which are sent between 04.02.2014 and 11.03.2014.

Next step is cleaning the data for the simplification of the dataset. First, tweets which have two different brand names are eliminated due to the prevention from confusions in sentiment analysis. Secondly, irrelative tweets that could not reflect GSM provider's usage or activity are also deleted such as tweets which contain location sharings and commercial tweets posted by the official accounts of the brands.

Sequentially, sentiment analysis is applied to the revised data with the assistance of ANN for polarity classification. For this reason, tweets related to GSM providers—27991 from Avea, 32370 from Vodafone and 55574 from Turkcell—are taken as input parameter and this existing data is normalized before ANN implementation.

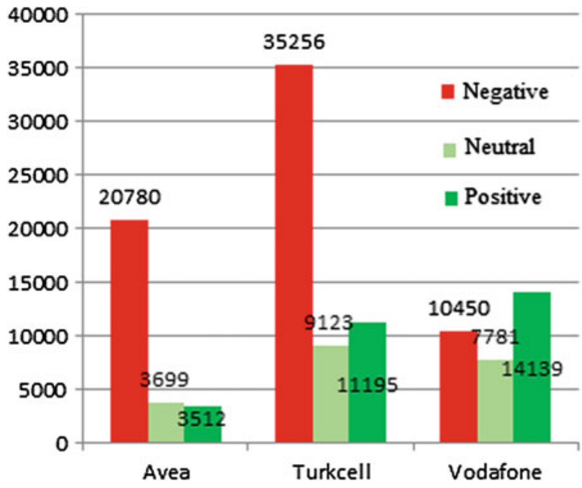

Fig. 19.4 Emotional sentiments (negative, positive and neutral) of GSM providers

Initially, weights are determined with small random numbers and output parameters—the negative, positive and neutral tweets are specified. The next processes are data training and determination of learning rate for gathering better accuracy. First of all, feature vector of tweets is gathered by lemmatization which implies the canonical form of the words. Thereafter, inputs are forwarded to the next step with their previous values. Finally, random search is applied to the test data with the assistance of gradient descent method and multilayer perception based learning procedure is adopted with 1000 replications number of replications. The replications are ended when weights of the connections are so smaller than the specified threshold. Figure 19.4 presents the number of positive, negative and neutral sentiments of customers with respect to GSM companies.

The next step in the process is the obtaining the term-document matrix which presents words as “frequency numbers” in order to measure the significance and importance levels of the terms appeared in the related documents. The literature provides various functions to be used for forming the TDM. In this study TF-IDF function given in Eq. 19.7 is utilized.

TF-IDF is a combination of term frequency and inverse document frequency that produces a composite weight for each term in each document. By forming TDM, the unstructured tweet data is transformed to structured form. As the third step, the tweets are clustered based on TDM data. Rapidminer 5.3 is used for the process. Before applying the cluster analysis, a preprocessing of the data takes place. Some of the preprocessing activities are; tokenization (disassemble tweets to words), switching all cases to lower case and filtering unnecessary words (prepositions, conjunctions). After preprocessing, K means clustering technique. In order to determine the most suitable number of clusters (K), different values in between 2 and 8 is applied. From the performance results, average distance from center indicates that the best clustering is performed when K = 6. In Table 19.4, all the average distance from center values for alternative K values are given.

Table 19.4 Results of the clustering performance in accordance with the number of clusters

Number of the clusters	Average distance from centre
2	0.741
3	0.731
4	0.723
5	0.715
6	0.655
7	0.659
8	0.657

Table 19.5 Most frequently used words in accordance with clusters

Attribute	cluster_0	cluster_1	cluster_2	cluster_3	cluster_4	cluster_5
arena	0.003	0.000	0 424	0.010	0	0.002
beşiktaş	0.001	0.000	0.230	0.001	0	0.001
stad	0.001	0.000	0.127	0.000	0.000	0.001
tanitim	0.000	0	0.082	0	0.000	0.000
yeniinonusta	0.000	0	0.073	0	0	0.000
yeni	0.010	0.007	0.069	0.009	0.011	0.059
inşaat	0.000	0	0.068	0.000	0	0

As the number of clusters is determined as six, next, the centroid table is formed. Table 19.5 presents a sample from the centroid table.

Next centroid table is investigated to determine most frequently used words in each cluster. Cluster names are gathered by investigating the TF-IDF scores of words and tweets that take place in the clusters. The names of clusters are determined as; Sport, Romantic, Internet, Purchasing, Commercial and Others. The most frequently used words of each cluster is given in Table 19.6.

As the clusters are determined, the sentiment analysis results can be integrated with the results of cluster analysis to get better insight about the brands. Figure 19.5 shows the number of negative, positive and neutral tweets with respect to each group.

Table 19.6 Most frequently used words in accordance with clusters

Internet (10684 times)	Sport (1445 times)	Shopping (2087 times)	Romantic (13166 times)	Advertisement (5594 times)	Others (69232 times)
Internet	Arena	Take	Message	Advertisement	Happened
Package	Beşiktaş	Start	Darling	Sabri	Even
Gift	Stadium	Drinking	Coming	Youtube	Telephone
Patience	Promotion	Been	Married	Superonline	Para
Use	Newinonustadium	In the past	Send	Forwarding	Bill
Free	Construction	Search	Suppose	New	Talk
Refer	Video	Only	Night	Day	Smart
Technology	February	Wait	Situation	Video	Time

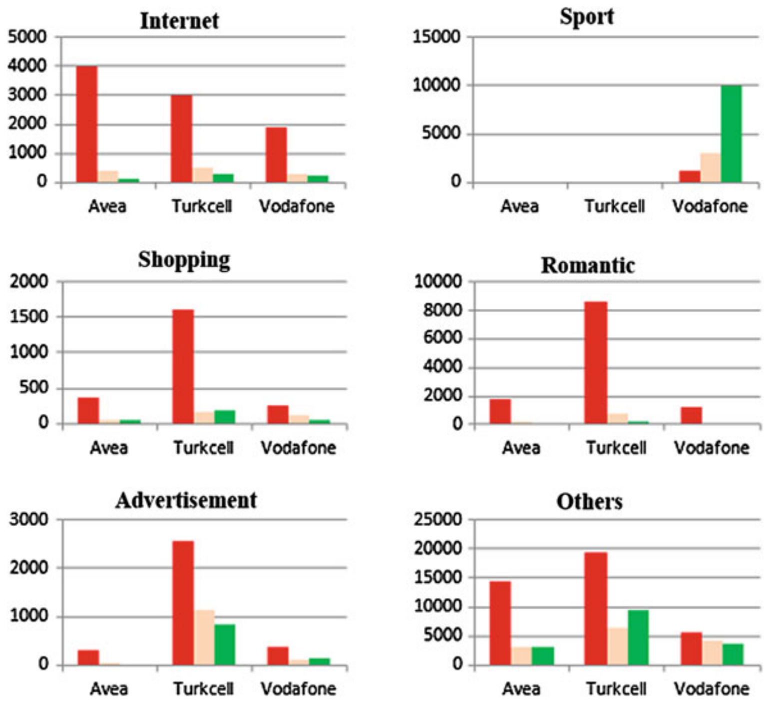

Fig. 19.5 Number of negative, positive and neutral tweets with respect to each group

19.5 Findings and Discussion

The results of the sentiment analysis and clustering analysis, six themes are determined as Internet, Sports, Shopping, Romantic, Advertisement, and Others. While the tweets in first five groups have specific terms, the tweets in the last group does not have any commonalities. This group has the highest amount of tweets thus it is named as Others. The results show that most of the comments are related to activities such as tariffs, concerts, investments, social responsibility activities. Figure 19.5 presents the negative, positive and natural tweets for all GSM operators in Turkey. Nearly in all clusters, number of negative tweets are higher than the positive ones. This can be interpreted as users are prone to write negative comments, and companies must work hard to get positive comments. As seen in Fig. 19.5, negative comments related to "Internet" have occurred in considerable amount since one of the major operations of the GSM providers is internet services. Additionally, "Sport" attracted most of the positive tweets of Vodafone because of the sponsorship for the construction of the new BJK stadium. In "Shopping" and "Advertisement" themes, negative and positive comments are mainly based on "purchasing" or "buying" and this group is directly influenced from the market share.

Results point out that actual market share and income levels are constituted correspondingly with tweet numbers. Additionally, it can be easily realized that if the brand has the biggest market share in the related sector, most of the tweets will be referred about the relevant GSM provider. However, there is no relationship between positive tweet numbers and actual subscriber quantities. In a general view, most of the tweets have negative sentiment scores which demonstrate users' tendency in sharing their bad experiences in social media.

From the analysis, one can conclude that one of the most noticeable result is either viral or classical commercials are mentioned too much in Twitter. So that, feedbacks about commercials can be taken from Twitter or other social media tools. Another remarkable result is that the sponsorships are very important to attract attention from private community such as sport fans. Besides that, negative ranks are very high in "Romantics" due to the restlessness about getting messages from their GSM operator instead of their lover.

As an important result, Twitter users are disposed to sharing their bad and good experiments and the number of tweets are hardly depend on company's income level and market share. Additionally, campaigns such as profitable packages in accordance with the diversified customers could increase positive tweets. Besides, performances on major operations such as internet speed consist of the most substantial part on tweets.

The findings of the analysis can be summarized as follows:

1. Number of subscribers, market share and company's income level are the most important indicators that have not been emphasized in the former studies. Although Vodafone entered to the market lately, it has most of the positive comments in Twitter.
2. Generally negative opinions were shared. Campaigns related to tariffs and extra activities could make an inversion to positive comments.
3. Sharings related to internet speed is a good indicator for improving service quality.
4. Making investments, art and social responsibility activities could influence the attraction on GSM firms.
5. High prices impress the sharings appeared in Twitter in a negative way.
6. Special day advertisements such as Valentine's Day could affect both in a negative and positive way. (People who do not have a girl/boyfriend could be annoyed when they see Valentine's Day messages. On the other hand, messages include both couples and singles could be beneficial to take attraction on Twitter.)

19.6 Conclusion

Since the increasing potential of online marketing and sales operations, social networks have become an essential tool for business users to understand and communicate with their customers. This study proposes a three-stage analysis based on sentiment analysis, clustering and ANN for analyzing tweets. At the end of the analysis, clusters related to the user comments are defined for the analysis of GSM providers' current situation in the market. The results show that for companies, there is a requirement for monitoring social media comments about their own company and the competitors. Moreover, benchmarking utilizing both competitors and their own sharings extracted from Twitter provides the conversion of the data to information which is the first stage of an effective and efficient way of decision making on the missing points for satisfying customer demand.

Future research will be on including useful buttons in Twitter such as "retweet", "favorites" and "reply", at the same time, for expanding this analysis with defining a "popularity index". Furthermore, cluster named "Others" should be downsized in order to get more accurate insight about the market.

This research will provide valuable information for investigating customer propensities to GSM providers in Turkey. By the use of social platforms for analyzing customer feedbacks and thoughts, further investments, sponsorships and advertisements could be planned and revised much more consciously in order to gain potential customers, satisfy customer expectations and evaluate new market opportunities which are essential parts of customer relationship management. Besides that, companies should be attentive to the evaluation of sentiment analysis results as a strategic tool of technology management in terms of making decisions for attractive innovations and promotions that will positively affect company reputation.

References

Anholt, R.M., Berezowski, J., Jamal, I., Ribble, C., Stephen, C.: Mining free-text medical records for companion animal enteric syndrome surveillance. Preventive veterinary medicine, **113**(4), pp. 417–422 (2014)

Aue, A., Gamon, M.: Customizing sentiment classifiers to new domains: a case study. In: Proceedings of RANLP (2005)

Al-Zaidy, R., Fung, B.C.M., Youssef, A.M., Fortin F.: Mining criminal networks from unstructured text documents. Digital Invest. **8**(3–4), pp. 147–160 (2012)

Basari, A.S.H., Hussin, B., Ananta, I.G.P., Zeniarja, J.: Opinion mining of movie review using hybrid method of support vector machine and particle swarm optimization. Proc. Eng. **53**, 453–462 (2013)

Beineke, P., Hastie, T., Vaithyanathan, S.: (2004). The sentimental factor: Improving review classification via human-provided information. In: Proceedings of the 42nd ACL Conference (2004)

Bollen, J., Mao, H., Zeng, X.: Twitter mood predicts the stock market. J. Comput. Sci. **2**, 1–8 (2011)

Buddhakulsomsiri, J., Zakarian, A.: Sequential pattern mining algorithm for automotive warranty data. Comput. Ind. Eng. **57**(1), pp. 137–147 (2009)

Chen, L.-S., Liu, C.-H., Chiu, H.-J.: A neural network based approach for sentiment classification in the blogosphere. J. Informetrics **5**, pp. 313–322 (2011)

Chougule, R., Rajpathak, D., Bandyopadhyay, P.: An integrated framework for effective service and repair in the automotive domain: An application of association mining and case-based-reasoning. Comput. Ind. **62**(7), pp. 742–754 (2011)

Costa, E., Ferreira, R., Brito, P., Bittencourt, I., Holanda, O., Machado, A., Marinho, T.: A framework for building web mining applications in the world of blogs: a case study in product sentiment analysis. Expert Syst. Appl. **39**, 4813–4834 (2012)

Danesh, S., Liu, W., French, T., Reynolds, M.: Advanced data mining and applications. Lect. Notes Artif. Intell. Part I **7120**, 162–174 (2011)

Eberhart, R.C., Shi, Y.: Computational Intelligence: Concepts to Implementations. Elsevier, Oxford (2011)

Eirinaki, M., Pisal, S., Singh, J.: Feature-based opinion mining and ranking. J. Comput. Syst. Sci. **78**(4), pp. 1175–1184 (2012)

Gallant, S.I.: Neural Network Learning and Expert Systems, pp. 365. MIT Press, London (1993)

Ghiassi, M., Skinner, J., Zimbra, D.: Twitter brand sentiment analysis: a hybrid system using n-gram analysis and dynamic artificial neural network. Expert Syst. Appl. **40**, 6266–6282 (2013)

Hijikata, Y., Ohno, H., Kusumura, Y., Nishida, S.: Social summarization of text feedback for online auctions and interactive presentation of the summary. Knowl. Based Syst. **20**(6), 527–541 (2007)

Huth, W.L., Eppright, D.R., Taube, P.M.: The indexes of consumer sentiment and confidence: leading or misleading guides to future buyer behavior. J. Bus. Res. **29**(3), 199–206 (1994)

Ikeda, K., Hattori, G., Ono, C., Asoh, H., Higashino, T.: Twitter user profiling based on text and community mining for market analysis. Knowl.-Based Syst. **51**, pp. 35–47 (2013)

Internet Source: http://www.botego.com

Ising, J., Schiereck, D., Simpson, M.W., Thomas, T.W.: Stock returns following large 1-month declines and jumps: evidence of overoptimism in the German market. Q. Rev. Econ. Finan. **46** (4), 598–619 (2006)

Kamakura, W.A., Gessner, G.: Consumer sentiment and buying intentions revisited: a comparison of predictive usefulness. J. Econ. Psychol. **7**(2), 197–220 (1986)

Kancherla, J.N., Vadlamani, R., Narravula, A., Indranil, B.: Soft computing based imputation and hybrid data and text mining: The case of predicting the severity of phishing alerts. Expert Syst. Appl. **39**(12), pp. 10583–10589 (2012)

Kearney, C., Liu, S.: Textual sentiment in finance: a survey of methods and models. Int. Rev. Financ. Anal. **33**, 171–185 (2014)

Keyvanpour, M.R., Javideh, M., Ebrahimi, M.R.: Detecting and investigating crime by means of data mining: a general crime matching framework. Proc. Comput. Sci. **3**, pp. 872–880 (2011)

Khare, V.R., Chougule, R.: Decision support for improved service effectiveness using domain aware text mining. Knowl.-Based Syst. **33**, pp. 29–40 (2012)

Kontopoulos, E., Berberidis, C., Dergiades, T., Bassiliades, N.: Ontology-based sentiment analysis of twitter posts. Expert Syst. Appl. **40**(10), 4065–4074 (2013)

Koppel, M., Schler, J.: The importance of neutral examples for learning sentiment. In: Workshop on the Analysis of Informal and Formal Information Exchange During Negotiations (FINEXIN) (2005)

Kosko, B.: Neural Networks for Signal Processing, p. 399. Prentice-Hall, London (1992)

Li, N., Wu, D.D.: Using text mining and sentiment analysis for online forums hotspot detection and forecast. Decis. Support Syst. **48**, 354–368 (2010)

Li, S.T., Tsai, F.C.: A fuzzy conceptualization model for text mining with application in opinion polarity classification. Knowl. Based Syst. **39**, 23–33 (2013)

Lin, W.-H., Wilson, T., Wiebe, J., Hauptmann, A.: Which side are you on? Identifying perspectives at the document and sentence levels. In: Proceedings of the 10th Conference on Computational Natural Language Learning (CoNLL-X), pp. 109–116, New York, (2006)

Marrese-Taylor, E., Velásquez, J.D., Bravo-Marquez, F.: A novel deterministic approach for aspect-based opinion mining in tourism products reviews. Expert Syst. Appl. **41**(17), pp. 7764–7775 (2014)

Medhat, W., Hassan, A., Korashy, H.: Sentiment analysis algorithms and applications: a survey. Ain Shams Eng. J. **5**(4), 1093–1113 (2014)

Montoyo, A., Martínez-Barco, P., Balahur, A.: Subjectivity and sentiment analysis: an overview of the current state of the area and envisaged developments. Decis. Support Syst. **53**(4), 675–679 (2012)

Moraes, R., Valiati, J.F., Neto, W.P.G.: Document-level sentiment classification: an empirical comparison between SVM and ANN. Expert Syst. Appl. **40**, 621–633 (2013)

Murray, A., Weiss, A.: The role of consumer and business sentiment in forecasting telecommunications traffic. J. Econ. Psychol. **9**(2), 215–232 (1988)

Nassirtoussi, A.K., Aghabozorgin, S., Wah, T.Y., Ngo, D.C.L.: Text mining of news-headlines for FOREX market prediction: a multi-layer dimension reduction algorithm with semantics and sentiment. Expert Syst. Appl. **42**, 306–324 (2015)

Ng, H.T., Wei, G, Kok, L.: Feature selection, perceptron learning, and a usability case study for text categorization. In: Presented at the ACM SIGIR Conference (1997)

No, H.J., An, Y., Park, Y.: A structured approach to explore knowledge flows through technology-based business methods by integrating patent citation analysis and text mining. Technol. Forecast. Soc. Chang. Corrected Proof, Available online 13 May 2014 (In Press)

Olsher, D.: Semantically-based priors and nuanced knowledge core for big data Social AI, and language understanding. Neural Netw. **58**, 131–147 (2014)

Ortigosa, A., Martín, J.M., Carro, R.M.: Sentiment analysis in Facebook and its application to e-learning. Comput. Hum. Behav. **31**, 527–541 (2014)

Ortigosa-Hernandez, J., Rodrıguez, J.D., Alzate, L., Lucania, M., Inza, I., Lozano, J.A.: Approaching sentiment analysis by using semi-supervised learning of multi-dimensional classifier. Neurocomputing **92**, 98–115 (2012)

Pereira, L., Rijo, R., Silva, C., Agostinho, M.: ICD9-based Text Mining Approach to Children Epilepsy Classification. Proc. Technol. **9**, pp. 1351–1360 (2013)

Poria, S., Cambria, E., Winterstein, G., Huang, G.-B.: Sentic patterns: dependency-based rules for concept-level sentiment analysis. Knowl. Based Syst. 45–63 (2014) http://dx.doi.org/10.1016/j.knosys.2014.05.005

Prabowo, R., Thelwall, M.: Sentiment analysis: a combined approach. J. Informetrics **3**, 143–157 (2009)

Priddy, K.L., Keller, P.E.: Artificial Neural Networks: An Introduction. SPIE Press, Washington (2005)

Qiu, L., Rui, H., Whinston, A.: Social network-embedded prediction markets: the effects of information acquisition and communication on predictions. Decis. Support Syst. **55**, 978–987 (2013)

Rajpathak, D.G.: An ontology based text mining system for knowledge discovery from the diagnosis data in the automotive domain. Comput. Ind. **64**(5), pp. 565–580 (2013)

Reby, D., Lek, S., Dimopoulos, I., Joachim, J., Lauga, J., Aulagnier, S.: Artificial neural networks as a classification method in the behavioral sciences. Behav. Process. **40**, 35–43 (1997)

Rill, S., Reinel, D., Scheidt, J., Zicari, R.V.: PoliTwi: early detection of emerging political topics on twitter and the impact on concept-level sentiment analysis. Knowl. Based Syst. (2014) doi: http://dx.doi.org/10.1016/j.knosys.2013.01.014

Ruiz, M, Srinivasan, P.: Hierarchical neural networks for text categorization. In: Presented at the ACM SIGIR Conference (1999)

Seol, H., Lee, S., Kim, C.: Identifying new business areas using patent information: A DEA and text mining approach. Expert Syst. Appl. **38**(4) pp. 2933–2941 (2011)

Seoud, R.A., Mabrouk, M.S.: TMT-HCC: A tool for text mining the biomedical literature for hepatocellular carcinoma (HCC) biomarkers identification. Comput. Methods Programs Biomed. **112**(3), pp. 640–648 (2013)

Suarez-Tangil, G., Tapiador, J.E., Peris-Lopez, P., Blasco, J.: Dendroid: A text mining approach to analyzing and classifying code structures in Android malware families. Expert Syst. Appl. **41** (4), Part 1 pp. 1104–1117 (2014)

Sun, J., Wang, G., Cheng, X., Fu, Y.: Mining affective text to improve social media item recommendation. Inf. Process. Manage, (2014) http://dx.doi.org/10.1016/j.ipm.2014.09.002

Tan, S., Wu, G., Tang, H., Cheng, X.: A novel scheme for domain-transfer problem in the context of sentiment analysis. In: Proceedings of CIKM'07, Lisboa, Portugal (2007)

Thorleuchter, D., Van den Poel, D.: Predicting e-commerce company success by mining the text of its publicly-accessible website. Expert Syst. Appl. **39**(17) pp. 13026–13034 (2012)

Tseng, Y.H., Ho, Z.P., Yang, K.S., Chen, C.C.: Mining term networks from text collections for crime investigation. Expert Syst. Appl. **39**(11), pp. 10082–10090 (2012)

Turban, E., Sharda, R., Delen, D.: Decision Support and Business Intelligence Systems, 9th edn. Prentice Hall, Upper Saddle River (2011)

Wang, G., Zhang, Z., Sun, J., Yang, S., Larson, C.A.: POS-RS: A Random Subspace method for sentiment classification based on part-of-speech analysis. Inf. Process. Manage. http://dx.doi.org/10.1016/j.ipm.2014.09.004 (2014)

Wang, H., Qian, G., Feng, X.Q.: Predicting consumer sentiments using online sequential extreme learning machine and intuitionistic fuzzy sets. Neural Comput. Appl. **22**(3–4), 479–489 (2013a)

Wang, S., Li, D., Zhao, L., Zhang, J.: Sample cutting method for imbalanced text sentiment classification based on BRC. Knowl. Based Syst. **37**, 451–461 (2013b)

Xianghua, F., Guo, L., Yanyan, G., Zhiqiang, W.: Multi-aspect sentiment analysis for Chinese online social reviews based on topic modeling and HowNet lexicon. Knowl. Based Syst. **37**, 186–195 (2013)

Vinodhini, G., Chandrasekaran R.M.: Measuring the quality of hybrid opinion mining model for e-commerce application measurement. **55**, pp. 101–109 (2014)

Yoon, B., Park, I., Coh, B.: Exploring technological opportunities by linking technology and products: Application of morphology analysis and text mining. Technol. Forecast. Soc. Chang. **86**, pp. 287–303 (2014)

Yu, Y., Duan, W., Cao, Q.: The impact of social and conventional media on firm equity value: a sentiment analysis approach. Decis. Support Syst. **55**, 919–926 (2013)

Zhang, K., Xie, Y., Yang, Y., Sun, A., Liu, H., Choudhary, A.: Incorporating conditional random fields and active learning to improve sentiment identification. Neural Netw. **58**, 60–67 (2014)

Zhang, Y., Mukherjee, R., Soetarman, B.: Concept extraction and e-commerce applications. Electron. Commer. Res. Appl. **12**(4), pp. 289–296 (2013)

Zheng, X., Zhu, S., Lin, Z.: Capturing the essence of word-of-mouth for social commerce: Assessing the quality of online e-commerce reviews by a semi-supervised approach. Decis. Support Syst. **56**, pp. 211–222 (2013)

Zhou, X., Peng, Y., Liu, B.: Text mining for traditional Chinese medical knowledge discovery: A survey. J. Biomed. Inform. **43**(4), pp. 650–660 (2010)

Zhu, J., Xu, C., Wang, H.: Sentiment classification using the theory of ANNs. J. China Univ. Posts Telecommun. **17**, 58–62 (2010)

Zhu, F., Patumcharoenpol, P., Zhang, C., Yang, Y., Chan, J., Meechai, A., Vongsangnak, W., Shen, B.: Biomedical text mining and its applications in cancer research. J. Biomed. Inform. **46** (2), pp. 200–211(2013)

Chapter 20
Intelligent Classification-Based Methods in Customer Profitability Modeling

Yeliz Ekinci and Ekrem Duman

Abstract The expected profits from customers are important informations for the companies in giving acquisition/retention decisions and developing different strategies for different customer segments. Most of these decisions can be made through intelligent Customer Relationship Management (CRM) systems. We suggest embedding an intelligent Customer Profitability (CP) model in the CRM systems, in order to automatize the decisions that are based on CP values. Since one of the aims of CP analysis is to find out the most/least profitable customers, this paper proposes to evaluate the performances of the CP models based on the correct classification of customers into different profitability segments. Our study proposes predicting the segments of the customers directly with *classification-based models* and comparing the results with the traditional approach (*value-based models*) results. In this study, *cost sensitive classification* based models are used to predict the customer segments since misclassification of some segments are more important than others. For this aim, Classification and regression trees, Logistic regression and Chi-squared automatic interaction detector techniques are utilized. In order to compare the performance of the models, new performance measures are promoted, which are *hit, capture* and *lift rates*. It is seen that *classification-based models* outperform the previously used *value-based models*, which shows the proposed framework works out well.

Keywords Customer profitability · Customer lifetime value · Regression · Classification

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20.1 Introduction

This study suggests an intelligent system approach to the Customer Profitability (CP) modeling problem of a Customer Relationship Management (CRM) system. This intelligent system provides controlling particular decisions automatically, which are once made manually by experts. Nowadays, CRM systems are intelligent systems; they give acquisition/retention decisions and develop different strategies for different customer segments automatically (Baxter et al. 2003). In order to perform these operations, they need CP values or segments of the customers. Therefore, we suggest embedding intelligent CP techniques in CRM systems.

Customer profitability (CP) and customer lifetime value (CLV) concepts have recently become popular in customer relationship management (CRM) literature. CLV can be defined as the present value of all future profits obtained from a customer over his or her life of relationship with a company while CP is the difference between the revenues earned from and the costs associated with the customer relationship during a specified period. The main distinction between these concepts is the time frame concerned. CLV deals with the whole life of relationship between the customer and the company where CP deals with a specified time period. However, when the CLV literature is examined, it is observed that although customer lifetime value is the value of the customer's entire lifetime with the company, the future forecast usually focuses on a specific time period namely 3–5 years (Donkers et al. 2007; Gurau and Ranchod 2002; Malthouse and Blattberg 2005; Mulhern 1999) since the models incorporating predicted future purchases are subject to a great deal of forecasting error (Mulhern 1999). This fact brings the CLV analysis to be narrowed to the CP analysis. Moreover, in this paper we formulise the relationship between CLV and CP as follows:

$$\text{CLV} = \text{CP}/\text{Probability of churn} \tag{20.1}$$

Here, *CP* is defined as the customer profitability in 1 year and the *probability of churn* is defined as the probability that the customer leaves the company in a year. In fact, when it comes to application, companies prefer contenting themselves with *customer profitability in one year* as they think that in the long run, most of the circumstances will change and CLV prediction will lead them to take wrong actions.

The definition of CP, grounds CP in the generally-accepted accounting profit notion applied to the individual customer relationship (Pfeifer et al. 2005). It helps firms quantify customer relationships, illustrate the profitability of its customers and provides references for the allocation of marketing resources to customers and market segments (Wang and Hong 2006). More and more companies keep information about their customers in their databases, this enables them to analyze customer profitability over time. These companies often seek to determine the most important customers as indicated by their current or historical profitability and focus attention on them since focusing on profitable customers can result in more efficient use of marketing resources (Rust et al. 2011). It is best practice for firms to consider customers' future profitability when allocating resources. Managers have long been aware that some customers are more profitable than others and have known that paying attention to more profitable customers can produce better results (Rust et al. 2011).

Customer profitability analysis is beneficial for segmentation and targeting strategies based on cost and profitability profiles (van Raaij et al. 2003). Some companies segment their customer base in platinum, gold, iron, and lead customers, based on their contributions to profits (Zeithaml et al. 2001). The previous studies propose estimating customer profitability for a given future time period and segmenting customers into several levels of a customer pyramid; such as profitable, less profitable and unprofitable (van Raaij et al. 2003; Zeithaml et al. 2001; Donkers et al. 2007; Malthouse and Blattberg 2005). These previous studies firstly try to forecast the profitability values of the customers and then determine their profitability segments accordingly. This traditional approach which uses mostly regression based prediction methods is named as *value-based models* in this paper. Companies use segment based customer relationship management since they manage their relationships with their customers based on some pre-defined segments. One reason for segment-based management is that managing relationships with individual customers is both difficult and not practical. Moving from this point on, this study proposes directly predicting the segments of the customers based on CP with classification-based models. Moreover, to the best of our knowledge, this study is the first one that uses classification-based models for predicting the levels of customer pyramids, i.e. customer segments, where customer segments are determined based on CP values. *Cost sensitive classification* analysis is used during classification-based modeling since misclassification of some segments are more important and the penalty of misclassifying those segments must be higher.

In the context of a multiservice financial organisation, the empirical evidence derived from the previous studies –all of them use value-based models- suggests that there is no advantage of complex service-level models of customer behaviour over simple models when predicting the individual customer profitability (Audzeyeva et al. 2012). The existing literature shows that for predicting future profitability values, simple methods, especially regression models tend to perform better than the complicated ones (Rust et al. 2011). This study also uses linear regression method to forecast the future customer profitability. Additionally, it proposes capping the data from the top values to eliminate the effect of outliers.

Additionally, a discussion about the definition of "best model" is also introduced in this study. The previous studies decide on the best model based on the R^2, MSE, and MAE values. However, this study approaches the definition of the best model from a different perspective based on its practical usage. For this aim the use of three performance measures, namely hit, capture and lift rates, is promoted.

This study tries to predict the profitabilities of the customers of a Turkish bank by developing alternative value-based and classification-based models, and the results of these models are compared. The best model will be embedded in the intelligent CRM system, so that most of the customer-oriented decisions will be automated. The paper continues with literature review in section two. The third section explains the methodology while the fourth section gives the empirical results of the developed models, and last section finalizes the paper with conclusions and future research.

20.2 Literature Review

20.2.1 Intelligent Systems in Customer Relationship Management

Intelligent system (IS) is a broad term, covering a range of computing techniques that have emerged from research into artificial intelligence (Hopgood 2012). It is about generating representations, procedures and strategies to handle tasks that were once thought only do-able by humans (Schalkoff 2009).

The underlying strategy in Customer Relationship Management (CRM) is to identify and manage the most valuable customer relationships (Baxter et al. 2003). In order to accomplish these goals, an intelligent CRM system should be able to forecast profitability values of the customers, successfully. The CP studies in the literature will be discussed below; however a summary of studies on intelligent CRM systems will be given firstly.

Baxter et al. (2003) build an intelligent CRM tool using agent-based modelling techniques. This tool aims to illustrate how CRM investments can influence a customer population. Kim and Street (2004) propose an intelligent system for customer targeting that uses artificial neural networks (ANNs) guided by genetic algorithms (GAs). Their predictive model allows the selection of an optimal target point where expected profit from direct mailing is maximized. Lee and Park (2005) present an intelligent profitable customer segmentation system based on business intelligence tools. It executes the customer satisfaction survey and conducts the mining of customer satisfaction survey, socio-demographic and accounting database through the integrated uses of business intelligence tools such as DEA (Data Envelopment Analysis), Self-Organizing Map (SOM) neural network and C4.5 for the profitable customers' segmentation. Chan (2008) propose an intelligent value-based customer segmentation method for campaign management for an automobile retailer. They also integrate selection of appropriate customers for each company strategy by using genetic algorithms. Namwar et al. (2010) presents a two phase clustering method for intelligent customer segmentation. Firstly, with K-means clustering, customers are clustered into different segments regarding their RFM; then, using demographic data, each cluster again is partitioned into new clusters; and finally, using LTV, a profile for each customer is created. Saberi et al. (2014) propose an intelligent online customer recognition (IOCR) framework, which will be implemented in a CRM tool, and which takes into consideration the presence of the more common or popular personal names of its customers. Kunder et al. (2014) represent an intelligent decision support system that will enable the service provider

Table 20.1 Summary of studies on intelligent systems in CRM

Studies	Aim	Methodology used
Questier et al. (2002), Fangming and Steven (2004)	Feature selection	Genetic algorithms
Francesco (2003)	Feature selection	Fuzzy C-means Algorithm
Yu et al. (2002)	Feature selection	Genetic algorithm and fuzzy set theory
Wang (2010)	Segmentation	Fuzzy equivalence relation
Wong (2001), Guo et al. (2006)	Segmentation	Fuzzy theory
Ammar et al. (2008)	Analysing customer satisfaction surveys	Fuzzy rule-based decision support system
Chan (2008)	Campaign management	Genetic algorithms
Au and Chan (2003)	Association rules	Fuzzy association rule mining
Kaufman and Graf (2012), Sousa et al. (2002)	Customer targeting	Fuzzy set theory
Cao and Li (2007)	Product recommendation system	Fuzzy set theory
Jonker et al. (2004)	Segmentation and marketing policy optimization	Genetic algorithms

to gain vital insights into the prevailing trends and judge the profits made. The knowledge thus gained can be utilized to identify the plans that need to be modified according to customer preference. Khobzi et al. (2014) develop an intelligent application of recency, frequency, and monetary (RFM)-based clustering and customer lifetime value analysis containing two extensions of RFM for guild segmentation for a bank. Table 20.1 summarizes other studies on intelligent systems in CRM. It can be seen from the table that, fuzzy set theory and metaheuristics are widely used in this area. We refer the readers to Meier (2012) for detailed information on using fuzzy methods for CRM.

20.2.2 Intelligent Customer Profitability Modeling

Before developing and suggesting a model for forecasting future customer profitability, it is necessary to compare the models developed in the literature. In order to measure CP and CLV; deterministic and stochastic models are encountered in the literature. Some of the models solely measure profitability while some try to maximize the customer profitability under some constraints or aims. Mostly used stochastic model follows Markov Chain technique. Markov Chains are widely used for modeling customer relationships (Morrison et al. 1982; Pfeifer and Carraway 2000; Dwyer 1997; Haenlein et al. 2007; Tirenni et al. 2007). The main challenge in these models lies in defining the states (ex: prime-non prime, recency 1, 2 etc., or something else), and determining the probabilities of transitions between states. When the definition of states change, the transition probability determination has to be changed as well. Another challenge is defining the rewards vector. The reward of a state may not be fixed for all customers in that state, generally there is a range. In the group of stochastic models, there are probabilistic models which employ probabilities for some variables and by this way try to estimate the customer profitabilities. For instance, most of the probabilistic models that try to compute customer profitability, predict whether an individual will still be active and what his purchasing behaviour will be with a probability (Jain and Singh 2002). The Pareto/NBD model is widely used for noncontractual settings (transactions ocur at any point in time) (Gupta et al. 2006). The challenge in probabilistic models is that they are generally based on so many assumptions. Furthermore, these models are applicable in situations where the time when the customer becomes inactive is unknown and the customer can make any number of purchases, at any time, and can become inactive any time. As a limitation, the model might give misleading results for very long customer purchase histories (Jain and Singh 2002).

The applications of deterministic models are simple mathematical formulations -which include the sum products of the expected profits of each product-, RFM (recency-monetary-frequency) models and data mining models. In RFM models, some scores are given according to the Recency-Frequency-Monetary values of the prior purchases of the customers (also some weights may be used to create scores) (Shih and Liu 2003). Bult and Wansbeek (1995) explain recency as the time period since the last purchase, frequency as the number of purchases made within a certain time period, monetary value as the amount of Money spent during a certain time period. The main disadvantage of these models is that they do not give a dollar value, they give a score (Gupta et al. 2006). Donkers et al. (2007) tried to estimate CLV of an insurance company via several data mining models. For all models, CLV for each customer is computed for a 4-year time horizon. They consider models at two levels: (1) relationship-level models and (2) service-level models. The relationship-level models focus on relationship length and total profits while the service-level models disaggregate a customer's profit into the contribution per service. The relationship-level models do not explicitly model buying behaviour of individual services as service-level models do, but rather consider retention and total profits aggregated across services. They measured the performance of their models based on classifying the customers into "most-profitable" and "least-profitable" customers. Malthouse and Blattberg (2005) tried to answer the central empirical question, via linear regression and Artificial Neural Networks, whether a customer's profitability can be estimated over some long period of time. They evaluated the performance of their models according to R^2 and a measure that is based on classification table. The main assumption of their performance measure is ranking the customers from best to worst based on their profit values. The 20 % with the largest predicted values are assigned "best-customer" status while the bottom 80 percent are assigned "worst-customer" status. They propose the 20–55 and 80–15 rules: Of the top 20 %, approximately 55 % will be misclassified and of the future bottom 80 %, approximately 15 % will be misclassified. Similar to the study of Malthouse and Blattberg (2005), Benoit and Van den Poel (2009) also used regression models to forecast the CLVs of a financial services company and showed that quantile regression outperformed the traditional regression on both absolute predictive performance and the ordering based predictive performance. The study presented that the smaller the top segment of interest, the better was the performance of quantile regression compared to least-squares solutions (Benoit and Van den Poel 2009). A similar study which belongs to Lariviere and Van den Poel (2005), analyzes a real-life sample of 100,000 customers taken from the data warehouse of a large European financial services company. Two types of random forest techniques are employed to analyze the data: random forests are used for binary classification, whereas regression forests are applied for the models with linear dependent variables. Their findings suggest that past customer behavior is important to generate repeat purchasing and favorable profitability evolutions.

Data mining models are found efficient since they use many variables at one time and see the effect of each variable. The existing literature shows that for predicting future profitability, simple methods tend to perform better than the complicated ones (Rust et al. 2011; Donkers et al. 2007). Therefore this study also aims to use simple regression in order to forecast the customer profitability values (in $). It is observed that the previous studies firstly try to forecast the profitability values of the customers and use these values for predicting their segments. Due to the necessity and high interest in segment-based customer relationship management, predicting the potential segment of the customer is seen important (Donkers et al. 2007 and Malthouse and Blattberg 2005). In order to fill a gap in the literature, this study proposes directly predicting the segments of the customers with some basic classification algorithms. The study takes the customer's annual profit value and corresponding profitability class as the dependent variables and many other properties of the customer as explanatory variables. Thus, it uses the explanatory variables to predict the customer profitability value or class for each customer.

The design and development of models, such as machine learning and data mining algorithms can allow the system to learn to recognize complex patterns based on the training data, and then make intelligent predictions for test data or real-world data, based on the learned models (Su and Khoshgoftaar 2009). By this way, an intelligent prediction system for CP is developed, which uses the data in the CRM system. This intelligent prediction system's results are used for making decisions for customers by the CRM system, as well.

20.3 Methodology

Due to the reasons explained in the introduction part, and the inefficiency of using Eq. 20.1 in practice, this study proposes to make the prediction of CLV for a short time period, namely 1 year. The alternative models used in this study can be grouped in two main titles: value-based models and classification-based models.

Value-based models include linear regression models which are often used in the studies in the literature. For the experiments generated in this study, linear regression models are also built for some portion of the data since the profitability of the whole population is not distributed normally. The performances of the models are measured for the true separation of most-least profitable customers. This point is the main motivation for us to predict the segments.

In this study, linear regression technique is used to predict customers' annual profit value. Since regression models are generally used for predicting a continuous dependent variable, in this study linear regression with original dependent variable (profit gained from the customer) and the logarithm of it are used. Logistic Regression, Classification and Regression Tree (CRT), and CHAID are used to classify the customers into the classes that are predetermined according to their profitabilities. *Cost sensitive classification* analysis by using CRT and CHAID are also performed (cost sensitive version of logistic regression was not available in the commercial software we used in our study). The reason for utilizing *cost sensitive classification* is that, misclassification of some classes are more important (Weiss et al. 2013; Min et al. 2011). Therefore, the penalty of misclassifying those segments must be higher. In the following sub-sections the methodological underpinnings of these techniques and the evaluation criteria that will be used to investigate their performance are presented.

20.3.1 Linear Regression

Simple linear regression describes the linear relationship between a predictor variable, plotted on the *x*-axis, and a response variable, plotted on the *y*-axis (Cohen et al. 2003). The technique includes an approach to model the relationship between a scalar variable *y* and one or more variables denoted as *x*. This approach is usually the Least Squares Estimation, which chooses estimates that minimize the sum of squared errors (*SSE*) of observed values with respect to the least-squares straight line. The general formulation of linear regression is given in Eq. 20.2. If $\beta_1 > 0$, then there is a positive association between the predictor and the target value; if $\beta_1 < 0$, then there is a negative association, and if it is zero, there is no association.

$$Y = \beta_0 + \beta_1 x + \varepsilon \qquad \varepsilon \sim N(0, \sigma) \tag{20.2}$$

20.3.2 Logistic Regression

Given a training set of N data points $D = \{(x_i, y_i)\}_{i=1}^{N}$, with input data x_i € R^n and corresponding binary class labels y_i € {0, 1}, the logistic regression approach to classification tries to estimate the probability $P(y = 1|x)$ as follows:

$$p(y = 1|x) = \frac{1}{1 + \exp(-(w_o + w^T x))} \tag{20.3}$$

where x € R^n is an n-dimensional input vector, w is the parameter vector and the scalar w_0 is the intercept. The parameters w_0 and w are then typically estimated using the maximum likelihood procedure (Duman et al. 2012). If the classification is not binary and there are more than two classes, then this is called multiple logistic regression (Giraud-Carrier and Povel 2003).

20.3.3 Classification and Regression Tree (CRT)

CRT is a recursive partitioning method to be used both for regression and classification. CRT is constructed by splitting subsets of the data set using all predictor variables to create two child nodes repeatedly, beginning with the entire data set. The best predictor is chosen using a variety of impurity or diversity measures (Gini, twoing, ordered twoing and least-squared deviation) (Ture et al. 2009). The goal is to produce subsets of the data which are as homogeneous as possible with respect to the target variable (Breiman et al. 1984).

20.3.4 Chi-squared Automatic Interaction Detector

CHAID (Chi-squared Automatic Interaction Detector) is a highly efficient statistical technique developed by Kass (1980). CHAID method is based on the χ^2 test of association. A CHAID tree is a decision tree that is constructed by repeatedly splitting subsets of the space into two or more child nodes, beginning with the entire data set. To determine the best split at any node, any allowable pair of categories of the predictor variables is merged until there is no statistically significant difference within the pair with respect to the target variable (Ture et al. 2009). The statistical test used depends upon the measurement level of the target field. If the target field is continuous, an F test is used. If the target field is categorical, a chi-squared test is used.

20.3.5 Evaluation Criteria

The performances of the models are measured by true prediction of the classes of most-least profitable customers. The customers are divided into 4 classes according to their profit values, unlikely the general segmentation of 2 classes (see Malthouse and Blattberg 2005 and Donkers et al. 2007) and the performance of the models are calculated by hit and capture rates which give us an opinion of the success of the

Table 20.2 Example chart

		Predicted			
		Class 1	Class 2	Class 3	Class 4
Actual	Class 1	True	False	False	False
	Class 2	False	True	False	False
	Class 3	False	False	True	False
	Class 4	False	False	False	True

models in putting the customers in the true classes. The table is generated as in the example chart (see Table 20.2) where the columns include predicted classes and rows include actual classes. Class 1 is the most profitable class and Class 4 is the least profitable class.

The models which are developed in this study are compared according to the capture, hit and lift rates. Capture and lift rates are firstly proposed to use as performance measures in CLV studies by us, while hit rate was previously used in the studies of Donkers et al. (2007) and Malthouse and Blattberg (2005).

Hit rate, which is also known as precision, is the number of correctly classified Class X examples divided by the number of examples labeled by the model as Class X (Duman et al. 2012):

$$Hit\,rate = TrueClassX/(TrueClassX + FalseClassX) \qquad (20.4)$$

Capture rate, also known as recall or sensitivity, is the number of correctly classified Class X examples divided by the number of Class X examples in the data. This rate determines the effectiveness of a classifier to identify Class X labels (Duman et al. 2012):

$$Capture\,rate = TrueClassX/(TrueClassX + FalseClassesExceptforX) \qquad (20.5)$$

Lift rate is based on the model's performance on predicting truly the Class (X) customers of this year who were in another class in the previous year.

$$Lift\,rate = TrueClassX_{thisyear}/\left(TrueClassesExceptforX_{previousyear}\right) \qquad (20.6)$$

Hit, capture and lift rates are selected in this study for performance measure since they are mostly used in the literature for classification models.

20.3.5.1 Proposed Performance Evaluation

There is a question that should be answered: "What is the best model?". In these types of studies, "best model" is defined as the model showing the best performance. The models are compared according to the capture and hit rates where the higher the rate the better the performance of the model is. Another question that should be answered is about the use of the model. The short answer to this question is that banks will use the best model developed here to predict their customers' future profitability segments and using this they will develop some marketing strategies to address different customer segments using this information.

Following the industry experience, this study evaluates the performance of the models in predicting the correct class of customers who belong to Class 1 and Class 2, which are the most profitable customer classes. There are two reasons for this decision. Firstly, companies should make some investments to retain these customers, therefore if the company does not make any investment to a customer who is potentially a Class 1 or 2 customer, the customer may churn. Secondly, if the customer invests on customers who do not have a potential of being a Class 1 or 2 customer, this will lead to misuse of the scarce resources of the company. These facts are also the reasons of utilizing cost sensitive classification analysis.

The companies should consider any of the performance criteria explained above according to their aims. Moreover, they can also take the averages of the hit and capture rate values and use the model which has the highest average value. *Lift* rate can also be used to select the best model which is based on the model's performance on predicting truly the Class 1(2) customers of this year who were not Class 1(2) in the previous year.

20.3.6 Cost Sensitive Classification Analysis

The misclassification costs for the classification-based models should be defined according to the aims of the companies. The basic approach could be taking the costs symmetrical. Based on this idea, a cost matrix is produced by giving misclassification cost 1 to the nearest cell and 3 to the furthest cell which is given in Table 20.3.

Another aim, which is defended by this study is increasing the number of correctly classified *Class 1* and *Class 2* customers. Therefore, the misclassification cost matrix should include higher costs on the upper side of the diagonal. Based on this idea, another cost matrix is produced by increasing the costs given in Table 20.3 by five times (see Table 20.4). The asymmetrical misclassification cost matrix will increase especially the capture rate of the models for Class 1 and Class 2.

Table 20.3 Misclassification costs matrix—symmetrical

		Predicted			
		Class 1	Class 2	Class 3	Class 4
Actual	Class 1	0	1	2	3
	Class 2	1	0	1	2
	Class 3	2	1	0	1
	Class 4	3	2	1	0

Table 20.4 Misclassification costs matrix—asymmetrical

		Predicted			
		Class 1	Class 2	Class 3	Class 4
Actual	Class 1	0	5	10	15
	Class 2	1	0	5	10
	Class 3	2	1	0	5
	Class 4	3	2	1	0

20.4 Empirical Study

20.4.1 The Structure of the Data

A major Turkish bank provided us the data of a randomly selected 10.000 customers. Their data warehouse stores detailed information about customers' banking transactions. A sample of 3030 customers with their values of dependent/independent variables is selected from the data warehouse.

The aim is to forecast the profitability of the customers of year 2009, using the variables of year 2008 (variables' values have been calculated periodically in monthly basis and stored in data marts). The average values of the variables and the annual profit values for years 2008 and 2009 are calculated. The profit value of year 2009 is the dependent variable for the regression model while other variables are selected as independent variables. For the classification methods, the dependent variable is the profitability class. Due to confidentiality reasons, the exact names of the independent variables can not be given but the group names of them are; types of products, number of products, number of product groups, number of new products, product usage behaviour, total assets, values of the specific services used by the customer (checking and saving accounts, wire transfers, credit cards, loans etc.) in local currency, value of them in foreign currencies, risk of default of loan payments (loans and credit cards), the total value of the salary payments, the number of active product groups owned, the number of active products owned.

Since the aim of this study is to forecast future profitability classes of customers and the years under concern are 2008 and 2009, the migration matrix of customers between 2008 and 2009 is derived. The reason for deriving this matrix is to use it as benchmark in evaluating the alternative models. The migration matrix includes the ratios of being in a class in 2009 given that the customer was in a class in 2008. The classes are generated based on the customer pyramid approach. Approximately the most profitable top 3 % of the customers are labeled as Class 1, 20 % as Class 2, 23 % as Class 3 and 54 % as Class 4. The left panel of Table 20.5 shows the capture rates while the right panel displays the hit rates for the migrations from year 2008 to 2009.

According to Table 20.5 note that 62.8 % of the 2009 Class 1 customers were Class 1 in 2008, too. Additionally, 54.6 % of the 2008 Class 1 customers were retained in 2009. Similarly 61.7 % of the Class 2 customers were retained in the next year. Thus, if the bank decides to develop a strategy based on the idea that the

Table 20.5 The migration matrix including the ratios of transitions between classes based on the years 2008 and 2009

	Migration from 2009 to 2008				Total (%)	Migration from 2008 to 2009			
	2008 Class 1 (%)	2008 Class 2 (%)	2008 Class 3 (%)	2008 Class 4 (%)		2008 Class 1 (%)	2008 Class 2 (%)	2008 Class 3 (%)	2008 Class 4 (%)
2009 Class 1	62.8	26.6	7.4	3.2	100	54.6	4.1	1.0	0.2
2009 Class 2	5.4	59.2	26.0	9.4	100	31.5	61.7	22.7	3.7
2009 Class 3	0.9	19.6	47.3	32.2	100	5.6	22.0	44.3	13.7
2009 Class 4	0.6	4.5	14.3	80.7	100	8.3	12.2	32.0	82.4
Total						100	100	100	100

Class 1 customers will continue to be Class 1 next year, it makes a 45.4 % of error and similarly if it assumes that Class 2 customers will be again Class 2, it makes a 38.3 % of error. This point will be of use while evaluating the performance of the developed models.

20.4.2 Experimental Results

In order to build value-based models, dependent variable values are analyzed. When the descriptives of the dependent variable is analyzed, it is seen that skewness is far from 0,000 and kurtosis is under 3,000 which means that the data is not distributed normally. The dataset includes very small and very high values and there are outliers. For the experiments generated in this study, linear regression models are built both for the whole data and for some modified data since the whole data is not distributed normally. Therefore, it is decided to remove some outlier values and the percentiles table (see Table 20.6) is derived. If the outliers are not removed, high R^2 is found but a careful eye can see that the predicted values do not match with the true values.

For the value-based models, different regressions are also run by capping the top percentiles. Since the data is not distributed normally and there is a great number of customers who have $0.000 of annual profitability, capping the high profit values - which are outliers- is seen as an approach to make the structure of the data more normal. While applying this approach, it was considered that 10 % of the data are at the lowest end and therefore an approximate percentage of the highest end is taken for capping. The cut points are taken as $900 (a value between 90–95 %-RM1),

Table 20.6 Percentiles about 2009 customer profit values of customer

	Percentiles						
	5	10	25	50	75	90	95
Customer profit 2009	0.00	0.00	0.98	52.78	232.98	572.86	932.75

Table 20.7 Performance values of the regression based models

		Capture				Hit			
Model type	R^2 value	Predicted							
		Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)	Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)
RM1	R^2: 0.537								
Actual	Class 1	50.0	39.4	6.4	4.3	50.0	5.9	0.9	0.2
	Class 2	6.2	62.5	22.7	8.6	41.5	62.5	21.1	3.3
	Class 3	0.7	21.7	46.5	31.1	5.3	23.3	46.5	13.0
	Class 4	0.2	3.2	13.1	83.5	3.2	8.3	31.6	83.5
RM2	R^2: 0.008								
Actual	Class 1	37.2	45.7	8.5	8.5	37.2	6.8	1.2	0.5
	Class 2	7.8	59.2	21.4	11.6	52.1	59.2	19.9	4.5
	Class 3	1.5	24.9	46.5	27.1	10.6	26.8	46.5	11.3
	Class 4	0.0	2.8	13.5	83.7	0.0	7.1	32.4	83.7
RM3	R^2: 0.498								
Actual	Class 1	54.3	35.1	6.4	4.3	54.3	5.2	0.9	0.2
	Class 2	5.7	63.5	21.7	9.0	38.3	63.5	20.2	3.5
	Class 3	0.6	20.5	48.7	30.2	4.3	22.1	48.7	12.6
	Class 4	0.2	3.6	12.6	83.7	3.2	9.2	30.2	83.7
RM4	R^2: 0.466								
Actual	Class 1	53.2	36.2	6.4	4.3	53.2	5.4	0.9	0.2
	Class 2	6.0	62.7	21.9	9.4	40.4	62.7	20.4	3.6
	Class 3	0.4	20.8	47.5	31.3	3.2	22.4	47.5	13.0
	Class 4	0.2	3.7	13.0	83.1	3.2	9.5	31.3	83.1
RM5	R^2: 0.821								
Actual	Class 1	51.1	37.2	6.4	5.3	51.1	5.6	0.9	0.3
	Class 2	5.4	55.4	24.1	15.1	36.2	55.4	22.4	5.8
	Class 3	1.0	19.9	39.7	39.4	7.4	21.4	39.7	16.4
	Class 4	0.3	6.8	15.4	77.5	5.3	17.6	37.0	77.5

$2000 (RM3) and $3200 (RM4) (these two points are determined in order not to exclude the customers from class 1). Moreover, in order to compare the performances of these models, the original data (RM5) and the logarithm of the original dependent variable (RM2) are also used to develop additional regression models. For all of the models (value-based and classification-based models), 70 % of the data is taken as the train set and 30 % as the test set. The results in Tables 20.7 and 20.8 are given for the test set.

Tables 20.7 and 20.8 include the capture and hit rates on the test set. Table 20.7 gives the results of the regression based models while Table 20.8 gives the results of the classification based models. Seven classification models are built for prediction. LR (Logistic Regression), CRT (Classification and Regression Tree), and CHAID are used in first three models in Table 20.8 (CM1, CM2, CM3). CRT and

Table 20.8 Performance values of the classification based models

Model type		Capture				Hit			
		Predicted							
CM1:LR		Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)	Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)
Actual	Class 1	45.7	44.7	3.2	6.4	**75.4**	7.1	0.5	0.3
	Class 2	1.9	63.5	21.6	13.0	21.1	67.5	22.2	4.6
	Class 3	0.0	16.8	47.8	35.4	0.0	19.2	52.9	13.6
	Class 4	0.1	2.3	9.2	88.4	3.5	6.2	24.5	81.4
CM2:CRT									
Actual	Class 1	56.4	26.6	6.4	10.6	61.6	5.0	0.9	0.6
	Class 2	3.3	54.8	27.3	14.6	24.4	**68.5**	24.9	5.3
	Class 3	0.7	14.5	49.4	35.4	5.8	19.4	48.4	13.7
	Class 4	0.4	2.2	11.0	86.4	8.1	7.1	25.9	80.4
CM3:CHAID									
Actual	Class 1	62.8	25.5	4.3	7.4	54.6	4.5	0.7	0.4
	Class 2	5.4	55.7	25.4	13.5	31.5	66.2	26.2	4.8
	Class 3	0.9	17.7	46.6	34.8	5.6	22.6	51.7	13.3
	Class 4	0.6	2.1	8.0	**89.3**	8.3	6.6	21.4	81.6
Cost sensitive classification based models (symmetrical cost matrix)									
MCM1:CRT									
Actual	Class 1	41.5	48.9	4.3	5.3	75.0	6.8	0.6	0.3
	Class 2	1.6	64.8	23.5	10.2	19.2	60.2	22.9	3.9
	Class 3	0.3	21.4	51.0	27.3	3.8	21.4	53.6	11.2
	Class 4	0.1	4.9	9.0	86.1	1.9	11.7	22.8	84.7
MCM2:CHAID									
Actual	Class 1	27.7	62.8	4.3	5.3	60.5	9.5	0.6	0.3
	Class 2	2.1	60.5	27.3	10.2	30.2	61.7	25.3	3.8
	Class 3	0.3	18.4	50.7	30.5	4.7	20.2	50.5	12.3
	Class 4	0.1	3.3	9.9	86.7	4.7	8.6	23.6	83.6
Cost sensitive classification based models (asymmetrical cost matrix)									
MCM3:CRT									
Actual	Class 1	52.1	45.7	0.0	2.1	71.0	2.6	0.0	0.2
	Class 2	2.1	**92.2**	0.5	5.2	18.8	34.8	5.4	2.7
	Class 3	0.4	84.4	3.2	11.9	4.3	34.3	39.3	6.6
	Class 4	0.2	29.1	1.9	68.8	5.8	28.3	55.4	90.6
MCM4:CHAID									
Actual	Class 1	**68.1**	25.5	4.3	2.1	44.8	1.9	0.8	0.2
	Class 2	9.8	79.7	6.8	3.7	43.4	40.5	8.8	2.0
	Class 3	1.0	63.6	25.7	9.7	4.9	34.8	35.7	5.7
	Class 4	0.6	17.3	16.3	65.7	7.0	22.8	54.6	92.2

[a]**Bold** numbers are the highest ratios in the column

CHAID are also employed by using misclassification costs. Results of these models with symmetrical misclassification costs matrix are given by MCM1 and MCM2 while with asymmetrical costs matrix are given by MCM3 and MCM4.

Tables 20.7 and 20.8 show that hit rates are generally higher than capture rates except for MCM3 and MCM4. For MCM3 and MCM4 the use of asymmetrical cost matrices has increased the capture rates as intended. An illustration of the calculations is given in Table 20.9. The illustration is generated using the model results for CRT with misclassification costs (MCM1). As an example; the capture rate 41.5 % is calculated as: 39/94 (which is the number of correctly classified Class 1 examples divided by the actual number of Class 1 examples in the data). On the other hand, the hit rate of the same cell is calculated as 39/52 = 0.750 (which is the number of correctly classified Class 1 examples divided by the number of examples labeled by the model as Class 1). It is apparent that the classification model labeled fewer number of customers as Class 1 (the model labeled 52 customers as Class 1 where the actual data includes 94 Class 1 customers). This fact resulted in higher value of hit rate compared to capture rate. Therefore, high hit rate does not always mean a better model since the denominator is usually small like in this situation. However, the companies might consider both of the performance criteria to meet their special objectives. For instance, if the company has a small budget but wants to obtain a high success rate a model with a high hit rate would be more useful. On the other hand, if the company is willing to spend more money but turn as many customers as possible into Class 1, then it should use the model which has a higher capture rate.

Another result which can be seen from Tables 20.7 and 20.8 is that, although the R^2 of the model developed by using the original data is higher than the other regression models, both capture and hit rates belonging to Class 1 and 2 are the worst ones (there is only one exception to this: hit rate of class 1 for RM1 is 0.500 while it is 0.511). An obvious result that can be derived from the results table is that classification-based models are superior to the regression-based models (see the **bold** written numbers in Tables 20.7 and 20.8). According to capture rate, the CHAID model which was run with misclassification costs (MCM4:CHAID) given in Table 20.8 is the best model for Class 1 and the CRT model with the same misclassification costs (MCM3:CRT) is the best model for Class 2. This result is obtained sine the costs assigned to misclassifying Class 1and Class 2 customers are higher. This increases the number of predicted Class 1 and Class 2 customers. however, the hit rates of the models that use these misclassifcation costs are lower compared to others.

Referring to Table 20.5, it was mentioned that, if the bank decided to develop a strategy based on the idea that the Class 1 customers would be again Class 1 next year, it would miss 45.4 % of the actual Class 1 customers of next year, whereas the corresponding percentage for Class 2 is 38.3 %. However, if the bank decides to develop a strategy based on the best model (MCM4:CHAID), the bank will miss 31.9 % of the actual Class 1 customers, which is lower than 45.4 %. Similarly, it will miss 7.8 % of the actual Class 2 customers, which is lower than 38.3 % (if

Table 20.9 An illustration of the calculations of capture and hit rates for MCM1

	Number of customers predicted as												
	Class 1	Class 2	Class 3	Class 4	Actual total	Capture (%)				Hit (%)			
Actual Class 1	39	46	4	5	94	41.5	48.9	4.3	5.3	75	6.8	0.6	0.3
Actual Class 2	10	408	148	64	630	1.6	64.8	23.5	10.2	19.2	60.2	22.9	3.9
Actual Class 3	2	145	346	185	678	0.3	21.4	51.0	27.3	3.8	21.4	53.6	11.2
Actual Class 4	1	79	147	1401	1628	0.1	4.9	9.0	86.1	1.9	11.7	22.8	84.7
Predicted total	52	678	645	1655	3030								

Table 20.10 Comparison of actual 2008–2009 customer profitability classes and predicted 2009 Customer profitability classes

	Actual 2009 Class 1					Actual 2009 Class 2				
	Predicted 2009 Class 1	Predicted 2009 Class 2	Predicted 2009 Class 3	Predicted 2009 Class 4	Actual 2009 Class 1 Total	Predicted 2009 Class 1	Predicted 2009 Class 2	Predicted 2009 Class 3	Predicted 2009 Class 4	Actual 2009 Class 2 Total
CM1:LR										
2008 Class 1	43	16			59	11	23			34
2008 Class 2		25			25	1	341	25	6	373
2008 Class 3		1	3	3	7		**35**	100	29	164
2008 Class 4				3	3		**1**	11	47	59
Total	43	42	3	6	94	12	400	136	82	630
CM2:CRT										
2008 Class 1	53	5		1	59	21	11		2	34
2008 Class 2		20	1	4	25		334	16	23	373
2008 Class 3			4	3	7			138	26	164
2008 Class 4			1	2	3			18	41	59
Total	53	25	6	10	94	21	345	172	92	630
MCM3:CRT										
2008 Class 1	49	10			59	13	21			34
2008 Class 2		25			25		372		1	373
2008 Class 3		6		1	7		**156**		8	164
2008 Class 4		2		1	3		**32**	3	24	59
Total	49	43		2	94	13	581	3	33	630
MCM4:CHAID										
2008 Class 1	59				59	34				34
2008 Class 2	**5**	20			25	28	345			373

(continued)

Table 20.10 (continued)

	Actual 2009 Class 1					Actual 2009 Class 2				
	Predicted 2009 Class 1	Predicted 2009 Class 2	Predicted 2009 Class 3	Predicted 2009 Class 4	Actual 2009 Class 1 Total	Predicted 2009 Class 1	Predicted 2009 Class 2	Predicted 2009 Class 3	Predicted 2009 Class 4	Actual 2009 Class 2 Total
2008 Class 3		4	3		7		**133**	27	4	164
2008 Class 4			1	2	3		**24**	16	19	59
Total	64	24	4	2	94	62	502	43	23	630

	Actual 2009 Class 3					Actual 2009 Class 4					General total—2008 Class
	Predicted 2009 Class 1	Predicted 2009 Class 2	Predicted 2009 Class 3	Predicted 2009 Class 4	Actual 2009 Class 3 Total	Predicted 2009 Class 1	Predicted 2009 Class 2	Predicted 2009 Class 3	Predicted 2009 Class 4	Actual 2009 Class 4 Total	
CM1:LR											
2008 Class 1		6			6	2	5		2	9	108
2008 Class 2		92	37	4	133		32	18	24	74	605
2008 Class 3		16	229	76	321			81	151	232	724
2008 Class 4			58	160	218			51	1262	1313	1593
Total		114	324	240	678	2	37	150	1439	1628	3030
CM2:CRT											
2008 Class 1	5	1			6	7	1		1	9	108
2008 Class 2		97	21	15	133		35	8	31	74	605
2008 Class 3			243	78	321			112	120	232	724
2008 Class 4			71	147	218			59	1254	1313	1593
Total	5	98	335	240	678	7	36	179	1406	1628	3030

(continued)

Table 20.10 (continued)

	Actual 2009 Class 3					Actual 2009 Class 4					General total—2008 Class
	Predicted 2009 Class 1	Predicted 2009 Class 2	Predicted 2009 Class 3	Predicted 2009 Class 4	Actual 2009 Class 3 Total	Predicted 2009 Class 1	Predicted 2009 Class 2	Predicted 2009 Class 3	Predicted 2009 Class 4	Actual 2009 Class 4 Total	
MCM3:CRT											
2008 Class 1	3	3			6	4	5			9	108
2008 Class 2		133			133		73		1	74	605
2008 Class 3		307		14	321		155		77	232	724
2008 Class 4		129	22	67	218		240	31	1042	1313	1593
Total	3	572	22	81	678	4	473	31	1120	1628	3030
MCM4:CHAID											
2008 Class 1	6				6	9				9	108
2008 Class 2	1	132			133	1	73			74	605
2008 Class 3		228	85	8	321		82	101	49	232	724
2008 Class 4		71	89	58	218		127	165	1021	1313	1593
Total	7	431	174	66	678	10	282	266	1070	1628	3030

MCM3:CRT is used). These figures give us an idea about the successfulness of the developed models.

When hit rate is considered, CM1:LR is seen as superior to others for Class 1 and CM2:CRT is seen as superior for Class 2. Thus, if the bank uses the model which gives the highest rate for Class 1 and targets them, among these customers 24.6 % are not (natural) actual Class 1 customers. Similarly, if the bank uses the model which gives the highest rate for Class 2 and targets them, among these customers 31.5 % are not (natural) actual Class 2 customers. When coupled with a campaign it is very likely that the hit rates will be even higher.

In order to compare the four best models based on the hit and capture rates, the analysis of migration of customers between 2008 and 2009 is also added utilizing *lift rate* as a third performance measure. Table 20.10 includes in its cells the numbers of customers who were in Class X in 2008 and in Class Y in 2009 and predicted as Class Z by the models, namely CM1:LR, CM2:CRT, MCM3:CRT and MCM4:CHAID. The basic idea here is to find the best model that can predict truly the Class 1(2) customers of 2009 who were not Class 1(2) in 2008. It is easy to predict the Class 1(2) customers of 2009 who were also Class 1(2) in 2008 (and the bank will continue providing better services to them), the main challenge is predicting the ones who were in some other Classes in 2008. Following this idea, it is seen from Table 20.10 that, only MCM4:CHAID was able to accomplish the objective for Class 1. It predicted truly 5 customers who were Class 2 in 2008 but became Class 1 in 2009. Similarly CM1:LR, MCM3:CRT and MCM4:CHAID predicted truly 36 (35 + 1), 188(156 + 32) and 157(133 + 24) customers respectively who were Class 3 and/or Class 4 in 2008 but became Class 2 in 2009. MCM3:CRT performs better for Class 2. This discussion motivates us to propose *lift* as a performance measure. *Lift* is proposed as a performance criteria in this area firstly by this study. Therefore, it will be beneficial to explain the usage of it by giving some examples for a model. For instance, for Model MCM4:CHAID, from a total of 25 customers who upgrade to Class 1 from Class 2, the model was able to predict 5 of them. So the hit rate is 5/25 = 20 %. On the other hand 25 out of 605 (or, 4 per cent) of class 2 customers were upgraded to class 1 in the next year. Thus, the lift is 20 %/4 % = 5 times. Similarly, from the 164 customers who upgrade from Class 3 to Class 2 this model predicted 133 of them, so the hit ratio is 133/164 = 81 %. On the other hand 164 customers out of 724 upgrade from Class 3 to Class 2 which gives the ratio 164/724 = 23 %. Here the lift is 81 %/23 % = 3.52. If the lift is considerably greater than 1 (which is the case here), the model can be treated as making a good job.

20.5 Conclusions and Future Research Directions

This study tries to develop an intelligent customer profitability prediction model to be embedded in an intelligent CRM system, so that the CRM system will be able to make decisions and apply them automatically. In order to predict the profitabilities of the customers of a Turkish bank; alternative models, namely value-based models and classification-based models are compared. It has been found that classification based models outperform the others. Value-based models include linear regression models and firstly try to forecast the profitability values of the customers and then determine the profitability segments of them, similar to the previous studies. CRT, LR and CHAID with and without misclassification costs are used for classification based models. These models predict the segments of the customers directly, which is firstly proposed in this paper for CLV analysis. The performances of the models used to be measured for the true separation of most-least profitable customers in the previous studies, while we propose a customer pyramid approach, which includes 4 profitability classes. The main conclusions that can be derived from this paper and the main contributions to the literature are given below:

1. CLV is formulized as "Customer profitability in 1 year/Churn probability" in this paper, which is a contribution to the literature.
2. To the best of our knowledge, this study is the first one that uses classification-based models for predicting directly the customer profitability segments. Moreover, it is seen from the empirical results that they outperform the classically used value-based models.
3. The models which are developed in this study are compared according to the capture, hit and lift rates. Capture and lift rates are firstly proposed to be used as performance measures in these types of studies by us, while hit rate was used in previous studies. The companies should consider any of the performance criteria according to their special objectives. However, if they are indifferent between them, they can use the model which has the highest rate after taking the averages of the hit and capture rate values. Another idea is to select the best model according to the model's performance on predicting truly the Class 1(2) customers of this year who were not Class 1(2) in the previous year, which is also called *lift* (see Table 20.10).
4. Cost-sensitive classification analysis is also utilized for the classification-based models. The models are run with both symmetrical and asymmetrical misclassification cost matrices. Models which use asymmetrical misclassification cost matrix, where the aim is to increase the number of correctly classified *Class 1* and *Class 2* customers, outperform the other models when capture rate is considered as performance measure.
5. The evaluation of models benchmarking on the migration matrix is also firstly proposed in this study.

The performance evaluation methods and the forecast models proposed in this study will give insightful directions to the researchers and practitioners who study in this area. Especially proposed performance measures and cost-sensitive classification based models (rather than classical value-based models) are important contributions to both literature and practice. However, the value of the study can be increased in a future study where models which make predictions for a longer time period are developed.

References

Ammar, S., Moore, D., Wright, R.: Analysing customer satisfaction surveys using a fuzzy rule-based decision support system: enhancing customer relationship management. J. Database Mark. Customer Strategy Manage. **15**, 91–105 (2008)

Au, W.H., Chan, K.C.: Mining fuzzy association rules in a bank-account database. IEEE Trans. Fuzzy Syst. **11**(2), 238–248 (2003)

Audzeyeva, A., Summers, B., Schenk-Hoppé, K.R.: Forecasting customer behaviour in a multi-service financial organisation: a profitability perspective. Int. J. Forecast. **xx**, xx–xx (article in press) (2012)

Baxter, N., Collings, D., Adjali, I.: Agent-based modelling—intelligent customer relationship management. BT Technol. J. **21**(2), 126–132 (2003)

Benoit, D.F., Van den Poel, D.: Benefits of quantile regression for the analysis of customer lifetime value in a contractual setting: an application in financial services. Expert Syst. Appl. **36**, 10475–10484 (2009)

Breiman, L., Friedman, J.H., Olshen, R.A., Stone, C.J.: Classification and Regression Trees. Wadsworth and Brooks/Cole, Montery (1984)

Bult, J.R., Wansbeek, T.J.: Optimal selection for direct mail. Mark. Sci. **14**(4), 378–394 (1995)

Cao, Y., Li, Y.: An intelligent fuzzy-based recommendation system for consumer electronic products. Expert Syst. Appl. **33**(1), 230–240 (2007)

Chan, C.C.H.: Intelligent value-based customer segmentation method for campaign management: a case study of automobile retailer. Expert Syst. Appl. **34**(4), 2754–2762 (2008)

Cohen, J., Cohen, P., West, S.G., Aiken, L.S.: Applied multiple regression/correlation analysis for the behavioral sciences, 2nd edn. Lawrence Erlbaum Associates, Hillsdale (2003)

Donkers, B., Verhoef, P.C., de Jong, M.G.: Modeling CLV: a test of competing models in the insurance industry. Quant. Mark. Econ. **5**, 163–190 (2007)

Duman, E., Ekinci, Y., Tanrıverdi, A.: Comparing alternative classifiers for database marketing: the case of imbalanced datasets. Expert Syst. Appl. **39**, 48–53 (2012)

Dwyer, F.R.: Customer lifetime valuation to support marketing decision making. J. Direct Mark. M **4**, 6–13 (1997)

Fangming, Z., Steven, G.: Feature selection for modular GA-based classification. Appl. Soft Comput. **14**, 381–393 (2004)

Francesco, M.: Feature selection based on a modified fuzzy c-means algorithm with supervision. Inf. Sci. **151**, 201–226 (2003)

Giraud-Carrier, Povel, O.: Characterising data mining software. Intell. Data Anal. **7**(3), 181–192 (2003)

Guo, L., Zhang, M., Sun, L., Wang, Z.: Fuzzy clustering model of CRM in securities trade. In: The Sixth World Congress on Intelligent Control and Automation, 2006. WCICA 2006, vol. 2, pp. 6052–6054. IEEE (2006)

Gupta, S., Hanssens, D., Hardie, B., Kahn, W., Kumar, V., Lin, N., Ravishanker, N., Sriram, S.: Modeling customer lifetime value. J. Serv. Res. **9**(2), 139–150 (2006)

Gurau, C., Ranchhod, A.: How to calculate the value of a customer–measuring customer satisfaction: A platform for calculating, predicting and increasing customer profitability. J. Target. Meas. Anal. Mark. **10**(3), 203–220 (2002)

Haenlein, M., Kaplan, A., Beeser, A.: A model to determine customer lifetime value in a retail banking context. Eur. Manage. J. **25**(3), 221–234 (2007)

Hopgood, A.A.: Intelligent Systems for Engineers and Scientists. CRC Press, Boca Raton (2012)

Jain, D., Singh, S.S.: Customer lifetime value research in marketing: a review and future directions. J. Interact. Mark. **16**(2), 34–45 (2002)

Jonker, J.J., Piersma, N., Van den Poel, D.: Joint optimization of customer segmentation and marketing policy to maximize long-term profitability. Expert Syst. Appl. **27**(2), 159–168 (2004)

Kass, G.V.: An exploratory technique for investigating large quantities of categorical data. Appl. Stat. **29**(2), 119–127 (1980)
Kaufmann, M., Graf, C.: Fuzzy target groups in analytic customer relationship management. In: Meier, A., Donzé, L. (eds.) Fuzzy Methods for Customer Relationship Management and Marketing: Applications and Classifications, pp. 168–192. IGI Global, Hershey (2012)
Khobzi, H., Akhondzadeh-Noughabi, E., Minaei-Bidgoli, B.: A new application of rfm clustering for guild segmentation to mine the pattern of using banks' e-payment services. J. Global Mark. **27**(3), 178–190 (2014)
Kim, Y.S., Street, W.N.: An intelligent system for customer targeting: a data mining approach. Decis. Support Syst. **37**(2), 215–228 (2004)
Kunder, C., Bhat, D., Kotian, H.: Decision support system for telecom company. Int. J. Comput. Eng. Technol. **5**(1), 103–111 (2014)
Lariviere, B., Van den Poel, D.: Predicting customer retention and profitability by using random forests and regression forests techniques. Expert Syst. Appl. **29**, 472–484 (2005)
Lee, J.H., Park, S.C.: Intelligent profitable customers segmentation system based on business intelligence tools. Expert Syst. Appl. **29**(1), 145–152 (2005)
Malthouse, E.C., Blattberg, R.C.: Can we predict customer lifetime value? J. Interact. Mark. **19**(1), 2–16 (2005)
Meier, A. (ed.).: Fuzzy Methods for Customer Relationship Management and Marketing: Applications and Classifications. IGI Global, Hershey (2012)
Min, F., He, H., Qian, Y., Zhu, W.: Test-cost-sensitive attribute reduction. Inf. Sci. **181**(22), 4928–4942 (2011)
Morrison, D.G., Chen, R.D.H., Karpis, S.L., Britney, K.E.A.: Modelling retail customer behaviour at Merrill Lunch. Mark. Sci. **1**(2), 123–141 (1982)
Mulhern, F.J.: Customer profitability analysis: measurement, concentration, and research directions. J. Interact. Mark. **13**(1), 25–40 (1999)
Namwar, M., Gholamian, M.R., KhakAbi, S.: A two phase clustering method for intelligent customer segmentation. In: 2010 International Conference on Intelligent Systems, Modeling and Simulation (ISMS), 27–29 January, Liverpool, pp. 215–219 (2010)
Pfeifer, P.E., Haskins, M.E., Conroy, R.M.: Customer lifetime value, customer profitability, and the treatment of acquisition spending. J. Manag. Issues **17**, 21–39 (2005)
Pfeifer, P.E., Carraway, R.L.: Modeling customer relationships as Markov chains. J. Interact. Mark. **14**(2), 43–56 (2000)
Questier, F., Walczak, B., Massart, D.L., Boucon, C., Jong, S.: Feature selection for hierarchical clustering. Anal. Chim. Acta **466**, 311–324 (2002)
Rust, R.T., Kumar, V., Venkatesan, R.: Will the frog change into a prince? Predicting future customer profitability, Int. J. Res. Market. **xxx**, xxx–xxx (article in press) (2011)
Saberi, M., Hussain, O.K., Chang, E.: Intelligent online customer recognition framework: dealing with common personal names. In: IEEE 9th Conference on Industrial Electronics and Applications (ICIEA), 9–11 June, Hangzhou, pp. 966–971 (2014)
Schalkoff, R.J.: Intelligent Systems: Principles, Paradigms and Pragmatics. Jones & Bartlett Publishers, Sudbury (2009)
Shih, Y., Liu, D.R.: A method for customer lifetime value ranking—combining the analytic hierarchy process and clustering analysis. J. Database Mark. Customer Strategy Manage. **11**(2), 159–173 (2003)
Sousa, J.M., Kaymak, U., Madeira, S.: A comparative study of fuzzy target selection methods in direct marketing. In: International Conference on Fuzzy Systems (2002)
Su, X., Khoshgoftaar, T.M.: A survey of collaborative filtering techniques. Adv. Artif. Intell. **2009**, 1–19 (2009)
Tirenni, G., Labbi, A., Berrospi, C., Elisseeff, A., et al.: Customer equity and lifetime management (CELM) Finnair case study. Mark. Sci. **26**(4), 553–577 (2007)
Ture, M., Tokatli, F., Kurt, I.: Using Kaplan-Meier analysis together with decision tree methods (C&RT, CHAID, QUEST, C4.5 and ID3) in determining recurrence-free survival of breast cancer patients. Expert Syst. Appl. **36**, 2017–2026 (2009)

van Raaij, E.M., Vernooij, M.J.A., van Triest, S.: The implementation of customer profitability analysis: a case study. Ind. Mark. Manage. **32**, 573–583 (2003)
Wang, H.-F., Hong, W.-K.: Managing customer profitability in a competitive market by continuous data mining. Ind. Mark. Manage. **35**, 715–723 (2006)
Wang, Y.J.: A clustering method based on fuzzy equivalence relation for customer relationship management. Expert Syst. Appl. **37**(9), 6421–6426 (2010)
Weiss, Y., Elovici, Y., Rokach, L.: The CASH algorithm-cost-sensitive attribute selection using histograms. Inf. Sci. **222**, 247–268 (2013)
Wong, K.W.: Data mining using fuzzy theory for customer relationship management. In: 4th Western Australian Workshop on Information Systems Research (WAWISR 2001), 26 November, Perth 428 (2001)
Yu, S., De Steve, B., Paul, S.: Genetic feature selection combined with composite fuzzy nearest neighbor classifies for hyperspectral satellite imagery. Pattern Recogn. Lett. **23**, 183–190 (2002)
Zeithaml, V.A., Rust, R.T., Lemon, K.N.: The customer pyramid: creating and serving profitable customers. Calif. Manage. Rev. **43**(4), 118–142 (2001)

Part IX
Project Management

Chapter 21
Intelligent Systems in Project Planning

Majid Shakhsi-Niaei and Seyed Hossein Iranmanesh

Abstract As a modern kind of engineering management tools, intelligent systems can facilitate better business or organizational decision-making. This chapter discusses several applications of intelligent systems in project management practice. First, the relevant literature is reviewed and different applications of intelligent tools are categorized into seven problem types, i.e. recognizing the relations between activities, estimating duration of activities and project completion time, project scheduling, resource leveling, forecasting project total cost, cash flow/S-curve estimation, and estimating project quality level. This categorization provides the basis for analyzing the underlying problem types and prepares the ground for future research via a faster access to the relevant literature. Then, a real case study and the corresponding results are discussed in order to show the potential usefulness and applicability of such intelligent tools in practice.

Keywords Project management · Applications of intelligent systems · Project time planning · Project cost planning · Project quality planning

21.1 Introduction

Project management is the application of knowledge, skills and tools to execute projects effectively and efficiently. Lewis (2010) has proposed a threefold framework for good project management which takes into account the tools, the people, and the systems (Fig. 21.1).

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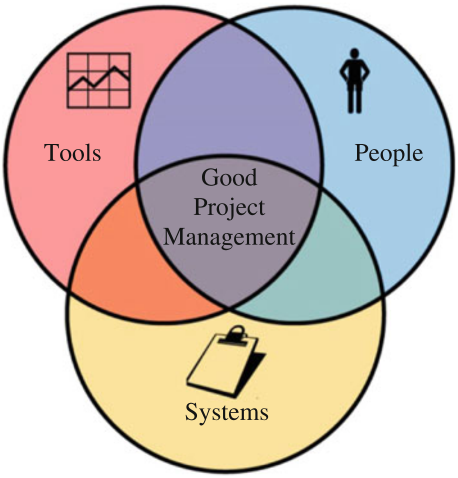

Fig. 21.1 Requirements for good project management (Lewis 2010)

Engineering management includes the application of engineering tools to business practice. Intelligent systems can provide such tools for better business or organizational decision-making.

After widespread application of classical project management tools including Gantt chart, earned value management (EVM), and scheduling methods, an upward trend in application of intelligent tools is observed. Figure 21.2 shows this trend which is formed via a rough search in Google scholar.

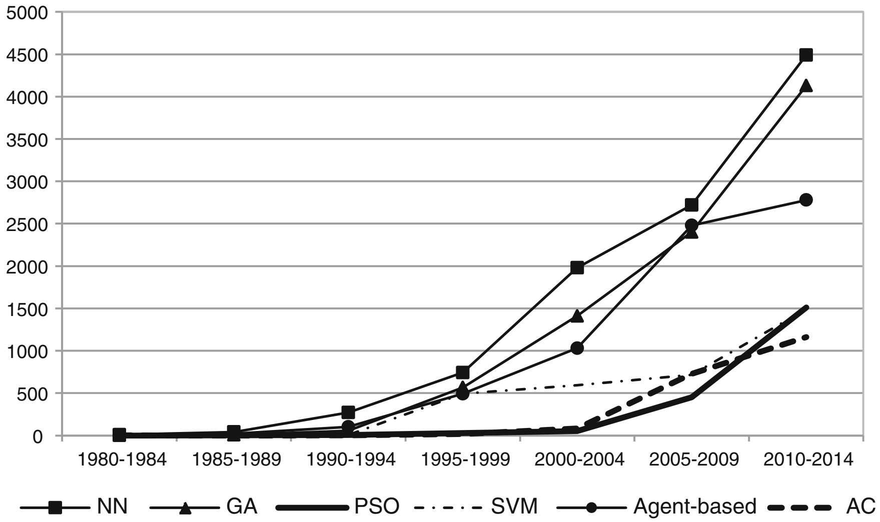

Fig. 21.2 Frequency of researches on application of some intelligent tools in project management

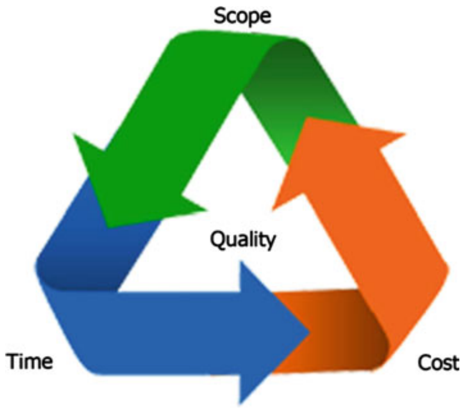

Fig. 21.3 Project planning triangle

Project planning is an important part of project management, which covers the greatest share of processes in the project management body of knowledge (PMI 2012). The project planning processes develop the project management plan and also the documents that will be used to perform the project. The project plans will be revised as significant changes occur throughout the project lifecycle.

The project planning processes can be done manually, but for managing complex and multiple projects, it is usually easier and faster to use project management software. Moreover, because of the uncertain nature of the project planning, it is worth to implement intelligent systems in project planning processes in order to achieve more accurate and reliable plans.

Project planning includes various tasks. Here, we focus on three main aspects of project planning, i.e. project time, project cost, and project quality planning which form the scope of a project, as demonstrated in Fig. 21.3.

The rest of this chapter is organized as follows. The relevant literature is reviewed in Sect. 21.2 which describes different applications of intelligent systems in three project planning aspects. A real case study and the corresponding results are discussed in Sect. 21.3. Finally, Sect. 21.4 concludes the chapter.

21.2 Categorizing the Applications of Intelligent Systems in Project Planning

Conducting an extensive search in several academic databases, many articles were selected, studied, and classified according to their tackled problems and the intelligent tools used.

21.2.1 Intelligent Systems in Project Time Planning

Weakness in project time planning may result in serious consequences for the project. Some of the most important consequences are: wasted opportunities, losing market in competitive situations, shortage in providing demands with specific delivery time, imposing additional costs, increasing the prices due to inflation, facing with new risks, possible changes in project goals, and even being infeasible in economic point of view.

Table 21.1 categorizes the problem types and also shows the intelligent tools used in the considered researches.

As shown in Figs. 21.4 and 21.5, the project scheduling problem clearly dominates research on for project time planning and the most popular intelligent tools are GA, PSO, and ACO.

21.2.2 Intelligent Systems in Project Cost Planning

Project cost planning is a dynamic process and interacts with other project management areas during the project life cycle. Intelligent tools have been used to facilitate this process. Table 21.2 categorizes the problem types and also shows the intelligent tools used in the considered researches.

As represented in Figs. 21.6 and 21.7, most of researches on project time planning have focused on forecasting project total cost and the most popular intelligent tool in this area is artificial neural networks while the next frequent tools are GA, fuzzy logic, SVM, and CBR.

21.2.3 Intelligent Systems in Project Quality Planning

Despite the existence of many articles about applying intelligent tools to general quality planning, little attention has been paid to project quality planning. All the researches presented here have focused on estimating project quality level, summarized in Table 21.3.

As shown in Fig. 21.8, the most popular intelligent tool in this area is artificial neural networks.

21.3 A Hybrid Intelligent Model for Cost Prediction in NPD Projects

New product development (NPD) has become the most important activity for many modern organizations. Some researchers believe that NPD is the engine of organization success, survival, and renewal (Brown and Eisenhardt 1996). In order to

Table 21.1 Problem types and intelligent tools used for project time planning

Problem type	Author(s)	Intelligent tool(s)	Notable consideration(s)
Recognizing the relations between activities	Sharifi et al. (2008)	Fuzzy logic	Fuzzy relations between activities
Estimating duration of activities and project completion time	López-Martín and Abran (2014)	Neural network (NN)	Three alternative NN models
	Wauters and Vanhoucke (2014)	Support vector machine (SVM)	Robustness checks
	Di Penta et al. (2011)	GA	Project interruptions and human resources
	Koo et al. (2010)	CBR and NN	Also forecasting project cost
	Cheng and Roy (2010b)	Evolutionary support vector machine inference model (EFSIM)	
	Pewdum et al. (2009)	NN	Also forecasting project cost
	Iranmanesh et al. (2009)	Emotional learning based fuzzy inference system (ELFIS)	
	Iranmanesh et al. (2008)	Adaptive neuro fuzzy inference system (ANFIS)	Earned value indexes
	Cho (2006)	Expert systems	Updating the estimates
	Lee and Lee (2006)	CBR	
	Dzeng and Tommelein (2004)	CBR	
Project scheduling	Shou et al. (2015)	Hybrid PSO	Preemption
	Wang et al. (2014)	Cloud GA	Multiple projects and critical chain network
	Agarwal et al. (2011)	NN and GA	NN used as a local search
	Fang and Chen (2010)	NN	
	Fengshan et al. (2010)	PSO	
	Duan and Warren Liao (2010)	Ant colony optimization (ACO)	Activity on node representation
	Pan and Chen (2010)	Multi-agent systems	
	Chen et al. (2010g)	ACO	Discounted cash flows
	Chen et al. (2010d)	ACO	
	Chen et al. (2010f)	ACO	Multi-mode activities and discounted cash flows
	Mobini et al. (2010)	Artificial immune systems	
	Bozorg Haddad et al. (2010)	Honeybee optimization	Non-resource-constrained

(continued)

Table 21.1 (continued)

Problem type	Author(s)	Intelligent tool(s)	Notable consideration(s)
	Montoya-Torres et al. (2010)	GA	Multi-array object-oriented modeling
	Abdallah et al. (2009)	ACO	Uncertainty
	Huang et al. (2009)	GA and fuzzy logic	Random fuzzy distribution for activity durations
	Guo et al. (2009a)	PSO	Two-stage analysis
	Aghaie and Mokhtari (2009)	ACO	Project crashing problem (PCP)
	Van Peteghem and Vanhoucke (2009)	Artificial immune systems	Multi-mode activities
	Lu et al. (2008)	PSO	Resources leveling
	Zhao and Ru (2008)	PSO	
	Peng and Wei (2008)	PSO	
	Liu and Wu (2007)	Multi-agent systems	Flexible constraints
	Agarwal et al. (2007)	Artificial immune systems	
	Miyuan et al. (2007)	ACO	Multiple projects
	Tseng and Chen (2006)	ACO and GA	
	Zhang et al. (2006)	PSO	Multi-mode activities
	Shou (2006)	ACO	Scarce resources
	Shou (2005)	NN	
Resource leveling	Ponz-Tienda et al. (2013)	Adaptive GA	Multiple resources
	Hashemi Doulabi el al. (2011)	Hybrid GA	Splitting some of activities
	Guo et al. (2009b)	PSO	Multiple resources for multiple projects
	Lu et al. (2008)	PSO	Within a scheduling software

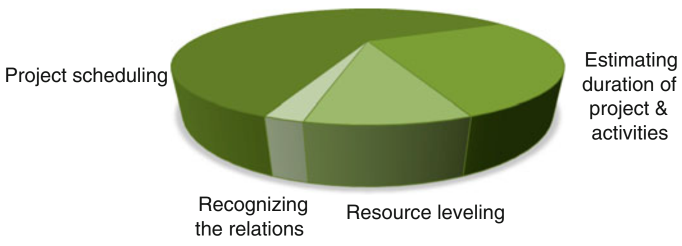

Fig. 21.4 Relative frequency of tackled problems in time-planning researches

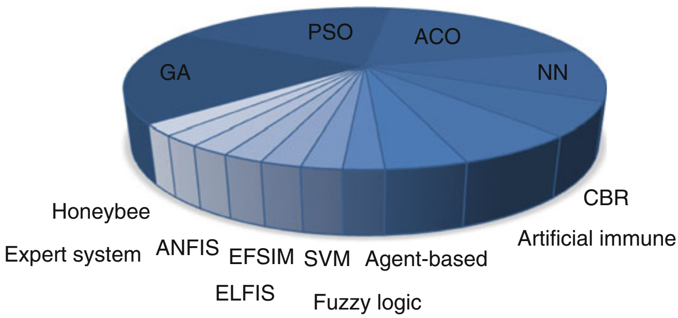

Fig. 21.5 Relative frequency of artificial tools used in time-planning researches

remain competitive in highly competitive environments, organizations are compelled to produce low-cost and high-quality products. The earlier a product hits the market, in fact, the greater chance the company has to command premium pricing, therefore, gaining market share and higher profits (Adler et al. 1996; Calantone and Benedetto 2000). With such huge stakes in NPD, organizations have no choice but to spend heavily on research and development (R&D) projects (Cooper 2001).

Cost prediction of NPD projects often affects management activities such as project planning and resource allocation (Li et al. 2009). Generally, cost prediction is done based on the required production operations. By determining these operations it is possible to predict the NPD costs (Weustink et al. 2000). NPD costs tend to increase with project uncertainty, complexity, and diversity in terms of tasks, resources, participants, and design characteristics (Xu and Khoshgoftaar 2004). Also, the inherent characteristic of NPD projects worsens the situation (Chen et al. 2003). Therefore, cost prediction should be considered accurately during the early stages of industrial research and development projects. To achieve this aim, a suitable mathematical model for cost data should be developed and then future values in the time series should be predicted based on established patterns, factors, and other related series (Cryer and Chan 2008; Cheng and Roy 2010b). Predicting time series of cost data using linear techniques cannot often be conducted accurately and precisely. Generally, real applications are not amenable to linear prediction techniques (Sapankevych and Sankar 2009). In fact, cost data applications in the NPD environment are uncertain, complicated, dynamic, and nonlinear in nature. It leads conventional linear prediction techniques to be inapplicable. Hence, advanced techniques such as intelligent systems for predicting time series data should be focused remarkably in the NPD projects. To overcome the shortcoming of the commonly used techniques, this section focuses on the cost prediction of these projects by introducing an intelligent hybrid model as described below.

Table 21.2 Problem types and intelligent tools used for project cost planning

Problem type	Author(s)	Intelligent tool(s)	Notable consideration(s)
Forecasting project total cost	Cirilovic et al. (2014)	NN	
	Kashyap and Misra (2013)	PSO	Constructive cost model (COCOMO) and quality function deployment
	Kazemifard et al. (2011)	Multi-agent system and fuzzy logic	COCOMO II
	Chou and Tai (2010)	NN	
	Chou et al. (2010)	NN and CBR	Make-to-order production system
	Xiaokang and Mei (2010)	NN	Theory of constraints for cost control
	Koo et al. (2010)	CBR, NN, and GA	Also time prediction
	Cheng and Roy (2010c)	SVM, fuzzy logic, and GA	Fast messy genetic algorithm
	Cheng et al. (2010a)	SVM and GA	Fast messy genetic algorithm
	Attarzadeh and Ow (2010a, 2010b)	NN	COCOMO
	Xin-Zheng and Li-ying (2010)	NN	Rough set theory
	Shi and Li (2010), (2008a)	NN	Rough set theory
	Ji and li (2009)	NN and artificial immune systems	
	Cheng et al. (2009a)	GA, fuzzy logic, and NN	Overall and particular cost estimations
	Li et al. (2009)	CBR and NN	Analogy-based estimation
	Pewdum et al. (2009)	NN	Continuous and seasonal data sets
	Papatheocharous and Andreou (2009)	NN and GA	
	Aghaie and Mokhtari (2009)	ACO	Project crashing problem
	HongWei (2009)	SVM	Rough set theory
	Kong et al. (2008)	SVM	
	Iranmanesh and Zarezadeh (2008)	NN	
	Yunna and Zhigun (2008)	CBR and fuzzy logic	

(continued)

Table 21.2 (continued)

Problem type	Author(s)	Intelligent tool(s)	Notable consideration(s)
Cash flow/S-curve estimation	Chao (2014)	Fuzzy inference system (FIS)	Inflection point
	Chao and Chien (2010)	NN	Controlling and updating S-curve
	Chao and Chien (2009)	NN	Polynomial estimation for S-curve
	Cheng et al. (2010e)	NN, fuzzy logic, and GA	
	Cheng et al. (2009b)	NN, fuzzy logic, and GA	

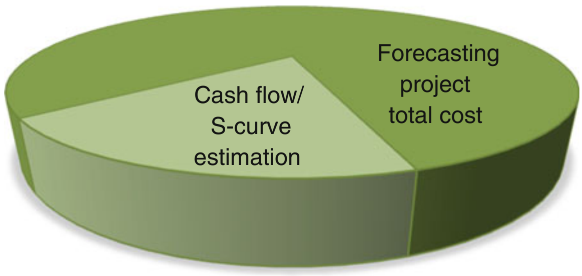

Fig. 21.6 Relative frequency of tackled problems in project cost-planning researches

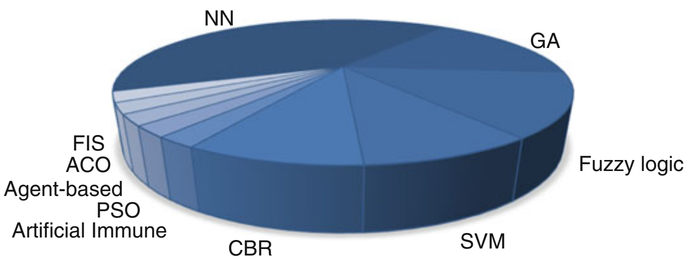

Fig. 21.7 Relative frequency of artificial tools used in project cost-planning researches

21.3.1 Support Vector Regression

Support vector machines, SVMs, were first introduced by Vapnik in the late 1960s on the foundation of SLT. However, since the middle of 1990s, the algorithms used for SVMs started emerging with greater availability of computing capacity, paving the way for numerous practical applications (Burges 1998). The basic SVM deals with two-class problems in which the data are separated by a hyper plane defined by

Table 21.3 Problem types and intelligent tools used for project quality planning

Problem type	Author(s)	Intelligent tool(s)	Notable consideration(s)
Estimating project quality level	Ahari and Niaki (2014)	NN and fuzzy logic	Local linear model tree (LOLIMOT) and TOPSIS
	Yang and Wang (2010)	NN	
	Shi and Li (2008b)	NN and PSO	
	Yang et al. (2007)	NN and fuzzy logic	

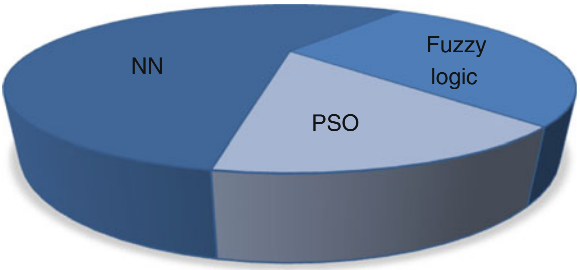

Fig. 21.8 Relative frequency of artificial tools used in project quality-planning researches

a number of support vectors. A simple introduction of the SVM is presented here and the interested reader is referred to the tutorials on SVMs (Burges 1998; Vapnik 1999) for detailed descriptions.

Support vector regression, SVR, is a new training technique based on the SVM; however, it requires only the solution of a set of linear equations instead of the long and computationally hard quadratic programming problem involved in the standard SVM. In fact, the SVR works with a least squares cost function (Vapnik 1999).

Consider a given training set$\{X_i, y_i\}_{i=1}^{N}$, where $X_i \in R^P$ represents a p-dimensional input vector and $y_i \in R$ is a scalar measured output, which represents the y_i model output. The objective is to construct a function $y = f(x)$ which represents the dependence of the output y_i on the input x_i (Salgado and Alonso 2007). We define the form of this function as:

$$y = W^T \varphi(X) + b, \qquad (21.1)$$

where **w** is the weight vector and b is the bias term. We construct this function to predict the cost of NPD projects. The regression model (1) can be constructed by using a nonlinear mapping function$\varphi(\cdot)$. By mapping the original input data onto a high–dimensional space, the nonlinear separable problem becomes linearly separable in the space. The function $\varphi(\cdot) : R^p \to R^h$ is a nonlinear function, which maps the data onto a higher-possibly infinite-dimensional feature space as illustrated in Fig. 21.9.

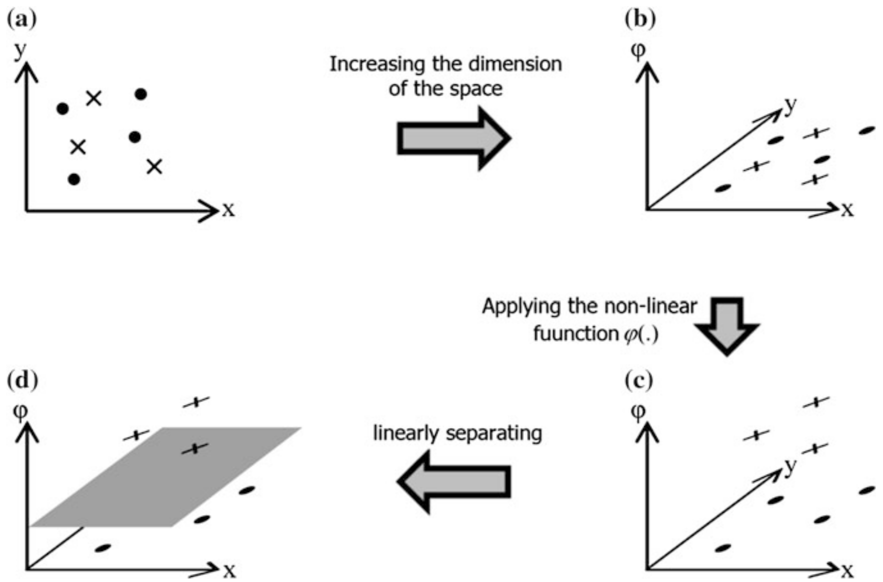

Fig. 21.9 Mapping input space X onto high-dimensional feature space

The optimization model and the equality constraints can be defined by Eqs. 21.2–21.10.

$$\begin{aligned} &\min\ J(\mathrm{w}, e) = \frac{1}{2}\mathrm{w}^T\mathrm{w} + C\frac{1}{2}\sum_{i=1}^{N} e_i^2 \\ &s.t. \\ &y_i = w^T\varphi(x_i) + b + e_i, \quad i = 1, \ldots, N, \end{aligned} \tag{21.2}$$

where e_i is the random error and $C \in R^+$ is a regularization parameter in optimizing the trade-off between minimizing the training errors and minimizing the model's complexity. Now, the objective is to find the optimal parameters that minimize the prediction error of the regression model (2). The optimal model will be chosen by minimizing the cost function (3) where the errors e_i are minimized (Vapnik 1999). This formulation corresponds to the regression in the feature space and, since the dimension of the feature space is high, possibly infinite, so this problem is difficult to solve (Salgado and Alonso 2007). Hence, the following Lagrange function is constructed to solve the optimization problem.

$$L(\mathrm{w}, b, \mathrm{e}; \alpha) = J(\mathrm{w}, \mathrm{e}) - \sum_{i=1}^{N} \alpha_i \{\mathrm{w}^{\mathrm{T}}\varphi(x_i) + b + e_i - y_i\}, \tag{21.3}$$

where $\alpha = [\alpha_1, \alpha_2, \ldots, \alpha_n]$ are the Lagrange multipliers. The solution of Eq. 21.3 can be obtained by partially differentiating with respect to **w**, b, e_i, and α_i:

$$\frac{\partial L}{\partial \mathrm{w}} = 0 \rightarrow \mathrm{w} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \alpha_i \varphi(x_i), \tag{21.4}$$

$$\frac{\partial L}{\partial b} = 0 \rightarrow b = \sum_{i=1}^{N} \alpha_i = 0, \tag{21.5}$$

$$\frac{\partial L}{\partial e_i} = 0 \rightarrow \alpha_i = Ce_i, \quad i = 1, \ldots, N, \tag{21.6}$$

$$\frac{\partial L}{\partial \alpha_i} = 0 \rightarrow \mathrm{w}^{\mathrm{T}} \varphi(x_i) + b + e_i - y_i = 0, \quad i = 1, \ldots, N. \tag{21.7}$$

The above equations in matrix form can be expressed as:

$$\begin{bmatrix} 0 & \vec{1}^T \\ \vec{1} & \Omega + C^{-1} I \end{bmatrix} \times \begin{bmatrix} b \\ \alpha \end{bmatrix} = \begin{bmatrix} 0 \\ y \end{bmatrix}, \tag{21.8}$$

where

$$\begin{aligned} \mathrm{y}^{\mathrm{T}} &= [y_1, y_2, \ldots, y_N], \\ \vec{1}^{\mathrm{T}} &= [1,\ 1, \ldots, 1], \\ \alpha^{\mathrm{T}} &= [\alpha_1, \alpha_2, \ldots, \alpha_N], \\ \Omega_{ij} &= K(\mathrm{x}_i,\ \mathrm{x}_j) = \varphi^T(\mathrm{x}_i)\, \varphi(\mathrm{x}_j), \quad j = 1, \ldots, N, \end{aligned}$$

where $K(\mathrm{x_i}, \mathrm{x_j})$ is an arbitrary kernel function, and Ω is the kernel matrix. Finally, the estimated values of b and α_i, i.e. $\hat{b}$ and $\hat{\alpha}_i$, can be obtained by solving the linear system (8), and the resulting SVR model can be expressed as:

$$\mathrm{y} = f(\mathrm{x}) = \sum_{i=1}^{N} \hat{\alpha}_i k(\mathrm{x}, \mathrm{x}_i) + \hat{b}, \tag{21.9}$$

where $K(\mathrm{x}, \mathrm{x_i})$ is a kernel function. Here we use a nonlinear radial basis function (RBF) kernel:

$$k(\mathrm{x}, \mathrm{x}_i) = \exp\left(-\frac{1}{2\sigma^2} \|\mathrm{x} - \mathrm{x}_i\|^2\right), \tag{21.10}$$

where σ is the parameter of RBF Kernel. In comparison with some other feasible kernel functions, the RBF is a more compact supported kernel and able to shorten the computational burden of training process. It also improves the generalization performance of SVR (Salgado and Alonso 2007). To achieve a high level of performance with SVR models, the regularization parameter C and the value of σ from the kernel function have to be set carefully. The main features of the SVR (Chen and Wang 2007) can be summarized as:

- It is able to model nonlinear relationships,
- Its training process is equivalent to solving linearly constrained quadratic programming problems, and the SVR embedded solution meaning is unique, optimal, and unlikely to generate local minima,
- It chooses only the necessary data points to solve the regression function which results in the sparseness of solution.

21.3.2 Cross Validation Technique

Cross validation (CV) technique was introduced for estimating generalization error based on "resampling" (Efron 1983; Efron and Tibshirani 1993). In general, the resulting estimates of generalization error are utilized for selecting among various models.

In k-fold CV as the common type of CV technique, the data are randomly divided into k mutually exclusive subsets of approximately equal size. Among $k-1$ subsets, the last subset is regarded as the validation. This procedure is repeated k times, so each subset is used once for testing. If k equals the data sample size, this is called the "leave-one-out" CV. In practice, the choice of the number of folds (k) depends on the size of the data. For a small data, it may be better to set a larger value for k, because this leaves more examples in the training set. $k = 10$ is a common choice for k-fold in many real world applications (Salzberg 1997).

It is worth noting that the CV technique is quite different from the "split-sample" or "hold-out" techniques which are commonly used for early stopping in the ANNs. In the split-sample technique, only a single subset, the validation set, is utilized to estimate the generalization error, instead of k different subsets; i.e. there is no "crossing". The distinction between the cross validation and split-sample validation is extremely important because the CV is remarkably superior for the small data; Goutte (1997) illustrates this fact remarkably. The main advantage of the k-fold CV technique is to provide the best compromise between computational cost and reliable parameter estimation. It has been also applied in numerous fields of time series forecasting, e.g. (Duan et al. 2001; Chen and Wang 2007; Salzberg 1997).

21.3.3 Particle Swarm Optimization

PSO is a population-based meta-heuristic and evolutionary computational technique. This technique simulates the social behavior among individuals to a promising position to achieve precise objectives in an n-dimensional search space. PSO is an evolutionary algorithm that performs searches by using a population, called swarm, of individuals, called particles, by updating generations. To discover the optimal solution, each particle *i* maintains a record of the position of its previous best experience in a vector called *pbest*. The *nbest* is another best value that is tracked by the particle swarm optimizer. So far this is the best value obtained by any particle in that particle's neighborhood. When a particle takes the entire population as its topological neighbors, the best experience is a global best, called *gbest*, i.e. the best experience of all other members (Huang and Dun 2008; Fei et al. 2009; Kuo and Lin 2010). All particles can share information about the search space. The *pbest* is called the cognition part, and *gbest* the social part (Shi and Eberhart 1998). The main features of PSO can be summarized as (Abido 2002):

- It only utilizes the performance index to illustrate the search in the problem space. Therefore, it is more appropriate for dealing with non-differentiable objective functions. This property relieves the PSO of certain assumptions on objective function, which are often needed in the traditional optimization techniques,
- It is a population-based search algorithm. This feature ensures the PSO to be less likely to become trapped in a local minimum,
- It applies probabilistic transition rules rather than deterministic rules. Hence, the PSO is a kind of stochastic optimization algorithm that is able to search a complicated and uncertain area. It is more flexible and robust than conventional techniques,
- It has the flexibility to control the balance between the global and local exploration of the search space. This unique feature of the PSO can overcome the premature problem and improve the search capability,
- Unlike other heuristic techniques, the solution quality of the PSO does not rely heavily on the initial population. Starting anywhere in the search space, the technique tries to converge to the optimal solution. Since the PSO depends only on the objective function to guide the search, it should be defined before the PSO is initialized.

As mentioned above, each particle moves in the direction of its *pbest* and *gbest* to find the optimal solution. For each particle *i* and dimension *j*, the velocity and position of particles can be updated by Eqs. 21.11 and 21.12.

$$v_{ij}^{t+1} = w \cdot v_{ij}^{t} + c_1 \cdot rand_1 \cdot (pbest_{ij}^{t} - p_{ij}^{t}) + c_2 \cdot rand_2 \cdot (gbest_{ij}^{t} - x_{ij}^{t}) \quad (21.11)$$

$$x_{ij}^{t+1} = x_{ij}^{t} + \beta \cdot v_{ij}^{t+1} \quad (21.12)$$

where t is the evolutionary generation, v_{ij} is the velocity of particle i on dimension j, whose value is limited to the range $[-v_{max}, v_{max}]$, x_{ij} is the position of particle i on dimension j, whose value is limited to the range $[-x_{max}, x_{max}]$. The inertia weight w is applied to balance the global exploration and local exploitation. The $rand_1$ and $rand_2$ are random function in the range [0, 1], β is constraint factor used to control the velocity weight, whose value is usually set to 1. Positive constant c_1 and c_2 are personal and social learning factors, respectively. Their values are usually set to 2. According to whether a designated value of the fitness or a maximum generation is reached, the termination criterion is determined for iterations. The detailed descriptions of the PSO can be found in Kennedy et al. (2001).

21.3.4 Proposed Hybrid Intelligent Model

The proposed hybrid model integrates PSO, CV, and SVR techniques in order to forecast cost of NPD projects. In this model, the SVR acts as a supervised learning tool to handle input-output mapping and focused on cost data characteristics in NPD projects. The PSO optimizes parameters of SVR. In fact, the generalization capability and accuracy of the SVR are determined by searched problem parameters, including free parameters, i.e. parameter C and the value of σ. To select these parameters, most researchers follow the trial-and-error procedure. They construct a few SVR models based on different parameter sets, then test them on a validation set to obtain the best combination of the parameters. However, this procedure requires some luck and often is time-consuming (Chen and Wang 2007).

The k-fold CV is utilized to train the SVR in order to reach a more realistic evaluation of the accuracy by dividing all datasets into multiple training and test sets, and to provide the reliable results. The proposed hybrid intelligent model is a computationally efficient combination and helpful in the cost prediction of NPD projects.

Figure 21.10 depicts the framework of the proposed hybrid intelligent model. The explanation of major steps involved in the hybrid model is provided in the following.

Step 1. Normalizing training data: The model applies sequential data as training data. In this step, sequential data reflects identified attributes, and training data are normalized into a same range (0, 1) which helps to avoid numerical difficulties. The function utilized to normalize data is illustrated in Eq. 21.13.

$$x_{sca} = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \tag{21.13}$$

After applying this transformation, all the variables become dimensionless.

Step 2. Training the SVR: In this step, the SVR is deployed to handle input-output mapping. The RBF kernel is applied as reasonable choice (Hsu et al. 2003). By using the k-fold CV technique on the training dataset, the SVR training is performed to obtain the prediction model.

Fitness definition: According to Chen and Wang (2007) the fitness of the training dataset can be obtained easily, but is prone to over-fitting. To handle this problem the k-fold CV technique is utilized. In this technique, after dividing the training dataset into k subsets randomly, the regression function is built with a given

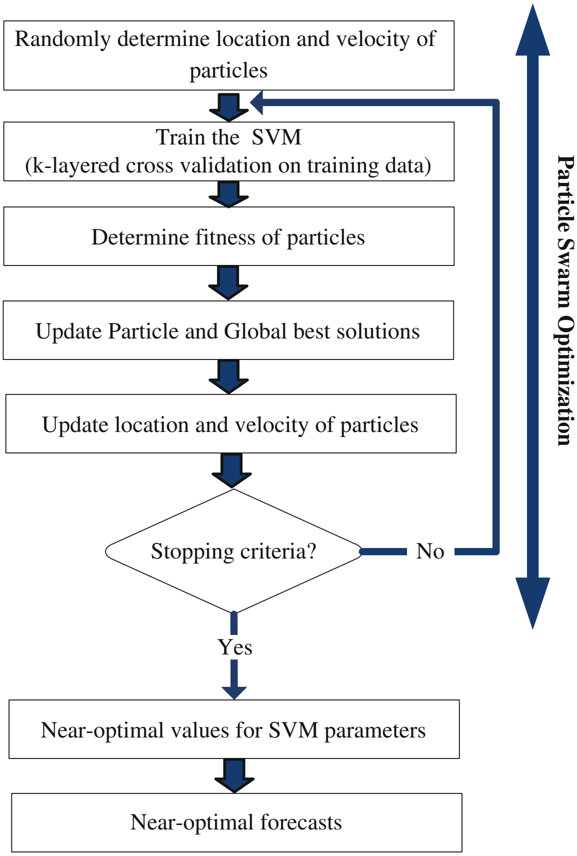

Fig. 21.10 Framework of the proposed hybrid intelligent model

set of parameters ($C_{i,}$ σ_i) by using $k - 1$ subsets as the training set. The last subset is considered for the validation. The above procedure is repeated k times. Consequently, the fitness function is defined as the MAPE_{CV} of the k-fold CV technique on the training dataset, which is as follows:

$$\text{Fitness} = \min\ f = \text{MAPE}_{\text{cv}}, \tag{21.14}$$

$$\text{MAPE}_{\text{CV}} = \frac{1}{l}\sum_{j=1}^{l}\left|\frac{y_j - \hat{y}_j}{y_j}\right| \times 100\ \% \tag{21.15}$$

where y_j is the actual value; $\hat{y}_j$ is validation value and l is the number of subsets. The solution with a smaller MAPE_{CV} of the training dataset has a smaller fitness value.

In addition, the SVR utilizes free parameters, which are randomly generated and employed by the PSO. By using the PSO, the intelligent model generates a population of particles and then evaluates it according to the SVR. This evolutionary algorithm is simple and straightforward for the SVR.

Step 3. Determining parameters by the PSO: In this step, the PSO is utilized to concurrently search for SVR parameters. The sub-steps of the PSO are:

Step 3-1. *Initialization*: Make a defined population of particle pairs (C_i, σ_i) with random positions (x_{Ci}, $x\sigma_i$) and velocities (v_{Ci}, $v\sigma_i$) where each particle contains n variables.

Step 3-2. *Fitness evaluation*: In this step, fitness value for each particle pair is evaluated by using Eqs. 21.14 and 21.15. Set the best position (x_{Ci}, $x\sigma_i$) of each particle pair and its objective value equal to its initial position and objective value respectively. Set the global best position (x_{Ci}, $x\sigma_i$) and its objective value equal to the best initial particle pair's position and its objective value.

Step 3-3. *Update the global and personal best values*: The global and personal best according to the fitness evaluation results are updated. If current value is better, then update its objective value with the current position and objective value.

Step 3-4. *Calculate the velocity of position change*: Each particle flies toward a new position by obtaining the velocity of position change. The velocity of each particle is obtained by Eq. 21.11.

Step 3-5. *Update position value*: Each particle moves to its next position according to Eq. 21.12.

Step 3-6. *Stopping criteria*: The same procedures from step 3-2 to step 3-5 are repeated until stopping criteria, e.g., prediction accuracy or predefined maximum iterations, are satisfied. It means that near optimal parameters are obtained.

21.3.5 Predicting the Cost of NPD Projects

Prediction of cost data in NPD projects is a time series forecasting problem. The SVR mapping function can be illustrated as below:

$$u_t = f(u_{t-1}, u_{t-2}, \ldots, u_{t-d}) \tag{21.16}$$

where u_t is the output value at time t, $(u_{t-1}, u_{t-2}, \ldots, u_{t-d})$ is the input vector and d is the dimension of the input vector. We employed cost data of a NPD project in a home appliances manufacturer in Iran. The studied company manufactures a wide range of home appliance products. Every year, the company identifies market requirements and comes up a list of potential NPD projects. The company considers a conceptual and operational model for moving a NPD project from idea to launch. To improve effectiveness and efficiency of the new product development process, the company breaks a project into identifiable and discrete phases, e.g. five or six phases. Each phase is designed to collect information needed to move the project forward to the next phase and/or decision point. Typically, these phases are including key activities as follows (Dwyer and Mellor 1991):

- Initial screening
- Preliminary marketing assessment
- Preliminary technical assessment

- Detailed market study
- Business/financial analysis
- Product development
- In-house product testing
- Customer tests of product
- Test market/trial sell
- Trial production
- Pre-commercialization business analysis
- Production start-up
- Market launch

21.3.5.1 Dataset Description

In order to test the effectiveness of the proposed hybrid intelligent model, we applied it to the cost data of a NPD project. The experimental data has been divided into two subsets: the training and the test datasets. Furthermore, the datasets should be enough to provide suitable training and test. The considered NPD project was updated week by week, and the cost of each key activity was calculated from its resources including labors, materials, and machines usage during the week. In addition, 13 key activities were separated to 131 tasks in this project and their costs were calculated in dollars. The cumulative cost data was employed to predict the time series and to facilitate the cash flow analysis. Table 21.4 illustrates the real cost dataset which is divided into training and test dataset in the ratio of 70 and 30 %. So, amongst 128 rows of available dataset, 90 rows have been used for training and 38 rows for testing.

Table 21.4 The cost dataset ($)

			Input		Output
	No.	1	2	3	4
Training data	1	750	2850	4650	5100
	2	2850	4650	5100	5780
	3	4650	5100	5780	7730
	⋮	⋮	⋮	⋮	⋮
	88	73,780	75,280	76,240	77,640
	89	75,280	76,240	77,640	78,640
	90	76,240	77,640	78,640	78,990
Test data	91	77,640	78,640	78,990	79,680
	92	78,640	78,990	79,680	80,130
	93	78,990	79,680	80,130	81,170
	⋮	⋮	⋮	⋮	⋮
	126	121,980	122,630	123,530	125,930
	127	122,630	123,530	125,930	127,180
	128	123,530	125,930	127,180	128,150

The rolling-based prediction procedure is conducted as shown in Table 21.4, which divides training data into two subsets, namely fed-in, 3 cost data, and fed-out, 1 cost data, respectively. First, the primary 3 cost data of fed-in subset are fed into the proposed model and the structural risk minimization principle is utilized to minimize the training error. Then, the one-step ahead prediction cost, namely the 4th predicting cost, is obtained. Second, the next 4 cost data, including 3 of the fed-in subset data, from 2nd to 3rd, pulsing the 4th data in the fed-out subset, are similarly again fed into the model and the structural risk minimization principle is also employed to minimize the training error. Then, one-step ahead predicting cost, namely the 5th predicting cost, is performed. The prediction procedure is repeated until the 131st predicting cost is obtained. Meanwhile, training error in the training period is calculated.

21.3.5.2 Model Validation and Comparison of Results

In this section, the performance of the proposed hybrid intelligent model is validated on the real world cost prediction problem. For this purpose, a personal computer with Intel Pentium IV 3.0 GHz CPU, 3 MB of RAM, and Windows Vista operating system is used.

The experimental data including training cost data and test cost data are normalized. The training cost datasets are utilized to construct training sample sets according to the dimension of the input vector. As mentioned before, the dimension of the input vector is set to 3.

The *k*-fold CV technique is applied to the cost dataset of the NPD project. Here, the value of *k* is set to 10. Hence, the training data is divided into 10 subsets, with each subset of the data sharing the same proportion of each subset of data. Nine subsets are employed in the training process, while the last one is applied in the testing process. It is repeated 10 times in order to each subset can take a turn as the test data. The $MAPE_{CV}$ in this classification is calculated by averaging the individual error estimation for each run of testing. The advantages of the CV are that all of test subsets are independent and lead to proper prediction results.

Cost data of the NPD project in a time series representation are fed into the proposed model to predict cost data in the next test period. While training errors improvement occurs, two parameters of the SVR, i.e. C and σ, are optimized by the PSO concurrently. The adjusted parameters with the smallest test $MAPE_{CV}$ value are selected as the most appropriate parameters in the studied case. Then, the test dataset are utilized to investigate the accuracy of the prediction error.

To set parameters of the PSO, parameters in the proposed model for the real dataset are experimentally set. The population size is 15 and the number of iterations is fixed as 100. The searching ranges for C and σ are as follows: $C \in [0, 10^6]$ and $\sigma \in [0.001, 3000]$, respectively. v_{max} for C and σ particles is clamped to be

Table 21.5 Settings of the PSO algorithm

Parameters	C	σ
Search range	(0, 10^6)	(0.001, 3000)
Velocity [$-v_{max}$, v_{max}]	(-10^5, 10^5)	(-300, 300)
Learning factors (C_1, C_2)	(2, 2)	(2, 2)
Constraint factor (β)	0.998	0.998

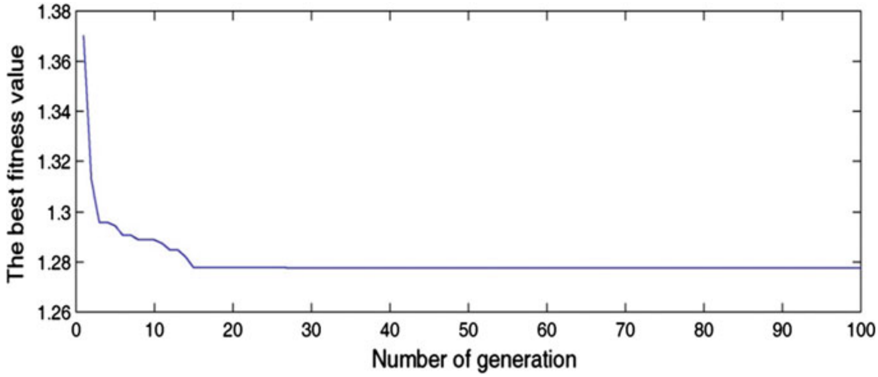

Fig. 21.11 Fitness values during the evolutionary process

10 % of their search space in the NPD environment. In addition, preliminary experiments let us set the personal and social learning factors (c_1, c_2) = (2, 2) that achieves better measure accuracy. The weight w is adjusted to 0.998. The parameter setting of the PSO is summarized in Table 21.5. The optimal values of SVR's parameters obtained by the proposed model are $C = 20.2570 \times 10^4$ and $\sigma = 60.95$. Figure 21.11 depicts the curve of optimal fitness in training stage arising from the number of generations and exhibits no significant improvements after 20 iterations.

To evaluate the performance of the proposed model, the experimental results are compared via four indices, i.e. mean absolute percent error (MAPE), root mean square error (RMSE), standard deviation error (SDE), and R-squared (R^2). These indices are calculated as follows:

$$MAPE = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{y_i - \hat{y}_i}{y_i}\right| \tag{21.17}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2\right]^{\frac{1}{2}} \tag{21.18}$$

Table 21.6 Overall comparative results

Techniques	MAPE	RMSE	SDE	R^2
Proposed hybrid model	0.4848	618.45	0.0033	0.9984
MLP	0.5239	629.17	0.0033	0.9983
NRBF neural network	0.5512	780.38	0.0053	0.9974
Pure SVR	0.5013	650.89	0.0037	0.9982

$$SDE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{|y_i - \hat{y}_i|}{y_i} - \frac{MAPE}{100}\right)^2} \tag{21.19}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{N}(y_i - \bar{y}_i)^2} \tag{21.20}$$

where y_i and $\hat{y}_i$ represent the actual and estimated values of the ith data respectively, $\bar{y}$ is the average of actual data and N is the number of data points.

Table 21.6 illustrates the detailed comparative results and shows the performances of four different techniques. In general, the predictions of the proposed

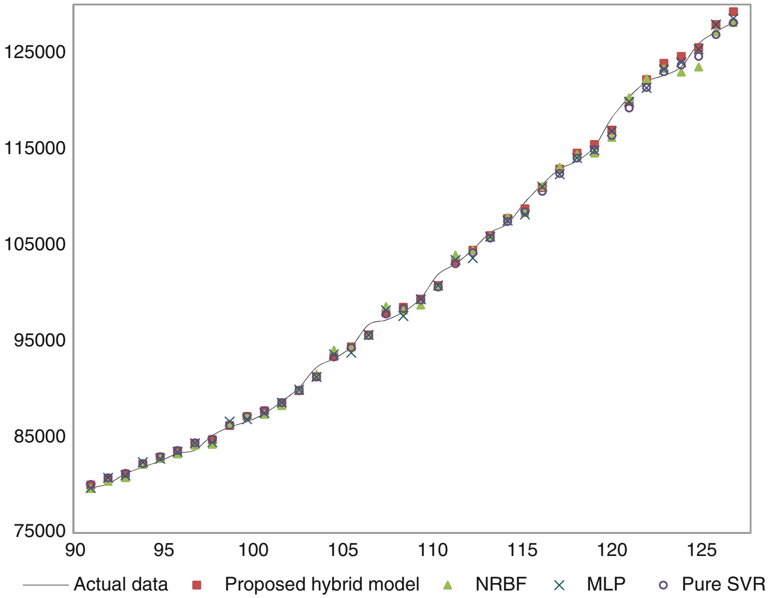

Fig. 21.12 The graphical presentation of predictions of different intelligent techniques

model are superior to those of other techniques. The main merits of the proposed model are as follows: First, the model implements the structural risk minimization principle which attempts to minimize an upper bound of the generalization error rather than minimize the training error. This critical inherent feature of the SVR leads to a better prediction error than that of other conventional neural network-based techniques. Second, the conventional neural network-based techniques may not reach global solutions (Chen and Wang 2007). However, in the proposed model the process for training is equivalent to solving a linearly constrained quadratic programming based on the 10-fold CV technique. In addition, the solution of the hybrid model is unique, optimal, and global by using the PSO.

The performance of four techniques are illustrated in Fig. 21.12.

21.4 Conclusions

In this chapter, the most researches on applications of intelligent systems in three aspects of project management, i.e. time, cost, and quality planning, have been categorized. This categorization shows the potential fields and also the research gaps which can be improved in future works. Moreover, a real case study on forecasting the costs of a new-product-development project is presented where a hybrid intelligent tool is developed and used for forecasting the project costs. The numerical results have demonstrated the superior performance of the hybrid intelligent system, compared to some other approaches, in terms of lower prediction error.

Consequently, top managers can utilize the proposed hybrid model to predict the cost data of the projects during the life cycle.

References

Abdallah, H., Emara, H.M., Dorrah, H.T., Bahgat, A.: Using ant colony optimization algorithm for solving project management problems. Expert Syst. Appl. **36**, 10004–10015 (2009)

Abido, M.A.: Optimal design of power-system stabilizers using particle swarm optimization. IEEE Trans. Energy Convers. **17**, 406–413 (2002)

Adler, P.S., Mandelbaum, A., Nguyen, V., Schwerer, E.: Getting the most out of your product development process. Harvard Bus. Rev. **74**, 134–152 (1996)

Agarwal, A., Colak, S., Erenguc, S.: A Neurogenetic approach for the resource-constrained project scheduling problem. Comput. Oper. Res. **38**(1), 44–50 (2011)

Agarwal, R., Tiwari, M.K., Mukherjee, S.K.: Artificial immune system based approach for solving resource constraint project scheduling problem. Int. J. Adv. Manuf. Technol. **34**, 584–593 (2007)

Aghaie, A., Mokhtari, H.: Ant colony optimization algorithm for stochastic project crashing problem in PERT networks using MC simulation. Int. J. Adv. Manuf. Technol. **45**(11), 1051–1067 (2009)

Ahari, R.M., Niaki, S.T.A.: A hybrid approach based on locally linear neuro-fuzzy modeling and TOPSIS to determine the quality grade of gas well-drilling projects. J. Petrol. Sci. Eng. **114**, 99–106 (2014)

Attarzadeh, I., Ow, S.H.: A novel soft computing model to increase the accuracy of software development cost estimation. In: Proceedings of 2nd International Conference on Computer Engineering and Technology (ICCET), vol. 3, pp. 603–607 (2010a)
Attarzadeh, I., Ow, S.H.: Proposing a new software cost estimation model based on artificial neural networks. In: Proceedings of 2nd International Conference on Computer Engineering and Technology (ICCET), vol. 3, pp. 487–491 (2010b)
Bozorg Haddad, O., Mirmomeni, M., Zarezadeh Mehrizi, M., Mariño, M.A.: Finding the shortest path with honey-bee mating optimization algorithm in project management problems with constrained/unconstrained resources. Comput. Optim. Appl. **47**, 97–128 (2010)
Brown, S.L., Eisenhardt., K.M.: The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organization. Admin. Sci. Q. **42**, 1–34 (1996)
Burges, C.J.C.: A tutorial on support vector machines for pattern recognition. Data Min. Knowl. Disc. **2**(2), 121–167 (1998)
Calantone, R.J., Benedetto, C.A.D.: Performance and time to market: accelerating cycle time with overlapping stages. IEEE Trans. Eng. Manage. **47**, 232–244 (2000)
Chao, L.C.: Estimating project s-curve based on project attributes and conditions. In: The 13th east Asia-pacific conference on structural engineering and construction, Sapporo, Japan (2014)
Chao, L.C., Chien, C.F.: Estimating project S-curves using polynomial function and neural networks. J. Constr. Eng. Manage. **135**(3), 169–177 (2009)
Chao, L.C., Chien, C.F.: A model for updating project S-curve by using neural networks and matching progress. Autom. Constr. **19**, 84–91 (2010)
Chen, C.-H., Ling, S.F., Chen, W.: Project scheduling for collaborative product development using DSM. Int. J. Proj. Manage. **21**, 291–299 (2003)
Chen, K.Y., Wang, C.H.: Support vector regression with genetic algorithms in forecasting tourism demand. Tour. Manage. **28**, 215–226 (2007)
Cheng, M.Y., Tsai, H. C., Hsieh, W. S.: Web-based conceptual cost estimates for construction projects using Evolutionary Fuzzy Neural Inference Model. Autom. Constr. **18**(2), 164–172 (2009a)
Cheng, M.Y, Tsai, H.C., Liu, C.L.:. Artificial intelligence approaches to achieve strategic control over project cash flows. Autom. Constr. **18**(4), 386–393 (2009b)
Cheng, M.Y., Peng, H.S., Wu, Y.W., Chen, T.L.: Estimate at completion for construction projects using evolutionary support vector machine inference model. Autom. Constr. **19**(5), 619–629 (2010a)
Cheng, M.Y, Roy, A.F.V.: Evolutionary fuzzy decision model for construction management using support vector machine. Expert Syst. Appl. **37**(8), 6061–6069 (2010b)
Cheng, M.Y., Roy, A.F.V.: Evolutionary fuzzy decision model for cash flow prediction using time-dependent support vector machines. Int. J. Proj. Manage. **29**(1), 56–65 (2010c)
Chen, W., Shi, Y., Teng, H., Lan, X., Hu, L.: An efficient hybrid algorithm for resource-constrained project scheduling. Inf. Sci. **180**(6), 1031–1039 (2010d)
Cheng, M.Y., Tsai, H.C., Sudjono, E.: Evolutionary fuzzy hybrid neural network for project cash flow control. Eng. Appl. Artif. Intell. **23**, 604–613 (2010e)
Chen, W.N., Zhang, J., Liu, O., Liu, H.: A Monte-Carlo ant colony system for scheduling multi-mode projects with uncertainties to optimize cash flows. In: Proceedings of IEEE Congress on Evolutionary Computation (CEC), pp. 1–8 (2010f)
Chen, W.N., Zhang, J., Chung, H.S.H., Huang, R.Z., Liu, O.: Optimizing discounted cash flows in project scheduling—an ant colony optimization approach. IEEE Trans. Syst. Man Cybern. Part C Appl. Rev. **40**(1), 64–77 (2010g)
Cho, S.: An exploratory project expert system for eliciting correlation coefficient and sequential updating of duration estimation. Expert Syst. Appl. **30**(4), 553–560 (2006)
Chou, J.S., Tai, Y.: Generalized regression neural nets in estimating the high-tech equipment project cost. In: Proceedings of Second International Conference on Computer Engineering and Applications, pp. 281–284 (2010)
Chou, J.S., Tai, Y., Chang, L.J.: Predicting the development cost of TFT-LCD manufacturing equipment with artificial intelligence models. Int. J. Prod. Econ. **128**, 339–350 (2010)

Cirilovic, J., Vajdic, N., Mladenovic, G., Queiroz, C.: Developing cost estimation models for road rehabilitation and reconstruction: case study of projects in Europe and Central Asia. J. Constr. Eng. Manage. **140**(3), 1–10 (2014)

Cooper, R.G.: Winning at New Products, 3rd edn. Perseus Books, Massachusetts (2001)

Cryer, J.D., Chan, K.S.: Time Series Analysis with Applications in R, 2nd edn. Springer, New York (2008)

Di Penta, M., Harman, M., Antoniol, G.: The use of search-based optimization techniques to schedule and staff software projects: an approach and an empirical study. Softw. Pract. Exper. **41** (5), 495–519 (2011)

Duan, K., Keerthi, S., Poo, A.: Evaluation of simple performance measures for tuning SVM hyperparameters. Technical report, Singapore: National University of Singapore, Department of Mechanical Engineering (2001)

Duan, Q., Warren Liao, T.: Improved ant colony optimization algorithms for determining project critical paths. Autom. Constr. **19**, 676–693 (2010)

Dwyer, L., Mellor, R.: Corporate environment and the proficiency of new product process activities. Technovation **11**(2), 63–78 (1991)

Dzeng, R.-J., Tommelein, I.D.: Product modeling to support case-based construction planning and scheduling. Autom. Constr. **13**, 341–360 (2004)

Efron, B.: Estimating the error rate of a prediction rule: improvement on cross-validation. J. Am. Stat. Assoc. **78**, 316–331 (1983)

Efron, B., Tibshirani, R.J.: An Introduction to the Bootstrap. Chapman & Hall, London (1993)

Fang, X., Chen, J.: A neural network model for resource scheduling optimization. In: The 2nd IEEE International Conference on Information Management and Engineering (ICIME), pp. 430–432 (2010)

Fei, S.W., Wang, M.J., Miao, Y.B., Tu, J., Liu, C.L.: Particle swarm optimization-based support vector machine for forecasting dissolved gases content in power transformer oil. Energy Convers. Manage. **50**, 1604–1609 (2009)

Fengshan, P., Chunming, Y., Jianjia, H., Xiaojie, Z.: The project research for optimal scheduling based on Intelligent algorithm. In: Proceedings of International Conference on E-Business and E-Government, pp. 207–210 (2010)

Goutte, C.: Note on free lunches and cross-validation. Neural Comput. **9**, 1211–1215 (1997)

Guo, H., Li, L., Zhu, K., Ding, C.: Application of PSO and MPSO in project scheduling of the first mining face in coal mining. In: Proceedings of International Joint Conference on Neural Networks (2009a)

Guo, Y., Li, N., Ye, T.: Multiple resources leveling in multiple projects scheduling problem using particle swarm optimization. In: Proceedings of Fifth International Conference on Natural Computation, pp. 260–264 (2009b)

Hashemi Doulabi, H., Seifi, S.A., Shariat, S.Y.: Efficient hybrid genetic algorithm for resource leveling via activity splitting. J. Constr. Eng. Manage. **137**(2), 137–146 (2011)

HongWei, M.: An improved support vector machine based on rough set for construction cost prediction. In: International Forum on Computer Science-Technology and Applications, pp. 3–6 (2009)

Hsu, C.W., Chang, C.C., Lin, C.J.: A practical guide to support vector classification, Technical Report. Department of Computer Science, National Taiwan University, Taipei, Taiwan (2003)

Huang, C.L., Dun, J.F.: A distributed PSO–SVM hybrid system with feature selection and parameter optimization. Appl. Soft Comput. **8**, 1381–1391 (2008)

Huang, W., Ding, L., Wen, B., Cao, B.: Project Scheduling problem for software development with random fuzzy activity duration times. Adv. Neural Netw. **5552**, 60–69 (2009)

Iranmanesh, S. H., Davoodpour, F., Geranmayeh Kashani, P.: Using adaptive network fuzzy inference systems (ANFIS) to estimate the completion time of projects. In: Proceedings of International Conference on Project Management (ICOPM 2008), pp. 128–133 (2008)

Iranmanesh, S. H., Zarezadeh, M.: Application of artificial neural network to forecast actual cost of a project to improve earned value management system. World Congress on Science, Engineering and Technology, pp. 240–243 (2008)

Iranmanesh, S. H, Mirseraji, G. H., Shahmiri, S.: An Emotional learning based fuzzy inference system (ELFIS) for improvement of the completion time of projects estimation. In: Proceedings of International Conference on Computers and Industrial Engineering (CIE 2009), pp. 470–475 (2009)

Ji, Z., Li, Y.: The application of RBF neural Network on construction cost forecasting. In: Proceedings of 2nd International Workshop on Knowledge Discovery and Data Mining, pp. 32–35 (2009)

Kashyap, D., Misra, A.K.: Software cost estimation using particle swarm optimization in the light of quality function deployment technique. In: Proceeding of international conference on computer communication and informatics (ICCCI), pp. 1–8 (2013)

Kazemifard, M., Zaeri, A., Ghasem-Aghaee, N., Nematbakhsh, M.A., Mardukhi, F.: Fuzzy emotional COCOMO II software cost estimation (FECSCE) using multi-agent systems. Appl. Soft Comput. **11**(2), 2260–2270 (2011)

Kennedy, J., Eberhart, R.C., Shi, Y.: Swarm Intelligence. Morgan Kaufmann Publishers Inc., San Francisco (2001)

Kong, F., Wu, X., Cai, L:. Application of RS-SVM in construction project cost forecasting. In: Proceedings of 4th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM'08), pp. 1–4 (2008)

Koo, C.W., Hong, T.H., Hyun, C.T., Koo, K.J.: A CBR-based hybrid model for predicting a construction duration and cost based on project characteristics in multi-family housing projects. Can. J. Civ. Eng. **37**(5), 739–752 (2010)

Kuo, R.J., Lin, L.M.: Application of a hybrid of genetic algorithm and particle swarm optimization algorithm for order clustering. Decis. Support Syst. **49**(4), 451–462 (2010)

Lee, J.K., Lee, N.: Least modification principle for case-based reasoning: a software project planning experience. Expert Syst. Appl. **30**(2), 190–202 (2006)

Lewis, J.P.: Project Planning, Scheduling, and Control: The Ultimate Hands-on Guide to Bringing Projects in on Time and on Budget, 5th edn. McGraw-Hill, USA (2010)

Li, Y.F., Xie, M., Goh, T.N.: A study of the non-linear adjustment for analogy based software cost estimation. Empir. Softw. Eng. **14**, 603–643 (2009)

Liu, J., Wu, B.: A Multi-agent system for the flexible resource constrained project scheduling. Proceedings of Third International Conference on Intelligent Information Hiding and Multimedia Signal Processing (IIHMSP), pp. 321–324 (2007)

López-Martín, C., Abran, A.: Neural networks for predicting the duration of new software projects. J. Syst. Softw. doi:10.1016/j.jss.2014.12.002 (2014) (In Press, Accepted Manuscript)

Lu, M., Lam, H.C., Dai, F.: Resource-constrained critical path analysis based on discrete event simulation and particle swarm optimization. Autom. Constr. **17**(6), 670–681 (2008)

Miyuan, S., Hong, Q., Juan, W.: Multi-mode multi-project scheduling problem for mould production in MC enterprise. In: Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing, pp. 5316–5320 (2007)

Mobini, M., Mobini, Z., Rabbani, M.: An for the project scheduling problem under resource constraints. Appl. Soft Comput. **11**(2), 1975–1982 (2010)

Montoya-Torres, J.R., Gutierrez-Franco, E., Pirachicán-Mayorga, C.: Project scheduling with limited resources using a genetic algorithm. Int. J. Proj. Manage. **28**, 619–628 (2010)

Pan, X., Chen, H.: A multi-agent social evolutionary algorithm for resource-constrained project scheduling. In: Proceedings of International Conference on Computational Intelligence and Security, pp. 209–213 (2010)

Papatheocharous, E., Andreou, A.S.: Hybrid computational models for software cost prediction: an approach using artificial neural networks and genetic algorithms. In: Filipe, J., Cordeiro, J. (eds.) Enterprise Information Systems, vol. 19, pp. 87–100. Springer, Berlin, Heidelberg (2009)

Peng, W., Wei, Y.: PSO for solving RCPSP. In: Proceedings of Control and Decision Conference (CCDC 2008), pp. 818–822 (2008)

Pewdum, W., Rujirayanyong, T., Sooksatra, V.: Forecasting final budget and duration of highway construction projects. Eng. Constr. Archit Manage. **16**(6), 544–557 (2009)

PMI: A Guide to the Project Management Body of Knowledge (PMBOK). Project Management Institute, USA (2012)
Ponz-Tienda, J.L., Yepes, V., Pellicer, E., Moreno-Flores, J.: The resource leveling problem with multiple resources using an adaptive genetic algorithm. Autom. Constr. **29**, 161–172 (2013)
Salgado, D.R., Alonso, F.J.: An approach based on current and sound signals for in-process tool wear monitoring. I. J. Mach. Tools Manuf. **47**, 2140–2152 (2007)
Salzberg, S.L.: On comparing classifiers: pitfalls to avoid and a recommended approach. Data Min. Knowl. Disc. **1**, 317–327 (1997)
Sapankevych, N.I., Sankar, R.: Time series prediction using support vector machine: a survey. Comput. Intell. Mag. IEEE Comput. Intell. Mag. **4**(2), 24–38 (2009)
Shi, Y., Eberhart, R.C.: A modified particle swarm optimizer. In: Proceeding of the IEEE Congress on Evolutionary Computation, pp. 69–73 (1998)
Shi, H., Li, W.: The integrated methodology of rough set theory and artificial neural-network for construction project cost prediction. Intell. Inf. Technol. Appl. **2**, 60–64 (2008a)
Shi, H., Li, W.: Application of PSO-based neural network in quality assessment of construction project. In: Proceedings of International Conference on MultiMedia and Information Technology (MMIT'08), pp. 54–57 (2008b)
Shi, H., Li, W.: A web-based integrated system for construction project cost prediction. Advancing computing, communication, control and management. Lecture Notes in Electrical Engineering, vol. 56, pp. 31–38 (2010)
Shou, Y.: A neural network based heuristic for resource-constrained project scheduling. In: Advances in Neural Networks, pp. 794–799. Springer, Berlin (2005)
Shou, Y.: Ant colony algorithm for scheduling resource constrained projects with discounted cash flows. In: Proceedings of International Conference on Machine Learning and Cybernetics, pp. 176–180 (2006)
Shou, Y., Li, Y., Lai, C.: Hybrid particle swarm optimization for preemptive resource-constrained project scheduling. Neurocomputing **148**(19), 122–128 (2015)
Tseng, L.Y., Chen, S.C.: A hybrid meta heuristic for the resource-constrained project scheduling problem. Eur. J. Oper. Res. **175**(2), 707–721 (2006)
Van Peteghem, V., Vanhoucke, M.: An artificial immune system for the multi-mode resource-constrained project scheduling problem. Evolutionary computation in combinatorial optimization, pp. 85–96. Springer, Berlin (2009)
Vapnik, V.N.: The Nature of Statistical Learning Theory. Springer, London (1999)
Wang, W.X., Wang, X., Ge, X.L., Deng, L.: Multi-objective optimization model for multi-project scheduling on critical chain. Adv. Eng. Softw. **68**, 33–39 (2014)
Wauters, M., Vanhoucke, M.: Support vector machine regression for project control forecasting. Autom. Constr. **47**, 92–106 (2014)
Weustink, I.F., Ten Brinke, E., Streppel, A.H., Kals, H.J.J.: A generic framework for cost estimation and cost control in product design. J. Mater. Process. Technol. **103**, 141–148 (2000)
Xiaokang, H., Mei, L.: Research on construction cost control based upon BP neural network and theory of constraint. In: Proceedings of International Conference on Management and Service Science (MASS), pp. 1–4 (2010)
Xin-zheng, W., Li-ying, X.: Application of rough set and neural network in engineering cost estimation. In: Proceedings of International Conference on Management and Service Science (MASS), pp. 1–4 (2010)
Xu, Z., Khoshgoftaar, T.M.: Identification of fuzzy models of cost estimation. Fuzzy Sets Syst. **145**, 141–163 (2004)
Yang, B., Yao, L., Huang, H.Z.: Early software quality prediction based on a fuzzy neural network model. In: Proceedings of International Conference on Natural Computation, vol. 1, pp. 760–764 (2007)
Yang, R., Wang, X.: The evaluation of construction quality based on BP neural network. In: Proceedings of International Conference on Mechanic Automation and Control Engineering (MACE), pp. 1582–1585 (2010)

Yunna, W., Zhijun, H.: Application of a case-based reasoning method in estimating the power grid project cost. In: Proceedings of 4th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM'08), pp. 1–5 (2008)

Zhang, H., Tam, C.M., Li, H.: Multimode project scheduling based on particle swarm optimization. Comput. Aided Civil Infrastr. Eng. **21**(2), 93–103 (2006)

Zhao, H., Ru, Z.: Construction schedule optimization using particle swarm optimization. In: Proceedings of 4th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM'08), pp. 1–4 (2008)

Chapter 22
A Fuzzy Evaluation of Projects for Business Processes' Quality Improvement

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Abstract Business process improvement is essential for success of enterprises according to the quality philosophy and ISO 9000:2008. On the way to achieving this goal, a very successful approach is the employment of quality improvement projects. This chapter proposes a model for evaluation of projects for business process quality improvement. The performances of the treated type of projects are analyzed in the scope of standard ISO 215000:2015 and the results of good practice. An arranged pair (relative importance, value) is associated to each performance. The relative importance of project performances is assessed on the basis of experts' judgments from the manufacturing industry and they are introduced by linguistic expressions which are close to human thinking. The values of project performances are determined by measurement or they are based on assessment by a project management team. Modeling of linguistic expressions is performed by fuzzy sets theory. The relative importance of each pair of business processes and project performances is determined on the level of the treated specimen of enterprises. The total score of the project is determined by using fuzzy logic. The model for evaluation of projects for business process quality improvement is verified through a case study example.

Keywords Project performances · Evaluation · Fuzzy set · Fuzzy AHP · Fuzzy logic

22.1 Introduction

Project management methods play a main role in continuous business process improvement which is one of the requests of ISO 9000:2008. The importance of project management methodologies is confirmed by a partial longitudinal study

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conducted by Fortune et al. (2011). Evaluation of projects and their success, and their delivery is essential for normal functioning of business activities in every organization.

In general, project success depends on: selection of projects, and continuous quality improvement projects. The selection of a project is a very important management task. The solution to this problem is propagated through all phases of project realization and through all treated business processes and has an impact on the improvement of the business processes. In the literature, there are many papers which deal with the issue of project selection which is solved by using different multi-criteria decision methods (Khalili-Damghani et al. 2013).

If a selected project is not sufficiently adequate, project success may not be achieved. At the same time, if the selected project is very suitable, improvement of business processes may not always be achieved. In practice, this problem frequently happens. The purpose of this study is to propose a fuzzy model for assessment of project performances (PPs) and evaluation of projects for business process quality improvement in small and medium manufacturing enterprises (SMEs).

In the literature, there are a few papers which treat the problem of evaluation and management of a continuous quality improvement project by using exact methods. However, according to the project performance measurement literature, there is a relationship between PPs and project success (Bryde 2008). The reasons for lack of exact approaches in the assessment of project success are numerous and varied. For instance, there are no standards or guidelines for determining performance of different projects, and different methods for evaluation have emerged for the evaluation of business performances (Jaakkola et al. 2010). A significant number of scholars have evaluated projects in the scope of cost, time and quality, as revealed in the literature (Ahadzie et al. 2008) and in this way have emphasized the influence of economic aspects. As recent research has illuminated the impact of additional criteria such as social aspects, the scope of project performance evaluation has improved to be defined as five pillars (Beck 2006; Ika et al. 2012): relevance, efficiency, effectiveness, impact and sustainability. As the current trend is to provide a multidimensional performance evaluation framework, this paper is based on performance. The mentioned methods have been based on a different mathematical and logical framework. There is no consensus between these methods, indicating the difficulty of this research field (Franco-Santos et al. 2007).

In the focus of this research are the projects related to business process quality improvement in manufacturing SMEs. The manufacturing SMEs are very important for the European economy as they are stimulating entrepreneurship, creating higher quality jobs, enhancing the research community (world class research) and creating new markets. From the perspective of production, SMEs' continuous improvement and sustainable development, projects for business process quality improvement are very significant. This chapter is focused on providing a reliable assessment tool that will enable suitable and easy usage of methodology for PP evaluation.

In general, PPs are defined by expert teams and their judgments are based on knowledge, previous experience, literature sources and results of good practice. The values of some PPs are impossible to quantify. In this chapter, the authors make an effort to treat, at the same time, crisp and uncertain PPs. The rating of the relative importance of business processes, the relative importance of PPs and uncertain PP values over time are based on uncertain and imprecise knowledge by decision makers who express the subjectivity and imprecision of their assessments by linguistic expressions. The concept of linguistic variables is introduced by Zadeh (1975), and it is very useful for dealing with situations which are not well defined. These linguistic terms can be modeled by using the fuzzy sets theory (Klir and Folger 1988; Zimmermann 2001). Fuzzy sets theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions (Kahraman et al. 2006), so that by applying the fuzzy approach all uncertainties and imprecision which have emerged due to lack of good evidence are eliminated. The fuzzy sets theory provides a strict mathematical framework in which vague conceptual phenomena can be precisely and rigorously studied (Zimmermann 2001).

The chapter is organized as follows. Section 22.2 presents the literature review. The evaluation framework is presented in Sect. 22.3. Modeling of existing uncertainties is presented in Sect. 22.4. In Sect. 22.5 the proposed fuzzy Algorithm is introduced. Section 22.6 talks about the application of the recommended Algorithm with real-life data. Finally, Sect. 22.7 sets the conclusions.

22.2 Literature Review

Traditional PPs for project evaluation are time, cost and quality which meeting technical requests is still considered good practice for some projects. However, there are many critics of these PPs indicating that they do not adequately cover aspects of performance measurement (Gardiner 2000). Barcaly and Osei-Bryson (2010) suggest that a project performance measurement criterion should consider diversity and both the technical and societal needs of the project. In recent years, many researchers have given emphasis to different PPs, for instance: the safety aspect (Billy et al. 2006; Zuo 2011), dispute resolution (Tabish and Jha 2011), environmental impact (Chen et al. 2010; Medineckiene et al. 2010; Tan et al. 2011), and community satisfaction (Shao and Müllier 2011).

From the foregoing discussion, it may be concluded that hardly anyone has provided a comprehensive performance evaluation framework for a developing project which encompasses economic, social and environmental aspects. Because of this, in the literature and in practice, there is no systematic grouping of the PPs which can be collected according to best practices (Coccoa and Alberti 2009) by using a model based on a survey questionnaire (Mir and Pinnington 2014), etc.

Nowadays, there are many multi-dimensional performance evaluation frameworks. In Taylan et al. (2014), the following PPs are considered: time, cost, safety, quality and environmental sustainability. A widely used four dimensional framework for assessing project success is proposed in Shenhar et al. (2001). Their framework includes: efficiency, impact to customers, business success and preparing for the future. Many authors consider that teamwork effectiveness should be included with the previous PPs (Bryde 2008; Müller and Judgev 2012). Bryde (2003) introduced the following PPs for evaluation of project success: (1) leadership, (2) staff, (3) policy and strategy, (4) partnership and resources, (5) project lifecycle management process, and (6) key performance indicators. Ngacho and Das (2014) define PPs: cost performance, time performance, quality performance, safety performance, site dispute performance and environmental performance. With respect to the results, the 586 projects were carried out in 24 countries.

In the literature, there are different performance measurement systems (PMS) that may be used for the description of project success (Neely et al. 2007; Nudurupati et al. 2011). There is no unique definition of the term project success. Mir and Pinnington (2014) have defined the responsive variables of overall project success such as project efficiency, impact to customer, impact to the team, business success and preparing for the future. It is known that the enhancing of project performances and project success, at the same time, leads to overall quality improvement.

Determination of the project success may be delivered by using different methods that are developed on a different mathematical and logical framework. Artificial intelligence is widely accepted in the solving of many management and engineering issues, including project management. Neural networks (Chua et al. 1997) and fuzzy hybrid neural networks (Cheng et al. 2012) may be used for assessment of project success with respect to different factors. For the prediction of engineering performance within projects, neuro fuzzy intelligent systems may be used (Georgy et al. 2005). Amongst many variables that have an influence on project performances, knowledge management is a very significant issue. In this manner, evolutionary optimization of model specification searches between management knowledge and engineering performance may be defined (Chou and Yang 2013). On some occasions, the time progress of project realization is very significant for the project success, so genetic algorithms (GA) may be used for evaluating the impact of different project acceleration strategies (Fan et al. 2012). For time management of project progress, a two-phase GA model for resource—constrained project scheduling may be used (Chen and Weng 2009).

With respect to the above presented, in-process control is a complex management task. The monitoring and continuous improvement of project quality introduce significant consumption in terms of time, money, human and other resources in each phase of project implementation but, at the same time, these activities may introduce an increase of the degree of project success.

Mir and Pinnington (2014) have used linear regression and correlation tests for determining the strength of relations between PPs and variables of project success. The significance of PPs for overall project performance is determined by using factor analysis (Ngacho and Das 2014).

Composite reliability of the risk of project outcomes and the evaluation of the relationship between PPs and outcomes are calculated by factor analysis. By using the proposed methodologies in the mentioned papers, a management team, with respect to the calculated significance of the relation between variables, needs to define the appropriate initiatives which should lead to improvement of the input variables (PPs) that have the greatest influence on the outcomes (variables of project success). In these papers, it is assumed that the relative importance of PPs is equal and values of all variables can be described by precise numbers.

Comparing the papers which propose a model for evaluation of PPs and project success, certain differences could be noted, which are further described. This analysis, at the same time, shows advantages of the proposed model.

In real project management problems, it is almost impossible to assume that all of the identified PPs have equal relative importance to project success. According to the referent literature (Kaya and Kahraman 2011), we suppose that an evaluation of the relative importance of PPs is stated as a fuzzy group decision making problem which should be based on the AHP framework. The linguistic variables are modeled by TFNs. A brief literature review of papers is presented as follows.

Determining the element values of fuzzy pair-wise comparison matrices of the relative importance of the considered variables is stated as a group decision making problem (Kaya and Kahraman 2011; Tadić et al. 2013). The aggregation opinions of decision makers into a group consensus can be performed by applying different methods. The consensus could be obtained by taking the geometric mean of individual decision makers and the Delphi method in Bozbura et al. (2007), by using the fuzzy averaging method in Kaya and Kahraman (2011), etc. There are many papers in which it is assumed that decision makers make a decision by consensus (Gumus 2009; Seçme et al. 2009; Paskoy et al. 2012).

In the literature, there are many developed approaches for handling FAHP. Chang (1996) introduced a new approach with the use of TFNs for the pair-wise comparison scale of FAHP, and the use of the extent analysis method for the synthetic extent value of the pair-wise comparison. By applying the method for comparison of fuzzy numbers (Dubois and Prade 1980; Bass and Kwakernaak 1977), the weight vectors of existing variables are obtained. The proposed approach in Chang (1996) has been widely used in a different research area because: (1) it does not involve cumbersome mathematical operations, (2) the steps are easier than other FAHP approaches. The normalized weight vectors are not fuzzy numbers (Kahraman et al. 2006; Büyüközkan et al. 2008). With respect to opinion, the authors have suggested that the FAHP developed in Chang (1996) is appropriate for determination of business process weight vectors and PP weight vectors under each business process (the used FAHP is not detailed here because of being a well-known application).

In this chapter, an effort is given to observe simultaneously both crisp and uncertain PPs in the problem of evaluation of PPs. The crisp PP values are given by a measurement procedure and can be expressed by different measurement units. The uncertain PP values are estimated by decision makers who use pre-defined linguistic expressions. These linguistic terms are modeled by TFNs, in similarity to the analyzed papers. The normalization procedure should be used to transform the various PP scales into a comparable scale. It can be mentioned that the normalization procedure can be performed with respect to PP type. In this chapter, the crisp PP values are normalized by using the vertex method presented in Gumus (2009) and in Seçme et al. (2009). The TFNs that describe uncertain PP values are normalized by the linear normalization method presented in Shih et al. (2007). By using the mentioned normalization method, the domains of TFNs are mapped into interval [0–1].

The overall project performance can be calculated as the sum of the weighted normalized values of PPs with respect to all treated business processes, simultaneously. Project success in the considered phase depends on the overall project performance. According to the results of good practice, it is very important how the obtained results are presented to decision makers. The graphical presentation of the calculated values provides an opportunity to the decision makers to analyse the problem in an easy and fast manner. With respect to these facts, project success in each project phase is presented by one of three linguistic expressions which are modeled by TrFNs. Determining project success is based on using fuzzy IF-THEN rules.

The rank of the identified PPs for each treated business process is given by using the method for comparison of fuzzy numbers in Bass and Kwakernaak (1977), Dubois and Prade (1980). The PP which has the lowest weighted normalized value is placed at first place in the rank. With respect to the obtained rank of PPs, the priority of the management initiatives which should be taken in order to increase management effectiveness and efficiency is determined.

22.3 The Framework for Project Performance Evaluation

The elements of the model for assessment of project potential are the identified PPs which are assessed in the scope of the reference model of SMEs which may be obtained by the process approach. It implies that an organization is viewed as a network of interrelated processes that are focused towards achieving organizational goals (Oakland 2004). In general, the business processes are presented by a set of indices $P = \{1, \ldots, p, \ldots, P\}$. The index for a business process is denoted as p, and P is the total number of business processes.

In this chapter, the PPs are defined with respect to standard ISO 21500:2015 and the results of research which are presented in Ngacho and Das (2014).

The identified PPs are presented by a set of indices $I = \{1, \ldots, i, \ldots, I\}$. The index for a PP is denoted as i, i = 1, …, I. The total number of PPs are denoted as I (Fig. 22.1).

The rating of the relative importance of business processes and the relative importance of PPs at each SME level is based on a pair-wise comparison (by analogy to AHP). Decision makers use the pre-defined linguistic expressions which are modeled by TFNs. It is more reliable when using a pair-wise comparison than when obtaining them directly.

Formally, SMEs are presented by a set of indices $E = \{1, \ldots, e, \ldots, E\}$ where e is the index for an SME and E is the total number of treated manufacturing SMEs. Similarly, the management teams (main manager, quality manager, financial manager, etc.) of the manufacturing SMEs are noted.

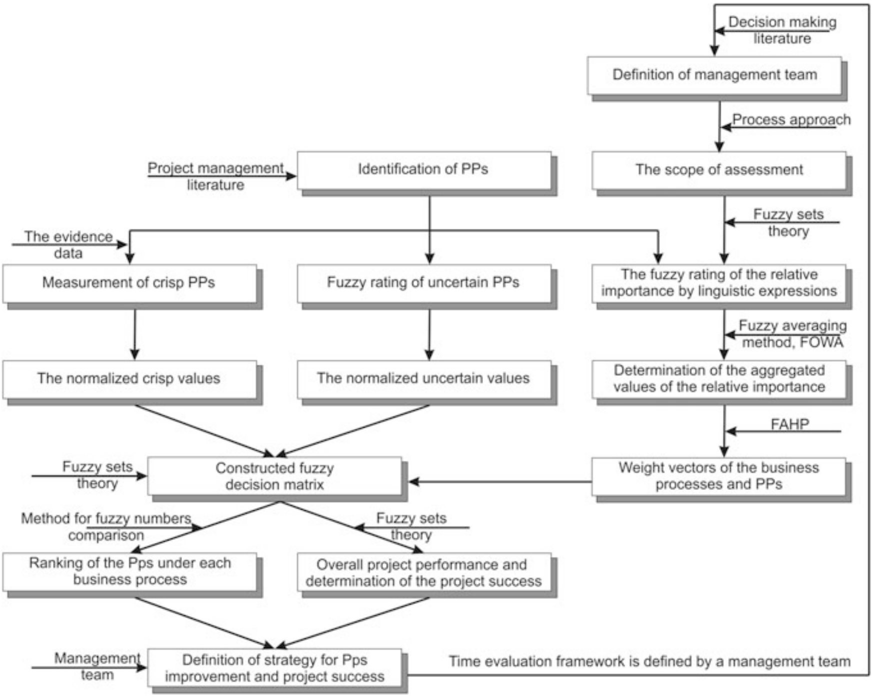

Fig. 22.1 The evaluation framework for Project Performance Evaluation

As SMEs are in the focus of this research, it is realistic to assume each management team makes a decision by consensus. The fuzzy rating of the relative importance of business processes and the relative importance of PPs with respect to an SME is stated as a fuzzy group decision making problem. In other words, management teams of SMEs have different levels of importance that correspond to the SMEs' importance. According to this assumption, it is necessary to conduct the classification of SMEs. In this chapter, the classification criterion is defined as the number of successful development projects that have been delivered within the last 10 years. The classification of all the considered SMEs is based on Pareto analysis, so that the considered SMEs should be divided into three groups A, B, and C. The management teams of SMEs of class A, SMEs of class B, and SMEs of class C have the highest, medium, and lowest importance, respectively, in the assessment of the relative importance of business processes. The importance of each group of management teams $w_g, g = 1, 2, 3$ is determined based on the results of good practice in the manufacturing SMEs. The aggregation of individual opinions of management teams under each group of manufacturing SMEs is performed by using a fuzzy averaging method. The weighted values of elements of fuzzy pair-wise comparison matrices of the relative importance of business processes and the relative importance of PPs are calculated by using the Fuzzy Ordered Weighted Averaging Operator (FOWA) (Merigó and Casanovas 2008).

The weight vectors of business processes, and the weight vectors of PPs are obtained by using fuzzy AHP (FAHP) which is developed in Chang (1996).

The PP values are given at the level of each business process for each SME. The values of measurable PPs are crisp. The uncertain PP values are given by a management team who use pre-defined linguistic terms. By using a normalization procedure, PP values can be compared. The weighted normalized PP values are calculated by using the fuzzy algebra rules (Klir and Folger 1988; Zimmermann 2001).

The overall project performance can be calculated as the sum of the weighted normalized evaluation of PPs for all business processes and it is described by a TFN. The representative scalar of the overall project score is given by applying the moment method (Dubois and Prade 1980). The determining of project success is based on fuzzy logic. In this chapter, the fuzzy IF-THEN rules are built from the expert team's knowledge, experience and from evidence data (Aleksić et al. 2013). Here, there are three production rules modeled by the TrFNs.

The PPs are ordered in decreasing order. The PP which is placed at first place in the rank has the lowest weighted normalized value so this PP needs to be improved, firstly, by applying the appropriate management initiatives.

22.4 Modeling of Uncertainties

Expressions which are used in a rating of uncertainties over time are based on uncertain, vague preference and imprecise knowledge, so that they more or less represent some degree of uncertainty of human thinking. It is assumed that uncertainties are described by predefined linguistic expressions which are modeled by TFNs and TrFNs. In the literature, these fuzzy numbers are commonly used for the modeling of different types of uncertainties. The authors' motivation for employment of the TFNs and TrFNs has arisen from the fact that these fuzzy numbers offer a good compromise between descriptive power and computational simplicity. Fuzzy sets of higher order make mathematical calculation more complex and at the same time do not improve the accuracy of the calculation. The domain of fuzzy sets can be defined on different measurement scales.

22.4.1 Modeling of the Relative Importance

It can be assumed that the relative importance of business processes and the relative importance of PPs do not have equal importance. Also, they can be considered as unchangeable during the considered period of time. They involve a high degree of subjective judgments and individual preferences, knowledge and experience of decision makers.

The relative importance of each pair of business processes and the relative importance of each pair of PPs are assessed by the management teams who use pre-defined linguistic expressions.

The fuzzy pair-wise comparison matrix of the relative importance of business processes is constructed. The elements of this fuzzy matrix are TFNs, $\tilde{W}^e_{pp'} = \left(x; l^e_{pp'}, m^e_{pp'}, u^e_{p'}\right)$ with the lower and upper bounds $l_{pp'}$,$u_{pp'}$ and modal value $m_{pp'}$, respectively, $p, p' = 1, \ldots, P; e = 1, \ldots, E$. The domains of the defined TFNs are defined on the measurement scale [1–5]. Value 1 and value 5 mean that the relative importance of business process p over business process p′ $p, p' = 1, \ldots, P$, has the lowest and the most importance, respectively.

If the strong relative importance of business process p′ over business process p holds, then the pair-wise comparison scale can be represented by the TFN, $\tilde{W}'_p p^e = \left(\tilde{W}^e_{pp'}\right)^{-1} = \left(\frac{1}{u^e_{pp'}}, \frac{1}{m^e_{pp'}}, \frac{1}{l^e_{pp'}}\right)$.

If $p = p'$, $p, p' = 1, \ldots, P$, then the relative importance of business process p over business process is represented by a single point 1 which is a TFN (1, 1, 1).

Similarly, the elements of the fuzzy pair-wise comparison matrix of PPs are described. These TFNs are given in the way presented in Fig. 22.2.

TFNs presented in Fig. 22.2 have different importance which is presented in Table 22.1.

22.4.2 Modeling of Uncertain PP Values

In this chapter, the fuzzy rating of uncertain PP values is described by linguistic expressions which can be represented as TFNs $\tilde{v}_{ip} = \left(y; L_{ip}, M_{ip}, U_{ip}\right)$ with the

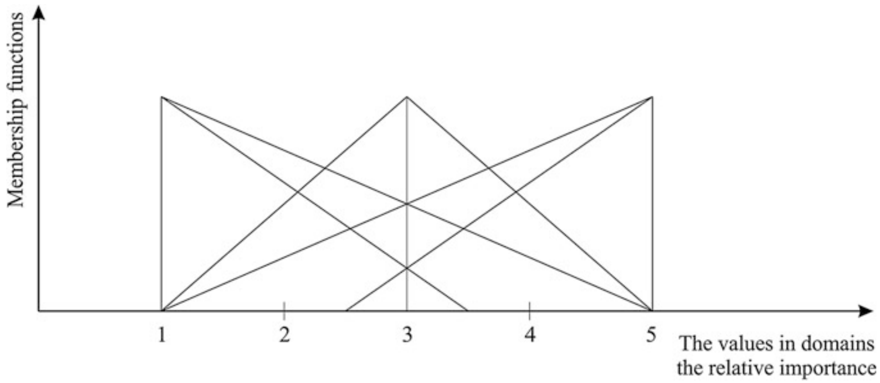

Fig. 22.2 The relative importance of business processes and PPs

Table 22.1 The importance of the business processes and PPs expressed by TFNs

Intensity of importance described by TFNs	Definition	Explanation
(1, 1, 3.5)	very low importance	The importance of one business process/PPs compared to another business process/PPs is very low
(1, 1, 5)	low importance	The importance of one business process/PPs compared to another business process/PPs is moderate
(1, 3, 5)	medium importance	The importance of one business process/PPs compared to another business process/PPs is strong
(1, 5, 5)	high importance	The importance of one business process/PPs compared to another business process/PPs is very strong
(2.5, 5, 5)	very high importance	The importance of one business process/PPs compared to another business process/PPs is the highest possible

lower and upper bounds L_{ip}, U_{ip} and modal values M_{ip}, respectively. The domain of these TFNs is defined on the common measurement scale, i.e. [1–9]. Value 1, and value 9 denote that PP i at the level of process p is at the lowest value, and the highest value, i = 1, …, I; p = 1, …, P.

The number and kinds of linguistic expressions are defined by a management team depending on the number of uncertain PPs.

Specifically, we use five linguistic expressions, which are modeled by TFNs (Fig. 22.3).

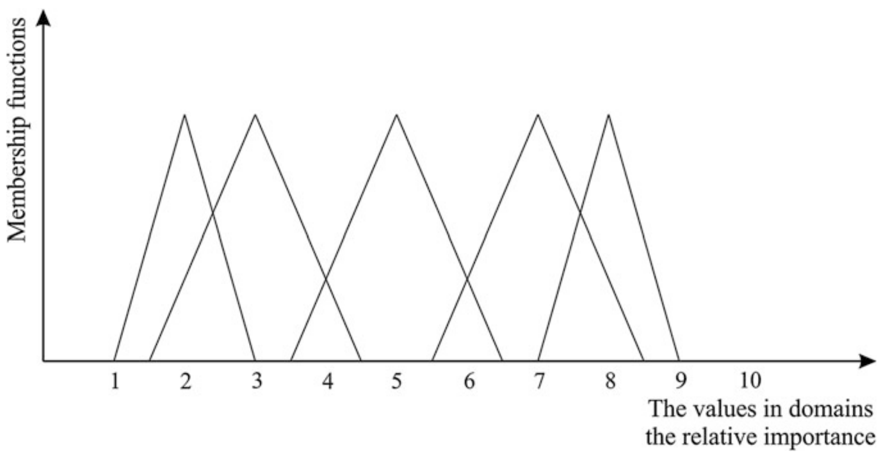

Fig. 22.3 Modeling of uncertain PP values

Table 22.2 The values of PPs expressed by TFNs

Intensity of importance described by TFNs	Definition	Explanation
(y; 1, 2, 3)	low	The assessed value based on experience of treated PP is low
(y; 1.5, 3, 4.5)	fairly moderate	The assessed value based on experience of treated PP is fairly moderate
(y; 3.5, 5, 6.5)	moderate	The assessed value based on experience of treated PP is moderate
(y; 5.5, 7, 8.5)	fairly high	The assessed value based on experience of treated PP is fairly high
(y; 7, 8, 9)	high	The assessed value based on experience of treated PP is high

The fuzzy numbers presented in Fig. 22.3 have different values of PPs (Table 22.2).

22.4.3 Modeling the Regions of Project Success

The success of a developing project in an organization, especially in manufacturing SMEs, may have different values. This chapter proposes the defining of the three states of project success: low project success, mid-point project success, and high project success.

The project success can be described by one of the three predetermined linguistic terms which are modeled by TrFNs (Fig. 22.4).

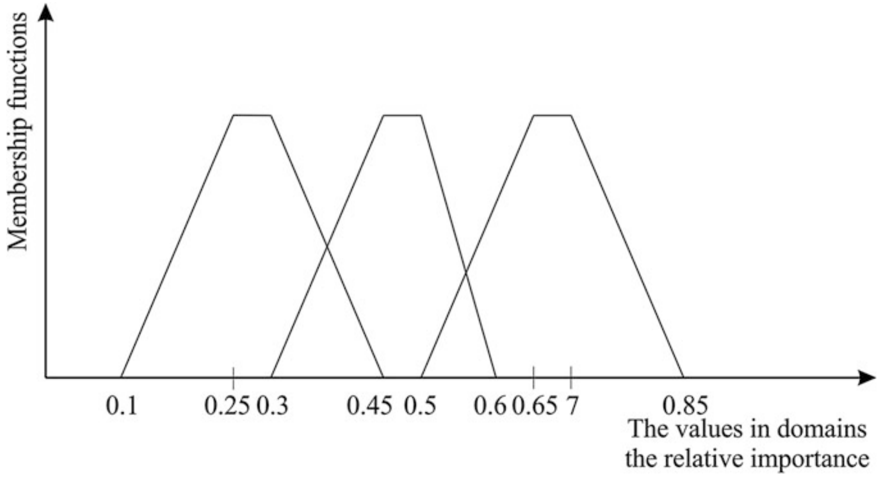

Fig. 22.4 Modeling the regions of project success

Table 22.3 The values s of project success regions given by TrFNs

Intensity of importance described by TFNs	Definition	Explanation
$\tilde{S}_1 = (z;\, 0.1, 0.25, 0.3, 0.45)$	low project success	The assessed value of treated project's success is low. The project is almost unacceptable
$\tilde{S}_2 = (z;\, 0.3, 0.45, 0.5, 0.6)$	mid-point project success	The assessed value of treated project's success is moderate. The project is acceptable with some revision
$\tilde{S}_3 = (z;\, 0.5, 0.65, 0.7, 0.85)$	high project success	The assessed value of treated project's success is high. The project is totally acceptable

The fuzzy numbers presented in Fig. 22.3 show different regions of project success (Table 22.3).

The lowest bound of TrFN $\tilde{S}_1$ is given according to the assumptions that the PPs which are cost type are described by the linguistic expression high and the benefit-type of PPs is associated with the linguistic term low. Similarly, the upper bound of the defined TrFN $\tilde{S}_3$ is determined. The rest of the values are determined on the basis of the decision makers' previous experience.

Since the overlap from one TrFN to the other is very high, it obviously indicates that there is a lack of knowledge on the regions of project potential or a lack of sufficient partitioning. These values may be changed due to project change or due to the specific needs of the manufacturing SMEs.

22.5 The Proposed Algorithm

The proposed procedure can be realized through steps.

Step 1. At the level of group g, calculate the aggregated values of: business processes and PPs by using the fuzzy averaging method:

$$\tilde{W}^{g}_{pp'} = \frac{1}{E_g} \cdot \sum_{e=1}^{E_g} \tilde{W}^{e}_{pp'} \quad p = 1, \ldots, P;\, e = 1, \ldots E_g;\, g = 1,.2,3 \tag{22.1}$$

$$\tilde{W}^{g}_{ii'} = \frac{1}{E_g} \cdot \sum_{e=1}^{E_g} \tilde{W}^{e}_{ii'} \quad i = 1, \ldots, I;\, e = 1, \ldots, E_g;\, g = 1,.2,3 \tag{22.2}$$

Step 2. Calculate the weighted aggregated values of: business processes and PPs given by using FOWA:

$$\tilde{W}_{pp'} = \sum_{g=1}^{G} w_g \cdot \tilde{W}^{g}_{pp'} = \left(x; l_{pp'}, m_{pp'}, u_{pp'}\right), \quad p = 1, \ldots, P; e = 1, \ldots, E_g; g = 1,2,3, \tag{22.3}$$

$$\tilde{W}_{ii'} = \sum_{g=1}^{G} w_g \times \left(\tilde{W}^{g}_{ii'}\right) = (y; L_{ii'}, M_{ii'}, U_{ii'}), \quad i = 1, \ldots, I;\ e = 1, \ldots, E_g; g = 1,2,3, \tag{22.4}$$

Step 3. Calculate the weight vectors of business processes, $w_p, p = 1, \ldots, P$, and weight vectors of PPs, $w'_i, i = 1, \ldots, I$.

Step 4. Calculate the normalized values for crisp PPs:

$$r_{ip} = \frac{1/v_{ip}}{\sqrt{\sum_{i=1}^{I_2} \left(1/v_{ip}\right)^2}} \quad i = 1, \ldots, I'; p = 1, \ldots, P \tag{22.5}$$

where I′ is the total number of crisp PPs.

Step 5. Transform all linguistic PP values, $\tilde{v}_{ip}$ into $\tilde{r}_{sk}$ by applying the linear normalization method:

(a) for benefit type

$$\tilde{r}_{ip} = \left(\frac{L_{ip}}{U^*}, \frac{M_{ip}}{U^*}, \frac{U_{ip}}{U^*}\right) \; i = 1, \ldots, I''; p = 1, \ldots, P, \tag{22.6}$$

(b) for cost-type

$$\tilde{r}_{ip} = \left(\frac{L^-}{U_{ip}}, \frac{L^-}{M_{ip}}, \frac{L^-}{L_{ip}}\right) i = 1, \ldots, I''; p = 1, \ldots, P, \tag{22.7}$$

where:

$$U^* = \max_{i=i,\ldots,I''; p=1,\ldots,P} U_{ip}$$

$$L^- = \min_{i=i,\ldots,I''; p=1,\ldots,P} L_{ip}$$

Step 6. Construct a fuzzy decision matrix, $\tilde{D}$:

$$\tilde{D} = \left[\tilde{d}_{ip}\right]_{IxP}, i = 1, \ldots I; p = 1, \ldots, P \tag{22.8}$$

where:

$$w_{ip} = w_p \cdot w'_i, i = 1, \ldots, I; p = 1, \ldots, P$$

$\tilde{d}_{ip} = (z; l_{ip}, m_{ip}, u_{ip}) = (w_{ip} \cdot r_{ip}, w_{ip} \cdot r_{ip}, w_{ip} \cdot r_{ip}),\ i = 1, \ldots, I'$ for crisp PPs
$\tilde{d}_{ip} = (z; l_{ip}, m_{ip}, u_{ip}) = (w_{ip} \cdot l_{ip}, w_{ip} \cdot m_{ip}, w_{ip} \cdot u_{ip}),\ i = 1, \ldots, I''$ for uncertain PPs

Step 7. Calculate the overall project performance value, $\tilde{V}$:

$$\tilde{V} = \sum_{p=1}^{P} \sum_{i=1}^{I} \tilde{d}_{ip},\ i = 1, \ldots, I; p = 1, \ldots, P \tag{22.9}$$

where $\tilde{V} = (z; l, m, u) = \left(z; \sum_{p=1}^{P} \sum_{i=1}^{I} l_{ip}, \sum_{p=1}^{P} \sum_{i=1}^{I} m_{ip}, \sum_{p=1}^{P} \sum_{i=1}^{I} u_{ip} \right)$.

Determine the scalar value of TFN $\tilde{V}$, v such as:

$$v = \frac{\int z \cdot \mu_{\tilde{V}}(z)}{\int \mu_{\tilde{V}}(z)} \tag{22.10}$$

Step 8. The project success in the observed manufacturing SMEs can be defined according to the rule:

IF the "overall project performance" equals v, THEN the project success is described by the linguistic expression where

$$\max_{q=1,2,3} \mu_{\tilde{S}_q}(z = v) = \mu_{\tilde{S}_{q^*}} \tag{22.11}$$

Step 9. Choose an i, i = 1, …, I under business process p, p = 1, …, P which is associated with the highest value of the fuzzy decision matrix, i^*, i = 1, …, I; p = 1, …, P. Rank all $\tilde{d}_{ip}$ in decreasing order of m_{ip}, $i = 1, \ldots, I; p = 1, \ldots, P$.

22.6 Case Study: Improvement of Competitiveness of SMES in Serbia

The proposed fuzzy model is tested on real-life data given from manufacturing SMEs in the Republic of Serbia. Development of the developed projects in the manufacturing industry has a very significant role in the growth of the Serbian economy (Republic Statistical Office of Serbia 2010) such as: an increase of Gross Domestic Product (GDP), creation of economic wealth, delivery of social welfare services. etc. At sometime, development projects may have the possibility of creating a negative impact.

Project management has become an important field for researchers and engineers in complex socio-technical systems such as manufacturing SMEs. The evaluation of projects presents one of the most important sub-problems of a project management problem. The solution to the considered problem is propagated through the treated business processes and it has an impact on project effectivity as well as on the efficiency of the enterprise.

In this chapter, we consider a development project of enhancement of competitiveness. The business processes that are impacted by the treated project are: development and research (p = 1), production process (p = 2), marketing and selling process (p = 3), and purchasing process (p = 4). The PPs are utilized from Ngacho and Das (2014): cost performance (i = 1), time performance (i = 2), quality performance (i = 3), safety performance (i = 4), site dispute performance (i = 5), and environmental performance (i = 6).

The specimen of 60 SMEs which are certified by ISO 9001:2008 is chosen due to specificity of their business processes and constraints related to the economic field. The considered SMEs are grouped into three groups, such that 4 SMEs belong to group A (g = 1), 11 SMEs belong to group B (g = 2) and the rest of the SMEs belong to group C (g = 3). The degree of impact of each SME group is determined by external experts so that: $w_1 = 0.45$, $w_2 = 0.35$, $w_3 = 0.2$.

In this case, the evaluation of project success is determined in pre-defined time periods of project delivery. With respect to the obtained results, the management team of each SME defines the priority of management initiatives that should enable successful implementation of the treated project in the SMEs.

By using the proposed Algorithm (Step 1 to Step 2), the weighted aggregated weights of the business processes and PPs are calculated. To avoid overloading the manuscript with calculations, the authors have presented the calculation oriented to a couple of business processes in the all treated organizations. The developed procedure may be illustrated on the example of defining aggregated weight business PPs p = 4 and p = 5:

$$\tilde{W}_{45}^{1} = \frac{1}{4} \cdot \left(\tilde{R}_5 + 2 \cdot \tilde{R}_4 + \tilde{R}_3\right) = (x; 1.37, 4.5, 5)$$

$$\tilde{W}_{45}^{2} = \frac{1}{11} \cdot \left(2 \cdot \tilde{R}_4 + 5 \cdot \tilde{R}_3 + 4 \cdot \tilde{R}_2\right) = (x; 1, 1.88, 4.67)$$

$$\tilde{W}_{45}^{3} = \frac{1}{45} \cdot \left(5 \cdot \tilde{R}_5 + 34 \cdot \tilde{R}_4 + 6 \cdot \tilde{R}_3\right) = (x; 1.17, 3.32, 4.97)$$

The weighted aggregated weight of the considered pair of PPs is given by the FOWA operator:

$$\tilde{W}_{45} = 0.45 \cdot \tilde{W}_{45}^{1} + 0.35 \cdot \tilde{W}_{45}^{2} + 0.2 \cdot \tilde{W}_{45}^{3} = (x; 1.2, 3.35, 4.88)$$

Similarly, the weight vectors of PPs and the weight vectors of the business processes are calculated.

The fuzzy pair-wise comparison matrix of the relative importance of business processes can be presented:

$$\begin{bmatrix} (x;1,1,1) & (x;1.26,3.96,4.98) & (x;1.05,3.91,5) & (x;1.67,3.72,4.98) \\ (x;0.20,0.25,0.79) & (x;1,1,1) & (x;1.01,4.07,5) & (x;1,3.67,4.99) \\ (x;0.20,0.26,0.95) & (x;0.20,0.25,0.99) & (x;1,1,1) & (x;1.14,4.21,5) \\ (x;10.20,0.27,0.86) & (x;0.20,0.27,1) & (x;0.2,0.24,0.88) & (x;1,1,1) \end{bmatrix}$$

By using FAHP the weight vectors of the business processes are given (see Step 3 of the proposed Algorithm):

$$w = \begin{pmatrix} 0.34 & 0.30 & 0.24 & 0.12 \end{pmatrix}$$

Similarly, the weight vectors of PPs are:

$$w' = \begin{pmatrix} 0.22 & 0.20 & 0.19 & 0.17 & 0.13 & 0.09 \end{pmatrix}$$

The evaluation of PPs and determination of project potential are tested on real-life data which are obtained from one randomly chosen SME. The fuzzy rating values of PPs for each business process are presented in Table 22.4.

By using the proposed algorithm (Step 4 to Step 5), the normalized PP values are given and presented in Table 22.5.

The weighted normalized values of PPs for the chosen SMEs are given by the proposed Algorithm (Step 6) and presented in Table 22.6.

By using the proposed Algorithm (Step 7 to Step 8), the overall project performance is calculated, so that:

$\tilde{V} = (z; 0.45, 0.52, 0.64)$ and $v = \text{defuzz}\left(\tilde{V}\right) = 0.529$

Determination of the project success:

$\mu_{\tilde{S}_2}(z = 0.529) = 0.91$ and $\mu_{\tilde{S}_3}(z = 0.529) = 0.09$

$$\max_{q=2,3} (0.91, 0.09) = 0.91 \Rightarrow q^* = 2$$

The obtained results indicating project success in the chosen SME can be described as mid-point. With respect to the obtained results, the management team

Table 22.4 Fuzzy rating of PP values

	p = 1	p = 2	p = 3	p = 4
i = 1 (monetary units)	5000	3000	6000	2000
i = 2 (worker/hours)	200	50	300	60
i = 3	High	Moderate	Fairly high	Fairly high
i = 4	Moderate	Fairly moderate	Fairly high	Moderate
i = 5	Moderate	Fairly high	Fairly moderate	Low
i = 6	High	Moderate	Fairly high	Fairly high

Table 22.5 The normalized PP values

	p = 1	p = 2	p = 3	p = 4
i = 1	0.31	0.51	0.25	0.76
i = 2	0.19	0.75	0.12	0.62
i = 3	(0.78, 0.89, 1)	(0.39, 0.56, 0.72)	(0.61, 0.78, 0.94)	(0.61, 0.78, 0.94)
i = 4	(0.39, 0.56, 0.72)	(0.17, 0.33, 0.50)	(0.61, 0.78, 0.94)	(0.39, 0.56, 0.72)
i = 5	(0.15, 0.20, 0.29)	(0.13, 0.14, 0.18)	(0.22, 0.33, 0.67)	(0.33, 0.50, 1)
i = 6	(0.78, 0.89, 1)	(0.39, 0.56, 0.72)	(0.61, 0.78, 0.94)	(0.61, 0.78, 0.94)

Table 22.6 The fuzzy decision matrix

	p = 1	p = 2	p = 3	p = 4
i = 1	(0.023, 0.023, 0.023)	(0.034, 0.034, 0.034)	(0.011, 0.011, 0.011)	(0.021, 0.021, 0.021)
i = 2	(0.013, 0.013, 0.013)	(0.054, 0.054, 0.054)	(0.006, 0.006, 0.006)	(0.014, 0.014, 0.014)
i = 3	(0.049, 0.056, 0.063)	(0.021, 0.031, 0.039)	(0.027, 0.014, 0.042)	(0.013, 0.017, 0.021)
i = 4	(0.022, 0.031, 0.040)	(0.008, 0.016, 0.025)	(0.051, 0.065, 0.079)	(0.007, 0.011, 0.014)
i = 5	(0.007, 0.009, 0.013)	(0.005, 0.006, 0.007)	(0.007, 0.011, 0.021)	(0.005, 0.008, 0.016)
i = 6	(0.024, 0.028, 0.031)	(0.011, 0.015, 0.019)	(0.013, 0.017, 0.021)	(0.007, 0.009, 0.010)

of the chosen SME cannot claim that the treated project will be sustainably reliable over time. In this manner, it is necessary to take appropriate measures that will enable improvement of PPs so the overall project performance and project success are enhanced.

Determining priorities of management initiatives is based on the rank of PPs under each business (by using Step 9 of the proposed Algorithm). In this example, the PPs' rank is presented in Table 22.7.

Table 22.7 The rank of PPs under each business process

	p = 1	p = 2	p = 3	p = 4
i = 1	3	5	2–3	5
i = 2	2	6	1	4
i = 3	6	4	4	6
i = 4	5	3	6	3
i = 5	1	1	2–3	1
i = 6	4	2	5	2

According to the results which are presented in Table 22.4, it can be concluded that it is necessary to take appropriate management initiatives that will lead to PP enhancement related to site dispute performance (i = 5). Having in mind that the treated SME has less than ten employees, the relationship with stakeholders is dominantly oriented to customers. In the conditions of a transitional economy which is the case in this region, it may be assumed that the rank of the mentioned PP should be higher but the lower value indicates the lack of support of other business processes to this kind of project. This is one of the major reasons why competitiveness is not significantly increasing in the region, so initiatives such as increasing awareness of competitiveness should be employed.

Under the business process marketing and selling (p = 3), the PP which has the lowest weighted normalized value is time performance (i = 2). This result is expected since in a transitional economy in the region a lot of SMEs are lacking in terms of human resources and capital. The management initiatives should face project difficulties related to the project's time framework because this issue, amongst them all, has a great influence on the overall enterprise's liquidity.

22.7 Conclusion

In this chapter, we have proposed a new fuzzy model for the assessment of PPs and project success in manufacturing SMEs. The proposed model can be used to successfully implement continuous quality improvement of developing projects in manufacturing SMEs, and represents a very relevant issue for long term sustainability.

The main contribution of this chapter to intelligent systems in engineering management is the introduction of a two-step model for assessment of developing project success in manufacturing SMEs which exist in an uncertain environment. This chapter contributes to both practice and research.

In the research domain, the PPs have been analyzed on the level of business processes which is novel in the analyzed domain. The assessments imply determination of the relative importance of business processes, the relative importance of PPs and their values as well as the determination of overall project performance by using linguistic expressions. Existing uncertainties in: the relative importance of business processes, relative importance of PPs as well as their values and the project success are described by linguistic expressions. This is very suitable to the human way of thinking. The fuzzy sets theory is a very suitable mathematical tool for the modeling of linguistic terms. In this chapter, uncertainties are modeled by TFNs or TrFNs because they offer a good compromise between descriptive power and computational simplicity. The project success is determined in an exact way by using fuzzy logic rules. Every solution that is obtained in an exact way is less burdened by the subjective thinking of decision makers. The obtained solution gives a chance to the management team to define measures to enhance the project success.

Another contribution in the research domain may be seen in the aspect of the proposed method's flexibility: (1) changes in the number and/or kind of PPs, (2) changes in their relative importance, and (3) can be easily extended to the analysis of other management decision problems in different research areas.

As a contribution to real-life practice and the engineering management field, the method could be very useful for: (1) management teams of manufacturing SMEs to increase the quality of products and efficiency of their businesses, (2) customers, and (3) other stakeholders.

The main advantages in the scope of engineering management of the presented model are user friendly assessment methodology, which is accomplished by the proposed linguistic expressions, and the general output of the model which may significantly facilitate the decisions of managers. This information may be very important for the analyzed SME, so its management team may define an appropriate strategy with a long term sustainability goal.

The general limitations of the model are scoped to: (1) the need for well-structured project performances, and (2) the need for well-structured management teams of manufacturing SMEs. The first need may be fulfilled by implementation of a Quality management system according to ISO 9001:2008. The second need may be fulfilled by structuring a team of SME experts that will follow the guidelines for evaluation described in the literature.

Future research should cover analysis of different developing projects in different SME types which may have different PPs as well as different impact on the achievement of business process continual improvement. This should enable knowledge transfer amongst SMEs that belong to the same industry sector and as a final consequence improve sustainable development. The development of the software solution could be expanded with additional functionalities for better project management.

References

Ahadzie, D.K., Proverbs, D.G., Olomolaiye, P.P.: Critical success criteria for mass house building projects in developing countries. Int. J. Project Manage. **26**(6), 675–687 (2008)

Aleksić, A., Stefanović, M., Arsovski, S., Tadić, D.: An assessment of organizational resilience potential in SMEs of the process industry, a fuzzy approach. J. Loss Prev. Process Ind. **26**, 1238–1245 (2013)

Barcaly, C., Osei-Bryson, K.M.: Project performance development framework: an approach for developing performance criteria and measures for information systems (IS) projects. Int. J. Prod. Econ. **124**, 272–292 (2010)

Bass, M.S., Kwakernaak, H.: Rating and ranking of multiple-aspect alternatives using fuzzy sets. Automatica **3** 47–58 (1977)

Beck, T.: Evaluating humanitarian action using the OECD-DAC criteria: an ALANP guide for humanitarian agencies. Overseas Development Institute, London (2006)

Billy, H., Cameron, I., Duff, A.R.: Exploring the integration of health and safety with pre-construction planning. Eng. Constr. Archi. Manage. **13**(5), 438–450 (2006)

Bozbura, T.F., Beskese, A., Kahraman, C.: Prioritization of human capital measurement indicators using fuzzy AHP. Expert Syst. Appl. **32**, 1100–1112 (2007)

Bryde, D.J.: Modeling project management performance. Inter. J. Qual. Reliab. Manage. **20**(2), 229–254 (2003)

Bryde, D.J.: Perceptions of the impact of project sponsorship practices on project success. Int. J. Project Manage. **26**(8), 800–809 (2008)

Büyüközkan, G., Feyzioğlu, O., Neobol, E.: Selection of the strategic alliance partner in logistics value chain. Int. J. Prod. Econ. **113**, 148–158 (2008)

Chang, D.Y.: Applications of the extent analysis method on fuzzy AHP. Eur. J. Oper. Res **95** 649–655 (1996)

Chen, P.H., Weng, H.: A two-phase GA model for resource-constrained project scheduling. Autom. Constr. **18**, 485–498 (2009)

Chen, Y., Okudan, G.E., Riley, D.R.: Sustainable performance criteria for construction method selection in concentrate buildings. Autom. Constr. **19**(2), 235–244 (2010)

Cheng, M.Y., Tsai, H.C., Sudjono, E.: Evolutionary fuzzy hybrid neural network for dynamic project success assessment in construction industry. Autom. Constr. **21**, 46–51 (2012)

Chou, J.S., Yang, J.G.: Evolutionary optimization of model specification searches between project management knowledge and construction engineering performance. Expert Syst. Appl. **40**, 4414–4426 (2013)

Chua, D.K.H., Loh, P.K., Kog, Y.C., Jaselskis, E.J.: Neural networks for construction project success. Expert Syst. Appl. **13**(4), 317–328 (1997)

Coccoa, P., Alberti, M.: A framework to assess performance measurement systems in SMEs. Int. J. Prod. Performance Manage. **59**(2), 186–200 (2009)

Dubois, D., Prade, H.: Fuzzy Sets and Systems: Theory and Applications. Academic press Inc., London (1980)

Fan, S.L., Sun, K.S., Wang, Y.R.: GA optimization model for repetitive projects with soft logic. Autom. in Constr. **21**, 253–261 (2012)

Fortune, J., White, D., Judgev, K., Walker, D.: Looking again at current practice in project management. Int. J. Project Manage. **4**(4), 553–572 (2011)

Franco-Santos, M., Kennerley, M., Micheli, P., Martinez, V., Mason, S., Marr, B., et al.: Towards a definition of a business performance measurement system. Int. J. Oper. Prod. Manage. **27**, 784–801 (2007)

Gardiner, K.S.: Revisting the golden triangle of cost, time, and quality: the role of NPV in project control, success, and failure. Int. J. Project Manage. **18**(4), 251–256 (2000)

Georgy, M.E., Chang, L.M., Zhang, L.: Prediction of engineering performance: a neuro fuzzy approach. J. Constr. Eng. Manage. **131**(5), 548–557 (2005)

Gumus, T.A.: Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology. Expert Syst. Appl. **36**, 4067–4074 (2009)

Ika, L.A., Daillo, A., Thuiller, D.: Critical success factors for World Bank projects: an empirical investigation. Int. J. Project Manage. **30**, 105–116 (2012)

Jaakkola, M., Möller, K., Parvinen, P., Evanschitzky, H., Mühlbacher, H.: Strategic marketing and business performance: A study in three European 'engineering countries'. Ind. Mark. Manage. **39**, 1300–1310 (2010)

Kahraman, C., Ertay, T., Büyüközkan, G.: A fuzzy optimization model for QFD planning process using analytic network process. Eur. J. Oper. Res. **171**, 390–411 (2006)

Kaya, T., Kahraman, C.: Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. Expert Syst. Appl. **38**, 6577–6585 (2011)

Khalili-Damghani, K., Sadi-Nezhad, S., Lotfi, H.F., Tavana, M.: A hybrid fuzzy rule-based multiple-criteria framework for sustainable project portfolio selection. Inf. Sci. **220**, 442–462 (2013)

Klir, G.J., Folger, T.: Fuzzy Sets, Uncertainty, and Information. Prentice Hall, Upper Saddle River (1988)

Medineckiene, M., Turskis, Z., Zavadskas, E.K.: Sustainable construction taking into account the building impact of the environment. J. Environ. Eng. Landscape Manage. **18**(2), 118–127 (2010)
Merigó, J.M., Casanovas, M.: Using fuzzy numbers in heavy aggregation operators. Int. J. Inf. Technol. **4**(4), 267–272 (2008)
Mir, A.F., Pinnington, H.A.: Exploring the value of project management: linking project management performance and project success. Int. J. Project Manage. **32**, 202–217 (2014)
Müller, R., Judgev, K.: Critical success factors in projects, pinto, slevin and prescott-the education of project success. Int. J. Proj. Manage. **5**(4), 757–775 (2012)
Neely, A.D., Kennerly, M., Adams, C.: Performance measurement frameworks: a review. In: Neely, A. (ed.) Business Performance Measurement: Theory and Practice, pp. 143–162. Cambridge University Press, Cambridge (2007)
Ngacho, C., Das, D.: A performance evaluation framework of development projects: an empirical study of constituency development fund (CFD) construction projects in Kenya. Int. J. Project Manage. **32**, 492–507 (2014)
Nudurupati, S.S., Bititci, U.S., Kumar, V. Chan, F.T.S.: State of the art literature review on performance measurement. Comput. Ind. Eng. **60**, 279–290 (2011)
Oakland, S.J.: Oakland on Quality Management. Elsevier, London (2004)
Paskoy, T., Pehlivan, Y.N., Kahraman, C.: Organizational strategy development in distribution channel management using fuzzy AHP and hierarchical fuzzy TOPSIS. Expert Syst. Appl. **39**, 2822–2841 (2012)
Seçme, Y.N., Bayrakdaroğu, Kahraman, C.: Fuzzy performance evaluation in turkish banking sector using analytic hierarchy 11709 Process and TOPSIS. Expert Syst. Appl. **36** 11699–11709 (2009)
Shao, J., Müllier, R.: The development of constructions of program context and program success: a qualitative study. Int. J. Proj. Manage. **29**(8), 947–959 (2011)
Shenhar, A.J., Dvir, D., Levy, O., Maltz, A.C.: Project success: a multidimensional strategic concept. Long Range Plan. **34** 699–725 (2001)
Shih, H.S., Shyur, H.J., Lee, E.S.: An extension of TOPSIS for group decision making. Math. Comput. Model. **45** (7/8), 801–813 (2007)
Tabish, S.Z.S., Jha, K.N.: Analysis of irregularities in public procurement in India. Constr. Manage. Econ. **29**(3), 261–274 (2011)
Tadić, D., Gumus, T.A., Arsovski, S., Aleksić, A., Stefanović, M.: An evaluation of quality goals by using fuzzy AHP and fuzzy TOPSIS methodology. J. Intell. Fuzzy Syst. **25**, 547–556 (2013)
Tan, Y., Shen, L., Yao, H.: Sustainable construction practice and constructors' competitiveness: a preliminary study. Habitat Int. **35**(2), 225–230 (2011)
Taylan, O., Bafail, A.O.A., Abdulaal, S.M.R., Kabli, R.M.: Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. Appl. Soft Comput. **17**, 105–116 (2014)
Zadeh, L.A.: The concept of a linguistic variable and its application to approximate reasoning. Inf. Sci. **8**(3), 199–249 (1975)
Zimmermann, H.J.: Fuzzy Set Theory and Its Applications. Kluwer Nijhoff Publishing, Boston (2001)
Zuo, P.X.W.: Fostering a strong construction safety culture. Leadersh. Manage. Eng. **11**(1), 11–22 (2011)

Chapter 23
Intelligent Systems in Project Performance Measurement and Evaluation

Seyed Hossein Iranmanesh and Zahra Tavassoli Hojati

Abstract Over the life cycle of a project, project costs and time estimations play important roles in baseline scheduling, schedule risk analysis and project control. Performance measurement is the ongoing, regular collection of information that can provide this controlling system. In this study, firstly, a new simulation approach is proposed to develop project progress time-series data, based on the complexity and specifications of the project as well as on the environment in which the project is executed. This simulator is capable of simulating fictitious projects, as well as real projects based on empirical data and helps project managers to monitor the project's execution, despite the lack of historical data. Besides, this chapter compares the effects of different inputs on generated time series, as estimated results obtained on a fictitious dataset. Secondly, the validated outputs can provide researchers with an opportunity to generate general and customized formulae such as project completion time estimation. This study also implies four soft computing methods, Artificial Neural Network (ANN), Adaptive Neuro-Fuzzy Interface System (ANFIS), Emotional Learning based Fuzzy Interface System (ELFIS) and Conventional Regression to forecast the completion time of project. Core variables in proposed model are known parameters in Earned Value Management (EVM). Finally, the result of using intelligent models and their performances in modeling the expert emotions are compared.

Keywords Project management · Project progress simulation · EVM · Emotional learning · ELFIS · ANFIS · ANN · Conventional regression

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23.1 Introduction

In the project management, on time delivery within budget is a fundamental factor that highlights the importance of monitoring how a project is doing. Performance measurement is the ongoing, regular collection of information that can provide this controlling system.

Evaluation is a specific, in-depth way to gather and analyze information and come to conclusions about the performance of the policy, program or strategy at the project level. Therefore, forecasting the completion time of the project during its execution can play a significantly important role to evaluate and control a project.

There are two general types of evaluations:

- "Formative" or "process" evaluations that are designed to improve the design and implementation of the program, policy or strategy as it unfolds, and
- "Summative" or "outcome" evaluations that are designed to judge a program, policy or strategy's relevance, success and/or cost-effectiveness (including its relative contribution to the intended outcomes).

In this section the second type will be focused and discussed.

With the growing importance of Intelligent Systems (IS) in various application domains, intelligent applications as a particularly interesting area of research can be developed and joint with other methods and techniques, which help project managers to supervise and evaluate a project.

Earned Value Management (EVM) is a systematic approach with wide range of performance measurements used to calculate variances and indices for both cost and time and evaluate different type of projects. Moreover, EVM is exerted as a powerful tool to forecast the total estimated cost and completion time during the project execution.

As a consequence, a new simulator was designed and run on project samples coming from well-known data sets. Due to the different type of projects that appear in the data set, in the first step, the general data is considered in the study, and they do not provide more specific information involving issues. Secondly, the case study is introduced, and its simulator outputs are demonstrated.

The nature of most data and relations are actually full of ambiguities or in one word is fuzzy. In this chapter it is introduced as a framework for using Adaptive Network Fuzzy Inference System (ANFIS), one of the intelligent computing methods, to forecast the completion time (cost) of a project. ANFIS is a class of adaptive networks that is basically equivalent to fuzzy inference systems which represent Sugeno e Tsukamoto fuzzy model. The model is validated by a simulation study using a progress generator program for typical Resource Constrained Project Schedule Problem (RCPSP) project library.

Estimative simulator is the process of predicting the amount of effort or the productivity required for the completion of the project. This program is developed in VBA-MSP and included some basic assumptions and required data generated daily and randomly. By using these data, EVM metrics are calculated, and the most proper earned value performance data as input parameters are set. The output parameter is the actual duration of the project that is gained by the simulation. ANFIS can be trained and determine relevant inputs, number of MF's for each input, number of rules and type of fuzzy models.

After using ANFIS to increase forecasting performance, the impacts of Emotional Learning based Fuzzy Inference System (ELFIS) is examined. ELFIS is capable of modeling expert emotion as emotional signal; thus, the accuracy of forecasting will be increased intelligently. For better judgment, a comparison among ANFIS, ELFIS, Artificial Neural Network (ANN) and conventional regression are presented. The achieved result is more precise estimate at completion in whole project's time than the result of other different methods which are based on crisp data and exact relations.

23.2 Evm

EVM or discrepancy analysis is an important technique which has been used in previous four decades that allow you to determine more precisely where your project stands in terms of your baseline schedule and budget.

It is a systematic project management process used to calculate the amount of the progress of the project with the aim of Reducing risk, Profitability analysis, Project forecasting, Better accountability, Performance tracking, Preventing scope creep and while this method using with intelligent forecasting methods, these combinations precise the estimation of time and cost of projects. EVM provides project managers with early indications of a project's performance and highlights the need for eventual corrective action. Since its advent, many studies have been dedicated to this area (Vanhoucke 2012; Lipke et al. 2009).

EVM as one of the most effective performance measurement and feedback tools for managing projects takes a snapshot view of where a project is against where it was planned to be and is used on the cost and schedule control and can be very useful in project forecasting. Likewise, Earned Value Management enables the project manager to measure project performance and identify the "problematic points" of the project and find the corrective action accordingly.

Earned Value Management System (EVMS) is a systematic approach for Estimate At Completion (EAC) estimations and its concept is used to measure project progress, calculate Earned Value (EV) of project and forecast EAC in every period of controlling the project progress and plan preventive actions during the project life cycle (Iranmanesh et al. 2007). Therefore, the role of EVMS as well as correct and on time forecasting is essential to achieve project goals.

To establish a basic foundation for understanding EVM's role in effective project management, it is important that the relationship between EVM and the process groups in areas of project management was found. This comparison shows that Planning, Executing and Controlling are the most applicable area that related with

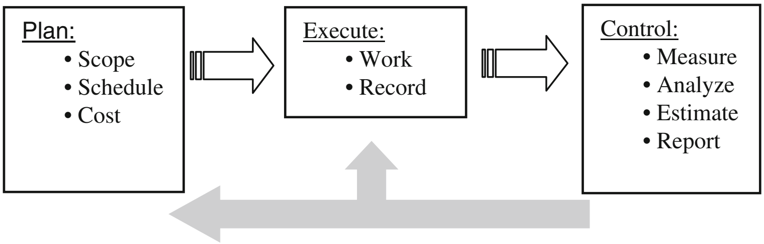


Fig. 23.1 EVM and the basic PM process

EVM concepts (Project Management Institute 2005). EVM and the Basic PM Process are shown in Fig. 23.1.

In general, if cost estimate and cost control processes are integrated, there will be a suitable transmission of information between these two processes to be used in future projects estimations; and also a good estimate may make cost control more efficient. So providing suitable condition for transmission of information between these three process areas is of a substantial importance.

Finally, EVM and other concepts such as sensitivity or risk analysis (with the use of a simulator to validate the results) were investigated in prior studies (Vanhoucke and Vandevoorde 2007; Elshaer 2013).

23.2.1 General Review of EVMS Measures

Earned Value Management in the 1960s emerged as a financial analysis specialty in United States Government programs, but it has since become a significant branch of project management and cost engineering and it develops in many project areas as project organization, scheduling, budgeting, accounting, analysis, reporting and change control (Feleming and Koppleman 1996).

In 2006 (Cioffi 2006) new formalism and a corresponding new notation for earned value analysis were used. Description of the basic principles and the use in practice and discussion about the EV concept and also using the well-known earned value metrics to forecast a project's duration using Planned Value Rate (PVR) and Time Variance (TV) is done in 2003 (Anbari 2003). Earned Duration (ED) (Jacob and Kane 2004) as a new term for producing the actual duration and forecasting duration was introduced for using the schedule performance index (SPI) in 2004.

A new method for EAC (Iranmanesh et al. 2007) of project's time to improve EVMS in 2007 was presented. The A-12 program, On 7 January 1991 cancelled because of certainly the problem of estimating its completed cost (Morrison 1991) and caused interest in forecasting the completed cost of a defense contract as an important contributing factor, a term EAC. In 1993 different EAC formulas and several studies that examine their accuracy was reviewed (Christensen 1993).

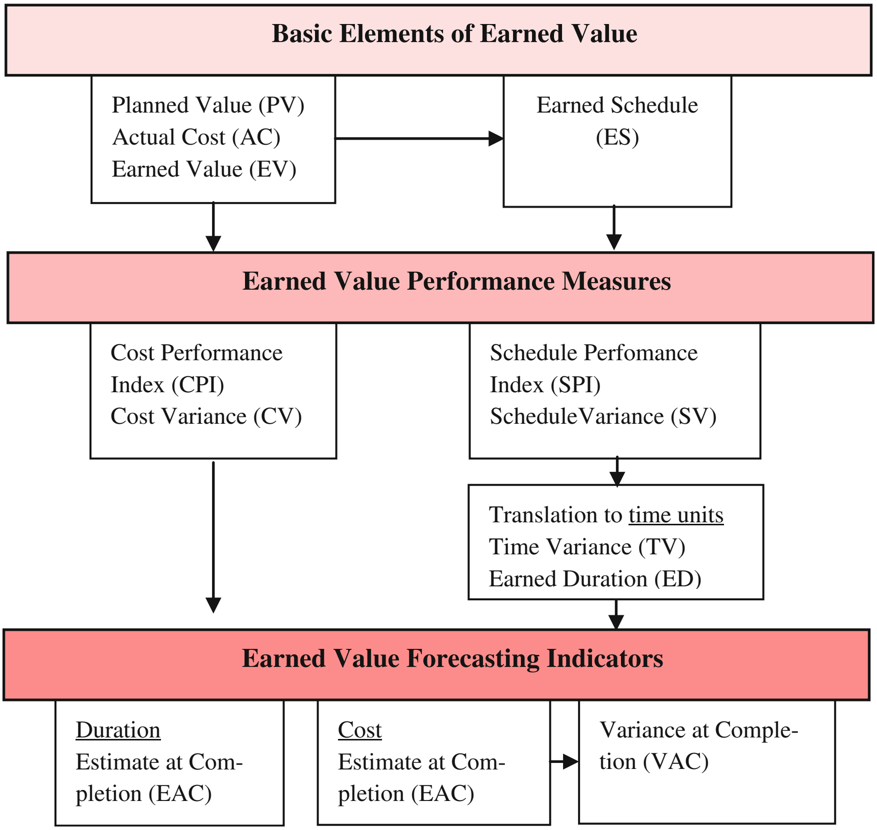


Fig. 23.2 Key parameters, performance measures and forecasting indicators of EV

In continuation, we review the different metrics of an EVM system, as Basic Elements of Earned Value Management, Earned Value Performance Measures and Earned Value Forecasting Indicators. Figure 23.2 shows the brief view of these parameters, measures and indicators and they relations.

23.2.2 Basic Elements of Earned Value Management

EVM has three basic key value elements as:

- ***Planned Value (PV)***

PV is a numeric reflection of the budgeted work as scheduled to be performed that describes how far along a project is supposed to be at any given point in the project schedule. It is the established baseline to reflect cost and schedule and also known as the performance measurement baseline against which the actual progress of the project is measured and also known as the Budgeted Cost for Work Scheduled (BCWS) and calculated as follows:

$$BCWS = \sum_{i=1}^{n} C_i \times P_i \tag{23.1}$$

Once it is established, this baseline may change only by necessitated changes in the scope of work. The charted PV is usually showing the cumulative resources budgeted across the project schedule.

- ***Earned Value (EV)***

EV reflects the amount of work that has actually been accomplished and expressed as the planned value for that work. Also it knows as the Budgeted Cost for Work Performed (BCWP) and calculated as follows:

$$BCWP = \sum_{i=1}^{n} C_i \times P_i' \tag{23.2}$$

- ***Actual Cost (AC)***

AC is an indication of the level of resources that have been expended to achieve the actual work performed to date or in the exact time period. Also known as the Actual Cost of Work Performed (ACWP).

23.2.3 EVM Performance Analysis and Forecasting

In this section we explain how these data points can be used to analyze the current status of a project and forecast its likely future in three categories as Variances, Indices and Forecasts.

The starting point for Performance Measurement is the ***Budget At Completion (BAC)***. This measure is the primary output of the estimation process and represents the total Planned Value for the project.

The plan that is associated with BAC is generally known as the ***Baseline Plan*** or simply the ***Baseline***. Furthermore the project baseline serves as a reference point for all EVM related activities.

Most common Project performance measures, both in terms of time and costs, ***schedule variance (SV), schedule performance index (SPI), cost variance (CV)*** **and** ***cost performance index (CPI)*** (Project Management Institute 2005) are determined by comparing the three key parameters PV, AC and EV, resulting in four well-known performance measures:

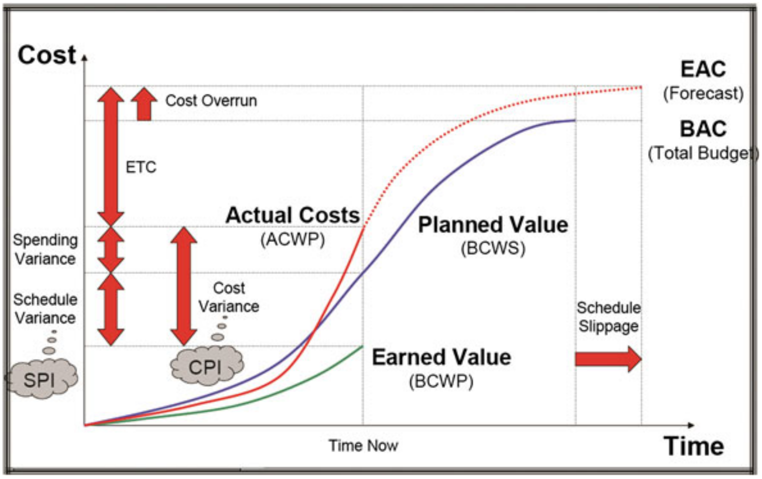


Fig. 23.3 Well known EVM curves

$$SV = EV - PV \tag{23.3}$$

$$SPI = EV/PV \tag{23.4}$$

$$CV = EV - AC \tag{23.5}$$

$$CPI = EV/AC \tag{23.6}$$

Figure 23.3 shows well known time-cost curve with S shape and Fig. 23.4 "at-a-glance" indicates Interpretations of Basic EVM Performance Measures in PMI standard.

Performance Measures		SV & SPI		
		>0 & >1.0	=0 & =1.0	<0 & <1.0
CV & CPI	>0 & >1.0	Ahead of Schedule Under Budget	On Schedule Under Budget	Behind Schedule Under Budget
	=0 & =1.0	Ahead of Schedule On Budget	On Schedule On Budget	Behind Schedule On Budget
	<0 & <1.0	Ahead of Schedule Over Budget	On Schedule Over Budget	Behind Schedule Over Budget

Fig. 23.4 Interpretations of basic EVM performance measures

It is possible to use other parameters as ***Scheduled Percent Complete by Duration (SPCD), Actual Percent Complete by Duration (APCD)*** and ***Sum of Durations to Due Time (SDDT)***, which are the predictor variables and to find real duration of project in any time. Although some other measures, ***Budget Variance (BV)*** and ***To-Complete Performance Index (TCPI)***, calculated similarly as:

$$BV = PV - AC \tag{23.7}$$

$$\mathrm{TCPI} = (\mathrm{BAC} - \mathrm{EV})/(\mathrm{BAC} - \mathrm{AC}) \tag{23.8}$$

The PV method of Anbari (2003) based on the well-known EV metrics, ***planned value rate (PVR)*** and ***time variance (TV)*** used to forecast a project's duration as follows:

$$\mathrm{PVR} = \mathrm{BAC}/\mathrm{PD} \tag{23.9}$$

$$\mathrm{TV} = \mathrm{SV}/\mathrm{PVR} \tag{23.10}$$

With

Planned Duration (PD)

In literatures ED (Earned Duration) method (Jacob and Kane 2004) as a reliable methodology for forecasting duration using the SPI and ES (Earned Schedule) method (Lipke 2003) with similar principles of the EV method and the concept of ES, were introduced as:

$$ED = AD * SPI \tag{23.11}$$

With

Actual Duration (AD)

$$\mathrm{ES} = \mathrm{t} + (\mathrm{EV} - \mathrm{PVt})/(\mathrm{PVt} + 1 - \mathrm{PVt}) \tag{23.12}$$

With

EV at the actual time

Planned Value at time instance t (PVt)

These two indicators, ED and ES, can be used to construct good and reliable alternatives of the ***Schedule variance Time (SV(t))*** and ***Schedule performance index time (SPI (t))*** as follows:

$$\mathrm{SV(t)} = \mathrm{ES} - \mathrm{AD} \tag{23.13}$$

$$\mathrm{SPI(t)} = \mathrm{ES}/\mathrm{AD} \tag{23.14}$$

We have many methods to estimate ***EAC*** for time and cost (Jacob and Kane 2004; Lipke 2003 and Hunt 2007) and in literatures (Vanhoucke and Vandevoorde 2007; Vandevoorde and Vanhoucke 2006) these methods were compared with each other in different scenarios. Furthermore influence of the network structure (Vanhoucke and Vandevoorde 2007) on the forecast accuracy was calculated with different methods. For instance the PV method of Anbari (2003) proposes three different time forecasting measures reflecting the three situations as follows:

$$EAC(t)PV1 = PD - TV \tag{23.15}$$

when the duration of remaining work is as planned

$$EAC(t)PV2 = PD/SPI \tag{23.16}$$

when the duration of remaining work follows the current SPI trend

$$EAC(t)PV3 = PD/SCI \tag{23.17}$$

when the duration of remaining work follows the current SCI trend

Generally, the EAC is the projected completion cost and is the actual cost of the completed work plus the budget for the remaining work and the generic formula is as follows:

$$EAC = AC + \frac{Work\text{ Remaining}}{CPI} = AC + \frac{BAC - EV}{CPI} \tag{23.18}$$

In the end we can define ***Variance at Completion (VAC)*** as:

$$\text{VAC} = \text{BAC} - \text{EAC}. \tag{23.19}$$

23.3 A Project Networks Generators and Data Sets

With the development of project scheduling models and methods, especially intelligent approaches, the need for data instance in order to benchmark the solution procedure have been aroused. Therefore the vast majority of the projects scheduling research efforts over the past several years have concentrated on the generation and development of benchmark sets of project networks to provide users and researchers successful project planning and evaluating tools to visualize different kinds of projects and evaluate solution procedure for single and multi-mode RCPSP (Patterson 1984).

This problem is the main problem in project scheduling and finding a feasible scheduling for activities by considering network constraints and within resource limitation is the goal of this problem. For more information about RCPSP the reader could refer to Brucker et al. (1999), Herroelen et al. (1998).

Generally, using intelligent forecasting methods to forecast time and cost of projects needs scientific representations of different kind of projects to produce basic time series. These representations can be called Standard Data Sets and are always based on the well-known concept of project network describing the

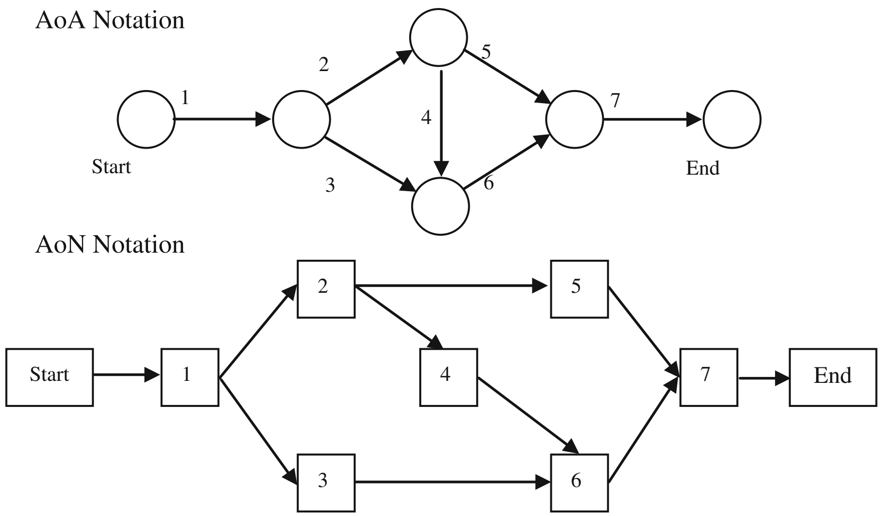


Fig. 23.5 The network model of a project using AoA and AoN notation

activities, their features and precedence restrictions of each project through a directed non-cyclic connected graph in order that the project will be feasible.

Moreover, simulation techniques were used in a number of studies based on implementing EVM concepts and measured the efficiency of controlling a project [4a]. Elshaer et al. investigated the prediction of project duration in EVM using three earned value methods, Planned Value Management (PVM), Earned Duration Management (EDM) and Earned Schedule Management (ESM) (Elshaer 2013).

Features of project networks have heavy influence on the performance of these methods to manage projects in the field of project scheduling, risk analysis and resources allocation of project and present projects using the notation AoN (Activities on Nodes) representing each precedence by an arrow with the same length and each activity by a circle of the same size or AoA (Activities on Arcs) where each arc describes an activity and each node represents the completion of the activities on it and the former is adopted herein. A typical sample of a project with 7 activities in AoA and AoN representation could be found in Fig. 23.5. Also Iranmanesh et al. introduced new representation of project with flexible links in Iranmanesh et al. (2008), Madadi and Iranmanesh (2012).

23.3.1 Definition of Morphology and Topology of a Network and Its Indicators and Measurements

Nowadays, any software of Project Management include project network simulators needs to consider the analysis and classification of the shape or morphology of each project network (serial, parallel or triangular shapes) to help the project manager identifying the level of difficulty to keep the project on time in terms of its project network.

The proposed concept of project network morphology is defined with three major morphological types as perspectives (Valadares Tavares et al. 1999):

- Undoubtedly, the AoN representation is the more direct, the more frugal and is unique therefore analysts find it sometimes preferable to adopt the AoA mode of representation (Elmaghraby 1995) so the graphical shape of the network's representation using the AoN rule (Fig. 23.6).
- The number of non-redundant direct precedence links, D. It should be consider that a network with a higher number of these links is more complex to be managed.
- The length, L, of the non-redundant direct precedence links of the network is defined by the difference between the progressive levels (defined in continuation of this section) of the two linked activities.

Each of the three previously presented perspectives can be described in terms of topological features that will be used to construct a set of indicators to measure the network structure.

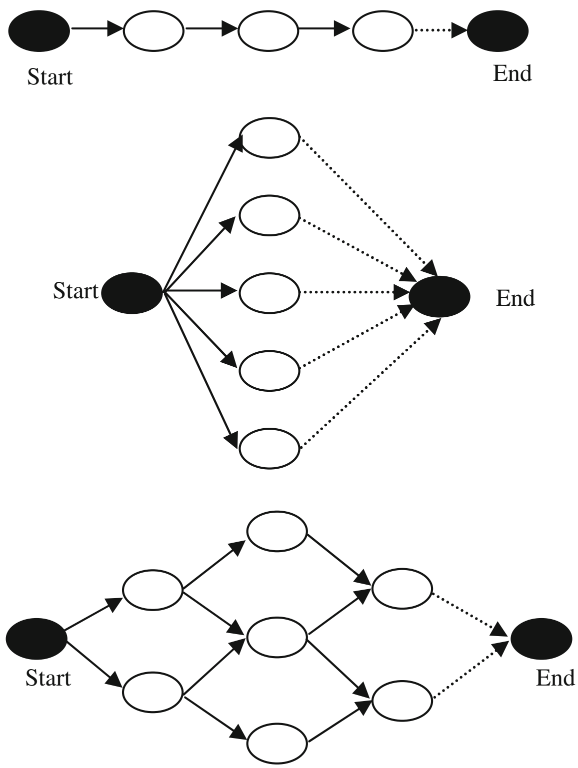


Fig. 23.6 Different morphologic types of project networks

Due to the rapid progress regarding project scheduling problems, a lot of attention has been paid to the description of the topological structure of the network and has been used to comparison between the existence data sets. These indicators will be very useful to categorize the networks into several classes between easy and hard instances and they will provide a basic framework for the generation of networks. Also these indicators allow the researchers to predict the difficulty of a particular problem for a particular solution procedure based on the structure of the network.

Well-known complexity measures that are used to describe the topological structure of a network (Vanhoucke et al. 2008) describe as:

1. *The Coefficient of Network Complexity* (CNC), calculated as the total number of precedence relations (arcs) divided by the total number of project activities (nodes).
2. *The Order Strength* (OS), measured as the number of precedence relations (including the dummy ones) divided by the theoretical maximum number of precedence relations.
3. *The Complexity Index* (CI) was originally defined for two-terminal AoA networks (Elmaghraby 1995) as the reduction complexity and measures the closeness of a network to a series-parallel directed graph and tells how "dense" is the network for any length. Furthermore CI of the networks has heavy influence on computational effort for some advanced network-based project management techniques (Kamburowski et al. 2000).

Moreover, we present in this section six additional complexity measures and the various definitions that are used to define these indicators to measure network structure. Topological definitions to describe the topological indicators (Vanhoucke et al. 2008) are described as:

1. *Progressive Level PL_i*

$$PL_i = \begin{cases} 1 & \text{if} \quad \mathrm{P_i} = \phi \\ \max_{j \in P_i} PL_j + 1 & \text{if} \quad \mathrm{P_i} \neq \phi \end{cases} \tag{23.20}$$

   P_i = The set of all nodes that precede node i
2. *Regressive Level RL_i*

$$RL_i = \begin{cases} 1 & \text{if} \quad \mathrm{S_i} = \phi \\ \max_{j \in S_i} RL_j - 1 & \text{if} \quad \mathrm{S_i} \neq \phi \end{cases} \tag{23.21}$$

   S_i = The set of all nodes that succeed node i
3. *Width W_a of each level a*
   The number of activities at a particular progressive level a
4. *Length l of an arc (i, j)*
   The difference between the progressive level of the end node j and the start node i
5. *Topological Float of Activity i*

The difference between the regressive and progressive level of activity i

The six topological indicators to measure the network structure (Valadares Tavares et al. 1999; Vanhoucke et al. 2008) (except the first one) have a value in the [0, 1]-interval. Each indicator measures a specific characteristic of the topological structure of the network defined as:

1. I_1—*Network Size Indicator*
   Measures the size of the network (the number of activities)
2. I_2—*Serial or Parallel Indicator*
   Measures the closeness of a network (for AoN networks) to a serial or parallel graph based on the number of progressive levels ("depth" of the network)
3. I_3—*Activity Distribution Indicator*
   Measures the distribution of the activities over the progressive levels (the width of each progressive level)
4. I_4—*Short Arcs Indicator*
   Measures the presence of short arcs (the difference between the progressive level of the end node and the start node of each arc)
5. I_5—*Long Arcs Indicator*
   Measures the presence of long arcs (difference between the progressive level of the end node and the start node of each arc)
6. I_6—*Topological Float Indicator*
   Measures the topological float of each activity (the difference between the regressive and progressive level of each activity)

A comparative study of different network generators which is often mentioned in literature (Vanhoucke et al. 2008; Valadares Tavares et al. 2002) based on these six morphologic indicators and the CI and also the relationships between these seven indicators are completely examined.

23.3.2 The Benchmark Sets

The most used Data sets in literatures in recent years are categorized as:

(2-2-1) *Patterson Set* (Patterson 1984)

This data set includes 110 instances (Patterson 1984) with a number of activities ranging from 5 to 49 from different sources with no systematic generator.

(2-2-2) *ProGen* (Kolisch et al. 1995)

This data set (Kolisch et al. 1995) is a generator that adopts the AoN representation and attempts to preserve the CI based on the average number of (non-redundant) arcs per node to estimate the network complexity and network restrictiveness (measures the number of precedence feasible activity sequences as a fraction of the total number of all activity sequences) and it focused on precedence- and resource-constrained (project) scheduling problems. This data set was modified (Drexl et al. 2000) with other parameters as partially renewable resources, Mode and set of mode identity, Changeover times, Mode-dependent minimum time-lags, Forbidden periods and costs.

(2-2-3) *PSPLIB* (Kolisch and Sprecher 1996)

This data set presented for the evaluation of solution procedure for single and multi-mode resource-constrained project scheduling problems (Kolisch and Sprecher 1996). These sets have been generated systematically by standard project generator ProGen and its input parameters. Some further parameters that include in this data set are minimum and maximum number of renewable resource and resource strength.

(2-2-4) *DAGEN* (Agrawal et al. 1996)

This network generator (Agrawal et al. 1996) Generates source-terminal directed acyclic project network in the AoA mode of networks presentation and is based on the "reduction complexity" index and measuring the non-conformity of a network to the series parallel case. In this network generator, the generation of large networks is quite difficult because of the strong interdependence between the lower and upper bounds of the proposed index, the number of nodes and the number of arcs.

(2-2-5) *RiskNet* (Tavares 1999)

This data set (Valadares Tavares et al. 1999; Tavares 1999) have proposed quite a different network generator that adopts the AoN notation and it is designed to preserve the morphology of each network in terms of the graphical shape, the number of non-redundant direct precedence links and the level length of the non redundant direct precedence links. Next research (Tavares 2002) compared these generators with the previous six morphologic indicators plus an additional indicator, the CI and then calculated correlations between these different indicators.

(2-2-6) *RanGen1* (Demeulemeester et al. 2002)

This generator (Demeulemeester et al. 2002) is a random network generator for generating AoN networks and accompanying data from different classes of project scheduling problems with the objective of satisfying the parameters used to control the hardness of a problem instance and implements both parameters which are related to the network topology and resource-related parameters. Number of network generated can be limit with both a CPU time and a limit on the number of networks.

(2-2-7) *RanGen2* (Vanhoucke et al. 2008)

This generator (Vanhoucke et al. 2008) is similar to RanGen1 with new topological indicators and is able to generate networks with a wide variety of topological measures but aims at generating networks with pre-specified values for I_1

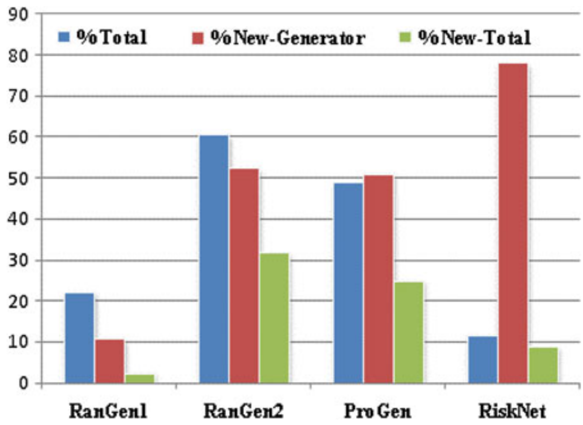


Fig. 23.7 Computational results for the four network generators

and I_2. The start values of I_4 and I_5 equal 1, I_6 equals 0 and a I_3 value randomly chosen from interval [0, 1].

Vanhoucke et al. (2008) showed the experimental results with 30 activities for the four network generator ProGen, RiskNet, RanGen1 and RanGen2 for comparison between these network generator and total amount of networks and each other (Vanhoucke et al. 2008). Figure 23.7 shows these computational results. In this Fig., "%Total" shows the percentage of all networks found with generator and the combination with it divided by all possible networks. The category "%New-Generator" presents the amount of network found with generator divided by all networks found with generator and with the combination with it and the category "%New-Total" presents the amount of network found with generator divided by all possible networks. The results show that RanGen2 found more network individually and jointly, so it has distinguished behavior.

23.4 Design Progress Simulators

Computer simulation is a powerful tool for analyzing complex and dynamic scenarios and improves decision-making in problems and provides a better mechanism for advanced project management. Also, Simulation helps project managers as decision makers identify different possible options by providing both detailed experience and strategic management perspective and analyzing enormous amounts of input data.

Furthermore, The effort of reporting progress at the process level (lowest level in a WBS) in projects can be justified with effective analysis of the resource loading needed to complete a task in a given time frame, based on current progress levels in a simulation model for progress control.

Project change notices affects the agreed upon total project hours and costs and the simulation model incorporates such changes, evaluates the baseline and forecast

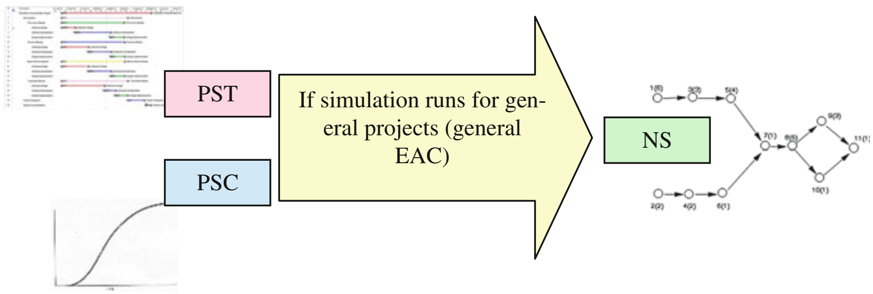


Fig. 23.8 Main structure of simulation study

values based on these new parameters and process the reminding of project with this new additional information and completes project progress. The output parameter of simulation also can be used in intelligent methods such as ANFIs to trained and increase forecasting performance.

In literatures some simulators introduced for general or a Special Purpose Simulation (SPS) tool for optimization of different parameters as manpower forecast loading and resource leveling (Hanna and Ruwanpura 2007), the project completion time (Huang and Chen 2006), the project cost (Al-Jibouri 2003) and etc.

We developed a research framework with a simulation model to help estimate the project completion time and cost and analyze the major factors that affect the estimation for project managers (Iranmanesh and Hojjati Tavassoli 2008) during execution and at the end of special projects (standard data sets). Therefore design the Network Simulation (NS) is not needed. In general cases design network simulation also is needed.

During project progress simulation, actual durations and costs for each activity will differ from the planned values. Based on these differences between them, we calculate the earned value metrics for reporting our forecasting indicators.

As it could be seen in Fig. 23.8 in this section we discuss about progress simulation in two viewpoints: Progress Simulation of Time (PST) and Progress Simulation of Cost (PSC).

23.4.1 Progress Simulation for Time

PST simulates progress of projects with calculating different indices in different time sections. To simulate PST in our simulator following tasks for each sample project were done:

(1) Setting the address of input data set and location for saving outputs.
(2) Reading sample project file which is in text format from the address on data set, setting task and resource specifications and making corresponding MSP file.

(3) Updating current date of the project day by day, in a loop till the project is finished. In each loop actual percent complete and schedule progress calculated and BCWS and BCWP updated.
(4) Calculating SPI, Scheduled Percent Complete by Duration (SPCD), Actual Percent Complete by Duration (APCD) and Sum of Durations to Due Time (SDDT).
(5) Reporting necessary indices and response variable in Microsoft Excel format in its location.

The underlying assumptions in developing this program, which most of them are based on authors' experience in different projects specially dam construction projects in Iran, were:

(1) The duration of 80 % of tasks are underestimated and the duration of remaining 20 % tasks are overestimated. It is notable that these parameters can be adapted with project types. For example New Product Development (NPD) inherently may face with high risks in tasks.
(2) In daily progress of the project, progress of an underestimated task can be 70–100 % of scheduled amount of the day and progress of an overestimated task can be 100–130 % of scheduled amount of the day.
(3) For the task of projects set work contour property and therefore the amount of daily progress of each task is up to its work contour.

The accuracy of forecasts depends on the measure the accuracy of index-based time forecasts as a function of the completion stage of the project and have important role in other estimations.

23.4.2 Progress Simulation for Cost

Designing the PSC mainly uses the similar assumptions and the basic data and process of PST as it was discussed above and has some more tasks for each project as follows:

(1) Setting work contour property shows how each resource of a task is to be distributed across the duration of the assignment.
(2) Calculating the physical percent complete according to the work contour which was set.
(3) While the project updates day by day, the cost of each task calculated from its resources usage on that day and the cost of each resource according to its inflation rate.
(4) At the end of each day, total cost for all tasks and at the end of the project, total cost of project, EAC calculated.

This project simulation was done with the set of project (ProGen, Kulich–Hartmann standard data set) for estimation of project completion cost and time and

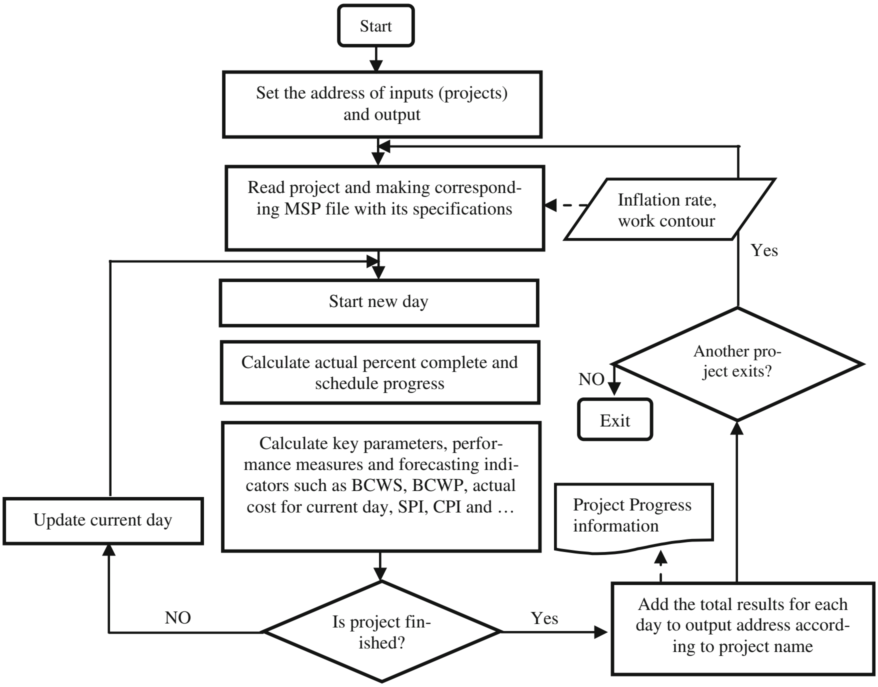


Fig. 23.9 Proposed algorithm for the progress simulator cost

calculates the progress of project day by day in different situation for better estimation. Many parameters such as inflation rates and work contours, can be tuned during the simulation and many outputs gained such as activity risks and number of delayed asks and many other parameter for intelligent models inputs thus using this methodology is useful to better cost or time estimation during the project execution. Figure 23.9 shows the proposed algorithm for the Progress simulator cost and time.

23.4.3 Results

23.4.3.1 Fictitious Project Results

This simulator run for 480 projects with 92 tasks and 4 resources of Kulich–Hartmann standard data set and demonstrate a software program (PSC and PST) using Visual Basic for Application (VBA) in the environment of Microsoft Project 2003 was developed. Figure 23.10 shows the user form designed for getting input parameters and run the simulation.

For instance, we set the parameters by default back-loaded work contour property which was as the same as S-Curve, inflation rate 0.2 for period of 6 months

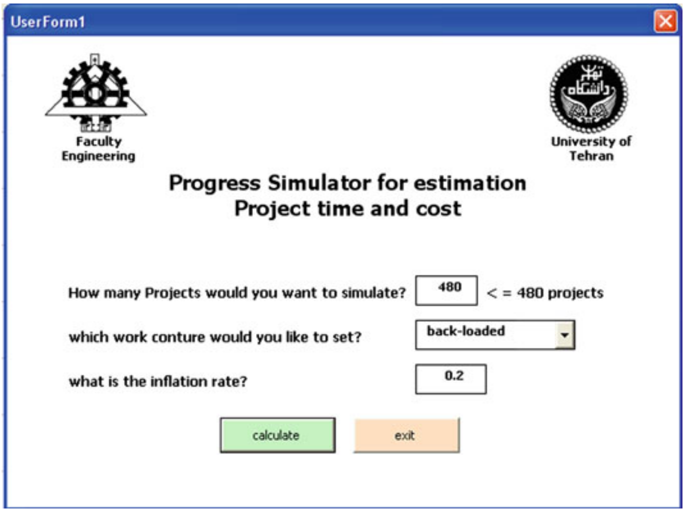


Fig. 23.10 User form for progress generator

Table 23.1 Effects of work contours on each work of tasks

Work contour property name	Flat	Back-loaded	Front-loaded	Double-peak	Early-peak	Late-loaded	Bell	Turtle
Shape of behavior	Uniform							
								

and total projects for simulation. Table 23.1 shows the effect of different work contours on the behavior of works of each task.

One random project of data set runs with different work contours and with and without inflation rate. Figures 23.11 and 23.12 show the result of simulation for CPI and Figs. 23.13 and 23.14 for AC.

Each curve in diagrams above shows the results according to different work contours set. The comparisons of four diagrams above demonstrate high effect of inflation rate in CPI and AC and also front loaded work contour has maximum delay and Double-peak work contour has minimum delay in completion time that conclude the effect of distribution of work during the tasks. Figures 23.15 and 23.16 are the SPI diagram for two states: with inflation rate and without inflation rate and show the same behavior but different delays in project completion.

Accordingly the results of this simulation presented highly effects of inflation rate on cost and delay of project during the execution and completion and a useful risk evaluation for better estimation and reducing the delay risks.

This simulation was focused on progress for calculating EAC but, it is notable that our purpose of this study was designing the progress simulator for special projects and estimated EAC for them and for calculating general EAC, design

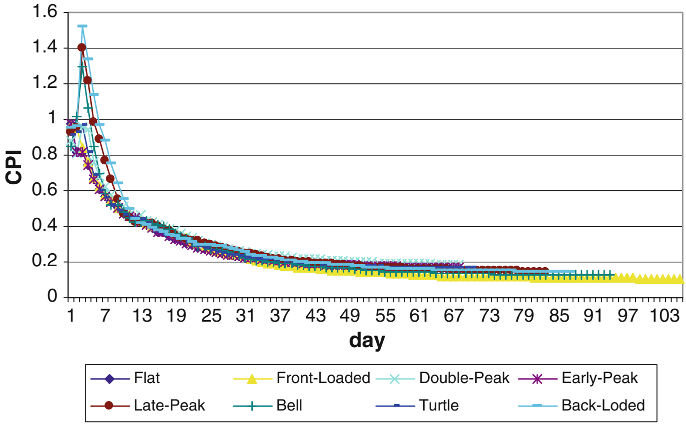


Fig. 23.11 CPI result of one random project with inflation rate

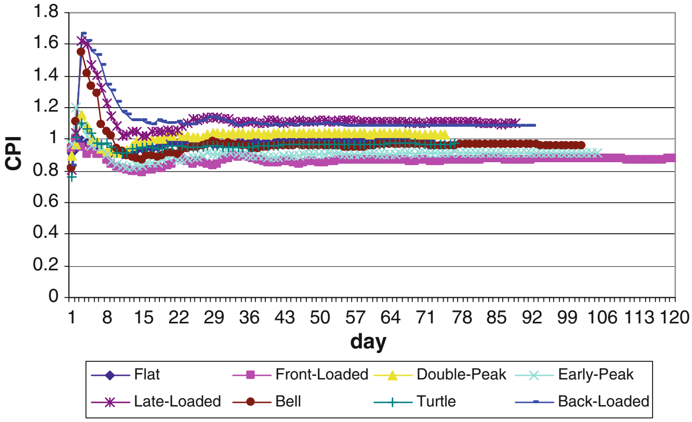


Fig. 23.12 CPI result of one random project without inflation rate

network simulation is needed. As there is a few researches focus on better estimation completion time and cost of project, then this simulator and its roadmap could be useful tool for researchers to produce new formula for EAC.

23.4.3.2 Case Study Results

Javadieh is an area located in south-west of Tehran in Iran. Javadieh underpass is a project which includes two bridges, one overpass with 90 m length and 8.20 m width, and one underpass with 80 m length and 8.20 m width. In addition, two entry

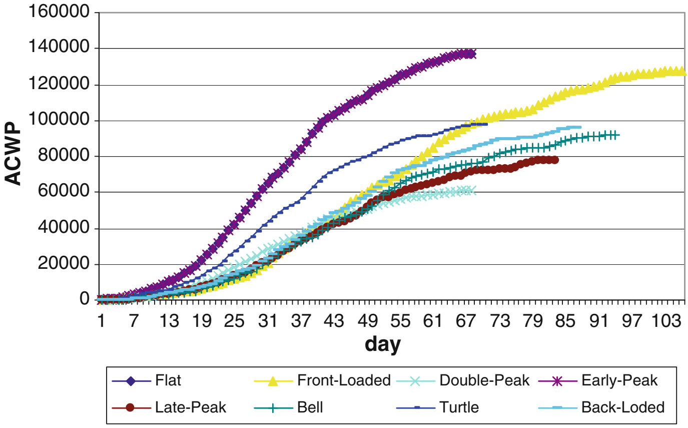


Fig. 23.13 ACWP result of one random project with inflation rate

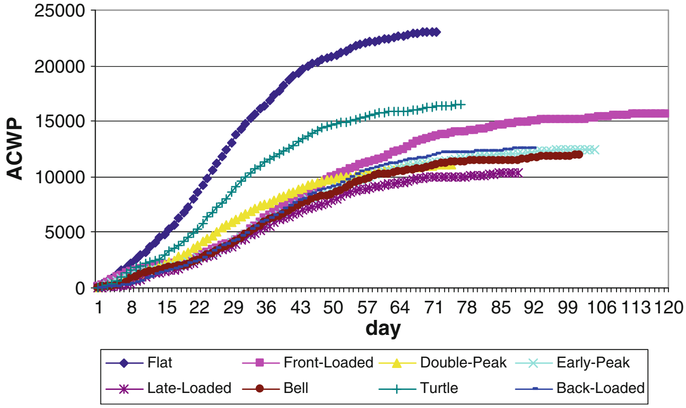


Fig. 23.14 ACWP result of one random project without inflation rate

ramps and one exit ramp connect this railway crossing with the northern city network (Shoosh Avenue) and southern city network (Noori Street).

The whole project utilizes four main disciplines: engineering, procurement, destruction and construction. The construction discipline includes some major sub-disciplines, such as excavation, formwork, concreting, waterproofing, embankment, pavement and other minor tasks such as curbs, signs, signaling and lighting.

This project was scheduled for 6 months with 223 tasks across the four mentioned disciplines. The contract price was considered as a fixed price, at about 66,869,542,003 Rials (approximately US$2.3 million at writing). The project network was considered as an activity-on-the-node project network with precedence relations between the activities based on the project data. The project was planned for 04/24/2013–10/20/2013; after 5 months, the project had progressed

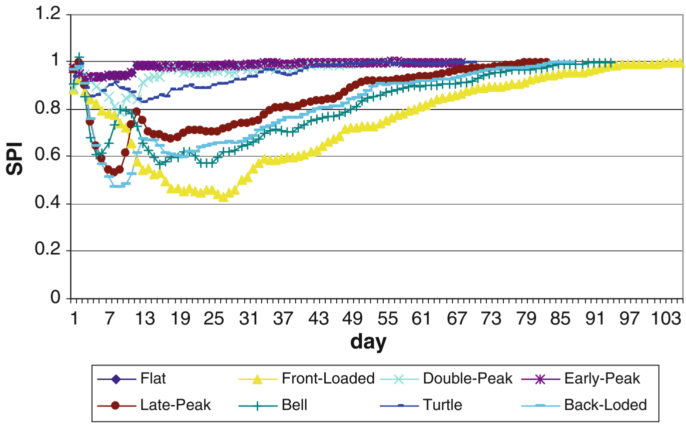


Fig. 23.15 SPI result of one random project with inflation rate

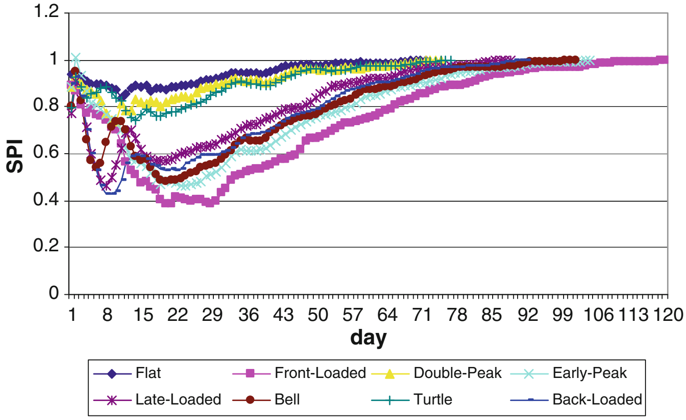


Fig. 23.16 SPI result of one random project without inflation rate

approximately 60 % and needed to be rescheduled due to delays. Therefore, the analysis of project condition, measurement factors and daily progress status was essential to measure the project's efficiency and risk effects. In this case, it could be rescheduled realistically, as this monitoring and controlling tool helped the project manager to estimate the remaining project cost and time, to allocate sufficient resources and to analyze other factors, such as control risks.

Figure 23.17 illustrates a simulation experiment on a construction project with a total project duration of 6 months and a budget at completion of BAC = 66,869,542,003 Rials. The project had 34 % delays for about 5 months since the project started, and the project was conducted under high-risk conditions; the inflation rate was considered 30 % for 6 months. As mentioned, the project was

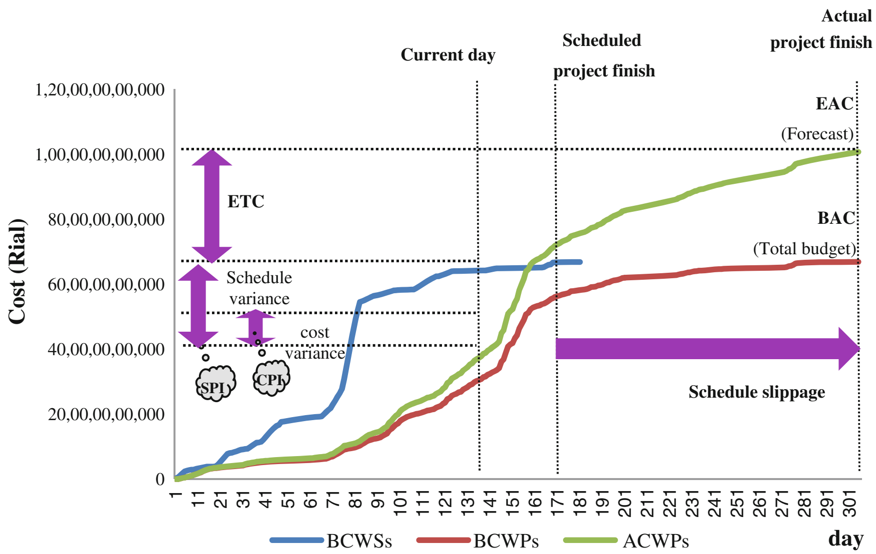


Fig. 23.17 Simulation results for the given project

structured to use four main disciplines and seven sub-disciplines related to the fourth main discipline. Here, we assume all tasks have uniform (flat) distribution. The baseline schedule is used as shown in the Gantt chart formed when the project was initially planned. The simulation is performed using the project progress simulator presented in this paper. After all other input parameters have been set according to current actual information, the simulation starts to fit the actual curve with actual project progress as 150 days of project have passed; therefore the completion trends can be estimated.

As seen in Fig. 23.17, the project will complete after 306 days (about 10 months) with a cost overrun. Consequently, the budget must be increased from 66,869,542 to 100,750,109,952 Rials, i.e. by about 35 %. Moreover, other project progress information is depicted in this figure. As a result, EVM measurements are now able to be calculated daily.

The progress simulator offers forecast and control methods that yield reliable results, and which greatly simplify daily and completion date forecasting. These early warning signals, if analyzed properly in comparison with the project schedule, allow corrective actions to be taken on those activities that are in trouble (especially those tasks which are on the critical path).

23.5 Intelligent Systems

Estimating the future has been an interesting and important problem in human mind for many decades. Estimating completion time and cost of projects during the project execution is one of the major aspects of project management. It is notable that EVM is a systematic approach to follow-up the performance of a project and to act as a warning signal to take corrective actions in the future. In EVM terminology, the general formula for estimating a project's final cost is given by the EAC.

Work Breakdown Structure (WBS) or activity list is considered to be the fundamental of other processes like scheduling, controlling, assigning responsibilities, etc. There are some tools in order to generate a project WBS, such as, mind mapping (Iranmanesh and Madadi 2008). Mind map is a method for thinking together and help a project manager to stimulate the mind of project team members to generate project WBS which can be involved with the building construction using mind map and the artificial intelligence (AI) programming language.

Although intelligent systems are widely used in different areas (Ebrahimpour et al. 2013; Abdollahzade et al. 2012), these systems are not addressed adequately in the field of project management.

As it is mentioned before, cost estimates are important to project feasibility studies and have impact on final project success. Since these estimates provide significant information that can be used in project evaluations, engineering designs, cost budgeting and cost management, some studies used intelligent systems like an artificial intelligence approach to improve conceptual cost estimate precision in specific sector, for instance, construction industry (Cheng et al. 2010).

This section concentrates on the time aspect of estimate at completion. Since it is needed to specify inputs for the proposed approach, this research has been focused on different new methods to forecast a project's final duration and try to use ELFIS as powerful prediction tool to forecast completion time of a project and show its performance compared with other methods.

23.5.1 Input and Output Data Configuration

In order to examine and validate the proposed methodology to forecast the completion time of projects, we need certain inputs and outputs. These data was generated through a project simulator which was previously developed by VBA-MSP tools in Microsoft Project software for other studies by authors. For more information about its structure may refer to Iranmanesh et al. (2007), (2008) and Iranmanesh and Hojjati Tavassoli (2008). It reads sample project file, which is in text format, and makes corresponding Microsoft Project file. It then updates current date of the project day by day, in a loop till the project is finished. The program calculates actual and planned percent complete for each activity, day by day randomly. Then, SPI and CPI as traditional indexes in EVM have been calculated based on this data. A sample data generated by the simulator for a project with 30 tasks could found in Appendix 23.1. It is notable that network of projects was borrowed from Kulisch–Hartman data set which is a standard data set for RCPSP and could be found via http://129.187.106.231/psplib/main.html.

The generator reports necessary indices and responses variables in Microsoft Excel format. After running the program, a data set with 44,183 rows of data was developed, each row representing 1 day of one of the sample projects. In order to validate the models a set of projects must be tested.

23.5.2 ANFIS Model

Fuzzy Logic Controllers (FLC) has played an important role in the design and enhancement of a vast number of applications. The proper selection of the number, the type and the parameter of the fuzzy membership functions and rules is crucial for achieving the desired performance and in most situations, it is difficult. Yet, it has been done in many applications through trial and error. This fact highlights the significance of tuning fuzzy system.

Adaptive Neuro-Fuzzy Inference Systems are fuzzy Sugeno models put in the framework of adaptive systems to facilitate learning and adaptation. Such framework makes FLC more systematic and less relying on expert knowledge. To present the ANFIS architecture, let us consider two-fuzzy rules based on a first order Sugeno model:

$$\begin{aligned} &\textit{Rule}\,1:\ \ \textit{if}\ \ (x\,\text{is}\,A_1)\ \ \textit{and}\ \ (y\,\text{is}\,B_1)\ \ \textit{then} \\ &(f_1 = p_1x + q_1y + r_1) \end{aligned} \tag{23.22}$$

$$\begin{aligned} &\textit{Rule}\,2:\ \ \textit{if}\ \ (x\,\text{is}\,A_2)\ \ \textit{and}\ \ (y\,\text{is}\,B_2)\ \ \textit{then} \\ &(f_2 = p_2x + q_2y + r_2) \end{aligned} \tag{23.23}$$

A possible ANFIS architecture to implement these two rules is shown in Fig. 23.18. In the following presentation OLi denotes the output of node i in a layer L.

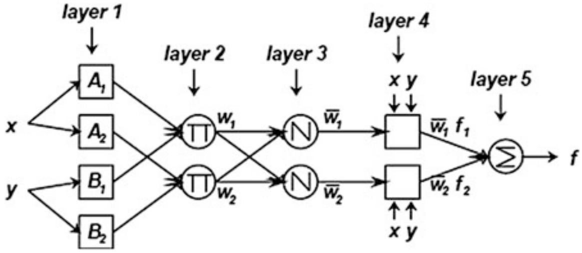


Fig. 23.18 Construct of ANFIS Adaptive Neuro-Fuzzy Interface System

Layer 1: All the nodes in this layer are adaptive nodes, i is the degree of the membership of the input to the fuzzy membership function (MF) represented by the node:

$$\begin{aligned} O_{l,i} &= \mu_{A_i}(x) \quad i = 1,2 \\ O_{l,i} &= \mu_{B_{i-2}}(y) \quad i = 3,4 \end{aligned} \tag{23.24}$$

A_i and B_i can be any appropriate fuzzy sets in parameter form.

Layer 2: The nodes in this layer are fixed (not adaptive). These are labeled M to indicate that they play the role of a simple multiplier. The outputs of these nodes are given by:

$$O_{2,i} = w_i = \mu_{A_i}(x)\mu_{B_i}(y) \quad i = 1,2 \tag{23.25}$$

The output of each node is this layer represents the firing strength of the rule.

Layer 3: Nodes in this layer are also fixed nodes. These are labeled N to indicate that these perform a normalization of the firing strength from previous layer. The output of each node in this layer is given by:

$$O_{3,i} = \bar{w}_i = {}^{w_i}\!/_{w_1 + w_2} \quad i = 1,2 \tag{23.26}$$

Layer 4: All the nodes in this layer are adaptive nodes. The output of each node is simply the product of the normalized firing strength and a first order polynomial:

$$O_{4,i} = \bar{w}_i f_i = \bar{w}(p_i x + q_i y + r_i) \quad i = 1,2 \tag{23.27}$$

where p_i, q_i and r_i are design parameters (consequent parameter since they deal with the then-part of the fuzzy rule).

Layer 5: This layer has only one node labeled S to indicate that is performs the function of a simple summer. The output of this single node is given by:

$$O_{5,i} = f = \sum_i \bar{w}_i f_i = \frac{\sum_i \bar{w}_i f_i}{\sum_i w_i} \quad i = 1,2 \tag{23.28}$$

The ANFIS architecture is not unique. Some layers can be combined and still produce the same output. In this ANFIS architecture, there are two adaptive layers (1, 4). Layer 1 has three modifiable parameters (a_i, b_i and c_i) pertaining to the input MFs. These parameters are called premise parameters. Layer 4 has also three modifiable parameters (p_i, q_i and r_i) pertaining to the first order polynomial. These parameters are called consequent parameters (Jang et al. 1997).

MATLAB software could be used to adopt an ANFIS predictor. Table 23.2 presents the structure of ANFIS predictor.

According to the type of training data, seven different membership functions (2 types of sigmoidal shape, gaussian shape, Π-shaped, Generalized bell-shaped, Trapezoidal-shaped, Triangular-shaped) are examined. Sample of examined MFs

Table 23.2 ANFIS structure

Model	AD, CPI, SPI (inputs) and actual duration (output)	
Training method		Hybrid
Input layer	Number of MF's*	3, 3, 3
	MF Type	gbellmf
Epoch		12
Output layer	MF Type	Linear
Fuzzy logic info.	Defuzzification method	Weighted average
	Type	Sugeno

**MF* Membership Function

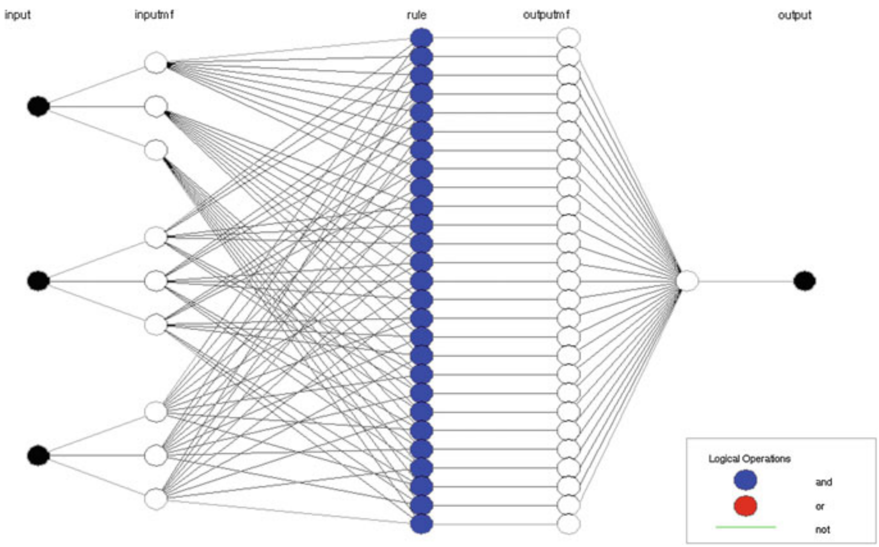


Fig. 23.19 ANFIS structure

shapes are illustrated in Appendix 23.2. From the brief results summarized in Table 23.2, the proposed structure of ANFIS model for time estimate at completion had three inputs with 3 membership functions per unit. Therefore the number of FIS[1] rules is 27. The structure of this model is shown in Fig. 23.19. The layers of this structure are input, inputmf, rule, outputmf and output, respectively.

[1]Fuzzy Inference System.

23.5.3 ANN and Conventional Regression

23.5.3.1 Artificial Neural Network Model

In general, ANNs are simply mathematical techniques designed to accomplish a variety of tasks. The research in the field has a history of many decades, but after a diminishing interest in the 1970s, a massive growth started in the early 1980s. Today, Neural Networks can be configured in various arrangements to perform a range of tasks including pattern recognition, data mining, classification, forecasting and process modeling. ANNs are composed of attributes that lead to perfect solutions in applications where we need to learn a linear or nonlinear mapping. Some of these attributes are: learning ability, generalization, parallel processing and error endurance. These attributes would cause the ANNs solve complex problem methods precisely and flexibly.

ANNs consists of an inter-connection of a number of neurons. There are many varieties of connections under study, however here we will discuss only one type of network which is called the Multi Layer Perceptron (MLP). In this network the data flows forward to the output continuously without any feedback. Figure 23.20 shows a typical three-layer feed forward model used for forecasting purposes.

The input nodes are the previous lagged observations while the output provides the forecast for the future value. Hidden nodes with appropriate nonlinear transfer functions are used to process the information received by the input nodes. The model can be written as:

$$y_t = a_0 + \sum_{j=1}^{m} a_j f\left(\sum_{i=1}^{m} \beta_{ij} y_{t-1} + \beta_{01}\right) + \varepsilon_t \quad i = 1, 2 \tag{23.29}$$

where m is the number of input nodes, n is the number of hidden nodes, f is a sigmoid transfer function such as the logistic:

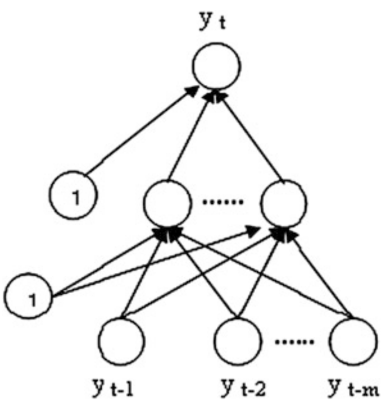


Fig. 23.20 A three layer MLP network

$$f(x) = \frac{1}{1 + \exp(-x)} \quad (23.30)$$

$\{\alpha_j, j = 0,\ 1, \ldots, n\}$ is a vector of weights from the hidden to output nodes and $\{\beta_{ij},\ i = 1, 2, \ldots, \mathrm{m}; j = 0, 1, \ldots, \mathrm{n}\}$ are weights from the input to hidden nodes. α_0 and β_{oj} are weights of arcs leading from the bias terms which have values always equal to 1. Note that Eq. (23.29) indicates a linear transfer function is employed in the output node as desired for forecasting problems.

The MLP's most popular learning rule is the error back propagation algorithm. Back Propagation learning is a kind of supervised learning introduced by Werbos (1974) and later developed by Rumelhart and McClelland. At the beginning of the learning stage all weights in the network are initialized to small random values. The algorithm uses a learning set, which consists of input–desired output pattern pairs. Each input–output pair is obtained by the offline processing of historical data. These pairs are used to adjust the weights in the network to minimize the Sum Squared Error (SSE) which measures the difference between the real and the desired values over, all output neurons and all learning patterns. After computing SSE, the back propagation step computes the corrections to be applied to the weights.

The attraction of MLP has been explained by the ability of the network to learn complex relationships between input and output patterns, which would be difficult to model with conventional algorithmic methods. There are three steps in solving an ANN problem which are (1) training, (2) generalization and (3) implementation.

Training is a process that network learns to recognize present pattern from input data set. We present the network with training examples, which consist of a pattern of activities for the input units together with the desired pattern of activities for the output units. For this reason each ANN uses a set of training rules that define training method.

Generalization or testing evaluates network ability in order to extract a feasible solution when the inputs are unknown to network and are not trained to network. We determine how closely the actual output of the network matches the desired output in new situations. In the learning process the values of interconnection weights are adjusted so that the network produces a better approximation of the desired output. ANNs learn by example. They cannot be programmed to perform a specific task. The examples must be selected carefully otherwise useful time is wasted or even worse the network might be functioning incorrectly. The disadvantage is that because the network finds out how to solve the problem by itself and its operation can be unpredictable.

In this section the effort is made to identify the best fitted network for the desired model according to the characteristics of the problem and ANN features. Using the following concepts and steps, we changed different parameters of neural network and best result with minimum error was gained through the many runs of network. Table 23.3 presents the structure of ANN predictor.

Table 23.3 ANN structure

Model	AD, CPI, SPI (inputs) and actual duration (output)	
Training	Method	Back propagation
	Learning rate	0.4
	Minimum MSE	1.00E-04
Input layer	# of neurons	3
Hidden layer	# of neurons	4
	Transformation function	Tan-sigmoid (tansig)
Output layer	# of neurons	1
	Transformation function	Pure-linear (purelin)
ANN Info.	Type	Multilayer perceptron

23.5.3.2 Conventional Regression Model

Regression analysis is one of the most used statistical tools to explain the variation of a dependent variable Y in terms of the variation of explanatory variables X as: $Y = f(X)$ where $f(X)$ is a linear function. It refers to a set of methods by which estimates are made for the model parameters from the knowledge of the values of a given input-output data set. The goal of the regression analysis is:

(a) To find an appropriate mathematical model, and
(b) To determine the best fitting coefficients of the model from the given data

The use of statistical regression is bounded by some strict assumptions about the given data. This model can be applied only if the given data are distributed according to a statistical model and the relation between X and Y is crisp. Overcoming such limitations, fuzzy regression is introduced which is an extension of the classical regression and is used in estimating the relationships among variables where the available data are very limited and imprecise and variables are interacting in an uncertain, qualitative and fuzzy way. In our study the inputs and output of forecasting model are crisp and we can use the conventional regression to determine the best fitting coefficients of the model from the given data. For this purpose we use MINITAB 13.20 software which is available on http://www.minitab.com.

The best fitted regression model was identified as a linear model which is the function of independent variable. Furthermore, it was selected among other models because of lower error and better fit. Using MINITAB, the equation of this regression is:

Actual duration = 189.570 + 0.231925 **AD** − 12.432 **CPI** − 100.316 **SPI**

Equation 23.29 has been developed and fitted with training data and has been used to forecast completion time based on experimental data.

23.5.4 ELFIS Model

The Emotional learning method is a psychologically motivated approach that is composed to reduce the complexity of computations in forecasting problems. Using emotional cue in a forecasting model leads to lower the forecasting error in some regions or according to some features. "It is notable that the ELFIS has the advantages of simplicity and low computational complexity in comparison with other multi-objective optimization methods. The emotional signal can be produced by any combination of objectives or goals which improve estimation or prediction (Lucas et al. 2003)."

In this learning method, a loss function will be defined as a function of emotional signal and the training algorithm will be simply developed to minimize this loss function. So the predictor model will be trained to provide the desired performance in a cognitive manner. The emotional learning algorithm has been used to enhance the performance of an adopted network trained by ANFIS predictor. The Takagi-Sugeno fuzzy inference system is constructed by fuzzy rules of the following type:

$$Rule: If \;\; u_1 = A_{i1} \;\; And \ldots And \;\; u_p = A_{ip} \;\; then \;\; \hat{y} = f_i(u_1, u_2, \ldots, u_p) \qquad (23.31)$$

where i = 1…M and M is the number of fuzzy rules. $u_1, \ldots, u_p$ are the inputs of network, each A_{ij} denotes the fuzzy set for input u_j in rule i and $f_i(.)$ is a crisp function which is defined as a linear combination of inputs in most applications such as:

$$\hat{y} = \omega_{i0} + \omega_{i1}u_1 + \omega_{i2}u_2 + \cdots + \omega_{ip}u_p \qquad (23.32)$$

Matrix form $\hat{y} = a^T(u) \cdot W$

Thus the output of this model can be calculated by

$$\hat{y} = \frac{\sum_{i=1}^{M} f_i(u)\mu_i(u)}{\sum_{i=1}^{M} \mu_i(u)}; \quad \mu_i(u) = \prod_{j=1}^{p} \mu_{ij}(u_j) \qquad (23.33)$$

where $\mu_{ij}(u_i)$ is the membership function of jth input in the ith rule and $\mu_i(u)$ is the degree of validity of the ith rule.

A loss function is defined on the base of emotional signal. A simple form is:

$$J = \frac{1}{2} K \sum_{i=1}^{N} es(i)^2 \qquad (23.34)$$

where *es(i)* is the of emotional signal to the ith sample of training data, and K is a weighting matrix, which can be simply replaced by unity. Learning is adjusting the weights of model by means of a nonlinear optimization method, e.g. the steepest descent or conjugate gradient. With steepest descent, the weights are adjusted by the following variations:

$$\Delta\omega = -\eta \frac{\partial J}{\partial \omega} \tag{23.35}$$

where η is the learning rate of the corresponding neurofuzzy controller and the right hand side can be calculated by chain rule:

$$\frac{\partial J}{\partial \omega} = \frac{\partial J}{\partial es} \cdot \frac{\partial es}{\partial y} \cdot \frac{\partial y}{\partial \omega} \tag{23.36}$$

According to (23.31): $\frac{\partial J}{\partial es} = K \cdot es$

And $\frac{\partial y}{\partial \omega}$ is accessible from (23.33) where $f_i(\cdot)$ is a linear function of weights. Calculating the remaining part, $\frac{\partial es}{\partial y}$, is not straightforward in most cases. This is the price to be paid for the freedom to choose any desired emotional cue as well as not having to impose presuppose any predefined model. However, it can be approximated via simplifying assumptions. If, for example error is defined by

$$e = \hat{y} - y \tag{23.37}$$

where $\hat{y}$ is the output to be estimated, then

$$\frac{\partial es}{\partial y} = -\frac{\partial es}{\partial e} \tag{23.38}$$

can be replaced by its sign (−1) in (23.36). The algorithm is after all, supposed to be satisfying rather than optimizing. Finally the weights will be updated by the following formula:

$$\Delta\omega = -K\eta \cdot es \cdot \frac{\partial y}{\partial \omega} = -K \cdot \eta \cdot es \cdot \frac{\sum_{i=1}^{M} u_i \mu_j(\underline{u})}{\sum_{i=1}^{M} \mu_i(\underline{u})} \tag{23.39}$$

The emotional cue is computed by a linguistic fuzzy inference system (fis) with error and rate of error change as inputs and the last targeted output. By defining appropriate membership functions for each of the inputs and 13 linguistic fuzzy rules, the desired behavior of emotional critic is provided to show exaggerated emotions in the completion time of projects maximum regions.

Five and three Gaussian membership functions, negative large, negative, zero, positive and positive large, are used for the inputs (error and rate of error change, respectively) and the emotional signal is calculated by a center of average defuzzifier from the rule base depicted by the surface in Fig. 23.21.

There are seven Gaussian membership functions for the emotional signal as the output of fuzzy critic. A sample plot of predicted values with ELFIS and ANN

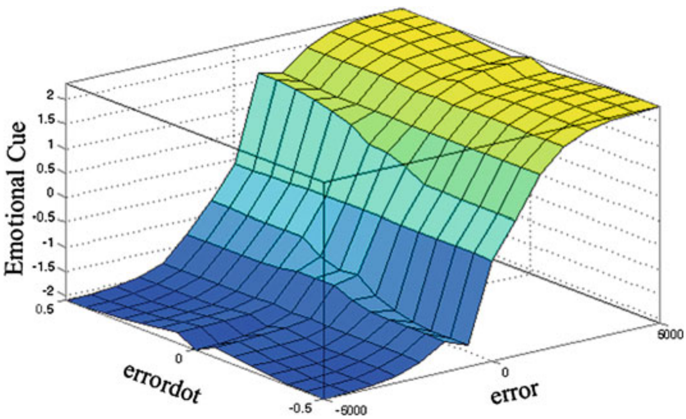


Fig. 23.21 The surface generated by linguistic fuzzy rules of the emotional critic

predictors compared to the actual duration values is shown in Fig. 23.22. As shown in Fig. 23.5 it is notable that ELFIS results more accurate prediction of the Peaks.

23.6 Results

For the purposes of comparisons of the forecasting performances for various methods, the mean absolute percentage error (MAPE), given by Eq. 23.40, and normalized mean square error (NMSE), given by Eq. 23.41, are used as the index of forecasting accuracy.

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{y_i - \hat{y}}{y_i}\right| \times 100\,\% \tag{23.40}$$

$$NMSE = \left(\frac{\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{N}(y_i - \bar{y}_i)^2}\right) \tag{23.41}$$

where y_i and $\hat{y}_i$ represent the actual and forecasted values of the ith data, respectively, $\bar{y}$ is the average of actual data and N is the number of data.

The overall comparative results based on MAPE and NMSE for following methods is shown in Table 23.4.

The emotional cue is composed to fine tune the weights of neuro-fuzzy model which has been initially adopted and trained by ANFIS predictor. The error index, NMSE, has been decreased from 0.8945 to 0.8224 and MAPE, has been decreased from 7.5928 to 7.4862 after using emotional learning. Since the number of test data is 5266, so the decrease of MAPE and NMSE from ANFIS to ELFIS with such as

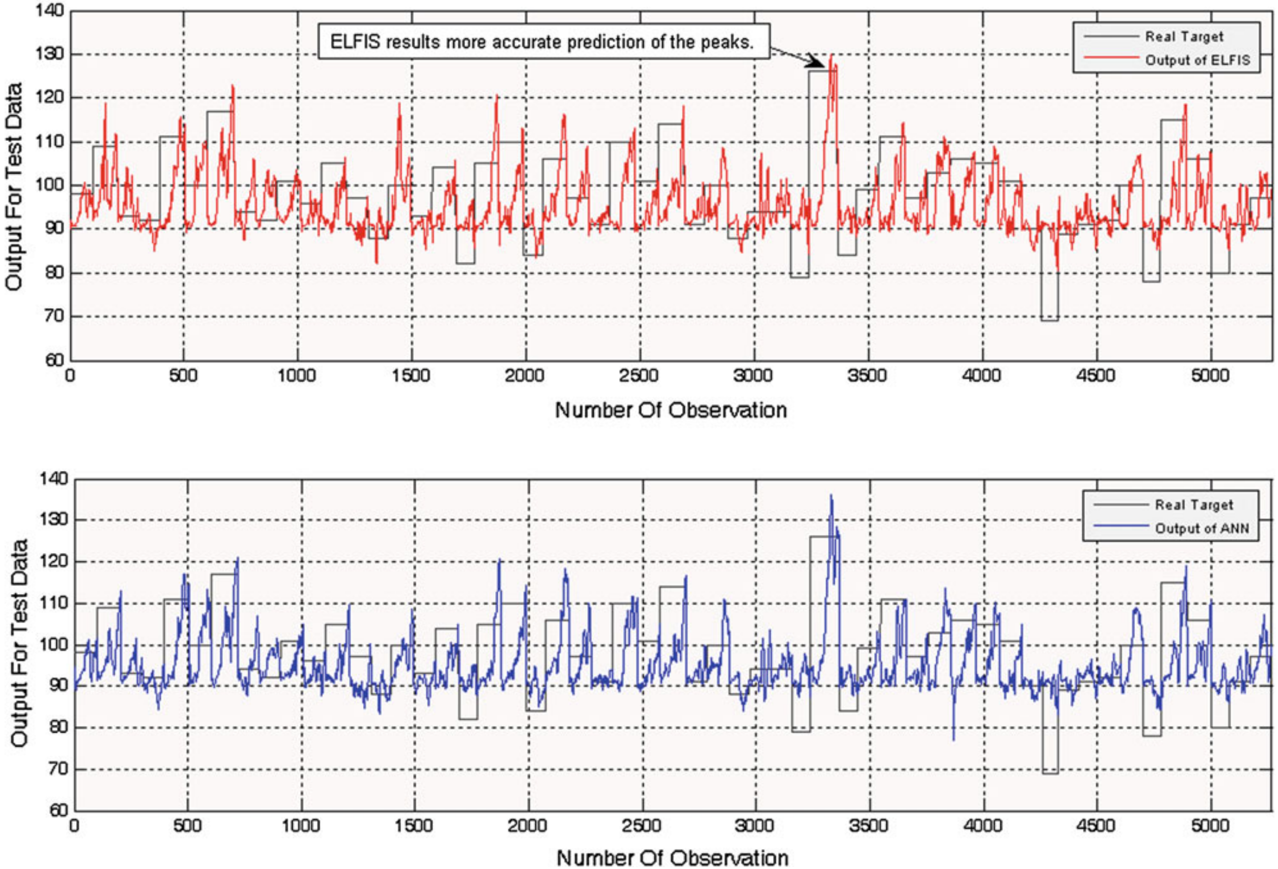


Fig. 23.22 A sample plot of predicted values with ELFIS and ANN predictors compared to the actual duration values

Table 23.4 Overall comparative results

	MAPE (%)	NMSE
Conventional regression	8.3714	1.0747
Artificial neural network	7.6383	0.8996
ANFIS	7.5928	0.8945
ELFIS	7.4862	0.8224

high volume of data is suitable and acceptable, and ensures that ELFIS is a valid and powerful method to forecast the completion time of projects. This is noticeably that the decrease of MAPE and NMSE from ANFIS to ELFIS is more than the decrease of them from ANN to ANFIS, and this fact is resulted from using and implementing cognition concepts in framework of an emotional signal composed to ANFIS predictor.

The improvement of forecasting accuracy, especially among the completion time of projects maximum regions, is noticeable. Combining ANFIS with the emotional learning is a fast efficient method to improve the accuracy of forecasting. Using ELFIS, excellent prediction accuracy has been achieved for the completion time of project estimation with considerable reduction in computational complexity. The proposed ELFIS has been used in the prediction of completion time of project where the emotional signal is determined with emphasis on the error and rate of error and it has shown better results in comparison with ANFIS, ANN and conventional Regression.

All methods in this study such as ANFIS, ELFIS, Conventional Regression and ANN are used in their optimal performance. Over fitting is prevented by observing the mean square error of several validation sets during training. It is observed that learning in ELFIS is more accurate than ANFIS. The empirical results, obtained in this study, by ELFIS yield more accurate forecasting than the other models and demonstrate that ELFIS is a valid and promising alternative for forecasting completion time of projects.

Appendix 23.1—A Sample Data for Proposed Models

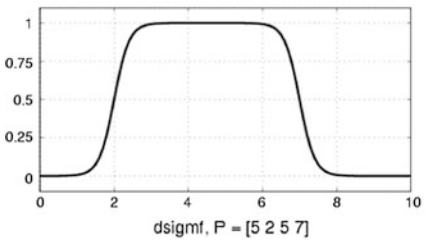
Period	CPI	SPI	BCWS	BCWP	ACWP	AD	PD	ED	EAC (t)
1	0.955	0.970	24	23	24	76	64	74	66
2	0.969	0.920	93	85	88	76	64	70	69
3	0.993	0.860	134	115	116	76	64	65	74
4	1.080	0.821	196	161	149	76	64	62	78
5	1.111	0.790	261	206	186	76	64	60	81
6	1.064	0.738	348	257	241	76	64	56	86
7	1.020	0.749	428	320	314	76	64	57	85

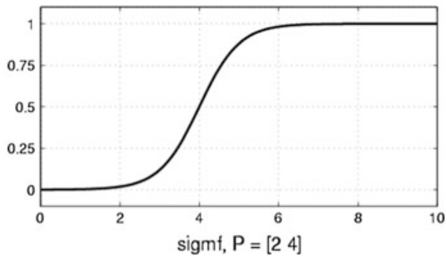
(continued)

Period	CPI	SPI	BCWS	BCWP	ACWP	AD	PD	ED	EAC (t)
8	1.056	0.712	578	412	390	76	64	54	89
9	1.057	0.784	699	548	518	76	64	60	81
10	1.049	0.718	913	655	625	76	64	55	89
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
74	0.700	0.993	11669	11592	16560	76	64	75	59
75	0.696	0.999	11669	11658	16739	76	64	76	59
76	0.697	1.000	11669	11669	16739	76	64	76	59

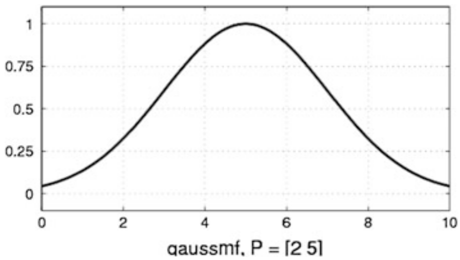
Appendix 23.2—The Membership Functions Shapes Are Illustrated and Explained in the Following

2 types of sigmoidal shape are shown bellow:

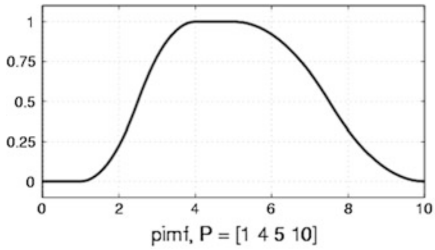


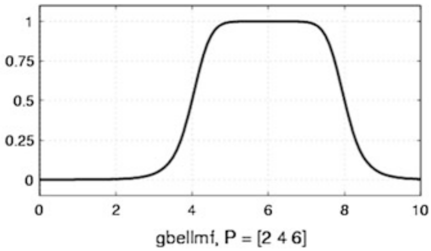


The gaussian shape is illustrated bellow:

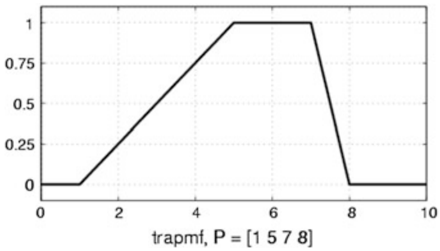


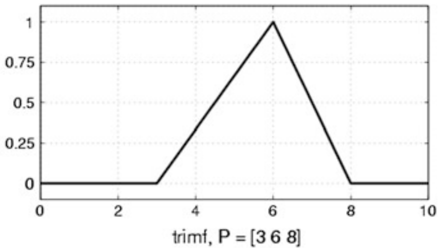
Π-shaped, generalized bell-shaped are as follows:





Trapezoidal-shaped and Triangular-shaped are illustrated bellow:





References

Abdollahzade, M., et al.: Application of emotional learning fuzzy inference systems and locally linear neuro-fuzzy models for prediction and simulation in dynamic systems. In: WCCI 2012 IEEE World Congress on Computational Intelligence, Brisbane, Australia, 10–15 June 2012

Agrawal, M.K., Elmaghraby, S.E., Herroelen, W.S.: DAGEN: a generator of test sets for project activity nets. Eur. J. Oper. Res. **90**, 376–382 (1996)

Al-Jibouri, Saad H.: Monitoring systems and their effectiveness for project cost control in construction. Int. J. Proj. Manage. **21**, 145–154 (2003)

Anbari, F.: Earned value project management method and extensions. Proj. Manage. J. **34**(4), 12–23 (2003)

Brucker P., Drexl, A., Mohring, R., Neumann, K., Pesch E.: Resource-constrained project scheduling: notation, classification, models, and methods. Eur. J. Oper. Res. **112**, 3–41 (1999)

Cheng, M.Y., et al.: Conceptual cost estimates using evolutionary fuzzy hybrid neural network for projects in construction industry. Expert Syst. Appl. **37**, 4222–4231 (2010)

Christensen, D.S.: The estimate at completion problem: a review of three studies. Proj. Manage. J. **24**, 37–42 (1993)

Cioffi, D.: Designing project management: a scientific notation and an improved formalism for earned value calculations. Int. J. Proj. Manage. **24**(2), 136–144 (2006)

Demeulemeester, E., Vanhoucke, M., Herroelen, W.: RanGen: a random network generator for activity on the node networks. J. Sched. **6**, 17–38 (2002)

Drexl, A., et al.: ProGen/px ± An instance generator for resource-constrained project scheduling problems with partially renewable resources and further extensions. Eur. J. Oper. Res. **125,** 59–72 (2000)

Ebrahimpour, V., et al.: An emotional learning-based fuzzy inference system for improvement of system reliability evaluation in redundancy allocation problem. Int. J. Adv. Manuf. Technol. **66**, 1657–1672 (2013)

Elmaghraby, S.E.: Activity nets: a guided tour through some recent developments. Eur. J. Oper. Res. **82**, 383–408 (1995)

Elshaer, R.: Impact of sensitivity information on the prediction of project's duration using earned schedule method. Int. J. Proj. Manage. **31**, 579–588 (2013)

Feleming, Q.W., Koppleman, J.M.: Earned value project management. Project Management Institute, Newtown square, PA (1996)

Hanna, M., Ruwanpura, J.Y.: Simulation tool for manpower forecast loading and resource leveling. In: the 2007 Winter Simulation Conference

Herroelen, W., et al.: Resource-constrained project scheduling: a survey of recent developments. Comput. Ops. Res. **25**(4) 279–302 (1998)

Huang, E., Chen, S.-J.: Estimation of project completion time and factors analysis for concurrent engineering project management: a simulation approach. Concurr. Eng. **14**, 329 (2006)

Hunt, B.: Parametric project monitoring and control: performance-based progress assessment and prediction. IEEEAC paper #1516, version 2, Accessed 8 Jan 2007

Iranmanesh, H., Davoodpour, F., Geranmayeh, P.: Using adaptive network inference systems (ANFIS) to estimate the completion time of projects. In: International Conference on Project Management (ICoPM 2008), pp. 128–133. Malaysia, Kuala Lumpur (2008)

Iranmanesh, H., Hojjati Tavassoli, Z.: Designing a progress simulator for estimation of project completion cost and time. In: International Conference on Project Management (ICoPM 2008), pp. 120–127. Malaysia, Kuala Lumpur (2008)

Iranmanesh, H., Madadi, M.: An Intelligent System Framework for Generating Activity List of a Project Using WBS Mind map and Semantic Network, vol. 2. Word Academy of Science, Engineering and Technology, Morgantown (2008)

Iranmanesh H., Sikandari M.R., Allahverdiloo M.: Finding pareto optimal front for multimode time, cost quality tradeoff in project scheduling. World Acad. Sci. Eng. Technol. **40** 346–350 (2008)

Iranmanesh, S.H., Kimiagari, S., Mojir, N.: A new formula to estimate at completion of a project's time to improve earned value management system. In: The IEEE International Conference on Industrial Engineering and Engineering Management (IEEM2007), pp. 1014–1020. Singapore (2007)

Jacob, D.S., Kane, M.: Forecasting schedule completion using earned value metrics. Revisited. The Measurable News (Summer), vol. 1, pp. 11–17 (2004)

Jang, R., Sun, C., Mizutani, E.: Neuro-Fuzzy and Soft Computation. Prentice Hall, New Jersey (1997)

Kamburowski J., et al.: Minimizing the complexity of an activity network. Networks **36**(1), 47–52 2000

Kolisch, R., Sprecher, A.: PSPLIB-A project scheduling problem library. Eur. J. Oper. Res. **96**, 205–216 (1996)

Kolisch, R., Sprecher, A., Drexl, A.: Characterization and generation of a general class of resource —constrained project scheduling problems. Manage. Sci. **41**, 1693–1703 (1995)

Lipke, W.: Schedule is different. The Measurable News (Summer), pp. 31–34 (2003)

Lipke, W., Zwikael, O., Henderson, K., Anbari, F.: Prediction of project outcome: the application of statistical methods to earned value management and earned schedule performance indexes. Int. J. Proj. Manage. **27**, 400–407 (2009)

Lucas, C., Abbaspour, A., Gholipour, A., Araabi, B.N., Fatourechi, M.: Enhancing the performance of neurofuzzy predictors by emotional learning algorithm. Informatica **27**, 137–145 (2003)

Madadi, M., Iranmanesh, H.: A management oriented approach to reduce a project duration and its risk (variability). Eur. J. Oper. Res. **219**(3), 751–761 (2012)

Morrison, D.C.: Deep-sixing the A-12. Government executive, pp. 30–35 (1991)

Project Management Institute.: Practice Standard for Earned Value Management. PMI Standard Committee, USA (2005)

Patterson.: A comparison of exact approaches for solving the multiple constrained resource, project scheduling problem. Manage. Sci. **30**(7), 854–867

Tavares, L.V.: Advanced Models in Project Management. Kluwer, Massachussetts (1999)

Tavares, L.V.: A review of the contribution of operational research to project management. Int. J. Oper. Res. **136**, 1–18 (2002)

Valadares Tavares, L., Antunes Ferreira, J., Silva Coelho, J.: The risk of delay of a project in terms of the morphology of its network. Eur. J. Oper. Res. **119**, 510–537 (1999)

Valadares Tavares, L., et al.: A comparative morphologic analysis of benchmark sets of project networks. Int. J. Proj. Manage. **20**, 475–485 (2002)

Vandevoorde, S., Vanhoucke, M.: A comparison of different project duration forecasting methods using earned value metrics. Int. J. Proj. Manage. **24**, 289–302 (2006)

Vanhoucke, M.: Measuring the efficiency of project control using fictitious and empirical project data. Int. J. Proj. Manage. **30**, 252–263 (2012)

Vanhoucke, M., Vandevoorde, S.: A simulation and evaluation of earned value metrics to forecast the project duration. J. Oper. Res. Soc. **58**, 1361–1374 (2007)

Vanhoucke, M., Coelho, J., Debels, D., Maenhout, B., Tavares, L.V.: An evaluation of the adequacy of project network generators with systematically sampled networks. Eur. J. Oper. Res. **187**, 511–524 (2008)

Werbos, P.I.: Beyond regression: new tools for prediction and analysis in the behavior sciences. Ph.D. Thesis, Harvard University, Cambridge (1974)

Part X
Supply Chain Management

Chapter 24
Multiple Experts Knowledge in Fuzzy Optimization of Logistic Networks

Juan Carlos Figueroa-García, Dusko Kalenatic and Cesar Amilcar López-Bello

Abstract Uncertainty in logistic networks is commonly handled by probabilistic tools, but sometimes the required statistical information is not available, so the experts of the network take an important role in decision making without statistical information. Some soft computing techniques such as fuzzy sets are useful to represent the knowledge of the experts because they can be combined with optimization models to find a set of possible choices to be taken in different scenarios. In this chapter, we present an application of fuzzy optimization models and methods to a logistic network design problem using linguistic information coming from multiple experts.

24.1 Introduction

Optimization over uncertain environments is a challenge for many decision makers who need solving different problems. Some of those problems require the use of computational intelligence techniques, so it is an interesting field to be covered. This way, we need to keep in mind that uncertainty affects their decisions and the way to solve the problem, and also requires specialized methods and models.

One of the most popular problems in logistic management is the design of the logistic network, where one of its variations includes multiple transportation means and the use of different transhipment facilities. In cases where the demands and

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supplies of the network are defined by multiple experts (using their own criterion), there is a need for finding a way to handle this kind of information, since there is no agreement about the most adequate opinion and/or perception.

Different approaches for designing logistic networks using fuzzy approaches have been proposed by Mirakhorli (2010, 2014), Vahdani et al. (2013), Qin and Ji (2010), Danzhu and Maoxiang (2013), and Roghanian and Kamandanipour (2013), who are mainly focused in including classical fuzzy sets into the analysis. Fuzzy transportation problems have been treated by Tada (1996), Basirzadeh (2011), Gani and Razak (2004), Pandian and Natarajan (2010), Chanas and Kuchta (1996), Chanas et al. (1984), Buckley and Jowers (1992), Gani et al. (2011), and Liu and Kao (2006), who proposed fuzzy models for transportation problems using fuzzy sets, and mostly based on using a single membership function per set. Figueroa-García and Hernández (2012) have proposed a model for transportation problems using Type-2 fuzzy sets.

Other soft computing techniques (genetic algorithms, agent based modeling, etc.) for solving logistic problems have been proposed by Chou and Yu (2013), Smirnov et al. (2004), Han and Damrongwongsiri (2005), Xie and Dong (2002), Fischer and Gehring (2005), Ko et al. (2006), Altiparmak et al. (2006). A comprehensive and extensive review of soft computing techniques applied to logistic networks design and management is provided by Ko et al. (2010).

This chapter is intended to present a model for a transhipment problem with multiple transportation means and fuzzy uncertainty in their supplies and demands using Interval Type-2 fuzzy sets and mathematical programming methods, such as the Zimmermann's method and convex optimization algorithms.

We also focus on modeling the problem using information coming from multiple experts represented by Interval Type-2 fuzzy sets in order to include all their opinions and perceptions. Some basics on Type-2 fuzzy sets, a model, and a method for finding an optimal solution are applied.

A pharmaceutical logistic network design problem including multiple-experts opinions is solved. We present an explanation of the procedure used, and some of their advantages are shown. Some technical details and a method for using linguistic information coming from multiple experts are discussed, giving more robustness to the optimization method.

24.2 Crisp Multiple Means Transhipment Model

A common logistic network problem involves transportation of products from suppliers to customers using different means e.g. trucks, train, trailers, airplane, etc., through transfer points (a.k.a. transhipment points). This is a combinatorial problem where decision making focuses on where to locate transfer points, how to satisfy the demands of the customers, and what transportation means should be used, at an optimal cost.

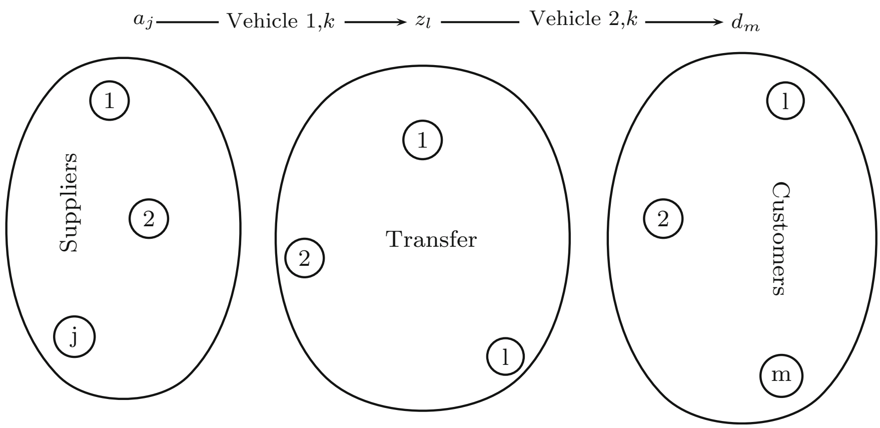


Fig. 24.1 Transhipment network

Figure 24.1 shows a network representation of the problem, where the main problem regards to the quantities x of products to be sent from the ith supplier to the jth customer using an amount v of the kth vehicle, through the lth transfer point. Here, products and vehicles are integer variables, and the decision of locating a transfer point is binary, so the whole problem becomes a combinatorial decision.

In addition, we have to separate transportation tasks into two legs: a first leg from suppliers to transfer points, and a second leg from transfer points to customers. Every leg has its own fleet $q_{1,k}, q_{2,k}$, so a decision about routes and quantities has to be made alongside with the decision of using a transfer point z_l. This decision making problem has three main goals:

- Obtain the best quantities per product to be sent from suppliers to customers through different transfer points
- Select transportation means per leg (suppliers → transfer → customers)
- Select transfer points to be installed

At a first glance we have three separated goals, but they are intimately related one another, so any strategy used to solve the problem should include all goals at the same time. One of the most used approaches to model this problem is minimizing global costs that includes transportation costs, vehicle setup costs, and costs of installing transfer points, put into a single objective goal where their constraints include decisions about vehicles, supplies, demands, and transfer facilities.

This kind of decisions require special models and methods, and they usually take high computational efforts for finding a solution due to its combinatorial nature. The mathematical programming model of the problem is:

$$\underset{(i,j,k,l,m)}{\text{Min}}\ z = \sum_{i,j,k,l,m} c_{ijkl}x_{ijkl} + c_{ilkm}y_{ilkm} + s_k(v_{jkl} + v_{lkm}) + c_l z_l \tag{24.1}$$

$$s.t.$$

$$\sum_k \sum_l x_{ijkl} \leq a_{ij} \ \ \forall\, i \in \mathbb{N}_I, j \in \mathbb{N}_J \tag{24.2}$$

$$\sum_k \sum_l y_{ilkm} \geq d_{im} \ \ \forall\, i \in \mathbb{N}_I, m \in \mathbb{N}_M \tag{24.3}$$

$$\sum_i a_i x_{ijkl} \leq p_k v_{jkl} \ \ \forall\, j \in \mathbb{N}_J, k \in \mathbb{N}_K, l \in \mathbb{N}_L \tag{24.4}$$

$$\sum_i a_i y_{ilkm} \leq p_k v_{lkm} \ \ \forall\, l \in \mathbb{N}_L, k \in \mathbb{N}_K, m \in \mathbb{N}_M \tag{24.5}$$

$$\sum_j \sum_k x_{ijkl} = \sum_k \sum_m y_{ilkm} \ \ \forall\, i \in \mathbb{N}_I, l \in \mathbb{N}_L \tag{24.6}$$

$$\sum_j \sum_l v_{jkl} \leq q_{1,k} \ \ \forall\, k \in \mathbb{N}_K \tag{24.7}$$

$$\sum_l \sum_m v_{lkm} \leq q_{2,k} \ \ \forall\, k \in \mathbb{N}_K \tag{24.8}$$

$$\sum_i \sum_j \sum_k a_i x_{ijkl} \leq cd_l z_l \ \ \forall\, l \in \mathbb{N}_L \tag{24.9}$$

$$x_{ijkl}, y_{ilkm}, c_{ijkl}, c_{ilkm}, s_k, c_l, a_{ij}, d_{im}, p_k, cd_l \in \mathbb{R}$$

$$v_{ijk}, q_{1,k}, q_{2,k} \in \mathbb{Z}, z_l \in \{0, 1\}$$

Decision Variables:

x_{ijkl} Quantity of the *i*th product to be sent from the *j*th supplier to the *l*th transfer point using the vehicle type *k*.

y_{ilkm} Quantity of the *i*th product to be sent from the *l*th transfer point to the *m*th customer using the vehicle type *k*.

v_{jkl} Amount of vehicles type *k* to be sent from the *j*th supplier to the *l*th transfer point.

v_{lkm} Amount of vehicles type *k* to be sent from the *l*th transfer point to the *m*th customer.

z_l Binary decision of activate the *l*th transfer point.

Parameters:

c_{ijkl} Unitary cost of carrying a unit of the *i*th product from the *j*th supplier to the *l*th transfer point using the *k*th vehicle.

c_{ilkm} Unitary cost of carrying a unit of the *i*th product from the *l*th transfer point to the *m*th customer point using the *k*th vehicle.

a_{ij} Availability of the *i*th product provided by the *j*th supplier.
d_{im} Demand of product of the *i*th product requested by the *m*th customer.
p_k Capacity (in volume units) of the *k*th vehicle.
cd_l Capacity (in volume units) of the *l*th transfer point.
$q_{1,k}$ Availability (in units) of the *k*th vehicle for the leg from suppliers to transfer points.
$q_{2,k}$ Availability (in units) of the *k*th vehicle for the leg from transfer points to customers.
s_k Unitary cost of operating the *k*th vehicle.
c_l Unitary cost of installing the *l*th transfer point.

In this model, $\leq$ and $\geq$ are partial orders, and all its parameters are defined as constants. In other words, we refer this model as the *Crisp transhipment model*.

The first two constraints are the classical equilibrium constraints of the transportation model, the third and fourth constraints refer to the availability of the vehicles that will be used to carry out products in different routes, the fifth constraint establishes an equilibrium between in-out products per transfer point, the sixth and seventh constraints define the maximum availability of vehicles per leg, and finally the eighth constraint is a binary decision of installing a transfer point among some available choices.

24.3 Multiple Experts and Information

Some decision making problems either have no historical data or information, so the knowledge of the experts is an alternative for solving the problem. LP models are popular in logistic planning, so its use in cases where only information coming from experts is available becomes an interesting field to be covered.

A common issue presented in logistic planning is related to the perception of different experts about the supplies and demands of the customers. This leads to misspecifications that increase uncertainty, so it should be considered in the solution of the problem.

Hence, we have to use the information provided by the experts, which usually is described using sentences such as *"I think that the availability of the product i given by supplier j should be between a and b"*, or "*think that the most possible value of the parameter* (i,j) *should be c"*. This way, we propose to enquire the availability of products from suppliers and the demands of the customers using simple questions such as:

What is the pessimistic and optimistic availability of the product "i" provided by the supplier "j"?

What is the pessimistic and optimistic demand of the product "i" required by the customer "m"?

It is possible to include this information using fuzzy sets to handle linguistic information. In the case of having multiple experts, Type-2 fuzzy sets are appropriate tools to handle this kind of uncertainty. Now we provide some concepts about Type-2 fuzzy sets before defining a strategy to handle information coming from multiple experts.

24.4 Basics on Fuzzy Sets

Firstly, we establish some basic notations of fuzzy sets to differentiate its meaning. A classical fuzzy set, namely Type-1 Fuzzy Set (T1FS), is denoted by capital letters e.g. A and its membership function is defined as $\mu_A(x)$ over $x \in X$, while an Interval Type-2 Fuzzy Set (IT2FS) is denoted by an emphasized capital letter $\tilde{A}$ and its membership function is denoted by $\mu_{\tilde{A}}(x)$ over $x \in X$. A fuzzy set is a generalization of a *Crisp* or Boolean set (see Klir and Folger 1992, Klir 1995). It is defined on an universe of discourse X and is characterized by a *Membership Function* namely $\mu_A(x)$ that takes values in the interval [0, 1]. A fuzzy set A may be represented as a set of ordered pairs of a generic element x and its grade of membership function, $\mu_A(x)$, i.e.,

$$A = \{(x, \mu_A(x)) \,|\, x \in X\} \tag{24.10}$$

Here, A is a *Linguistic Label* which defines the sense of the fuzzy set through the word A. This word defines how an expert perceives the variable X and the shape of each set. The membership function $\mu_A(x)$ of the set A is a function which provides a measure of degree of affinity of any $x \in X$ to the set A. It takes values in the interval [0, 1], that is:

$$\mu_A(x) : X \to [0, 1] \tag{24.11}$$

Henceforth we do not make any distinction between a membership function $(x, \mu_A(x))$ and its degree of membership $\mu_A(x)$ when refer to a membership function, and we will refer to a T1FS as $\mu_A(x)$.

24.4.1 Single and Multiple Experts

Type-1 fuzzy sets refer to the perception of a single expert due to its shape is a single function which represents its knowledge. When multiple experts provide their own perception about the same variable, then it increases its complexity. To do so, we propose the use of Type-2 fuzzy sets to involve the opinion of multiple experts.

This way, Interval Type-2 Fuzzy Sets (IT2FS) are useful measures to represent the knowledge of multiple experts (or alternatively, ambiguity about the definition of a fuzzy set). This kind of fuzzy sets involve an infinite amount of Type-1 fuzzy sets into a single set, which is a representation of linguistic uncertainty itself.

Linguistic uncertainty appears when different fuzzy sets are defined to represent the same concept (linguistic label). In a practical scheme it appears when different people define different fuzzy sets regarding the same linguistic label. This is an uncertainty source itself which can be modeled using IT2FS.

IT2FS allows to model linguistic uncertainty, Mendel (2001, 1999, 2000, 2001, 2002, 2006) and Melgarejo (2007a, b) provided formal definitions of IT2FS, and Figueroa-García (2008, 2009, 2011, 2012) proposed an extension of the FLP to include constraints with linguistic uncertainty represented by IT2FS called Interval Type-2 Fuzzy Linear Programming (IT2FLP) which are shown next.

24.4.2 Basic Definitions of IT2FNs

According to Mendel (2001, 1999, 2000, 2001, 2003a, b, 2002, 2006, 2007), and Melgarejo (2006, 2007a, b), a Type-2 Fuzzy Set (T2FS) $\tilde{A}$ represents uncertainty about A which comes from different sources: a possible source is that $\tilde{A}$ contains the perception of *multiple* experts about A, and another source is that $\tilde{A}$ contains *ambiguity* of an expert about his/her perception about A. This way, a Type-2 fuzzy set provides a mathematical framework to represent concepts, words and perceptions involving uncertainty which comes from natural language.

A Type-2 fuzzy set is a collection of infinite T1FSs into a single set. It is defined by two membership functions: the first one defines the degree of membership of the universe of discourse X, and the second one f_x weights each one of the first T1FSs regarding x. This way, a T2FS is an ordered pair $\{((x,u),\mu_{\tilde{A}}(x,u)) : x \in X, u \in J_x \subseteq [0,1]\}$, where A is its linguistic label, $\tilde{A}$ represents uncertainty around the word A, J_x is the *primary membership* of x, u is its *domain of uncertainty*, and $\mathcal{F}_2(\mathbb{X})$ is the class of all Type-2 fuzzy sets. Their mathematical definitions are:

$$\tilde{A} : X \rightarrow \mathrm{F}([0,1])$$

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \mid x \in X\}$$

$$\tilde{A} = \int_{x \in X} \int_{u \in J_x} f_x(u)/(x,u), \; J_x \subseteq [0,1]$$

where $\mu_{\tilde{A}}(x)$ is composed by an infinite amount of embedded Type-1 fuzzy sets namely A_e. Every element x has associated a set of primary memberships J_x

weighted by a *Secondary* fuzzy set $f_x(u)$ where u is the domain of uncertainty of x, $u \in J_x \subseteq [0,1]$. An alternative definition of $\tilde{A}$ is

$$\tilde{A} = \{((x,u), J_x, f_x(u)) \,|\, x \in X; u \in J_x \subseteq [0,1]\} \tag{24.12}$$

Therefore, $\tilde{A}$ evolves J_x weighted by the secondary membership function $f_x(u)/(x,u)$. These Type-2 fuzzy sets are known as *Generalized* Type-2 fuzzy sets, *(T2FS)*, since $f_x(u)/u$ is a Type-1 membership function. Now, an *Interval Type-2* fuzzy set, *(IT2FS)*, is a simplification of a T2FS in the sense that the secondary membership function is assumed to be 1 e.g. $(f_x(u)/u = 1)$, as follows

Definition 4.1 (Interval Type-2 fuzzy set) *An Interval Type-2 fuzzy set, $\tilde{A}$, is described as:*

$$\tilde{A} = \int_{x\in X}\int_{u\in J_x} 1/(x,u) = \int_{x\in X}\left[\int_{u\in J_x} 1/u\right]\Big/ x, \tag{24.13}$$

where x is the primary variable, J_x is the primary membership function associated to x; u is the secondary variable and $\int_{u\in J_x} 1/u$ is the secondary membership function.

Uncertainty about the linguistic label A is conveyed by the union of all J_x into the *Footprint Of Uncertainty* of $\tilde{A}$, namely $\mathrm{FOU}(\tilde{A})$, defined as follows:

$$\mathrm{FOU}(\tilde{A}) = \bigcup_{x\in X} J_x \tag{24.14}$$

The $\mathrm{FOU}(\tilde{A})$ is bounded by two functions: An *Upper* membership function $\mathrm{UMF}(\tilde{A}) = \bar{\mu}_{\tilde{A}}(x) \equiv \bar{A}$ and a *Lower* membership function $\mathrm{LMF}(\tilde{A}) = \underline{\mu}_{\tilde{A}}(x) \equiv \underline{A}$. Its graphical representation is shown in the Fig. 24.2.

In Fig. 24.2, $\tilde{A}$ is an IT2FS, the universe of discourse for the primary variable x is the set $x \in X$, the *support* of $\tilde{A}$, *supp* $(\tilde{A})$ is the interval $x \in [\bar{\bar{x}}, \bar{\hat{x}}]$ and $\mu_{\tilde{A}}$ is a triangular membership function with parameters $\bar{\bar{x}}, \bar{\hat{x}}, \underline{\check{x}}, \underline{\hat{x}}$ and $\bar{x}$. ${}^{\alpha}\bar{\mu}_{\tilde{A}}(x)$ is the degree of membership that a specific value x has regarding its UMF, $\bar{A}$; ${}^{\alpha}\underline{\mu}_{\tilde{A}}(x)$ is the degree of membership that a specific value x has regarding its LMF, $\underline{A}$. Note that a specific value x has an interval of membership degrees $u \in [{}^{\alpha}\underline{\mu}_{\tilde{A}}(x), {}^{\alpha}\bar{\mu}_{\tilde{A}}(x)]$ (Fig. 24.2).

24.4.3 Obtaining IT2FSs from Multiple Experts

Now, when n different experts namely $E_1, \ldots, E_k, \ldots, E_n$ are asked for their opinion about the supplies and/or demands of the network a_{ij}, d_{im} using the sentences shown

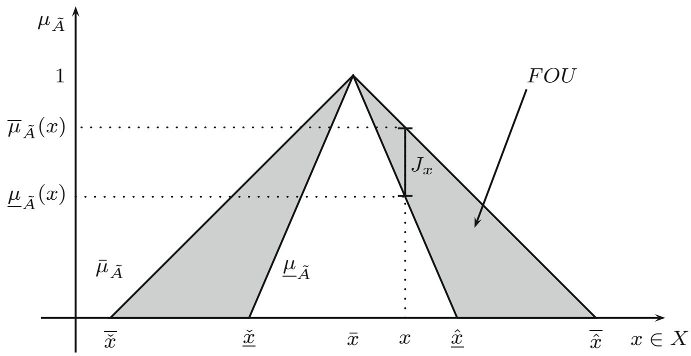


Fig. 24.2 Interval Type-2 fuzzy set $\tilde{A}$

in Sect. 24.5.1, they are not agree about their perceptions. To deal with this information and use it into the design of a logistic network, we propose to define the supplies and demands of the network as Type-2 fuzzy constraints.

This leads us to define constraints (24.2) and (24.3) as Interval Type-2 Fuzzy Constraints (IT2FC), using the following definition based on the results of Figueroa-García (2009, 2011, 2012, 2014, 2012):

Definition 4.2 (IT2FC) *Let $\tilde{b}$ an IT2FS, then the binary relation $\succsim$ is said to be an IT2FC if it has the form:*

$$f(x) \succsim \tilde{b} \tag{24.15}$$

where $f(x)$ is a crisp function, and $\tilde{b}$ is characterized by two membership functions $\underline{\mu}_{\tilde{b}}(x)$ (LMF) with parameters $\underline{\check{b}}$ and $\underline{\hat{b}}$ and $\bar{\mu}_{\tilde{b}}(x)$ (UMF) with parameters $\bar{\check{b}}$ and $\bar{\hat{b}}$ (see Fig. 24.3).

Now, the FOU of $\tilde{b}$ can be composed by two distances called Δ and ∇, defined as follows:

$$\nabla = \bar{\check{b}} - \underline{\check{b}} \tag{24.16}$$

$$\Delta = \bar{\hat{b}} - \underline{\hat{b}} \tag{24.17}$$

A graphical representation of $\succsim$, the distances Δ, ∇, and the FOU of $\tilde{b}$ are shown in Fig. 24.3.

In Fig. 24.3, $\tilde{b}$ is an IT2FS with linear membership functions $\underline{\mu}_{\tilde{b}}$ and $\bar{\mu}_{\tilde{b}}$. A particular value b has an interval of membership degrees $u \in J_b$, where $J_b \in \left[{}^{\alpha}\overline{b}, {}^{\alpha}\underline{b}\right] \; \forall \, b \in \mathbb{R}$ is the set of all possible membership degrees associated to $b \in \mathbb{R}$.

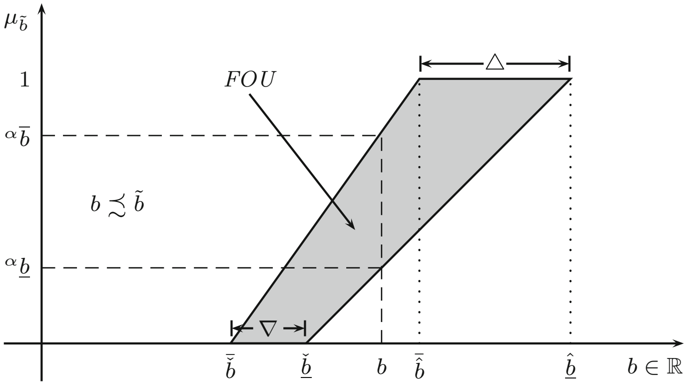


Fig. 24.3 IT2FS constraint with joint uncertain Δ and ∇

Going back to the idea of having n different experts $E_1,\ldots,E_n$ who are asked about its optimistic and pessimistic perceptions about the supplies and demands of the network, we have to compose all constraints using the information given by the experts. Every expert is asked about its pessimistic $\check{b}$ and optimistic $\hat{b}$ perception about b, so we obtain an IT2FS from k experts using next equations:

$$\overline{\check{b}} = \min_k(\check{b}_k) \tag{24.18}$$

$$\overline{\hat{b}} = \min_k(\hat{b}_k) \tag{24.19}$$

$$\underline{\check{b}} = \max_k(\check{b}_k) \tag{24.20}$$

$$\underline{\hat{b}} = \max_k(\hat{b}_k) \tag{24.21}$$

To simplify the analysis, we assume that both the UMF and LMF of every $\tilde{b}$ have linear membership functions whose parameters are computed as follows:

$$\text{UMF}(\tilde{b}) \rightarrow \bar{\mu}_{\tilde{b}} = \begin{cases} \frac{x-\overline{\check{b}}}{\overline{\hat{b}}-\overline{\check{b}}}, & \text{if} \quad \overline{\check{b}} \leq x \leq \overline{\hat{b}} \\ 1, & \text{if} \quad x \geq \overline{\hat{b}} \end{cases}$$

$$\text{LMF}(\tilde{b}) \rightarrow \underline{\mu}_{\tilde{b}} = \begin{cases} \frac{x-\underline{\check{b}}}{\underline{\hat{b}}-\underline{\check{b}}}, & \text{if} \quad \underline{\check{b}} \leq x \leq \underline{\hat{b}} \\ 1, & \text{if} \quad x \geq \underline{\hat{b}} \end{cases}$$

Now, we can solve an uncertain transhipment problem using multiple experts opinions using both the model and method proposed in next sections.

24.5 The IT2FLP Model

Given the concept of an uncertain constraint and the crisp transhipment model, its fuzzified version is:

$$\underset{(i,j,k,l,m)}{\text{Min}} \quad z = f(\cdot) \tag{24.22}$$

$$s.t.$$

$$-\sum_k \sum_l x_{ijkl} \gtrsim -\tilde{a}_{ij} \quad \forall\, i \in \mathbb{N}_I, j \in \mathbb{N}_J \tag{24.23}$$

$$\sum_k \sum_l y_{ilkm} \gtrsim \tilde{d}_{im} \quad \forall\, i \in \mathbb{N}_I, m \in \mathbb{N}_M \tag{24.24}$$

$$g(\cdot) \leq, = b \tag{24.25}$$

where (24.25) is the set (24.4)–(24.9) of crisp constraints, and $f(\cdot)$ is equal to Eq. (24.22):

$$f(\cdot) = \sum_{i,j,k,l,m} c_{ijkl}x_{ijk} + c_{ilkm}y_{ilkm} + s_k(v_{jkl} + v_{lkm}) + c_l z_l$$

$\gtrsim$ is a binary relation (see Figueroa-García et al. 2015). Note that Eq. (24.23) is defined as negative to change its direction to $\gtrsim$. Then, the lower-upper membership functions of $\tilde{a}_{ij}$ are:

$$\underline{\mu}_{\tilde{a}_{ij}}(x; \check{\underline{a}}_{ij}, \hat{\underline{a}}_{ij}) = \begin{cases} 0, & x \leq \check{\underline{a}}_{ij} \\ \frac{x - \check{\underline{a}}_{ij}}{\hat{\underline{a}}_{ij} - \check{\underline{a}}_{ij}}, & \check{\underline{a}}_{ij} \leq x \leq \hat{\underline{a}}_{ij} \\ 1, & x \geq \hat{\underline{a}}_{ij} \end{cases} \tag{24.26}$$

$$\bar{\mu}_{\tilde{a}_{ij}}(x; \check{\bar{a}}_{ij}, \hat{\bar{a}}_{ij}) = \begin{cases} 0, & x \leq \check{\bar{a}}_{ij} \\ \frac{x - \check{\bar{a}}_{ij}}{\hat{\bar{a}}_{ij} - \check{\bar{a}}_{ij}}, & \check{\bar{a}}_{ij} \leq x \leq \hat{\bar{a}}_{ij} \\ 1, & x \geq \hat{\bar{a}}_{ij} \end{cases} \tag{24.27}$$

and the lower-upper membership functions of $\tilde{d}_{im}$ are:

$$\underline{\mu}_{\tilde{d}_{im}}(x; \check{\underline{d}}_{im}, \hat{\underline{d}}_{im}) = \begin{cases} 0, & x \leq \check{\underline{d}}_{im} \\ \frac{x - \check{\underline{d}}_{im}}{\hat{\underline{d}}_{im} - \check{\underline{d}}_{im}}, & \check{\underline{d}}_{im} \leq x \leq \hat{\underline{d}}_{im} \\ 1, & x \geq \hat{\underline{d}}_{im} \end{cases} \tag{24.28}$$

$$\bar{\mu}_{\tilde{d}_{im}}(x;\bar{\check{d}}_{im},\bar{\hat{d}}_{im}) = \begin{cases} 0, & x \leq \bar{\check{d}}_{im} \\ \frac{x-\bar{\check{d}}_{im}}{\bar{\hat{d}}_{im}-\bar{\check{d}}_{im}}, & \bar{\check{d}}_{im} \leq x \leq \bar{\hat{d}}_{im} \\ 1, & x \geq \bar{\hat{d}}_{im} \end{cases} \tag{24.29}$$

Remark 5.1 We have selected linear membership functions for $\tilde{a}_{ij}$ and $\tilde{d}_{im}$ in order to simplify the optimization process since linear membership functions are easier to obtain by using simple questions to experts. Nonlinear membership functions are computationally harder to compute and more difficult to ask to experts, which is an important issue to be solved in practical applications.

24.6 Optimization Strategy

Figueroa-García (2014a, b, 2012) proposed a method that uses Δ, ∇ as auxiliary variables with weights c^{Δ} and c^{∇} respectively, in order to find an optimal fuzzy set embedded into the FOU of the problem and then solve it using the Zimmermann's method. Its fuzzified version is presented next.

1. Compute an optimal upper boundary called Z *minimum* $(\hat{z})$ using $\bar{\hat{a}}_{ij} + \Delta_{ij}$ and $\bar{\hat{d}}_{im} + \Delta_{im}$, where Δ_{ij}, Δ_{im} are auxiliary variables weighted by c^{Δ} which represents the lower uncertainty interval subject to:

$$\Delta_{ij} \leq \bar{\hat{a}}_{ij} - \underline{\hat{a}}_{ij} \tag{24.30}$$

$$\Delta_{im} \leq \bar{\hat{d}}_{im} - \underline{\hat{d}}_{im} \tag{24.31}$$

To do so, $\Delta^*_{ij}, \Delta^*_{im}$ are obtained solving the following LP problem

$$\underset{(i,j,k,l,m)}{\text{Min}} \quad z = f(\cdot) + c^{\Delta}_{ij}\Delta_{ij} + c^{\Delta}_{im}\Delta_{im}$$

$$s.t.$$

$$-\sum_i \sum_k x_{ijk} + \Delta_{ij} \geq -\underline{\hat{a}}_{ij} \quad \forall\, i \in \mathbb{N}_I, j \in \mathbb{N}_J \tag{24.32}$$

$$\sum_j \sum_k x_{ijk} + \Delta_{im} \geq \underline{\hat{d}}_{im} \quad \forall\, i \in \mathbb{N}_I, m \in \mathbb{N}_M \tag{24.33}$$

$$\Delta_{ij} \leq \bar{\hat{a}}_{ij} - \underline{\hat{a}}_{ij} \quad \forall\, i \in \mathbb{N}_I, j \in \mathbb{N}_J$$

$$\Delta_{im} \leq \bar{\hat{d}}_{im} - \underline{\hat{d}}_{im} \quad \forall\, i \in \mathbb{N}_I, m \in \mathbb{N}_M$$

$$g(\cdot) \leq, = b$$

2. Compute an optimal lower boundary called *Z maximum* ($\check{z}$) using $\bar{\check{d}}_{ij} + \nabla_{ij}$ and $\bar{\check{d}}_{im} + \nabla_{im}$, where ∇_{ij}, ∇_{im} are auxiliary variables weighted by c^{∇} which represents the lower uncertainty interval subject to:

$$\nabla_{ij} \leq \bar{\check{d}}_{ij} - \underline{\check{a}}_{ij} \tag{24.34}$$

$$\nabla_{im} \leq \bar{\check{d}}_{im} - \underline{\check{d}}_{im} \tag{24.35}$$

To do so, $\Delta^*_{ij}, \Delta^*_{im}$ are obtained solving the following LP problem

$$\underset{(i,j,k,l,m)}{\text{Min}} \quad z = f(\cdot) + c^{\nabla}_{ij}\nabla_{ij} + c^{\nabla}_{im}\nabla_{im}$$

$$s.t.$$

$$-\sum_i \sum_k x_{ijk} + \nabla_{ij} \geq -\underline{\check{a}}_{ij} \quad \forall\, i \in \mathbb{N}_I, j \in \mathbb{N}_J \tag{24.36}$$

$$\sum_j \sum_k x_{ijk} + \nabla_{im} \geq \underline{\check{d}}_{im} \quad \forall\, i \in \mathbb{N}_I, m \in \mathbb{N}_M \tag{24.37}$$

$$\nabla_{ij} \leq \bar{\check{a}}_{ij} - \underline{\check{a}}_{ij} \quad \forall\, i \in \mathbb{N}_I, j \in \mathbb{N}_J$$

$$\nabla_{im} \leq \bar{\check{d}}_{im} - \underline{\check{d}}_{im} \quad \forall\, i \in \mathbb{N}_I, m \in \mathbb{N}_M$$

$$g(\cdot) \leq, = b$$

3. Compute following values of $\check{b}$ and $\hat{b}$

$$\hat{a}_{ij} = \underline{\hat{a}}_{ij} - \Delta^*_{ij} \quad \forall\, i \in \mathbb{N}_I, j \in \mathbb{N}_J \tag{24.38}$$

$$\hat{d}_{im} = \underline{\hat{d}}_{im} - \Delta^*_{im} \quad \forall\, i \in \mathbb{N}_I, m \in \mathbb{N}_M \tag{24.39}$$

$$\check{a}_{ij} = \underline{\check{a}}_{ij} - \nabla^*_{ij} \quad \forall\, i \in \mathbb{N}_I, j \in \mathbb{N}_J \tag{24.40}$$

$$\check{d}_{im} = \underline{\check{d}}_{im} - \nabla^*_{im} \quad \forall\, i \in \mathbb{N}_I, m \in \mathbb{N}_M \tag{24.41}$$

4. Zimmermann (1978, 1993) proposed a method for solving this fuzzy constrained problems, described as follows:

(a) Compute the inferior boundary of optimal solutions $\min\{z^*\} = \check{z}$ using $(\check{a}_{ij}, \check{d}_{im})$ as a right hand side of the model.

(b) Compute the superior boundary of optimal solutions $\max\{z^*\} = \hat{z}$ using $(\hat{a}_{ij}, \hat{d}_{im})$ as a right hand side of the model.

(c) Define an L-R fuzzy set $Z(x^*)$ with parameters $\check{z}$ and $\hat{z}$. This set represents the set of all feasible solutions regarding the objective. In other words, a thick solution of the fuzzy problem (See Moore et al. 2009 and Mora 2001). Given a maximization objective, then its membership function is:

$$\mu_Z(x; \check{z}, \hat{z}) = \left(\begin{array}{cc} 0, & c'x \leq \check{z} \\ \frac{c'x - \hat{z}}{\hat{z} - \check{z}}, & \check{z} \leq c'x \leq \hat{z} \\ 0, & c'x \geq \hat{z} \end{array} \right. \tag{24.42}$$

Its graphical representation is shown in Fig. 24.4.

(d) Create an auxiliary variable α and solve the following model:

$$Max \ \{\alpha\}$$

$$s.t.$$

$$f(\cdot) + \alpha(\hat{z} - \check{z}) = \hat{z}$$

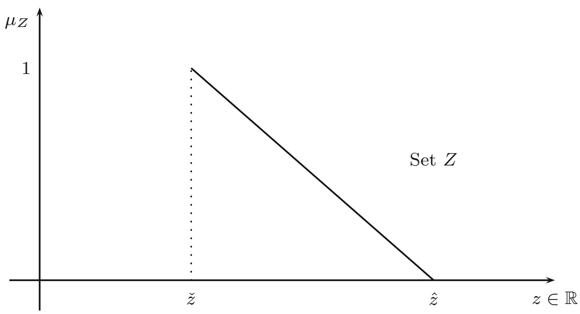
$$-\sum_i \sum_k x_{ijk} + \alpha(\hat{a}_{ij} - \check{a}_{ij}) \geq -\check{a}_{ij} \quad \forall \ i \in \mathbb{N}_I, j \in \mathbb{N}_J \tag{24.43}$$

$$\sum_j \sum_k x_{ijk} - \alpha(\hat{d}_{im} - \check{d}_{im}) \geq \check{d}_{im} \quad \forall \ i \in \mathbb{N}_I, m \in \mathbb{N}_M \tag{24.44}$$

$$g(\cdot) \leq, = b$$

The Zimmermann method uses α as a *global* satisfaction degree of all constraints regarding the fuzzy set of optimal solutions Z. We can see α as an equilibrium point between the use of the resources (supplies and demands) and the optimal cost z^*. Then, the goal of the method is to find an overall satisfaction degree of both goals

Fig. 24.4 Fuzzy set Z



(costs and supplies-demands usage) which maximizes the satisfaction degree while minimizing global uncertainty.

The costs c^{Δ} and c^{∇} (see Algorithm 4) are weights for Δ and ∇. In our model, $c_{ij}^{\Delta}, c_{ij}^{\nabla}, c_{im}^{\Delta}, c_{im}^{\nabla}$ are the unitary cost associated to decrease the availability of each resource $\hat{\underline{a}}_{ij}, \check{\underline{a}}_{ij}, \hat{\underline{d}}_{im}$ and $\check{\underline{d}}_{im}$ respectively. The main goal of this transhipment model is to obtain minimum costs, not just send more products that increase costs.

24.7 Application Example

We have applied our algorithm to a pharmaceutical logistic network with the following characteristics:

- 19 products
- 12 suppliers in different cities
- 147 customers in different cities
- Two fleets (one per leg) with 5 types of vehicle
- 11 available transfer points

This problem involves 12.540 decision variables regarding quantities x_{ijkl}, and 660 variables regarding fleet v_{jkl} in the first leg; the second leg involves 153.615 decision variables regarding quantities y_{ilkm}, and 8085 variables regarding fleet v_{lkm} in the second leg, plus 11 binary decisions z_l regarding transfer points.

In principle, we do not have a complete set of statistical information of the availability of each product provided by every supplier, and the demand of every product required by every customer, so we have to ask different experts from different disciplines about those parameters.

To simplify the task, we have asked every supplier and customer for a simple question:

Supplier: *What is the pessimistic and optimistic availability of the product "i" provided by your company?*

Customer: *What is the pessimistic and optimistic demand of the product "i" required by your company?*

Every supplier and customer were also asked for information provided by at least three experts; while some of them just found the three required experts, some of them sent information of 6 experts or more, which added reliability to the study; 73 experts coming from suppliers and 622 experts coming from customers were asked for information about their availabilities/requirements. The values of the pessimistic and optimistic supplies and demands were used to obtain $\check{\bar{a}}_{ij}, \hat{\bar{a}}_{ij}, \check{\underline{a}}_{ij}, \hat{\underline{a}}_{ij}$, and $\check{\bar{d}}_{im}, \hat{\bar{d}}_{im}, \check{\underline{d}}_{im}, \hat{\underline{d}}_{im}$ using Eqs. (24.18), (24.19), (24.20) and (24.21).

After computing the boundaries of the IT2FCs, we have applied the Algorithm 4 to find a solution of the problem. The costs $c_{ij}^{\Delta}, c_{ij}^{\nabla}, c_{im}^{\Delta}, c_{im}^{\nabla}$ were obtained as the the

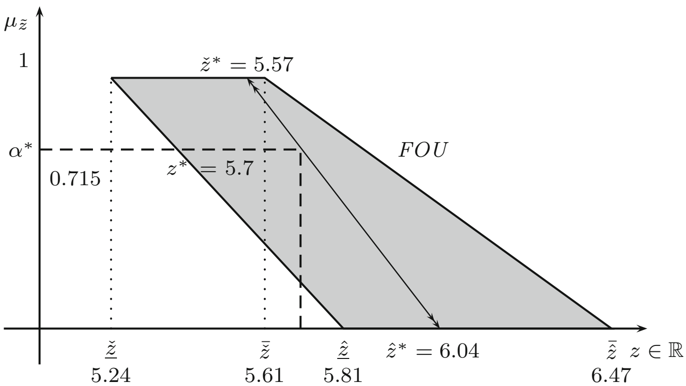


Fig. 24.5 Interval Type-2 fuzzy set $\tilde{z}$ of optimal costs (in million USD)

cost of increasing a unit of supply, or increasing a unit of demand to be satisfied, and they were provided by every supplier and customer (accounting information).

Although we cannot provide all obtained results, we provide the values of the optimistic and pessimistic optimal solutions given the perceptions of the experts. In Appendix, we show the solution of the problem for $\bar{\bar{z}}, \bar{\hat{z}}, \underline{\check{z}}, \underline{\hat{z}}$ in terms of v_{jkl}, v_{lkm} and z_l.

Figure 24.5 shows the Type-reduced fuzzy set of optimal solutions $\tilde{z}$ which is embedded into the FOU of $\tilde{z}$, where the global satisfaction degree $\alpha^* = 0.715$ allows us to find an optimal solution of the problem.

Figure 24.5 shows the set of all possible costs, given the perceptions of all experts. The set defined by $\hat{z}^* = 6.04$ and $\check{x}^* = 5.57$ comes from solving (24.43) (Zimmermann's method) which obtains a global satisfaction degree of $\alpha^* = 0.715$ which in turn obtains an optimal cost of $z^* = 5.7$ million USD. The problem has been solved using CPLEX for GAMS© over a multi-processor server.

It is important to note that every solution embedded into $\tilde{z}$ has a set of decision variables, so there is an infinite amount of possible choices. This is the major advantage of using our proposal: we do not evaluate all possible solutions, just a one that provides a global satisfaction degree between uncertain constraints and the desired goal.

24.8 Discussion of the Results

The set of optimal solutions goes from 5.24 to 6.47 million USD, so we can see that the most pessimistic scenario costs 6.47 million USD which implies to cover the maximum demands of all customers while requiring maximum supplies, more vehicles and more transfer points; on the other hand, the most optimistic scenario costs 5.24 million USD which implies a minimum covering of the demands using less supplies, less vehicles and less transfer points.

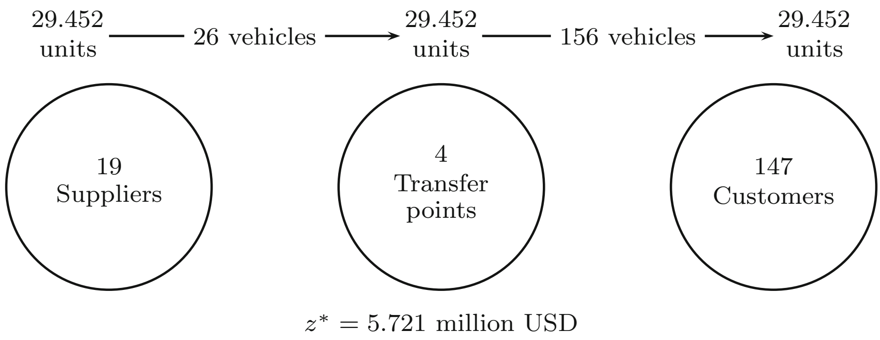


Fig. 24.6 Optimal transhipment network

The Appendix shows the behavior of the problem given the demands and supplies provided by the experts. Note that as more demand is satisfied, more transfer points and vehicles are required, which is a natural consequence of increasing the use of available resources. Also note that the proposed solution ($z^* = 5.7$ million USD) represents an optimal balance between resources usage and minimization of transfer facilities, vehicle assignment, and transportation costs.

For the sake of understanding, the method obtains a fuzzy set embedded into the FOU of $\tilde{b}$ and $\tilde{z}$; this set is used to find an optimal solution using the Zimmermann's method which finally returns the values of x^*, v^*, z_l^* and α^*. Figure 24.6 presents a brief description of the defuzzified solution.

The selection of c^{Δ} and c^{∇} is a key aspect of the method, since it should increase the delivering costs, but this does not happen as seen before. Now, the method selects some auxiliary variables which (at a first glance) increase delivering costs of the demand from the suppliers to the customers.

This happens for some reasons: the method selects the constraints that decreases the global costs, using Δ and ∇ to weight its importance; it also prefers to reduce global costs even by increasing satisfied demands and/or decreasing available supplies, since the idea of the transhipment model is to keep an equilibrium between demands and supplies.

24.9 Concluding Remarks

We have found a solution of a transhipment problem that includes Type-2 fuzzy constraints using known fuzzy optimization techniques. Through information of multiple experts coming from every supplier and customer, we have composed demands and supplies and then solved the problem as a fuzzy optimization problem.

The methodology used in this chapter (see Sect. 24.5) has achieved a global solution of the transhipment problem through establishing a balance between supplies, demands, and costs via a satisfaction degree α, which in turn provides information that complements decision making.

In practice, the obtained solution is a reference point for implementation since it provides a minimum cost of the logistic network with maximum satisfaction of demands and supplies. In other words, the method achieves a maximum fulfillment of the goal with minimum uncertainty.

24.10 Future work

The use of other soft computing techniques (genetic algorithms, meta-heuristics, etc.) alongside IT2FSs could solve more complex logistic problems, inducing researchers to new directions when managing logistic networks that involve different uncertainties.

Appendix

In this appendix, we present the solution for every boundary of the set $\tilde{z}$, and the global solution as well (Tables 24.1 and 24.2).

Table 24.1 Binary decision z_l of installing a transhipment (transfer) point

Transfer point	1	2	3	4	5	6	7	8	9	10	11
$\underline{\check{z}}$					1	1		1		1	
$\underline{\hat{z}}$					1	1		1			1
$\overline{\check{z}}$		1	1	1	1		1	1			
$\overline{\hat{z}}$		1					1		1	1	
$\check{z}^*$					1		1	1	1		
$\hat{z}^*$		1				1				1	1
z^*		1				1		1		1	
Capacity[a]	1.2	1.9	0.8	0.57	1.3	2.1	3.2	3	3.7	3.8	4.7

[a]Capacity in hundred cubic meters

Table 24.2 Amount of vehicles used per leg

Leg	Vehicles used in leg 1					Vehicles used in leg 2				
Vehicle k	1	2	3	4	5	1	2	3	4	5
$\underline{\check{z}}$	10	6	4	4	3	64	24	35	25	5
$\underline{\hat{z}}$	10	6		5	4	64	24	37	27	5
$\overline{\check{z}}$	10	6	3	4	4	64	24	39	25	6
$\overline{\hat{z}}$	10	6	3	4	5	64	24	45	27	8
$\check{z}^*$	8	5	3	4	4	64	24	45	24	5
$\hat{z}^*$	10	6	2	4	5	64	24	45	25	7
z^*	10	6	3	3	4	64	24	39	25	4
Capacity[a]	8	11	33	65	115	3	4	8	11	33

[a]Capacity in cubic meters

References

Altiparmak, F., Gen, M., Lin, L., Paksoy, T.: A genetic algorithm approach for multiobjective optimization of supply chain networks. Comput. Ind. Eng. **51**(1), 196–215 (2006)

Basirzadeh, H.: An approach for solving fuzzy transportation problem. Appl. Math. Sci. **5**(32), 1549–1566 (2011)

Buckley, J.J., Jowers, L.J.: Fuzzy transportation problem. In: J. Kacprzyk, M. Fedrizzi (eds.) Monte Carlo Methods in Fuzzy Optimization. Springer, New York (1992)

Chanas, S., Kolodziejczyk, W., Machaj, A.: A fuzzy approach to the transportation problem. Fuzzy Sets Syst. **13**, 211–221 (1984)

Chanas, S., Kuchta, D.: A concept of the optimal solution of the transportation problem with fuzzy cost coefficients. Fuzzy Sets Syst. **82**, 299–305 (1996)

Chou, C.C., Yu, K.W.: Application of a new hybrid fuzzy AHP model to the location choice. Math. Probl. Eng. **2013**(Article ID 592138), 12 (2013)

Danzhu, W., Maoxiang, L.: Research on fuzzy demand-oriented logistics network optimization method for railway freight enterprises. Adv. Inf. Sci. Serv. Sci. **5**(3), 182–191 (2013)

Escobar, H.M.M.: Optimización No Lineal y Dinámica. Universidad Nacional de Colombia (2001)

Figueroa, J.C.: Linear programming with interval type-2 fuzzy right hand side parameters. In: 2008 Annual Meeting of the IEEE North American Fuzzy Information Processing Society (NAFIPS) (2008)

Figueroa-García, J.C.: Solving fuzzy linear programming problems with interval type-2 RHS. In: Conference on Systems, Man and Cybernetics, pp. 1–6. IEEE (2009)

Figueroa-García, J.C.: Interval type-2 fuzzy linear programming: uncertain constraints. In: IEEE Symposium Series on Computational Intelligence, pp. 1–6. IEEE (2011)

Figueroa-García, J.C., Chalco-Cano, Y., Román-Flores, H.: Distance measures for interval type-2 fuzzy numbers. Discrete Appl. Math. (To appear) (1) (2015)

Figueroa-García, J.C., Hernández, G.: Computing optimal solutions of a linear programming problem with interval type-2 fuzzy constraints. Lect. Notes Comput. Sci. **7208**, 567–576 (2012a)

Figueroa-García, J.C., Hernández, G.: A transportation model with interval type-2 fuzzy demands and supplies. Lect. Notes Comput. Sci. **7389**(1), 610–617 (2012b)

Figueroa-García, J.C., Hernández, G.: Linear programming with interval type-2 fuzzy constraints. In: Ceberio, M., Kreinovich, V. (eds.) Constraint Programming and Decision Making, vol. 539, pp. 19–34. Springer, New York (2014a)

Figueroa-García, J.C., Hernández, G.: A method for solving linear programming models with interval type-2 fuzzy constraints. Pesquisa Operacional **34**(1), 73–89 (2014b)

Figueroa-García, J.C., Kalenatic, D., Lopez-Bello, C.A.: Multi-period mixed production planning with uncertain demands: fuzzy and interval fuzzy sets approach. Fuzzy Sets Syst. **206**, 21–38 (2012)

Fischer, T., Gehring, H.: Planning vehicle transhipment in a seaport automobile terminal using a multi-agent system. Eur. J. Oper. Res. **166**(3), 726–740 (2005)

Gani, A.N., Razak, K.A.: Two stage fuzzy transportation problem. Eur. J. Oper. Res. **153**, 661–674 (2004)

Gani, A.N., Samuel, A.E., Anuradha, D.: Simplex type algorithm for solving fuzzy transportation problem. Tamsui Oxford J. Inf. Math. Sci. **27**(1), 89–98 (2011)

Han, C., Damrongwongsiri, M.: Stochastic modeling of a two-echelon multiple sourcing supply chain system with genetic algorithm. J. Manuf. Technol. Manage. **16**(1), 87–108 (2005)

Karnik, N.N., Mendel, J.M.: Operations on type-2 fuzzy sets. Fuzzy Sets Syst. **122**, 327–348 (2001)

Karnik, N.N., Mendel, J.M., Liang, Q.: Type-2 fuzzy logic systems. Fuzzy Sets Syst. **17**(10), 643–658 (1999)

Klir, G.J., Folger, T.A.: Fuzzy Sets, Uncertainty and Information. Prentice Hall, Englewood Cliffs (1992)

Klir, G.J., Yuan, B.: Fuzzy Sets and Fuzzy Logic: Theory and Applications. Prentice Hall, Englewood Cliffs (1995)

Ko, H., Ko, C., Kim, T.: A hybrid optimization/simulation approach for a distribution network design of 3PLS. Comput. Ind. Eng. **50**(4), 440–449 (2006)

Ko, M., Tiwari, A., Mehnen, J.: A review of soft computing applications in supply chain management. Appl. Soft Comput. **10**(3), 661–674 (2010)

Liang, Q., Mendel, J.M.: Interval type-2 fuzzy logic systems: theory and design. IEEE Trans. Fuzzy Syst. **8**(5), 535–550 (2000)

Liu, S.T., Kao, C.: Solving fuzzy transportation problems based on extension principle. J. Phys. Sci. **10**, 63–69 (2006)

Melgarejo, M.A.: A fast recursive method to compute the generalized centroid of an interval type-2 fuzzy set. In: Annual Meeting of the North American Fuzzy Information Processing Society (NAFIPS), pp. 190–194. IEEE (2007a)

Melgarejo, M.A.: Implementing interval type-2 fuzzy processors. IEEE Comput. Intell. Mag. **2**(1), 63–71 (2007b)

Melgarejo, M.A., Peña, C.A., Sanchez, E.: A genetic-fuzzy system approach to control a model of the HIV infection dynamics. In: IEEE (ed.) 2006 International Conference on Fuzzy Systems, pp. 2323–2330. IEEE (2006)

Mendel, J.M.: Uncertain Rule-Based Fuzzy Logic Systems: Introduction and New Directions. Prentice Hall, Englewood Cliffs (2001)

Mendel, J.M.: Fuzzy sets for words: a new beginning. In: The IEEE International Conference on Fuzzy Systems, pp. 37–42 (2003a)

Mendel, J.M.: Type-2 fuzzy sets: some questions and answers. IEEE coNNectionS. A publication of the IEEE Neural Netw. Soc. **1**(8), 10–13 (2003b)

Mendel, J.M., John, R.I.: Type-2 fuzzy sets made simple. IEEE Trans. Fuzzy Syst. **10**(2), 117–127 (2002)

Mendel, J.M., John, R.I., Liu, F.: Interval type-2 fuzzy logic systems made simple. IEEE Trans. Fuzzy Syst. **14**(6), 808–821 (2006)

Mendel, J.M., Liu, F.: Super-exponential convergence of the Karnik-Mendel algorithms for computing the centroid of an interval type-2 fuzzy set. IEEE Trans. Fuzzy Syst. **15**(2), 309–320 (2007)

Mirakhorli, A.: Multi-objective optimization of reverse logistics network with fuzzy demand and return-product using an interactive fuzzy goal programming approach. In: 2010 40th International Conference on Computers and Industrial Engineering (CIE), pp. 1–6 (2010)

Mirakhorli, A.: Fuzzy multi-objective optimization for closed loop logistics network design in bread-producing industries. Int. J. Adv. Manuf. Technol. **70**(1), 349–362 (2014)

Moore, R.E., Kearfott, R.B., Cloud, M.J.: Introduction to Interval Analysis. SIAM, Philadelphia (2009)

Pandian, P., Natarajan, G.: A new algorithm for finding a fuzzy optimal solution for fuzzy transportation problems. Appl. Math. Sci. **4**, 79–90 (2010)

Qin, Z., Ji, X.: Logistics network design for product recovery in fuzzy environment. Eur. J. Oper. Res. **202**(2), 479–490 (2010)

Roghanian, E., Kamandanipour, K.: A fuzzy-random programming for integrated closed-loop logistics network design by using priority-based genetic algorithm. Int. J. Ind. Eng. Comput. **4** (1), 139–154 (2013)

Smirnov, A., Sheremetov, L., Chilov, N., Cortes, J.: Soft-computing technologies for configuration of cooperative supply chain. Appl. Soft Comput. **4**(1), 87–107 (2004)

Tada, M.: An integer fuzzy transportation problem. Comput. Math Appl. **31**(9), 71–87 (1996)

Vahdani, B., Tavakkoli-Moghaddam, R., Jolai, F.: Reliable design of a logistics network under uncertainty: a fuzzy possibilistic-queuing model. Appl. Math. Model. **37**(5), 3254–3268 (2013)

Xie, J., Dong, J.: Heuristic genetic algorithms for general capacitated lot-sizing problems. Comput. Math Appl. **44**(1), 263–276 (2002)

Zimmermann, H.J.: Fuzzy programming and linear programming with several objective functions. Fuzzy Sets Syst. **1**(1), 45–55 (1978)

Zimmermann, H.J., Fullér, R.: Fuzzy reasoning for solving fuzzy mathematical programming problems. Fuzzy Sets Syst. **60**(1), 121–133 (1993)

Chapter 25
Intelligent Algorithms for Warehouse Management

Eleonora Bottani, Roberto Montanari, Marta Rinaldi and Giuseppe Vignali

Abstract Warehouses are important links in the supply chain; here, products are temporarily stored and retrieved subsequently from storage locations to fulfill customer' orders. The order picking activity is one of the most time-consuming processes of a warehouse and is estimated to contribute for more than 55 % of the total cost of warehouse operations. Accordingly, scientists, as well as logistics managers, consider order picking as one of the most promising area for productivity improvements. This chapter is intended to provide the reader with an overview of different intelligent tools applicable to the issue of picking optimization. Specifically, by this chapter, we show how different types of intelligent algorithms can be used to optimize order picking operations in a warehouse, by decreasing the travel distance (and thus time) of pickers. The set of intelligent algorithms analyzed include: genetic algorithms, artificial neural networks, simulated annealing, ant colony optimization and particles swarm optimization models. For each intelligent algorithm, we start with a brief theoretical overview. Then, based on the available literature, we show how the algorithm can be implemented for the optimization of order picking operations. The expected pros and cons of each algorithm are also discussed.

Keywords Order picking · Warehouse optimization · Items allocation · Intelligent algorithms

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25.1 Introduction

The efficiency and effectiveness of logistics activities and of distribution networks in particular is largely determined by the operation of the nodes of the network, i.e. the warehouses. Warehouses are important links in the supply chain; here, products are temporarily stored and retrieved subsequently from storage locations to fulfil customer' orders. The logistic costs related to the warehouse activities, including receiving, storage, order picking and shipping, are large (Rouwenhorst et al. 2000). Order picking, in particular, consumes a large part of the total labor activities in the warehouse. Order picking consists in the process of selecting a set of items, retrieving them from their storage locations and, in the case, transporting them to a sorting/consolidation process, for order fulfillment and shipment in response to a customer's request (Rouwenhorst et al. 2000). Typically, orders from customers consist of different order lines, each line representing a unique product, or a stock keeping unit (SKU), which is requested in a defined quantity. The picking process can be either performed manually or (partly) automated. In the case of a manual process, it is estimated that picking operations contribute for more than 55 % of the total cost of warehouse operations (Coyle et al. 1996; Tompkins et al. 1996). In turn, such high cost is mainly due to the fact that approx. 50 % of the total order picking time is spent by pickers on unproductive traveling. This contribution to the order picking time is commonly known as the "travel time" of pickers and affects the total order picking time to the largest extent (Tompkins et al. 1996). Obviously, the travel time is an increasing function of the travel distance and thus minimizing the travel distance is the main leverage for optimizing the total picking time of warehouses (Jarvis and McDowell 1991; Hall 1993; Petersen 1999; Roodbergen and De Koster 2001; Petersen and Aase 2004).

Reducing the travel distance of pickers has a direct impact on the warehouse performance, in terms of cost and delivery time, thus also affecting the whole supply chain's performance. Indeed, the faster items are picked from the warehouse, the shorter the time spent for order fulfilment; hence, the lead time required for delivering the product to the final customer decreases correspondingly (de Koster et al. 2007). This is why researchers, as well as logistics managers, consider order picking as one of the most promising area for productivity improvements (de Koster et al. 2007).

Several factors impact the performance of an order picking system, including, among others (Parikh and Meller 2009; de Koster et al. 2007; Roodbergen and De Koster 2001; Yu 2005):

- the proper design of the warehouse layout (in terms of number of blocks, number of aisles in a pick zone, length and width of aisles in a block, and position of the depot);
- the storage assignment policy for items, i.e. the set of rules used to assign products to storage locations (random, class-based, volume based, family-based, COI-based…);
- the picking policy (e.g., discrete picking, batching or zoning);

- the routing strategy, i.e. the set of rules to identify a visit sequence for order pickers who should pick multiple products on the pick list (e.g., S-shaped, largest gap, aisle-by-aisle, mid-point, return, or traversal);
- the number and type of handling equipment be used in the warehouse and the opportunity of adopting automated systems.

All the factors listed above contribute to the minimization of the travel distance, both per se and due to interdependencies between them (de Koster et al. 2007). In this chapter, we examine the use of different intelligent algorithms to optimize the picking process, by acting on the different factors that affect the picking time. The set of intelligent algorithms analysed include: genetic algorithms, neural networks, simulated annealing, ant colony optimization and particles swarm optimization models. For each algorithm, we start with a brief theoretical overview. Then, based on the available literature, we show how the algorithm can be implemented for the optimization of order picking operations. The next sections of the chapter deal with the different intelligent algorithms (Sects. 25.2–25.6). Section 25.7 summarises the main contributions of the chapter and highlight future research steps.

25.2 Genetic Algorithms

25.2.1 Background

Genetic algorithms (GAs) are stochastic search techniques aimed at reproducing the mechanism of natural selection and natural genetics (Holland 1975). A GA works to optimize (i.e., maximize or minimize) an objective function, moving from a current collection of entities, called "chromosomes", to a new one. The new set of entities is identified by means of natural operations, called selection, crossover, mutation and inversion. According to the GA terminology (Beasley et al. 1993; Goldberg 1989), a chromosome is a string of genes, representing a particular solution to the problem under investigation. The term allele describes a specified set of alternatives for each gene. The set of alternatives for genes is problem-specific, although the original GAs code such alternatives using binary representation (i.e., 0 versus 1). The position of a gene in the chromosome is known as locus. The set of chromosomes used to solve a problem (reflecting the set of solutions found) is called population. The typical operations performed when running a GA include: (1) chromosome selection according to the fitness function; (2) crossover operations to reproduce the new generation of chromosomes; (3) inversion; (4) random mutation of chromosomes. The starting population of the GA is an initial set of random solutions for the problem under investigation. The chromosomes of the population evolve through successive iterations, called generations, by means of an initial evaluation and different subsequent operations. As a first step, the chromosomes are selected to identify those which will be allowed to reproduce; the choice is made on the basis of a measure of their fit to a defined objective function, and in particular the chromosomes with the best fit to the function are selected for reproduction. The crossover is an operation between two chromosomes, and consists in exchanging some parts of them, following the natural procedure of recombination between two single-chromosome. The mutation is a random operation, which arbitrarily changes the allele value of some locations in the chromosomes. Finally, by inversion we mean an operation which reverses the order of a contiguous section of the chromosome. By evolving through different generations through the operations mentioned above, the algorithm converges to the best solution for the problem examined.

25.2.2 Genetic Algorithm for Order Picking Optimization

In the context of picking GA-based optimization models have been proposed by Zhang and Lai (2006), Hsu et al. (2005), Yao and Chu (2008), Silva et al. (2008) and Bottani et al. (2012).

Silva et al. (2008) examined the problem of optimizing the logistics processes of a warehouse, and, in particular, the order fulfilment activity. They simulated a simplified scenario, taken from a real case study company, and propose the combined application of GA and ant colony optimization to improve the order fulfilment process. Hsu et al. (2005) exploited GA to define a procedure for automatically grouping customer orders into batches; the approach can be easily adapted to different kinds of batch structure and of warehouse layout. The authors conclude that GAs provide interesting results to the order batching problems, for which an exact solution is extremely difficult to obtain, due to its dependence on the configuration of formed batches and the layout of warehouse.

Bottani et al. (2012) applied GAs to the problem of optimizing the picking process. The purpose of the GA developed by the authors is to optimize the allocation of items in a warehouse so as to reduce the travel distance covered by pickers. The GA model is developed and implemented in Microsoft Excel™, exploiting several macros programmed under Visual Basic for Applications (VBA); then, the model is tested on a numerical case study, reproducing a fast moving consumer goods (FMCG) warehouse, whose characteristics and processes were deduced from previous studies in the field of FMCG (i.e., Bottani and Rizzi 2008; Bottani et al. 2010; Oke and Long 2007; Pourakbar et al. 2009; Dallari et al. 2009). A low-level, picker-to-part system with an order picking strategy is hypothesised, which represents the very large majority of picking systems in manual FMCG warehouses (Dallari et al. 2009). At the beginning of the analysis, products are assumed to be allocated in the warehouse according to a class-based storage policy, i.e. three classes characterised by different probability of being requested in a customer's order and including a different percentage of items. The GA is exploited to optimize the allocation of items. Therefore, in the model proposed by the authors, each chromosome is a viable solution of the problem under investigation, and thus it reflects a possible allocation of items in the warehouse locations. Each gene of the chromosome indicates the location of a particular item, while the allele indicates the item stored in the location. The initial population of chromosomes is a group of possible solutions to the problem of items allocation for the warehouse investigated. The fitness function measures the distance covered by pickers to fulfil the overall amount of orders. By running the GA on the scenario considered, the authors found that the approach proposed is effective in identifying a new allocation of items in the warehouse, which decreases the travel distance of pickers up to 20 %.

25.3 Ant Colony Optimization

25.3.1 Background

Ant colony optimization (ACO) algorithms were originally introduced by Colorni et al. (1991) and Dorigo et al. (1996), as a new approach to distributed problem solving and optimization based on the result of low-level interactions among many cooperating simple agents (i.e., the ants) that are not aware of their cooperative behaviour. The authors were inspired by the study of real ant colonies. In those systems, each ant performs very simple actions and does not explicitly know what other ants are doing; nonetheless, the resulting behaviour of the colony is highly structured. More precisely, the ants have a simple medium used to communicate information regarding the paths they are following, i.e. the pheromone trails. When moving, ants lay some pheromone on the ground, thus marking the path. An isolated ant is expected to move essentially at random; conversely, an ant encountering a previously laid trail can detect it and decide with higher probability to follow it, thus reinforcing the trail with its own pheromone. The collective behaviour that emerges is that the more are the ants following a trail, the more that trail becomes attractive for being followed (Dorigo et al. 1996).

ACO is commonly adopted with the purpose of finding the shortest path; for instance, it has been applied, to this extent, to the traveller salesman problem. From the mathematical point of view, the application of the ACO requires a set of point (n, denoted with the subscript $j = 1,\ldots n$) to be visited. At time t, there are $b_i(t)$ ($i = 1, \ldots, n$) ants in each point, resulting in $m = \sum_{i=1}^{n} b_i(t)$ total ants in the system. The shortest path between points i and j is denoted as $path_{ij}$. The track left by an ant on each path is denoted as the intensity of trail (or pheromone); at time $t + 1$, the intensity accounts for $\tau_{ij}(t+1) = \rho * \tau_{ij}(t) + \Delta\tau_{ij}(t, t+1)$, where ρ ($0 < \rho < 1$) is the evaporation coefficient of the pheromone, $\Delta\tau_{ij}(t, t+1) = \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t, t+1)$ and $\Delta\tau_{ij}^{k}(t, t+1)$ is the quantity of pheromone per unit of length left by ant k on $path_{ij}$. At time $t = 0$, the intensity of trail can be set at an arbitrary value for each path. A further parameter of the model is the visibility $\eta_{ij} = \frac{1}{d_{ij}}$. On the basis of the parameters described above, the probability that, at time t, an ant moves from point i to point j accounts for $p_{ij}(t) = \frac{[\tau_{ij}(t)]^{\alpha}(\eta_{ij})^{\beta}}{\sum_{j=1}^{n}[\tau_{ij}(t)]^{\alpha}(\eta_{ij})^{\beta}}$, where α and β are two parameters that are defined by the user with the purpose of modifying the relative importance of η_{ij} and $\tau_{ij}(t)$. With respect to the definition of $\Delta\tau_{ij}^{k}(t, t+1)$, Colorni et al. (1991) propose different approaches, such as the ANT-density and ANT-quantity approaches. According to the first approach, the increase in the pheromone intensity on $path_{ij}$ when an ant moves from i to j is inversely proportional to d_{ij}, so that shorter paths are preferred. Conversely, in the ANT-quantity model the pheromone intensity is independent of d_{ij}.

25.3.2 ACO Applied to Order Picking Optimization

The application of ACO for the optimization of order picking is mainly carried out with the purpose of minimizing the travel distance of pickers, by identifying the optimal routing strategy. Chen et al. (2013) exploited an ACO algorithm exactly with this intention. The authors developed a routing algorithm based on ACO for two order pickers, with congestion considerations. The performance of the ACO-based algorithm is assessed and compared to that of the traditional S-shaped routing strategy, this latter reflecting the most frequently investigated heuristic in the order picking literature. The authors consider a warehouse with narrow pick aisle, where the pickers drive along the aisle to pick items. Each ant represents a picker, whose route is incrementally built by visiting the picking locations; the route ends when the picker has visited all the locations of its picking list. The performance of the ant is evaluated based on the total distance covered during picking activities. The authors carry out extensive simulation studies with different settings in terms of warehouse structure (e.g. number of pick aisles, length of pick aisles, number of cross aisles and number of picks) and demonstrate that their ACO-based algorithm performs better than the traditional S-shaped routing policy in most of the scenarios examined.

In a further publication, the same authors (Chen et al. in press) carried out a similar study by extending the previous work to the case of multiple order pickers. They found that their proposed algorithm is particularly effective when dealing with congestions in multiple-block picker-to-parts warehouses.

Xing et al. (2010a) exploited ACO in the context of automated storage and retrieval systems (AS/RS) warehouses. They aimed at optimizing the machine travel path for batch order picking. Compared to traditional (manual) picking systems, AS/RS warehouses can be characterised by a series of smaller pick requests; therefore, an order consolidation policy is frequently applied to rearrange the customer's requests into batches. On the basis of this consideration, the goal of Xing et al.'s study is to minimise the total travel distance of the S/R machine. The

ACO approach is used to solve this issue, i.e. to identify the shortest travel path to pick all the items in an order from their relative location in a picking cycle (considering the constraint of the S/R capacity). In their algorithm, therefore, each ant represents an S/R machine, moving from an item location to another. The same authors (Xing et al. 2010b) also applied a similar approach for the optimization of the travel distance of a bridge crane used for batch order picking systems.

25.4 Particle Swarm Optimization

25.4.1 Background

Particle Swarm Optimization (PSO) has been developed by Russel C. Eberhart and J. Kennedy (Eberhart and Kennedy 1995) and is based on the behavioural mechanisms of swarms of birds and schools of fishes. PSO shares many aspects with evolutionary computational techniques, such as, for example, GAs. Indeed, the system is initialized with a population of random solutions and the algorithm looks for the optimal solution by creating new generations of solutions. Unlike GAs, however, PSO does not exploit evolutionary operators (e.g., crossover or mutation); rather, the potential solutions, called *particles* "fly" through the problem space by following the path of the optimum particles. From the mathematical point of view, the problem could be expressed as the minimization of an objective function $f : \Theta \rightarrow \Re$, with $\Theta \subseteq \Re^n$. Solutions to this objective function belong to the set

$$\Theta^* = \arg\min_{\vec{\theta} \in \Theta} f\left(\vec{\theta}\right) = \left\{\vec{\theta}^* \in \Theta : f\left(\vec{\theta}^*\right) \leq f\left(\vec{\theta}\right), \forall \vec{\theta} \in \Theta\right\}, \tag{25.1}$$

where $\vec{\theta}$ is a n-dimensional vector that belongs to the set of Θ acceptable solutions, which describe the "research space".

The swarm consists of a set of particles, $P = \{p_1, p_2, \ldots, p_k\}$, whose position is considered as a potential solution of the optimisation problem defined by the objective function f. At each step t, two parameters (i.e., position $\vec{x}_i^t$ and velocity $\vec{v}_i^t$) are associated to the particle p_i. The best position reached by p_i at step t is recorded into the vector $\vec{b}_i^t$, which is also called the *personal best* of the i-th particle at step t. In addition, a particle receives information from its neighbourhood $N_i \subseteq P$. The proximity relationships between the particles are commonly shown by a graph $G = \{V, E\}$, where each vertex V is a particle of the swarm, while each arc of E describes the proximity relationship between a couple of particles. The resulting graph is commonly referred to as the *topology of the population of the swarm*.

Figure 25.1 shows an example of *fully connected* topology, for which $N_i = P$, $\forall p_i \in P$ (the connections of a node with itself are not shown for simplicity). Nonetheless, different typologies of graphs can also be used. Examples of different typologies are the *von Neumann* one, where each node has n connections, or the *ring* one, where every particle is connected with two neighbouring particles.

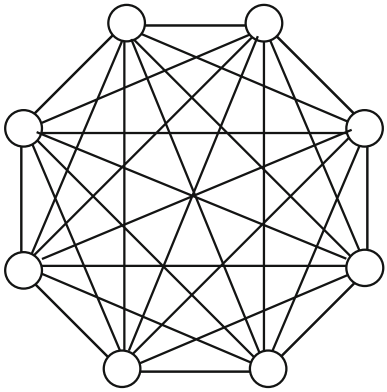

Fig. 25.1 Example of topology for a fully connected swarm population

PSO proceeds in the following way. When the algorithm is launched, the position of the particles is generated randomly, inside an initialization region $\Theta' \subseteq \Theta$. The particles' speed is usually initialized at a value inside Θ', but can also be initialized to zero or to a small random number, to avoid that the particles leave the search space during the first iteration. During the running of the algorithm, the particles' velocity and position are updated until a termination criterion of the algorithm is reached. The update rules are as follows:

$$\vec{v}_i^{t+1} = w\vec{v}_i^t + \varphi_1 \vec{U}_1^t \left(\vec{b}_i^t - \vec{x}_i^t\right) + \varphi_2 \vec{U}_2^t \left(\vec{l}_i^t - \vec{x}_i^t\right) \tag{25.2}$$

$$\vec{x}_i^{t+1} = \vec{x}_i^t + \vec{v}_i^{t+1} \tag{25.3}$$

where w reflects the *inertia weight*, φ_1 and φ_2 are *coefficients of acceleration*, and $\vec{U}_1^t$ and $\vec{U}_2^t$ are two diagonal $(n \times n)$ matrices where the values on the main diagonal are random numbers, uniformly distributed in the interval [0,1]. At each step t, these matrixes are regenerated. The vector $\vec{l}_i^t$, related to the best neighbour, corresponds to the best position found by a particle in the vicinity of the particles, namely:

$$f\left(\vec{l}_i^t\right) \le f\left(\vec{b}_j^t\right), \forall p_j \in N_i \tag{25.4}$$

By appropriately setting w, φ_1 and φ_2, diverging of particle velocity can be avoided.

25.4.2 PSO Applied to Order Picking Optimization

Öztürkoglu et al. (2014) developed a network-based warehouse model of individual pallet locations and their interactions with appropriate cross aisles in order to evaluate the expected travel distance of a given design. The model is constructive in that it uses PSO to determine the best angles of cross aisles and picking aisles for multiple, pre-determined pickup and deposit (P&D) points in a unit-load warehouse. The application of PSO model identified a two cross aisle solution in a warehouse, with two P&D points at the bottom, as the best solution, able to offer 9–12 % benefit over a traditional design. For two P&D points on adjacent sides, a new design offers 5–6 % benefit. These results suggest that alternative designs offer reduced expected travel distance, but at the expense of increased storage space. The opportunity for benefit also seems to decline as P&D points increase in number and dispersion.

Zhang et al. (2007) proposed an immune PSO model combined with an immune algorithm to solve the fixed shelf order-picking problem. The combinative algorithm is proved to be fast convergent and exact in simulation and can be used to find the optimized order-picking schedule. They applied three different algorithms to as many different scenarios. In one case there are ten waiting goods in AS/RS. The locations of ten cargos have been defined. There are 60 × 40 storage cells in the shelf. The sizes of every storage cell are all 100 × 100 cm. The distances between every position are given. Compared with the traditional PSO, immune PSO algorithm added immunity and enhanced global optimization ability, so the combinative algorithm is more accurate and reliable than the traditional one. With the increase in the number of storage cell, the number of order-picking project will be largely increased and the calculation will become very complicated, so manual calculation is extremely difficult and impracticable.

Xinmin et al. (2008) developed a model to solve the order picking scheduling problem of AS/RS. The authors start from the consideration that, because of the differences in the horizontal and vertical velocities, different directions of the stacker, although covering the same distance, may take different time. Sometimes, the order picking time on a long distance route can be shorter than that on a short distance. On the basis of these considerations, the authors develop a mathematical model for AS/RS order-picking optimization based on the "least time" rule. In the model, immune PSO is combined with a GA, which is run at the beginning of the implementation, to avoid that the solution identified by PSO is affected by the initial particle swarm. The approach aims at minimizing the total order picking time, based on the least time criterion (objective function). In the GA, each gene of a chromosome is a storage location to be visited; therefore, the chromosome represents the sequence of the locations. After running the GA, the solution generated is taken as an initial particle for the application of PSO. The authors apply this approach to an illustrative example of an AS/RS warehouse with 15 × 15 storage locations, with 10 products to be picked. They found that the solution obtained by means of the GA can be further improved (of approx. 15 %) applying immune PSO. Therefore, the combined implementation of the two algorithms is effective in improving the efficiency of the AS/RS. It is expected that the improvements gained could be even higher with the increase in the number of storage cells.

Wang et al. (2011) adopted an evolutionary algorithm inspired PSO (EA-PSO) model to optimize the storage location problem based on cost considerations (i.e., cost of order picking and storage space). An evolutional mechanism (EM) is introduced after each PSO particle's position change step, to overcome some of the limitations of PSO and EA. By applying the model to a case example, the authors concluded that PSO can effectively solve the class-based warehouse location problem and that EA-PSO algorithm has potential to improve PSO successfully for this kind of problem.

Onut et al. (2008) analysed the problem of designing a multiple-level warehouse considering the handling costs in three dimensions, i.e. length, width and height of the warehouse. The objective function of their model considers the average travel distances along the three dimensions and the material handling cost. The developed warehouse design model is applied to a distribution-type warehouse, which is considered on the construction phase, and the solution is obtained by using improved PSO algorithm. The warehouse is planned to serve for six product groups, i.e. personal cleaning products, house and kitchen cleaning products, food products, chemical raw materials, electronics, and ceramic objects of which include 10, 14, 6, 2, 11 and 7 item types, respectively. Items belonging to different product groups are stored for different periods on the shelves of the warehouse. As a result, the mathematical model is expected to derive the optimal number of storage spaces along a shelf and the optimum number of shelves of the warehouse. Because of the non-linearity of a warehouse design problem, the authors develop an ad hoc PSO algorithm able to the model and find near optimal results in a relatively short number of iterations.

25.5 Simulated Annealing

25.5.1 Background

The Simulated Annealing (SA) strategy was proposed by Kirkpatrick et al. (1983). The concept of annealing is derived from the science of metals, where it is used to describe the process of eliminating the networking defects from the crystals through a procedure of heating, followed by a slow cooling. In its original formulation, therefore, SA uses the thermodynamics analogy on controlling the evolution of a system by means of an external parameter, i.e. the temperature T. To see how the system changes, its energy E is monitored.

Any system configuration is characterised by an initial amount of energy $E_{initial}$. When the configuration is perturbed, the energy variation $\Delta E = E_{\text{final}} - E_{\text{initial}}$ will be computed. The new state of the system will be acceptable if $\Delta E \leq 0$. Conversely, when $\Delta E > 0$, the probability of the new state to be accepted $P(\Delta E)$ should be computed, according to the probability distribution of the Boltzmann equation:

$$P(\Delta E) = \exp\left(\frac{-\Delta E}{T}\right) \tag{25.5}$$

When a new state is accepted, it will become the starting point for the subsequent disturbance. Otherwise, if the new state is not accepted, the initial configuration is retained and will be used as the starting point of further disturbance.

The temperature T plays a crucial role in the process of accepting or rejecting a new configuration. At high temperatures, new configurations are generally accepted. Conversely, at low temperatures, all unfavourable situations are rejected, while only those with negative energy variation are accepted. In the case of a mono-objective optimization problem, the definition of energy can be easily assimilated to that of a scalar function like cost; it is, however, more difficult to define the energy of the system in the case of a of multi-objective optimisation problem.

The SA algorithm proceeds through the following steps:

- Step 1: at each iteration, the n initial points (or individuals) of the system are perturbed and generate n new points;
- Step 2: a rank r_i is assigned to each point of the population (whose size is now $2n$, considering both the initial and the newly generated individuals), on the basis of the number of the remaining $2n - 1$ points that dominate it. If $r_i = 0$ (no points dominate the i-th individual considered), it can be stated that the i-th individual belongs to the local Pareto frontier. Conversely, if $r_i = 2n - 1$ (all points dominate the i-th individual), the point is absolutely unfavourable;
- Step 3: the energy value E_i for the i-th individual is computed as:

$$E_i = \frac{r_i}{2n - 1} \tag{25.6}$$

  Equation 25.6 shows that E_i is simply a normalized version of r_i, whose values range in the interval [0,1];
- Step 4: the effect of the disturbance is evaluated, by averaging the difference in the energy value of an individual out of the different problem objectives. As mentioned, if $\Delta E \leq 0$ the new individual is accepted; otherwise, the probability of accepting it is computed according to Eq. 25.5, setting an appropriate value of T.

To clarify, let us suppose that a perturbation of the original points A, B, C and D has generated the new points $A', B', C'$and D$'$ depicted in Fig. 25.2.

This perturbation is favourable for points A and B and unfavourable for others, because:

$$\Delta E_A = (0 - 0)/7 = 0, \ \Delta E_B = (0 - 2)/7 = -2/7$$

$$\Delta E_C = (1 - 0)/7 = +1/7, \ \Delta E_D = (2 - 0)/7 = +2/7$$

During the algorithm run, the evolution of the temperature will be properly governed by a scheduler, so as to generate an initial situation with a high temperature ($T > 0$), followed by a "cold" stage with $T = 0$. During the "hot" stage,

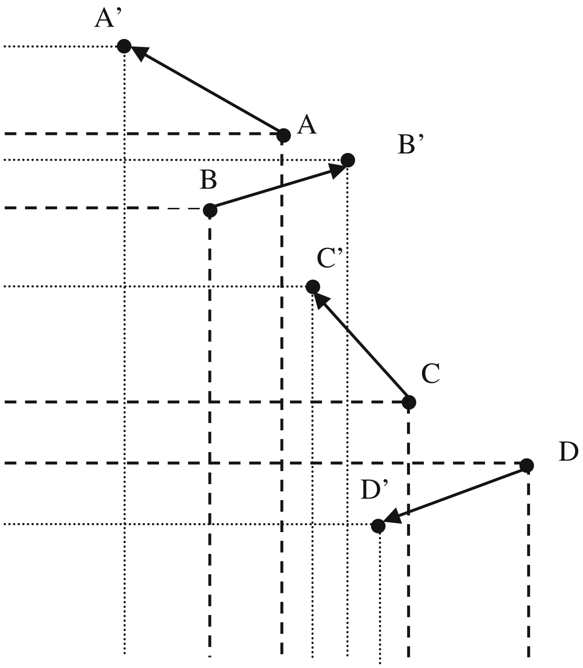

Fig. 25.2 Example of evolution of 4 points (*source* ESTECO, 2003)

the temperature decreases progressively from the initial value T_0 according to the following relation:

$$T = T_0 \left(1 - \frac{N}{N_{\text{hot}}}\right)^2 \tag{25.7}$$

where N describes the total number of iterations and N_{hot} the number of iterations spent in the hot phase. Equation 25.7 describes a gradual decrease of the temperature, which allows the "hot" and "cold" phases to be connected as shown in Fig. 25.3.

The "hot" and "cold" phases of the treatment are both necessary. Indeed, the "hot" phase allows exploring the research field, avoiding, therefore, to converge to local optima solutions. The subsequent "cold" phase allows the system to converge to a final solution. The "hot" stage has the disadvantage of reaching poor convergence, which is, however, counterbalanced by the robustness of the algorithm. Without that phase, in fact, the algorithm would converge very fast, but identifying only local optimum solutions.

With respect to the disturbance, the points are moved from their original position randomly. The new position of the individual is generated according to a uniform distribution of the possible directions. The length covered by the particle during the disturbance is randomly generated following a Gaussian distribution scaled through the parameter $l \in [0, 1]$, whose evolution is again properly governed by a scheduler.

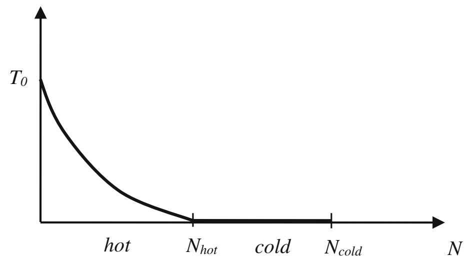

Fig. 25.3 Example of temperature decrease (*source* ESTECO, 2003)

This latter is similar to that governing the system temperature, with the only exception that is also includes an additive constant, called *minimum disturbance* $l_{\min}$, which describes the evolution of the system in the "cold" phase. The evolution of the l parameter is shown in Fig. 25.4.

25.5.2 SA Applied to Order Picking Optimization

Atmaca and Ozturk (2013) develop a mixed-integer model, which minimizes simultaneously storage allocation, storage retrieval (i.e. order picking) and storage keeping costs, for an AS/RS system. The model is solved through SA in the following way. The initial population is obtained by assigning the locations of items randomly in the warehouse. For each iteration, the SA identifies a neighbour solution (i.e., a new location of items for the AS/RS warehouse), which is retained if it generates a lower value of the objective function. The model is runned in 6 unit periods for 72 storage locations and for 103 materials; the optimal solution is gained after 2466 iterations. Overall, the SA approach was found to be effective in finding an optimal solution for the problem examined.

Boysen and Stephan (2013) treated the deterministic product location problem (PLP), where products SKUs are assigned to storage locations and the sequences of locations visited by a picker when retrieving the SKUs according to an "out and

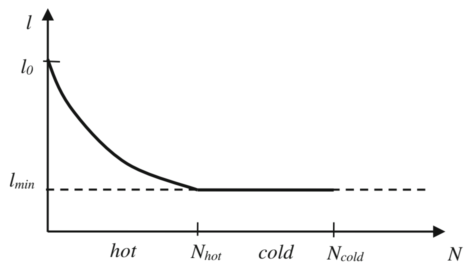

Fig. 25.4 Example of the evolution of the perturbation length

back" policy are determined. The PLP problem aims at minimizing the total order picking distance. A SA heuristic is exploited by the authors to assess the performance of a decomposition approach of the PLP for belt picking. The case studied concerns a belt picking environment with multiple aisles, where the layout consists of a central conveyor passing multiple aisles (each having two parallel storage racks on both sides serviced by a separate logistics worker) and leading to a sorting and packing depot. As per the previous study, the solution vector of the SA procedure describes the assignment of SKUs to the different warehouse locations.

Ho and Chien (2006) analysed a real problem observed in a distribution centre in Taiwan, i.e. finding the best zone-visitation sequence a picker can follow. In this distribution centre, human pickers perform order-picking operations; the picking area has been divided into different zones. Each zone has a beginning point and an end point, as well as two storage racks (one on each side); each storage rack has many storage locations. Two zone-visitation sequencing strategies (called "fixed zone-visitation sequencing" strategy and "dynamic zone-visitation sequencing" strategy) are proposed to solve the problem and the related results are compared. Both strategies incorporate a two-phase optimization process. An initial starting solution is found using a nearest-neighbour type generative algorithm; then, a simulated annealing improvement algorithm brings this solution towards optimality. This ensures that each strategy is represented by good exemplars of their class. Simulation experiments are conducted to evaluate the performance of the proposed strategies against three performance measures, namely the total travel distance of pickers (TTD), the total required system time to complete the picking operations (TRST), and total picking time of pickers (TPT). The simulation results show that the fixed zone-visitation strategy is about 20.9 % better than the dynamic strategy with respect to the TTD, but about 17 % less effective than the dynamic strategy in TRST and TPT.

Ho and Tseng (2006) investigated the performance of different order-batching methods that are made up of one seed-order selection rule and one accompanying-order selection rule. A seed-order selection rule selects the first order (i.e. the seed order) in an order batch, while an accompanying-order selection rule selects the rest of orders (i.e. the accompanying orders) to be added to the order batch. They investigated also the performance of nine seed-order selection rules and 10 accompanying-order selection rules under two different route-planning methods and two different aisle-picking-frequency distributions. The problem environment is a distribution centre's warehouse which has an I/O point at one of its corners and two cross-aisles, one front cross-aisle and one back cross-aisle. Two order-picking route-planning methods are considered: the largest gap method and the largest gap method with SA improvement. The rationale behind the use of SA in the problem in exam is not to find the optimal route, but, rather, to identify alternative routes that are no worse than those found by the largest gap method.

Hong et al. (2012) developed strategies to control picker blocking that challenge the traditional assumptions regarding the trade-off between wide- and narrow-aisle order picking systems. They proposed an integrated batching and sequencing procedure called the indexed batching model (IBM), with the objective of minimizing the total retrieval time (i.e., the sum of travel time, pick time and congestion delays). The IBM differs from traditional batching formulations by assigning orders to indexed batches, whereby each batch corresponds to a position in the batch release sequence. A mixed integer programming problem for exact control is developed by the authors and SA is used to find a solution to the problem. Different order picking environments require different routing strategies, depending on aisle-structure, such as one-way traversal route, s-shape route, and bi-directional traversal route (Hall 1993), which gives rise to different blocking problems. The authors design their experiments to analyse the impact on walk time and delay time of the proposed integrated batch creation and sequencing framework compared to alternative order batching and release approaches. Experimental results showed that the consideration of blocking in an integrated batching and sequencing approach offer substantial benefits. The authors found that the proposed simulated annealing algorithm is able to improve order picking by efficiently managing the batching and sequencing model.

Matusiak et al. (2014) presented a Precedence-Constrained Estimated Savings (PCES) problem, based on optimal precedence-constrained routing in combination with a SA algorithm which estimates the travel distance savings to group orders in batches. The case studied has a given number of trucks, which pick the orders. Each truck starts completely empty and then receives a set of orders to be picked. The number of received orders per truck does not exceed *N*, i.e. the number of bins carried by a truck. Before the items of an order can be picked, for each order an empty bin has to be collected at the empty bin depot. Subsequently, each truck travels through the warehouse to pick the items of the orders in the pre-specified sequence per order. Once all items of an order have been picked, the truck delivers the order at its drop-off location. Once all orders have been completed and the truck is empty again, it receives a new batch of orders. A batch is the set of orders handled in a route by a truck between the moment the truck receives this set and the moment it has dropped off all orders and is empty again. The study proposed a generic method for solving the difficult problem of batching orders with precedence-constrained pick tours. The method uses an estimate for savings generated by combining orders, which appears to perform remarkably well. The estimate uses exact savings from forming batches of size two to generate savings for larger batches. By using the estimate, the number of routings to be calculated reduces dramatically, particularly for larger batches. For batches of three customer orders, the introduced algorithm produces results with an error of less than 1.2 % compared to the optimal solution. The PCES algorithm is able to generate significant savings of up to 15.7 % compared to the original batching, or over 5000 km for a 3-month period. These savings can be achieved without making changes to the warehouse layout or customer order composition.

Muppani and Adil (2008) developed a SA algorithm to form storage classes efficiently considering storage-space cost, order-picking cost, and class formation (part grouping) without ordering restrictions. The authors assume that storage and retrieval are performed in single command cycles and all items are stored and transported on identical storage media (e.g., pallets or totes). The class-based storage policy is used. Each location is uniformly utilized and the assigned items are distributed homogeneously in the space allocated for the class. A distribution warehouse, which stores food and beverage products, having 45 items is considered. The historical demand data for each item over an 11 month period were collected. Inventory and total demand were in the range of 10–8640 units per month and 19–16,843 units, respectively. Computational experience on randomly generated data sets and an industrial case shows that the algorithm adopted on average performed better than dynamic programming algorithm for class formation with COI ordering restriction.

Grosse et al. (2014) studied the order batching problem in a manual order picking system where the item weight constrains the number of items an order picker is able to carry. This paper studies order picking in a standard picker-to-parts warehouse with parallel aisles; the warehouse consists of several picking aisles, front and back access aisles and a depot in the middle of the front aisle. Every pick tour starts and ends at the depot. Cross aisles (front and back) exist only at the respective ends of the picking aisles, and there are no cross aisles in-between. Order picking is performed manually in this warehouse, and that in each storage location, one type of item is stored. Items are assumed to be available on the shelves without limitation. The replenishment of shelves is therefore not considered. Order batches were generated with simple heuristics and improved with a SA approach. Numerical experiments showed that the heuristics for order batching and routing studied in this paper can be complemented well by a SA algorithm. The results indicate that the SA refinement strategy can help improve popular division heuristics, as the average travel time could be reduced by applying SA for all heuristics. With the help of our SA algorithm, managers are able to reduce the average time an order picker needs for completing customer orders. The intention of the study was to develop an approach that is easy to understand and that can easily be implemented in practice, for example in Java.

25.6 Artificial Neural Networks

25.6.1 Background

Artificial neural networks (ANNs) have been designed by Warren McCulloch and Walter Pitts in order to model complex problems using the logic of the typical activities of the human brain (McCulloch and Pitts 1943).

In the nervous system, there are billions of neurons. A neuron consists of a cell body and a lot of branched extension, called dendrites, through which the neuron receives electric signals from other neurons. Each neuron also has an extension, called axon, which allows spreading electrical signals to other cells or other neurons. The point of connection between the terminal and the dendrite is called synapses. A neuron becomes “active”, i.e. it sends an electrical impulse through its axon, when an electric potential difference between the inside and the outside of the cell occurs. The human brain is a complex, non-linear and parallel calculator; even though it is composed of very simple elements (neurons), it is able to perform complex computations (Schalkoff 1997). Moreover, the brain is able to change the connections between neurons based on the experience, meaning that it is able to learn. Into the brain, there is not a centralized control, but the different areas work together, influencing each other and contributing to the achievement of a specific task.

In order to reproduce the human brain artificially, we need a network composed of very simple elements, with a parallel structure, able to learn and produce outputs corresponding to inputs not seen during the training process. Typically, an artificial neuron has many inputs and one output, as shown in Fig. 25.5.

Considering a generic neuron k, n denotes the number of input channels ($x_1, \ldots, x_n$) and each one is connected to a weight ($w_{k1}, \ldots, w_{kn}$). The weights w_{ki} are real numbers and their absolute value represents the strength of the connection. The activation of the neuron is function of the weighted sum of the inputs $\left(a_k = \sum_{i=1}^{n} w_{ki} * x_i\right)$. The output ($y_k$), i.e. the final signal transmitted by the neuron k, is calculated by applying the activation function to the inputs weighted sum, according to the following formula:

$$y_k = f(a_k) = f\left(\sum_{i=1}^{n} w_{ki} * x_i\right) \tag{25.8}$$

In the neuron model shown in the previous figure, a threshold is included (b_k), which has the effect of lowering the input value of the activation function. Thus, the output becomes:

$$y_k = f(a_k) = f\left(\sum_{i=1}^{n} w_{ki} * x_i - b_k\right) \tag{25.9}$$

Moreover, interpreting the threshold as the weight associated to a further input channel x_0, whose value is constant and set as −1, the following formula can be derived:

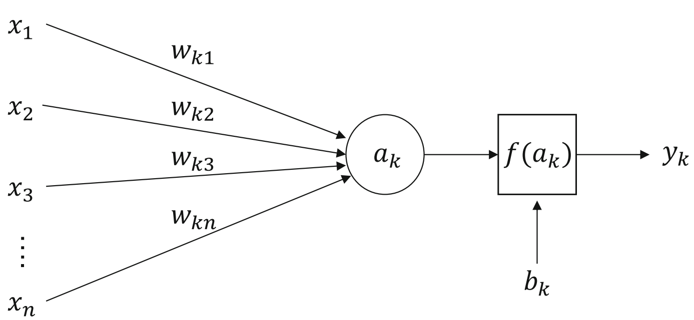

Fig. 25.5 Operation diagram of a generic artificial neuron

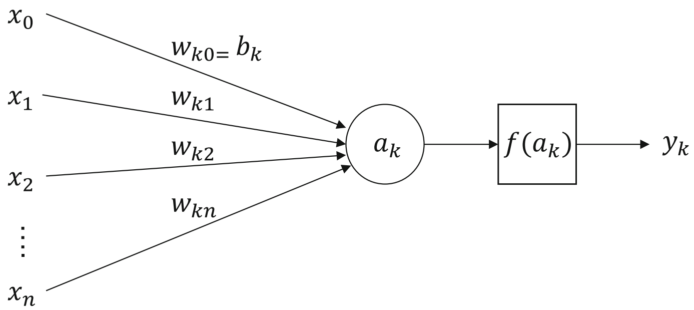

Fig. 25.6 Operation diagram of a generic artificial neuron in presence of a threshold

$$y_k = f(a_k) = f\left(\sum_{i=1}^{n} w_{ki} * x_i\right) \text{ with } \mathrm{w_{k0}} = \mathrm{b_k} \tag{25.10}$$

Embodying the previous formulae in the diagram of Fig. 25.5, the model of the generic neuron k becomes:

The activation function $f(a_k)$, which defines the output of a neuron as a function of the activation level a_k, can be a real number, a real number belonging to a given interval (for example, [0,1]), or a number belonging to a discrete set (typically {0,1} or {−1, +1}). Depending on the model of the neural network, only one neuron at a time can be activated or all the neurons can simultaneously be activated (Fig. 25.6).

The correct operation of the neural network depends on the architecture of the network (i.e. the number of levels and the number of neurons per level), the function of activation of the neurons and the weights. The first two parameters are fixed before the training phase. Therefore, their task is to update the weights so that the network produces the required responses. One of the most common ways to enable the network learning is the supervised learning: for each example, the given answer from the network is compared with the required one; then the difference (error) is calculated and the weights improved. At the beginning of the training phase, the weights are usually initialized with random values. Secondly, all the examples of the training set are implemented one at a time and, for each one, the error is calculated. Finally, the error is used to improve the weights. This process is repeated over the entire training set as long as the outputs of the network produce an error lower than a predefined threshold. After the training phase, the network is tested by checking its behaviour considering a set of data, called test set, consisting of examples not used during the training phase. At the end of this process, we can say that the network is able to provide results for inputs not considered during the training phase. Obviously, the performance of a neural network strongly depends on the examples of the training set; therefore, these examples must be representative of the reality that the network must learn. In fact, the training is an ad hoc process referred to a specific problem. The most common rule used to update the weights is the Delta rule, which is special case of the more general back-propagation algorithm (Rumelhart et al. 1986).

In general, neural networks find a valid application in areas such as prediction (Luxhøj et al. 1996; Aburto and Weber 2007), classification (Garetti and Taisch 1999), recognition and control (Shervais et al. 2003) and they often contribute to find a solution of problems, which cannot be treated with classical methods. To provide a practical implementation example, the Traveling Salesman Problem could be solved using the Kohonen Networks. The first step consists on define the network which include N cities and M neurons (M > N); each city is characterized by a couple of coordinates (input pattern), such as the neurons which are placed initially in a central position.

The learning process can be designed as follows:

1. Define the size of neighbourhoods (D);
2. initialise (randomly) the weights of the network;
3. loop until weight changes are negligible: for each neuron
   - calculate the output
   - Find the winning neuron (neuron with the weight vector that has the smallest Euclidean distance to the input pattern)
   - find all neurons in the neighbourhood of the winner (neurons with a distance < D)
   - update the weight vectors for all those neurons
4. reduce D if required.

The algorithm ends when D is less than a defined value. This process will move each neuron in the neighbourhood closer to the input pattern. Thanks to it, their coordinate values will move to the coordinates of the cities; at the end of the algorithm, the vectors of all the neurons will derive the order to visit the cities.

25.6.2 ANN Applied to Order Picking Optimization

Because of the complexity of the order picking process, trying to optimize it through analytical approaches is often ineffective. In this context, ANNs are usually applied to identify intelligent order picking sequences to minimize the total travel distance of pickers.

Su, in the 90's, integrated neural network and SA to propose an intelligent control mechanism for order picking operations of an automated warehouse (Su 1995). The problem dealt with by the author consists in developing a methodology to plan and control the order picking route by batching several orders into one trip, satisfying at the same time the capacity constraint of a crane. A competitive network was developed to perform order classification. Thus, an order centre has been developed to represent the location information for a given picking order; this first step was used as the starting point to perform order grouping by neural network.

The solution could be considered as an initial solution and as an input to the simulated annealing approach to generate final solution. Although the full investigation of system performance was not conducted in the study, the author asserts that the testing results suggest that the proposed method can generate good solution to the problem. Moreover, there are several attractive features provided by the proposed method: (1) it simplifies the problem by dividing it into several simple problems; (2) it is easy to implement and explain to user; and (3) the structure is applicable to different types of problems.

Kuo et al. (2012, 2013 and 2014) developed an artificial immune system (AIS)-based fuzzy neural networks (FNN), to the problem of picking cart's position estimation. Their studies aim to propose a less expensive positioning system, which uses RFID. Unlike the typical ANN model, the advantage of FNN is that the fuzzy inference rules can be explained, allowing the causal relationship to be more easily understood by users. The proposed RFID-based positioning system consists of four steps. The first phase is the collection of RFID signal data, while the second one is the RFID data transformation and elaboration. The third part uses the collected data to train the proposed AIS-FNN to establish the initial network parameters (initial weights and fuzzy numbers). The final step fine-tunes the network parameters, using the steepest descent method, similar to the error back-propagation learning algorithm. Since the proposed network couples AIS and FNN, it is able to avoid falling into the local optimum and possesses a learning capability. The results of the evaluation of the model show that the proposed AIS-based FNN really can predict the picking cart position more precisely than conventional FNN and, unlike an ANN, it is much easier to interpret the training results.

25.7 Conclusions

The optimal operating conditions of a warehouse are achieved when customers are completely satisfied according to their order and when all warehouse and logistic processes are completed in the shortest possible time, with minimal cost and optimal utilization of resources. Order picking is one of the most important warehousing operations, as it consumes a large amount of the total labour activities of a warehouse and accounts for a significant percentage of its total operational cost. To make the picking process more efficient and to increase the efficiency of the warehouse as well, the order picking system needs to be adequately designed. In this regard, this chapter has provided an overview of some selected intelligent algorithms that have been applied by researchers to improve the efficiency of order picking operations. The set of intelligent algorithms considered include genetic algorithms, artificial neural networks, simulated annealing, ant colony optimization and particles swarm optimization models. The efficiency of the order picking process depends on several factors, ranging from the warehouse layout to the possibility of automating the picking activities. Therefore, heuristic algorithms have been adopted to optimise different facets of the order picking problem, although the general aim of the implementation is to decrease the travel time of pickers. More precisely, we found examples of algorithms applied with the purpose of optimizing the storage assignment policy of the warehouse, i.e. the way the items are located in the warehouse. This is, for instance, the case of genetic algorithms and simulated annealing algorithms. Conversely, other algorithms, e.g. ant colony optimization models, are applied with the primary purpose of identify the optimal routing strategy of pickers.

Overall, this chapter provides the reader with an overview of different heuristic algorithms and of the related application potentials in the context of warehouse management.

References

Aburto, L., Weber, R.: Improved supply chain management based on hybrid demand forecasts. Appl. Soft Comput. **7**, 136–144 (2007)

Atmaca, E., Ozturk, A.: Defining order picking policy: a storage assignment model and a simulated annealing solution in AS/RS systems. Appl. Math. Model. **37**(7), 5069–5079 (2013)

Beasley, D., Bull, D.R., Martin, R.R.: An overview of genetic algorithms: parts 1 and 2. Univ. Comput. **15**, 2–4 (1993)

Bottani, E., Cecconi, M., Vignali, G., Montanari, R.: Optimisation of storage allocation in order picking operations through a genetic algorithm. Int. J. Logistics Res. Appl. **15**(2), 127–146 (2012)

Bottani, E., Montanari, R., Volpi, A.: The impact of RFID and EPC network on the bullwhip effect in the Italian FMCG supply chain. Int. J. Prod. Econ. **124**(2), 426–432 (2010)

Bottani, E., Rizzi, A.: Economical assessment of the impact of RFID technology and EPC system on the fast moving consumer goods supply chain. Int. J. Prod. Econ. **112**(2), 548–569 (2008)

Boysen, N., Stephan, K.: The deterministic product location problem under a pick-by-order policy. Discrete Appl. Math. **161**(18), 2862–2875 (2013)

Chen, F., Wang, H., Qi, C., Xie, Y.: An ant colony optimization routing algorithm for two order pickers with congestion consideration. Comput. Ind. Eng. **66**(1), 77–85 (2013)

Chen, F., Wang, H., Xie, Y., Qi, C.: An ACO-based online routing method for multiple order pickers with congestion consideration in warehouse. J. Intell. Manuf. (In press). doi: 10.1007/s10845-014-0871-1

Colorni, A., Dorigo, M., Maniezzo, V.: Distributed optimization by ant colonies. In: Proceedings of ECAL91—European Conference on Artificial Life, pp. 134–142. Paris (France), (1991). http://faculty.washington.edu/paymana/swarm/colorni92-ecal.pdf Accessed Sept 2014

Coyle, J.J., Bardi, E.J., Langley, C.J.: The Management of Business Logistics. West Publishing Company, Mason (1996)

Dallari, F., Marchet, G., Melacini, M.: Design of order picking system. Int. J. Adv. Manuf. Technol. **42**(1–2), 1–12 (2009)

de Koster, R., Le-Duc, T., Jan Roodbergen, K.: Design and control of warehouse order picking: a literature review. Eur. J. Oper. Res. **182**, 481–501 (2007)

Dorigo, M., Maniezzo, V., Colorni, A.: The ant system: optimization by a colony of cooperating agents. IEEE Trans. Syst. Man Cybern. Part B **26**(1), 1–13 (1996)

ESTECO.: MOSA—multi objective simulated annealing. Technical Report 2003-003 (2003).

Garetti, M., Taisch, M.: Neural networks in production planning and control. Prod. Plan. Control **10**(4), 324–339 (1999)

Goldberg, D.: Genetic Algorithms in Search, Optimization and Machine Learning. Addison-Wesley, Reading (1989)

Grosse, E.H., Glock, C.H., Ballester-Ripoll, R.: A simulated annealing approach for the joint order batching and order picker routing problem with weight restrictions. Int. J. Oper. Quant. Manage. **2**(20), 65–83 (2014)

Hall, R.W.: Distance approximation for routing manual pickers in a warehouse. IIE Trans. **25**, 77–87 (1993)

Ho, Y.-C., Chien, S.-P.: A comparison of two zone-visitation sequencing strategies in a distribution centre. Comput. Ind. Eng. **50**(4), 426–439 (2006)

Ho, Y.-C., Tseng, Y.-Y.: A study on order-batching methods of order-picking in a distribution centre with two cross-aisles. Int. J. Prod. Res. **44**(17), 3391–3417 (2006)

Holland, J.: Adaptation in Natural and Artificial Systems. University of Michigan Press, USA (1975)

Hong, S., Johnson, A.L., Peters, B.A.: Batch picking in narrow-aisle order picking systems with consideration for picker blocking. Eur. J. Oper. Res. **221**(3), 557–570 (2012)

Hsu, C.-M., Chen, K.-Y., Chen, M.-C.: Batching orders in warehouses by minimizing travel distance with genetic algorithms. Comput. Ind. **56**(2), 169–178 (2005)

Jarvis, J.M., McDowell, E.D.: Optimal product layout in an order picking warehouse. IIE Trans. **23**(1), 93–102 (1991)

Kennedy, J., Eberhart, R.: Particle swarm optimization. Proc. IEEE Int. Conf. Neural Networks **4**, 1942–1948 (1995). doi:10.1109/ICNN.1995.488968

Kirkpatrick, S., Gelatt, C.D., Vecchi, M.P.: Optimization by simulated annealing. Science **220** (4598), 671–680 (1983)

Kuo, R.J., Tseng, W.L., Tien, F.C., Warren Liao, T.: Application of an artificial immune system-based fuzzy neural network to a RFID-based positioning system. Comput. Ind. Eng. **63**, 943–956 (2012)

Kuo, R.J., Shieh, M.C., Zhang, J.W., Chen, K.Y.: The application of an artificial immune system-based back-propagation neural network with feature selection to an RFID positioning system. Robot. Comput. Integr. Manuf. **29**, 431–438 (2013)

Kuo, R.J., Hung, S.Y., Cheng, W.C.: Application of an optimization artificial immune network and particle swarm optimization-based fuzzy neural network to an RFID-based positioning system. Inf. Sci. **262**, 78–98 (2014)

Luxhøj, J.T., Riis, J.O., Stensballe, B.: A hybrid econometric-neural network modeling approach for sales forecasting. Int. J. Prod. Econ. **43**, 175–192 (1996)

Matusiak, M., De Koster, R., Kroon, L., Saarinen, J.: A fast simulated annealing method for batching precedence-constrained customer orders in a warehouse. Eur. J. Oper. Res. **236**(3), 968–977 (2014)

McCulloch, W., Pitts, W.: A logical calculus of the ideas immanent in nervous activity. Bull. Math. Biophys. **5**, 115–133 (1943)

Muppani, V.R., Adil, G.K.: Efficient formation of storage classes for warehouse storage location assignment: a simulated annealing approach. Omega **36**(4), 609–618 (2008)

Oke, A., Long, M.: An analysis of the downstream logistics operations of a South African FMCG producer. Int. J. Prod. Econ. **108**(1–2), 176–182 (2007)

Onut, S., Tuzkaya, U.R., Dogac, B.: A particle swarm optimization algorithm for the multiple-level warehouse layout design problem. Comput. Ind. Eng. **54**(4), 783–799 (2008)

Öztürkoğlu, Ö., Gue, K.R., Meller, R.D.: A constructive aisle design model for unit-load warehouses with multiple pickup and deposit points. Euro. J. Oper. Res. **236**(1), 382–394 (2014)

Parikh, P.J., Meller, R.D.: Estimating picker blocking in wide-aisle order picking systems. IIE Trans. **41**(3), 232–246 (2009)

Petersen, C.G.: The impact of routing and storage policies on warehouse efficiency. Int. J. Oper. Prod. Manage. **19**(10), 1053–1064 (1999)

Petersen, C.G., Aase, G.: A comparison of picking, storage, and routing policies in manual order picking. Int. J. Prod. Econ. **92**, 11–19 (2004)

Pourakbar, M., Sleptchenko, A., Dekker, R.: The floating stock policy in fast moving consumer goods supply chains. Transp. Res. Part E: Logistics Transp. Rev. **45**(1), 39–49 (2009)

Roodbergen, K.J., De Koster, R.: Routing methods for warehouses with multiple cross aisles. Int. J. Prod. Res. **39**(9), 1865–1883 (2001)

Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G.J., Mantel, R.J., Zijm, W.H.M.: Warehouse design and control: framework and literature review. Eur. J. Oper. Res. **122**, 515–533 (2000)

Rumelhart, D.E., Hinton, G.E., Williams, R.J.: Learning representations by back-propagating errors. Nature **323**, 533–536 (1986)

Schalkoff, R.J.: Artificial neural networks. McGraw-Hill, New York (1997)

Shervais, S., Shannon, T.T., Lendaris, G.G.: Intelligent supply chain management using adaptive critic learning. IEEE Trans. Syst. Man Cybern—Part A: Syst. Humans **33**(2), 235–244 (2003)

Silva, C.A., Sousa, J.M.C., Runkler, T.A.: Rescheduling and optimization of logistic processes using GA and ACO. Eng. Appl. Artif. Intell. **21**(3), 343–352 (2008)

Su, C.T.: Intelligent Control Mechanism of part picking operations of automated warehouse. In: Proceedings of the International IEEE/IAS Conference on Industrial Automation and Control: Emerging Technologies pp. 256–261, Taipei, 22–27 May 1995 (1995). doi: 10.1109/IACET.1995.527572

Tompkins, J.A., White, J.A., Bozer, Y.A., Frazelle, E.H., Tanchoco, J.M.A., Trevino, J.: Facilities Planning, 2nd edn. Wiley, New York (1996)

Wang, Y., Zheng, J., Wang, S.: Evolutionary algorithm inspired particle swarm optimization (EA-PSO) for warehouse allocation problem. In: Proceedings of the 3rd International Conference on Computer Research and Development (ICCRD2011), Shanghai (China), 11–13 March 2011, (2011). doi: 10.1109/ICCRD.2011.5764079

Xing, B., Gao, W.-J., Nelwamondo, F.V., Battle, K., Marwala, T.: Ant colony optimization for automated storage and retrieval system. In: IEEE Congress on Evolutionary Computation (CEC), Barcelona (Spain), 18–23 July 2010, (2010a). doi: 10.1109/CEC.2010.5586237

Xing, B., Gao, W.-J., Battle, K., Marwala, T., Nelwamondo, F.V.: Intelligent travel route planning for bridge crane type of material handling equipment in cellular manufacturing. In: Proceedings of the IEEE International Conference on Systems Man and Cybernetics (SMC), Istanbul (Turkey), 10–13 Oct. 2010, (2010b). doi: 10.1109/ICSMC.2010.5641894

Xinmin, Z., Xiangzhuo, K., Xiaoguang, H., 2008. Modeling and optimizing fixed shelf order-picking for AS/RS based on least time. In: Proceedings of the IEEE International Conference on Automation and Logistics, Qingdao (China), 1–3 Sept 2008. doi: 10.1109/ICAL.2008.4636249

Yao, M.-J., Chu, W.-M.: A genetic algorithm for determining optimal replenishment cycles to minimize maximum warehouse space requirements. Omega **36**(4), 619–631 (2008)

Yu, M.: Enhancing warehouse performance by efficient order picking. Ph.D. thesis—Rotterdam School of Management, Erasmus University (2005). http://repub.eur.nl/pub/13691/EPS2008139LIS9058921673YU.pdf Accessed Sept 2014

Zhang, X., Ma, T., Han, X.: Optimizing fixed shelf order-picking for AS/RS based on immune particle swarm optimization algorithm. In: Proceedings of the IEEE International Conference on Automation and Logistics (ICAL 2007), Jinan (China), 18–21 Aug 2007. doi: 10.1109/ICAL.2007.4339062

Zhang, G.Q., Lai, K.K.: Combining path relinking and genetic algorithms for the multiple-level warehouse layout problem. Eur. J. Oper. Res. **169**(2), 413–425 (2006)

Chapter 26
Several Intelligent Techniques to Solve Various Warehouse Problems in Uncertain Environment

K. Maity

Abstract In this chapter, several intelligent techniques to solve several warehouse problems have discussed in uncertain environment. In first model, analogous to chance constraints, real-life necessary and possibility constraints in the context of two warehouses multi-item dynamic production-inventory control system with imprecise holding and production costs are defined and defuzified following fuzzy relations. Hence, a realistic two warehouse multi-item production-inventory model without shortages and fuzzy constraints has been formulated and solved for optimal production with the objective of having maximum profit. Here, the rate of production is assumed to be a function of time and considered as a control variable. Also the present system produces some defective units alongwith the perfect ones and the rate of produced defective units is stochastic in nature. Here demand of the units is stock dependent and known and the defective units are selling with reduced prices. The space required per unit item, available storage space are assumed to be imprecise. The budget constraints is also imprecise. The space and budget constraints are of necessity and/or possibility types. The model is reduced to an equivalent deterministic model using necessary and possibility constrained and solved for optimum production function using Pontryagin's Optimal Control policy, the Kuhn-Tucker conditions and mathematica software 9.0. The engineering students in Optimization engineering and M.B.A.s in the business curriculum can used the model easily. In second model, a three layer supply chain production inventory model (TLSCPIM) under conditionally permissible delay in payments is formulated in fuzzy-rough and Liu uncertain environment. Supplier's supply the item at a finite rate. Manufacturer has also purchased the said item from supplier and produced the item in a certain rate which is the decision variable. Manufacturer sale his product to the retailer and also give the delay in payment to the retailer. Retailer purchase the item from manufacture and to sale the customers. Ideal costs of supplier, manufacturer and retailer have been taken into account. Also using expectation of fuzzy rough number and Liu uncertain number, the fuzzy rough

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inventory parameters and Liu uncertain inventory parameters are converted into equivalent crisp problem. Then the problem is solved by Mathematica software 9.0. The model is illustrated through numerical examples and results are presented in tabular and graphical form. In this chapter, various type of warehouse/supply chain problems have been developed where some warehouse parameters are fuzzy/fuzzy-rough/Liu-uncertain in nature. Then several intelligent techniques are used to convert the uncertain warehouse problems into crisp problems and to solve the problems. In addition, this chapter has also included several uncertain techniques/ soft computing techniques which are used in seminar classes in industry and teaching an introductory production planning and control or an operations management course for M.B.A. students.

Keywords Imperfect production with rework · Two warehouses · Three layers supply chain · Optimal control theory · Uncertain variables

26.1 Introduction

The classical inventory models have been developed by the researchers (cf. Harris (1915), Naddor (1966) and others) with the single storage facility. Now-a-days, with the advent of multi-nationals, specially in developing countries, there is an acute scarcity of marketing space in important market places like municipality market, super market, corporation market, etc. Normally, the production of large amount of units of an item that can not be stored in its existing storage (viz., market warehouse MW at the market place due to limited capacity), then excess units are stocked in another warehouse of large capacity at a near by place from the market or some distance away from MW. The second warehouse is at an out skirt place with respect to market, treated as rented warehouse, RW. Several authors have considered this type of inventory model. Hartely (1976) first discussed two warehouse model neglecting the cost of transporting a unit from RW to MW. Taking the fixed transportation cost into consideration, Sarma (1983, 1984) presented a model with instantaneous replenishment assuming the cost of transportation depending on the quantity to be transported. Later, Pakkala and Achary (1992a, b), Bhunia and Maiti (1998), Maity (2011), Agrawal et al. (2013), Bhunia et al. (2014) and others developed the two warehouse models for defective/deteriorating items. In the first model, we developed a two warehouse production inventory model with fuzzy budget and space constraints.

Now a days, companies are racing for improving their organizational competitiveness in order to compete in the global market. According to Gunasekaran and Ngai (2004), global market is completely connected and dynamic in nature. Therefore, companies are trying to improve their agility level with the objective of being flexible and responsive in order to meet the changing market requirements. To compete in a new global market, organizations should be capable of reconfiguring its resources to meet the changing requirements. Market factors such as customer requirements, competitors, and price affect the way organizations manage their operations. IT helps through advertisement by electric media, print media, etc. to improve the accurate information flow to the customers to support the business process in an effort to meet the changing market requirements. So in second model, we developed a supply chain imperfect production inventory problem with advertisement policy using IT.

Production of defective units is a natural phenomenon due to different difficulties in a long-run production process. The production of defective items is increased with time and decreased with reliability parameters. So the production of defective units is a natural phenomenon due to different difficulties in a long-run production process. The defective items as a result of imperfect quality in production process were initially considered by Porteus (1986) and later by several researchers such as Salameh and Jaber (2000), Roy et al. (2009), Selçuk and Agrali (2012), Hazari et al. (2014a, b, c) and others.

Quality of a product is defined as the amount by which the product satisfies the customers' requirements. It is in part a function of design and conformance to design specifications. It also depends on the production of the system and on adherence to the manufacturing procedures and tolerances. Thus quality is achieved through a good quality assurance program consisting of a planned set of processes and procedures. Again, reliability of a system means how long it gives designed product perfectly once it becomes operational. Reliability deals with reducing failures over a time interval and is a measure of the odds for failure free operation during a given interval, improving reliability occurs at an increase development cost. Mettas (2000) developed reliability allocation and optimization for complex systems and later by several researchers such as Panda et al. (2008), Panda and Maiti (2009), Sarkar (2012), Maity (2014a) and others.

Several imperfect production inventory model have been developed without rework in uncertain environment. But, Rework is a process using materials (defective items) into new products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution in production inventory system. So, in this process, defective items are reworked at a cost to make the products as new as perfect one keeping in mind the spitting image of trademark of the manufacturing scheme. Lin et al. (2008) developed a model on optimal replenishment policy for imperfect production inventory model with rework and backlogging. Next, Chiu et al. (2010) generalized the optimization of the finite production rate model with scrap, rework and stochastic machine breakdown. Recently, Maity (2014a) developed an imperfect production process with rework in fuzzy rough environment.

Moreover, recent studies indicated that industrial solid waste (ISW) in production industry has been an important contributor to greenhouse gas (GHG) emissions. So, modern technologies are implemented by the industry to increase the reliability of the production system and decrease the GHG emission in the environment. The waste of defective amount is reduced by improve the system reliability and rework process. Andrade et al. (2012) has managed the hazardous waste in the printing industry. Braschel and Posch (2013) were review of system boundaries of GHG emission inventories in waste management. In the second model of this chapter, pollution gases are controlled through several processes like technological development, rework, ISW management, green plantation, etc. So, production cost is dependent on raw material cost, development cost and wear-tear cost.

Different types of uncertainty such as randomness, fuzziness, roughness, bi-fuzzyness are common factors in any production inventory problem. In many cases, it is found that some inventory parameters involve fuzzy rough in nature. For example, the inventory related costs like holding costs, ordering costs and ideal costs depend on several factors such as bank interest, stock amount, market situation, etc. which are uncertain in fuzzy rough sense. To be more specific, inventory holding cost is sometimes represented by a fuzzy rough number and it depends on the storage amount which may be imprecise and range within an interval due to several factors such as scarcity of storage space, market fluctuation, human estimation/thought process. Das et al. (2007) developed a two warehouse supply-chain model in imprecise environment. Islam and Roy (2007) developed an economical production quantity model with flexibility and reliability consideration and demand dependent unit production cost under a space constraint in imprecise environment. Maity and Maiti (2007) developed two plant optimal production inventory model with imprecise parameters. Xu and Zhao (2010) have developed a multi-objective decision-making model with fuzzy rough coefficients and its application to the inventory problem. Maity (2011) and Hazari et al. (2014b) developed a two warehouse production-inventory problem in imprecise environment. Glock et al. (2012) developed an economic order quantity model with fuzzy demand and learning in fuzziness. Jana et al. (2013b) developed multi-item production inventory model in fuzzy-Rough environment. Also, Jana et al. (2013b) developed a bi-fuzzy production-recycling-disposal inventory problem with environment pollution cost via genetic algorithm. Recently, Maity (2014) developed a supply-chain production inventory model with warehouse facilities under fuzzy environment.

Uncertainty is common in real life problems such as randomness, fuzziness and roughness. Since Liu (2007) introduced uncertain theory in 2007, uncertain theory has been well developed and applied in a wide variety of real problems. Recently, Liu (2010) proposed an uncertain measure and developed an uncertainty theory which can be used to handle subjective imprecise quantity. Much research work has been done on the development of uncertainty theory and related theoretical work. You (2009) proved some convergence theorems of uncertain sequences. Liu (2008) has defined uncertain process and Liu (2009) has discussed uncertain theory. Recently Hazrai et al. (2014c) developed Optimal dynamic production and pricing for reliability depended imperfect production with inventory-level-dependent demand in uncertain environment. It is often difficult to estimate the initial selling price, holding cost and raw material cost. Depending upon different aspects, they fluctuate due to uncertainty in judgement, lack of evidence, insufficient information, etc. Sometimes it is not at all possible to get relevant precise data. So these parameters are assumed to be flexible/imprecise in nature i.e., uncertain sense and may be represented by uncertain variables.

In the second model, we have developed a three layers supply chain imperfect production inventory model under permissible delay in payments in fuzzy-rough and Liu uncertain environment. On behave of this model, the objective for a advertisement policy, reliability dependent an imperfect production supply chain inventory problem are developed in fuzzy rough and Liu uncertain environment. Also using expectation of fuzzy rough number and Liu uncertain number, the fuzzy rough inventory parameters and Liu uncertain inventory parameters are converted into equivalent crisp problem. Then the problem is solved by Mathematica software 9.0. The model is illustrated through numerical examples and results are presented in tabular and graphical form.

In this chapter, several methods on optimal control theory are established for engineering students in Mechanical, Electrical, Optimization engineering and M.B. A.s in the business curriculum. It can also be used by professional scientists and engineers working in a variety of industries and research organizations. In addition, this chapter has also included several uncertain techniques/soft computing techniques which are used in seminar classes in industry and teaching an introductory production planning and control or an operations management course for M.B.A. students.

26.2 Literature Review

The summary of related literature for two-warehouse (TW)/supply chain model (SCM) inventory models is given in Table 26.1.

26.3 Solution Methodologies

26.3.1 Kuhn-Tucker's Necessary and Sufficient Conditions Considering Optimality

Let us consider a maximization problem as

$$\begin{aligned} &\text{Maximization}\, Z = J(x) \\ &\quad \text{subject to}\, f_i(x) \le 0,\ i = 1, 2, \ldots, m, \quad \text{where}\, x = x(x_1, x_2, \ldots, x_n)^T \end{aligned} \tag{26.1}$$

for (26.1), to determine optimal x*, Kuhn-Tucker's necessary conditions are

Table 26.1 Summary of related literature for two-warehouse inventory models

Author(s) and year	TW/SCM with deteriorating item/defective item	Demand rate	Delay in payment	Imprecise environment
Sarma (1987)	TW deteriorating item	Constant	No	No
Benkherouf (1997)	TW deteriorating item	Time-dependent	No	No
Yang (2004)	TW deteriorating item	Constant	No	No
Zhou et al. (2005)	TW deteriorating item	Stock-dependent	No	No
Yang (2006)	TW deteriorating item	Constant	No	No
Lee (2006)	TW deteriorating item	Constant	No	No
Huang (2006)	TW deteriorating item	Constant	No	No
Hsieh et al. (2007)	TW deteriorating item	Constant	No	No
Chung (2007)	TW deteriorating item	Constant	Yes	No
Das et al. (2007)	TW and SCM for defective item	Stock dependent	No	Yes
Rong et al. (2008)	TW deteriorating item	Price-dependent	No	Yes
Dey et al. (2008)	TW deteriorating item	Time-dependent	No	Yes
Maiti (2008)	TW deteriorating item	Time-dependent	No	Yes
Maity (2011)	TW defective item	Stock-dependent	No	Yes
Liang (2011)	TW deteriorating item	Constant	Yes	No
Liao et al. (2012)	TW deteriorating item	Constant	Yes	No
Jana et al. (2013a, b)	TW deteriorating item	Stock-dependent	Yes	Yes
Agrawal et al. (2013)	TW deteriorating item	Ramp-type dependent	No	No
Bhunia et al. (2014)	TW deteriorating item	Constant	Yes	No
Maity (2014a, b)	TW and SCM for defective item	Constant/ stochastic	Yes	yes

$$
\begin{aligned}
\frac{\partial J(x)}{\partial x_j} - \sum_{i=1}^{m} \lambda_i \frac{\partial f_i(x)}{\partial x_j} &= 0, \quad j = 1, 2, \ldots, n \\
\lambda_i f_i(x) &= 0 \\
\text{i.e } \lambda_i &= 0, \quad f_i(x) \leq 0 \\
\text{or } \lambda_i &> 0, \quad f_i(x) = 0
\end{aligned}
$$

and sufficient conditions are:

$J(x)$ and all $f_i(x)$ are convex functions of x.

26.3.2 Optimal Control Theory (Pontryagin Maximum Principle)

The optimal control problem and the problem in hand is to

Maximize $J(u,x) = \int_0^T F(x(t),u(t),t)dt + S(x(T))$

subject to $\frac{dx(t)}{dt} = f_1(x(t),u(t),t),\ x(0) = x_0$

where F stands for the scalar integrated function in the objective function and $S(x(T))$ is the salvage value function of the terminal state of the system.

The problem is to choose the control function $u(t),\ t \epsilon (0,t)$ which maximizes the objective function J subjected to the dynamics constraints of the system.

Generally $u(t)$ is taken as unconstrained. But in most practical cases of interest $u(t)$ is restricted to lie within the set of admissible functions and to satisfy some constraint equation represented by the vector equation $g(x(t),u(t),t) \leq b$.

The formulation of the problem now becomes

Maximize $J(u,x) = \int_0^T F(x(t),u(t),t)dt + S(x(T))$

subject to $\frac{dx(t)}{dt} = f_1(x(t),u(t),t),\ \ x(0) = x_0$

u(t) is a piece-wise continuous function and $g(x(t),u(t),t) \leq b$

To solve the above optimal control problem in Bolza from we defined two function,viz (i) Hamitonion and (ii) Lagrangian. Hamiltonion(H) can be expressed as

$$H(x,u,q,t) = F(x,u,t) + q^T(t)f_1(x,u,t),$$

here, $q(t)$ is a vector function of adjoint variables and are multipliers associated with the dynamic system constraint. Again Lagrangian function can be expressed as:

$L(x,u,q,\lambda,t) = H(x,u,q,t) + \lambda^T(g(x,u,t) - b), \lambda$ is the Lagrange multipliers associated with the constraints $g(x(t),u(t),t) \leq b$

The necessary conditions (not sufficient) to be satisfied for a control function to be optimal are as follows:

(A) Hamiltonian Maximizing condition: $H(x^*,q^*,u^*,t) \geq H(x^*,u,q^*,t)$ for all admissible u.

(B) System Dynamic Constraints:

$$\frac{dx^*(t)}{dt} = f_1(x^*(t),u^*(t),t),\ x^*(0) = x_0$$

(C) Stationary of the gradient of the Lagrangian w.r.t. u(t) at (x^*,u^*,λ^*,t^*) is $L_u(x^*,u^*,\lambda^*,\mu^*,t) = \phi$, a zoro vector

(D) Complementary slackness condition:

$$\lambda^*(t) \geq \phi,\ \lambda^*(t)^T \cdot (g(x^*(t),u^*(t),t) - b) = 0$$

(E) Adjoint equation:

$$\frac{dq(t)}{dt} = -L_x(x^*(t), u^*(t) \cdot q^*(t), \lambda^*(t), t)$$

where L_x is the vector of partial derivatives of the Lagrangian w.r.t. $x(t)$.

The terminal condition in $q(t)$ as $q^*(T) = S_x(x(T))$ is the Gradient of the Salvage value function S w.r.t. $x(t)$ at $t = T$. For $x^*(t), u^*(t), q^*(t), \mu^*(t)$, the above conditions are to be solved simultaneously.

26.3.3 Possibility/Necessity/Credibility/Expectation Measures Under Fuzzy Environment

Any fuzzy subset $\tilde{a}$ of $\Re$ (where $\Re$ represents a set of real numbers) with membership function $\mu_{\tilde{a}}(x) : \Re \to [0, 1]$ is called a fuzzy number. Let $\tilde{a}$ and $\tilde{b}$ be two fuzzy quantities with membership functions $\mu_{\tilde{a}}(x)$ and $\mu_{\tilde{b}}(x)$ respectively. Then according to Dubois and Prade (1983), Liu and Iwamura (1998) and others, the measure of $\widetilde{a} * \widetilde{b}$ in optimistic and pessimistic sense are

$$Pos(\tilde{a} * \tilde{b}) = sup\{(min(\mu_{\tilde{a}}(x), \mu_{\tilde{b}}(y)), \ x, y \in \Re, x * y\} \tag{26.2}$$

$$Nes(\tilde{a} * \tilde{b}) = inf\{(max(1 - \mu_{\tilde{a}}(x), \mu_{\tilde{b}}(y)), \ x, y \in \Re, x * y\} \tag{26.3}$$

where the abbreviation Pos and Nes stand for possibility and necessity respectively, and $*$ is any of the the relations $>, <, =, \leq, \geq$.

Let $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ be a triangular fuzzy numbers. Then for these fuzzy numbers, following Das et al. (2007), Maity and Maiti (2007) and Maity (2011), we have used Lemmas 1, 2.

Lemma 1 *Nes* $(\tilde{a} > \tilde{b}) > \eta$ *iff* $\frac{b_3 - a_1}{a_2 - a_1 + b_3 - b_2} < 1 - \eta, \ (a_2 > b_2, \ b_3 > a_1)$

Lemma 2 *Pos* $(\tilde{a} \geq \tilde{b}) > \eta$ *iff* $\frac{a_3 - b_1}{b_2 - b_1 + a_3 - a_2} > \eta, \ (a_2 < b_2, \ a_3 > b_1)$

If the attitude of the DM is toward optimistic, Eq (26.2) *is the measure of best case and in pessimistic sense* Eq (26.3) *gives the measure of worst case of that event. Now if we consider* ρ *the optimistic and pessimistic index determine the combined attitude of DM, then the measure of Weighted Possibility and Necessity (WPN) of* $\widetilde{a} * \widetilde{b}$ is

$$WPN(\widetilde{a} * \widetilde{b}) = \rho Pos(\widetilde{a} * \widetilde{b}) + (1 - \rho) Nes(\widetilde{a} * \widetilde{b}) \tag{26.4}$$

Note: *In particular when* $\rho = \frac{1}{2}$, *WPN is known as credibility of that event, i.e.,*

$$Cr(\widetilde{a} * \widetilde{b}) = \frac{1}{2}(Pos(\widetilde{a} * \widetilde{b}) + Nes(\widetilde{a} * \widetilde{b})) \tag{26.5}$$

based on the credibility measure, Liu and Liu (2002) *presented the expected value operator of a fuzzy variable as follows.*

The expected value of a normalized fuzzy variable $\tilde{a}$ *is defined by*

$$E[\tilde{a}] = \int_{0}^{\infty} Cr(\tilde{a} \geq r)dr - \int_{-\infty}^{0} Cr(\tilde{a} \leq r)dr \tag{26.6}$$

when the right hand side of (6) is of form $\infty - \infty$, *the expected value is not defined.*

Lemma 3 *The expected value of triangular fuzzy variable* $\tilde{a}$ *is defined as*

$$E[\tilde{a}] = \frac{1}{2}[(1-\rho)a_1 + a_2 + \rho a_3] \tag{26.7}$$

$$= \frac{1}{2}[a_1 + 2a_2 + a_3], \mathit{for}\ \rho = \frac{1}{2} \tag{26.8}$$

Lemma 4 *The expected value operation has been proved to be linear for bounded fuzzy variables, i.e., for any two bounded fuzzy variables* $\tilde{a}$ *and* $\tilde{b}$, *we have* $E[c\tilde{a} + d\tilde{b}] = cE[\tilde{a}] + dE[\tilde{b}]$ *for any real numbers* c *and* d.

26.3.4 Single Objective Problem Under Necessity/Possibility/ Credibility Measures

A general single-objective mathematical programming problem with fuzzy parameters should have the following form:

$$\begin{aligned} &\text{Min} \quad f(u,\xi) \\ &\text{subject to} \quad g_j(u,\xi) \leq m_j, \quad j = 1,2,\ldots,k \end{aligned} \tag{26.9}$$

where u is the decision vector, ξ is a vector of fuzzy parameters, f(u,ξ) is an imprecise objective function, $g_j(u,\xi)$s are constraint functions, $j = 1,2,\ldots,k$. To convert the fuzzy objective and constraints to their crisp equivalents, Liu and Iwamura (1998) proposed a method to convert the problem (26.9) into an equivalent fuzzy programming problem under possibility constraints. Similarly we can convert (26.9) to the following fuzzy programming problem under necessity/possibility/credibility constraints.

$$\text{Min} \quad \alpha \tag{26.10}$$

$$\begin{aligned} \text{subject to} \quad & \text{Pos}\,(\alpha = f(u,\,\xi)) > \eta \\ \text{and} \quad & \text{Nes}\{\xi|g_j(u,\xi) \le m\} > \eta_{1j} \text{ or } \quad \text{Pos}\{\xi|g_j(u,\xi) \le m\} > \eta_{2j} \end{aligned} \tag{26.11}$$

$$\text{or} \quad \text{Cr}\{\xi|g_j(u,\xi) \le m\} > \eta_j \tag{26.12}$$

where η_{1j}, η_{2j} and $\eta_j, j = 1, 2 \cdots k.$ are predetermined confidence levels for fuzzy constraints. Nes $\{.\}$ denotes the necessity of the event in $\{.\}$. So a point ξ is feasible if and only if necessity of the set $\{\xi/g_j(u,\xi) < m\}$ is at least η_{1j}. Similarly, Pos $\{.\}$ and Cr $\{.\}$ denotes the possibility and credibility of the event in $\{.\}$. So a point ξ is feasible if and only if possibility of the set $\{\xi/g_j(u,\xi) \le m\}$ is at least η_{2j} and η_j respectively. $j = 1, 2, \ldots, k$.

26.3.5 Necessary Knowledge About Fuzzy Rough Theory

Following Pawlak (1982), Dubois and Prade (1990), Demrc (2003), Xu and Zhou (2009), Maity (2014a), some basic concepts, theorems and lemma on fuzzy rough sets (cf. Fig. 26.1) are stated. The Theorems 1 and 2 and Lamma 2 are used to converted the fuzzy rough numbers to a equivalent crisp number.

The primary feature of fuzzy sets is that their boundaries are not precise. There exists an alternative way to formulate sets with imprecise boundaries. Sets formulated in this way are called rough sets. a rough set is basically an approximate representation of a given crisp set in terms of two subsets of a crisp partition defined on the universal set involved. The two subsets are called a lower approximation and an upper approximation. The lower approximation consists of all blocks whose intersection with the set is not empty.

To define the concept of a rough set more precisely, let X denoted a universal set, and let R be an equivalence relation on X. Moreover, let X/R denoted the family

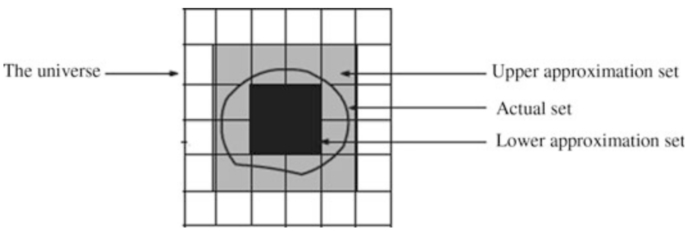

Fig. 26.1 A rough set

of all equivalence classes induced on X by R(a quotient set), and let $[x]_R$ denote the equivalence class in X/R that contains $x \in X$.

A rough set, $R(A)$ is a representation of a given set $A \in P(x)$ by two subsets of the quotient set X/R, $\underline{R}(A)$ and $\overline{R}(A)$, which approach A as closely as possible from inside and out side, respectively. That is $R(A) = (\underline{R}(A), \overline{R}(A))$, where $\underline{R}(A)$ and $\overline{R}(A)$ are the lower approximation and an upper approximation of A respectively, by equivalence classes in X/R. The lower approximation $\underline{R}(A) = \bigcup\left\{[x]_R \middle| [x]_R \subseteq A, x \in X\right\}$, is the union of all equivalence classes in X/R that are contains in A. The upper approximation, $\overline{R}(A) = \bigcup\left\{[x]_R \middle| [x]_R \bigcap A \neq \phi, x \in X\right\}$ is the union of all equivalence classes in X/R that overlap with A. The figure of a rough set is depicted in Fig. 26.1.

Fuzzy sets and rough sets model different type of uncertainty. Since both types are relevant in some applications, it is useful to combine the two concepts. Rough sets based on fuzzy equivalence relations are usually called fuzzy rough sets.

Given an arbitrary crisp subset A of X and a fuzzy equivalence relation R_F on X, the fuzzy rough sets approximation of A in terms of R_F is represented at each α cut of R_F by the rough set $R_F^\alpha(A) = (\underline{R^\alpha}_F(A), \overline{R^\alpha}_F(A))$.

Theorem 1 *If fuzzy rough variables* $\tilde{\bar{c}}_{ij}$ *are defined as* $\tilde{\bar{c}}_{ij}(\lambda) = (\bar{c}_{ij1}, \bar{c}_{ij2}, \bar{c}_{ij3}, \bar{c}_{ij4})$ *with* $\bar{c}_{ijt} \vdash ([c_{ijt2}, c_{ijt3}], [c_{ijt1}, c_{ijt4}])$, *for* $i = 1, 2, \ldots, m, j = 1, 2, \ldots, n, t = 1, 2, 3, 4$, $x = (x_1, x_2, \ldots, x_m)$, $0 \le c_{ijt1} \le c_{ijt2} < c_{ijt3} \le c_{ijt4}$ *then* $E[\tilde{\bar{c}}_1^T x]$, $E[\tilde{\bar{c}}_2^T x]$, $\ldots$, $E[\tilde{\bar{c}}_n^T x]$ *is equivalent to*

$$\frac{1}{16}\sum_{j=1}^{n}\sum_{t=1}^{4}\sum_{k=1}^{4} c_{1jtk}x_j, \frac{1}{16}\sum_{j=1}^{n}\sum_{t=1}^{4}\sum_{k=1}^{4} c_{2jtk}x_j, \ldots, \frac{1}{16}\sum_{j=1}^{n}\sum_{t=1}^{4}\sum_{k=1}^{4} c_{njtk}x_j, \tag{26.13}$$

Theorem 2 *If fuzzy rough variables* $\tilde{\bar{a}}_{rj}, \tilde{\bar{b}}_r$ *defined as follows,* $\tilde{\bar{a}}_{rj}(\lambda) = (\bar{a}_{rj1}, \bar{a}_{rj2}, \bar{a}_{rj3}, \bar{a}_{rj4})$ *with* $\bar{a}_{rjt} \vdash ([a_{rjt2}, a_{rjt3}], [a_{rjt1}, a_{rjt4}])$, $\tilde{\bar{b}}_r(\lambda) = (\bar{b}_{r1}, \bar{b}_{r2}, \bar{b}_{r3}, \bar{b}_{r4})$ *with* $\bar{b}_{rt} \vdash ([b_{rt2}, b_{rjt3}], [b_{rt1}, b_{rt4}])$, *for* $r = 1, 2, \ldots, p, j = 1, 2, \ldots, n, t = 1, 2, 3, 4, 0 \le a_{rt1} \le a_{rt2} < a_{rt3} \le a_{rt4}, 0 \le b_{rt1} \le b_{rt2} < b_{rt3} \le b_{rt4}$.

Then $E[\tilde{\bar{a}}_{rj}^T x] \le E[\tilde{\bar{b}}_{rj}], r = 1, 2, \ldots, p$ *is equivalent to*

$$\frac{1}{16}\sum_{j=1}^{n}\sum_{t=1}^{4}\sum_{k=1}^{4} a_{rjtk}x_j \le \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} b_{rtk}, r = 1, 2, \ldots, p \tag{26.14}$$

Lemma 5 *Assume that* ξ *and* η *are the introduction of variables with finite expected values. Then for any real numbers a and b, we have*

$$E[a\xi + b\eta] = aE[\xi] + bE[\eta] \tag{26.15}$$

26.3.6 Single-Objective Fu Ro Model

Let us consider the following single-objective decision making model with fuzzy rough coefficients:

$$\begin{cases} Max & \{f(x,\xi)\} \\ s.t & \begin{cases} g_r(x,\xi) \le 0, r = 1,2,\ldots,p \\ x \in X \end{cases} \end{cases} \tag{26.16}$$

where x is a n-dimensional decision vector, $\xi = (\xi_1, \xi_2, \xi_3, \ldots, \xi_n)$ is a Fu-Ro vector, $f(x,\xi)$ is objective function. Because of the existence of Fu-Ro vector ξ, problem (26.16) is not well-defined. That is, the meaning of maximizing $f(x,\xi)$ is not clear and constraints $g_r(x,\xi) \le 0, r = 1,2,\ldots,p$ do not define a deterministic feasible set.

26.3.7 Equivalent Crisp Model for Single Objective Problem with Fu Ro Parameters

For the single-objective model (26.16) with Fu-Ro parameters, we cannot deal with it directly, we should use some tools to make it have mathematical meaning, we then can solve it. In this subsection, we employ the expected value operator to transform the fuzzy rough model into Fu-Ro EVM i.e. crisp model. Based on the definition of the expected value of fuzzy rough events $f(x,\xi)$, $g_r(x,\xi)$ and Theorems 1, 2 the Fu-Ro EVM is proposed as follows,

$$\begin{cases} Max & E[f(x,\xi)] \\ s.t & \begin{cases} E[g_r(x,\xi)] \le 0, r = 1,2,\ldots,p \\ x \in X \end{cases} \end{cases} \tag{26.17}$$

where x is n-dimensional decision vector and ξ is n-dimensional fuzzy rough variable.

26.3.8 Necessary Knowledge About Uncertain Variable

To better describe the subjective imprecise quantity, Liu (2007) proposed an uncertain measure and further developed an uncertainty theory which is an axiomatic system of normality, monotonicity, self-duality, countable subadditivity and product measure. Following Liu (2007, 2008), theorems and lemma on uncertain variable are stated. The theorems and lamma are used to converted the uncertain variable to a equivalent crisp number.

Definition 1 Let Γ be a nonempty set, and $\mathcal{L}$ a σ algebra over Γ. Each element Λ, $\mathcal{L}$ is called an event. A set function $M\{\Lambda\}$ is called an uncertain measure if it satisfies the following three axioms Liu (2007):

Axiom 1 (Normality) $\mathcal{M}\{\Gamma\} = 1$

Axiom 2 (Monotonicity) $\mathcal{M}\{\Lambda\} + \mathcal{M}\{\Lambda^C\} = 1$, for any event Λ

Axiom 3 (Countable Subadditivity) For every countable sequence of events $\Lambda_1, \Lambda_2, \cdot$, we have

$$\mathcal{M}\left\{\sum_{i=1}^{\infty} \Lambda_i\right\} \leq \sum_{i=1}^{\infty} \mathcal{M}\{\Lambda_i\}$$

Definition 2 Liu (2007) The uncertainty distribution $\Phi : R \to [0, 1]$ of an uncertain variable $\widehat{\xi}$ is defined by

$$\Phi(t) = \mathcal{M}\{\widehat{\xi} \leq t\}$$

in this chapter, we give zigzag uncertain variable in Fig. 26.2.

Definition 3 Let $\widehat{\xi}$ be an uncertain variable with regular uncertainty distribution Φ. Then the inverse function Φ^{-1} is called the inverse uncertainty distribution of $\widehat{\xi}$.

Definition 4 Liu (2007) Let $\widehat{\xi}$ be an uncertain variable. Then the expected value of $\widehat{\xi}$ is defined by

$$E[\widehat{\xi}] = \int_0^{\infty} \mathcal{M}\{\widehat{\xi} \geq r\}dr - \int_{-\infty}^{0} \widehat{M}\{\widehat{\xi} \leq r\}dr$$

provided that at least one of the two integrals is finite.

Theorem 3 Liu (2008) *Let* $\widehat{\xi}$ *be an uncertain variable with uncertainty distribution* Φ. *If the expected value exists, then* $E[\widehat{\xi}] = \int_0^1 \Phi^{-1}(\alpha)d\alpha$

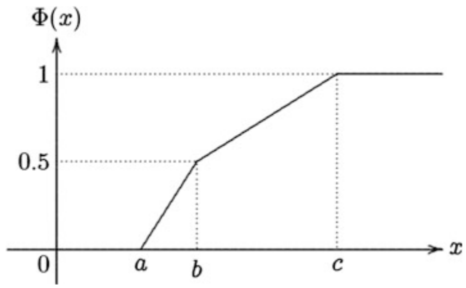

Fig. 26.2 Zigzag Uncertainty variable

Theorem 4 Liu (2008) *Let $\widehat{\xi}$ and $\widehat{\eta}$ be independent uncertain variables with finite expected values. Then for any real numbers a_1 and a_2, we have*

$$E[a_1\widehat{\xi} + a_2\widehat{\eta}] = a_1E[\widehat{\xi}] + a_2E[\widehat{\eta}] \tag{26.18}$$

Lemma 6 *Let $\widehat{\xi} \sim \mathcal{Z}(a, b, c)$ be a zigzag uncertain variable* (cf. Fig. 26.2). *Then its inverse uncertainty distribution $\Phi^{-1}(\alpha) = \frac{1}{2}[(1-\alpha)a + b + \alpha c]$ and it can be expressed as*

$$E[\widehat{\xi}] = \int_0^1 \frac{1}{2}[(1-\alpha)a + b + \alpha c]d\alpha = \frac{a + 2b + c}{4} \tag{26.19}$$

Lemma 7 *Assume $x_1, x_2, \ldots, x_n$ are nonnegative decision variables, and $\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n, \widehat{\xi}$ are independent zigzag uncertain variables $\mathcal{Z}(a_1, b_1, c_1), \mathcal{Z}(a_2, b_2, c_2), \ldots, \mathcal{Z}(a_n, b_n, c_n), \mathcal{Z}(a, b, c)$, respectively. Then for any confidence level $\alpha \geq 0.5$, the chance constraint*

$$\mathcal{M}\left\{\sum_{i=1}^{n} \widehat{\xi}_i x_i \leq \widehat{\xi}\right\} \geq \alpha \tag{26.20}$$

holds if and only if

$$\sum_{i=1}^{n} \{(2-2\alpha)b_i + (2\alpha - 1)c_i\}x_i \leq \alpha(2-2\alpha)a + (2-2\alpha)b \tag{26.21}$$

26.3.9 Uncertain Single Objective Programming

Uncertain programming is a type of mathematical programming involving uncertain variables. Since an uncertain objective function $f_i(x, \widehat{\xi})$ cannot be directly minimized, we may minimize its expected value. Assume that x is a decision vector, $\widehat{\xi}$ is an uncertain vector, f is an objective function and g_j are constraints functions for $j = 1, 2, \ldots, p$. Let us examine

$$\begin{cases} Min & f(x, \widehat{\xi}) \\ s.t & \begin{cases} g_j(x, \widehat{\xi}) \leq 0, j = 1, 2, \ldots, p \\ x \in X \end{cases} \end{cases} \tag{26.22}$$

in order to obtain a decision with minimum expected objective value subject to a set of chance constraints, Liu (2007) proposed the above uncertain programming model (26.22) is equivalent to the crisp model (26.23) as follows:

$$\begin{cases} \min_x & E\left[f(x,\widehat{\xi})\right] \\ \text{subject to} & \\ & \mathcal{M}\left\{g_j(x,\widehat{\xi})\leq 0\right\}\geq \alpha_j, \quad j=1,2,\ldots,p. \end{cases} \tag{26.23}$$

where $f(x,\widehat{\xi})$ is the objective function, $g_j(x,\widehat{\xi})$ are constraint functions and $0\leq\alpha_j\leq 1$ for $j=1,2,\ldots,p$.

26.4 Two Warehouses Production-Inventory Problem with Imprecise Budget and Space Constraints

Normally, in production-inventory control systems, it is fact that available resources are not unlimited. These resource constraints are normally assumed deterministic. In real life, it may not be so. For example, at the beginning of the business, it may be started with some capital and warehouse space. But during the period of business, it may happen that to meet the unexpected increased demand, the production is speeded up and for that, some extra capital and additional storage space are augmented. These augmented amounts are normally fuzzy in nature. Again, in some situations, the available storage space may fall short of the proposed space for the system. Hence the resource constraints i.e. total capital and storage space become imprecise in nature.

Most of the inventory models are developed with a single warehouse. Now-a-days, with the advent of multi-nationals, specially in developing countries, there is an acute scarcity of marketing space in important market places like municipality market, super market, corporation market, etc. Normally, due to large stock and limited capacity of exiting storage (market warehouse, MW), an additional storage of infinite capacity (with sufficient space) (rented warehouse, RW) which is located away from MW is rented to store the excess items. Several authors like Bhunia and Maiti (1998) and Maity (2011) have considered this type of inventory model for defective/deteriorating items.

In this model, following Liu and Iwamura (1998), Maity (2011), the fuzzy constraints represented as possibility and necessity or possibility constraints respectively. A new type of representation for these constraints is presented. For application, a new type of two warehouse optimal production inventory model has been formulated and solved under imprecise budget and imprecise storage capacity constraints which are reduced to possibility or necessity types respectively. These imprecise constraints are defuzified following Liu and Iwamura (1998), Maity (2011).

Usually, the holding cost is greater in MW than in RW. The actual service to customers is done at MW only. Considering the reality, it is assumed here that holding cost at MW is made by the management to keep MW full of goods to attract more customers (due to stock dependent demand) and also to protect from the loss of goodwill though the holding cost at MW is higher than that in RW. So, in order to meet the demand, continuously the items are first transported from production centre to MW and after filling the MW fully, the excess items are stocked in RW. After some time the production is stopped in the production centre and then the items are continuously transported to MW from RW.

The total profit is expressed as an integral and maximized formulating the problem as an optimal control problem. It is solved following the Pontryagin's principle (cf. Pontryagin et al. (1962)), the Kuhn-Tucker conditions and mathematica 9.0.1 software. The optimum production and stock levels are determined for known demand function. The model is illustrated through numerical examples and results are presented graphically also.

26.4.1 *Optimal Control Framework for Two Warehouses Problem*

Assumption and Notation:
For a defective multi-item inventory control model, following assumptions and notations are used (Fig. 26.3).

(i) there are n items, For ith ($i = 1, 2, \ldots, n$) item, it is assumed that
(ii) Demand rate is stock dependent,
(iii) rate of defectiveness (δ_i) is constant
(iv) shortages are not allowed,
(v) defective units occur only when the item is effectively produced and they are to be sold at reduced prices (s_i),
(vi) the holding cost of RW ($h_{iR}(= h_{iR1} + \frac{h_{iR2}}{ds_1^k})$) is distance ($ds_1$) (from production center to RW) dependent and the holding cost of MW (h_{iM}) is constant and greater than that in RW,

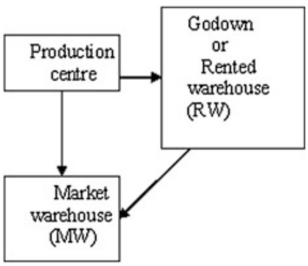

Fig. 26.3 Production centre and two warehouses

(vii) the distance of MW from RW is always constant,
(viii) unit production cost (C_{ui}) is known and constant,
(ix) the inventory level at MW ($X_{iM}(t)$), and at RW ($X_{iR}(t)$), demand at MW ($D_{iM}(X(t)) = d_{i0} + d_{ik}X_{iM}(t)$) and production ($U_i(t)$) are assumed to be continuous function of time with appropriate units,
(x) lead time is negligible,
(xi) the items from production centre or RW are continuously transferred to MW,
(xii) this is a single period inventory model with finite time(T) horizon,
(xiii) transportation is made first from the production centre to MW and after fulfilling MW, the produced items are transported to RW and after some time, the production is stopped in production center. Then the items are transported from RM to MW. The transported cost from production center to RW ($tr_{iR}(= tr_{iR1} + tr_{iR2}\, ds_1^k\, (tr_{iR1}\; tr_{iR2})$ and RW to MW ($tr_{iRM}(= tr_{iRM1} + tr_{iRM2}\, ds_2^k\, (tr_{iRM1}$ and tr_{iRM2}) is distance dependent but it is constant from production center to MW (tr_{iM}),
(xiv) setup cost ($set_1 + \frac{set_2}{ds_1^k}$) is distance dependent (set_1, set_2 and k are positive constants),
(xv) selling price (p_i) is constant,
(xvi) the storage area ($\tilde{a}_i$), maximum space available for storage ($\tilde{M}$) and total budgetary capital ($\tilde{Z}$) are triangular fuzzy numbers.

26.4.2 *Optimal Control Problem Formulation*

26.4.2.1 Proposed Production-Inventory Model in Fuzzy Environment

A defective n-items production-inventory system with budget and stock dependent demand is considered. Here, the items are produced at a variable rate $U_i(t)$, of which δ_i fraction is defective. Demand of the items is stock dependent and the stock level at time t decreases due to defectiveness and consumption. Shortages are not allowed. The space and budgetary constraints are satisfied with some predefined necessity and possibility respectively. Also capacity of MW is limited but the capacity of RW is unlimited. We assume that initially the produced items of production center is continuously transfered to MW and keeping the stock in fullfill level, the extra items are transported to RW and onces the production is stoped, then to meed the demand and keep the MW in fullfill level, we supply the items from RW and at a time the RW is exhousted and the stock of MW meets the demand of MW.

Then the differential equation for ith item to MW during a fixed time-horizon, T is

$$\dot{X}_{iM}(t) = (1 - \delta_i)U_i(t) - D_{iM}(X(t)) \quad \text{in} \quad (0,\ t_1), ((1 - \delta_i)U_i(t) > D_{iM}(X(t))) \tag{26.24}$$

Keeping fulfill the stock in MW, the stock equation in MW and RW are

$$\dot{X}_{iM}(t) = D_{iM}(X(t)) - D_{iM}(X(t)) = 0 \quad \text{in} \quad (t_1, t_{2i}) \tag{26.25}$$

$$\dot{X}_{iR}(t) = (1-\delta_i)U_i(t) - D_{iM}(X(t)) \quad \text{in} \quad (t_i, t_{2i})((1-\delta_i)U_i(t) > D_{iM}(X(t))) \tag{26.26}$$

After production, the stock equation in MW and RW are

$$\dot{X}_{iM}(t) = D_{iM}(X(t)) - D_{iM}(X(t)) = 0 \quad \text{in} \quad (t_{2i},\, t_{3i}) \tag{26.27}$$

$$\dot{X}_{iR}(t) = -D_{iM}(X(t)) \quad \text{in} \quad (t_{2i}, t_{3i}) \tag{26.28}$$

After the exhaust of stock in RW, the equation in MW are

$$\dot{X}_{iM}(t) = -D_{iM}(X(t)) \quad in \quad (t_{3i},\, T) \tag{26.29}$$

with boundary conditions $X_{iM}(0) = 0,\, X_{iR}(t_1) = 0, X_{iR}(t_{3i}) = 0,\, X_{iM}(T) = 0.$

Assuming the warehouse of finite capacity and investment constraint, total profit consisting of selling price, holding and production costs leads to

$$\begin{aligned} \text{Max PF} = \sum_{i=1}^{n} \left(\int_0^T (p_i D_{iM}(X(t)) \right) + s_i \delta_i U_i(t) \\ - h_{iM} X_{iM}(t) - h_{iR} X_{iR}(t) - C_{ui} U_i(t))dt - \int_0^{t_1} tr_{iM}(1-\delta_i)U_i(t)dt \\ - \int_{t_1}^{t_{2i}} tr_{iM} D_{iM}(X(t))dt - \int_{t_1}^{t_{2i}} tr_{iR}((1-\delta_i)U_i(t) - D_{iM}(X(t)))dt \\ - \int_{t_{2i}}^{t_{3i}} tr_{iRM} D_{iM}(X(t)))dt + \left(set_1 + \frac{set_2}{ds_1^k} \right) \end{aligned} \tag{26.30}$$

$$\text{subject to (24)–(29)}, \sum_{i=1}^{n} \tilde{a}_i X_i(t) \le \tilde{M} \tag{26.31}$$

$$\text{and} \sum_{i=1}^{n} \int_0^T C_{ui} U_i(t)dt \le \tilde{Z} \tag{26.32}$$

$$0 \le U_i(t) \le u_i, \quad 0 \le t \le T. \tag{26.33}$$

The fuzzy constraints (26.31) and (26.32) actually stand for the fuzzy relations. There are several representations of fuzzy relations. Here, these relations are interpreted in the setting of possibility/necessity theory Maity and Maiti (2007), Maity (2011) and others).

According to Liu and Iwamura (1998) and others, the constraints (26.31) and (26.32) reduce to following respective necessity and possibility constraints. There may be two different combinations of the fuzzy constraints depicting the different scenarios.

Scenario-1

$$\text{Nes}\ \left\{\sum_{i=1}^{n}\tilde{a}_i X_{iM}(t)\leq\tilde{M}\right\}>\eta_{11}$$
$$\text{Pos}\left(\sum_{i=1}^{n}\int_0^T C_{ui}U_i(t)\leq\tilde{Z}\right)>\eta_2.$$

Scenario-2

$$\text{Pos}\ \left\{\sum_{i=1}^{n}\tilde{a}_i X_{iM}(t)\leq\tilde{M}\right\}>\eta_{12}$$
$$\text{and Pos}\left(\sum_{i=1}^{n}\int_0^T C_{ui}U_i(t)\leq\tilde{Z}\right)>\eta_2.$$

26.4.2.2 Equivalent Crisp Representation of the Proposed Model

Let $\tilde{a}_i=(a_{i1},a_{i2},a_{i3})$, $\tilde{M}=(M_1,M_2,M_3)$, and $\tilde{Z}=(Z_1,Z_2,Z_3)$ be triangular fuzzy numbers. Then using Lemmas 1 and 2, the problem represented by ((26.30)–(26.32)) reduces to following single objective crisp problem:

$$\begin{aligned}\text{Max}\,PF=\sum_{i=1}^{n}(&\int_0^T(p_iD_{iM}(X_i(t))+s_i\delta_i)U_i(t)-h_{iM}X_{iM}(t)-h_{iR}X_{iR}(t)\\&-\ C_{ui}U_i(t))dt-\int_0^{t_1}tr_{iM}(1-\delta_i))U_i(t)dt\\&-\int_{t_1}^{t_{2i}}(tr_{iM}-tr_{iR})D_{iM}(X(t))dt-\int_{t_1}^{t_{2i}}tr_{iR}(1-\delta_i))U_i(t)dt\\&-\int_{t_{2i}}^{t_{3i}}tr_{iRM}D_{iM}(X(t))dt)+(set_1+\frac{set_2}{ds_1^k})\end{aligned}\tag{26.34}$$

subject to the constraint (26.24)–(26.29) for all scenarios and for Scenario-1:

$$\frac{\sum_{i=1}^{n} a_{i3}X_{iM}(t) - M_1}{M_2 - M_1 + \sum_{i=1}^{n} a_{i3}X_{iM}(t) - \sum_{i=1}^{n} a_{i2}X_{iM}(t)} < 1 - \eta_{11}(\text{using Lemma 1}) \tag{26.35}$$

$$\text{and } \sum_{i=1}^{n} C_{ui}U_i(t) \le \frac{(\eta_2 Z_2 + (1-\eta_2)Z_3)}{T}, (\text{using Lemma 2}) \tag{26.36}$$

for Scenario-2:

$$\frac{M_3 - \sum_{i=1}^{n} a_{i1}X_{iM}(t)}{M_3 - M_2 + \sum_{i=1}^{n} a_{i2}X_{iM}(t) - \sum_{i=1}^{n} a_{i1}X_{iM}(t)} > \eta_{12}(\text{using Lemma 2}) \tag{26.37}$$

$$\text{and } \sum_{i=1}^{n} C_{ui}U_i(t) \le \frac{(\eta_2 Z_2 + (1-\eta_2)Z_3)}{T}, (\text{using Lemma 2}) \tag{26.38}$$

26.4.2.3 Mathematical Technique to Solve the Above Crisp Model

For the problem (26.34)–(26.36) (Scenario-1) and (26.34), (26.37)–(26.38) (Scenario-2), the corresponding Hamiltonian function is

$$\begin{aligned} H = \sum_{i=1}^{n} &(p_i D_{iM}(X(t)) + (s_i\delta_i - C_{ui})U_i(t) - h_{iM}X_{iM}(t) \\ &- tr_{iM}(1-\delta_i))U_i(t) + q_{iM}(t)((1-\delta_i)U_i(t) - D_{iM}(X(t)))) \text{ in } (0, t_1), \end{aligned} \tag{26.39}$$

$$\begin{aligned} = \sum_{i=1}^{n} &(p_i D_{iM}(X(t)) + (s_i\delta_i - C_{ui})U_i(t) \\ &- h_{iM}X_{iM}(t) - h_{iR}X_{iR}(t) - tr_{iM}D_{iM}(X(t)) + (q_{iR}(t) - tr_{iR})((1-\delta_i)U_i(t) \\ &- D_{iM}(X(t)))) \text{ in } (t_1, t_{2i}), \end{aligned} \tag{26.40}$$

$$\begin{aligned} = \sum_{i=1}^{n} &(p_i D_{iM}(X(t)) - h_{iM}X_{iM}(t) - h_{iR}X_{iR}(t) - tr_{iRM}D_{iM}(X(t)) \\ &- q_{iR}(t)D_{iM}(X(t))) \text{ in } (t_{2i}, t_{3i}), \end{aligned} \tag{26.41}$$

$$= \sum_{i=1}^{n} (p_i D_{iM}(X(t)) - h_{iM} X_{iM}(t) - q_{iM}(t) D_{iM}(X(t))) \text{ in } (t_{3i}, T). \tag{26.42}$$

And the Lagrangian function for the constraints (26.23)–(26.26) for the jth ($j = 1, 2$) scenario is

$$\begin{aligned} L = H - \lambda_1 (\sum_{i=1}^{n} X_{iM}(t) a_{i1j} - M_{1j}) \\ - \lambda_2 (\sum_{i=1}^{n} C_{ui} U_i(t) - \frac{(\eta_2 Z_2 + (1 - \eta_2) Z_3)}{T}) \end{aligned} \tag{26.43}$$

where $\lambda_1, \lambda_2 (\geq 0)$ is the Lagrange multipliers respectively and $a_{i11} = a_{i2}(1 - \eta_{11}) + a_{i3}\eta_{11}; a_{i12} = a_{i1}(1 - \eta_{12}) + a_{i2}\eta_{12}; M_{11} = M_2(1 - \eta_{11}) + M_1\eta_{11}$ and $M_{12} = \eta_{12} M_2 + (1 - \eta_{12}) M_3$

Then, the Kuhn-Tucker conditions for jth (j = 1, 2) scenario are

$$\lambda_1 (\sum_{i=1}^{n} X_{iM}(t) a_{i1j} - M_{1j}) = 0 \tag{26.44}$$

$$\lambda_2 (\sum_{i=1}^{n} C_{ui} U_i(t) - \frac{\eta_2 Z_2 + (1 - \eta_2) Z_3}{T}) = 0, \quad \lambda_i > 0, \; i = 1, 2. \tag{26.45}$$

The corresponding adjoint functions $q_{iM}(t)$ and $q_{iR}(t)$ are given by first order differential equation,

$$\dot{q}_{iM}(t) = -\frac{\partial L}{\partial X_{iM}(t)} \tag{26.46}$$

$$\text{or } \dot{q}_{iM}(t) = -p_i d_{i1} + h_{iM} + \lambda_1 a_{i1j} + q_{iM}(t) d_{i1} \text{ in } (0, t_1) \tag{26.47}$$

$$= -p_i d_{i1} + h_{iM} + tr_{iM} d_{i1} + \lambda_1 a_{i1j} + (q_{iR}(t) - tr_{iR}) d_{i1} \text{ in } (t_1, t_{2i}) \tag{26.48}$$

$$= -p_i d_{i1} + h_{iM} + tr_{iRM} d_{i1} + \lambda_1 a_{i1j} + q_{iR}(t) d_{i1} \text{ in } (t_{2i}, t_{3i}) \tag{26.49}$$

$$= -p_i d_{i1} + h_{iM} + \lambda_1 a_{i1j} + q_{iM}(t) d_{i1} \text{ in } (t_{3i}, T) \tag{26.50}$$

$$\text{and } \dot{q}_{iR}(t) = -\frac{\partial L}{\partial X_{iR}(t)} \tag{26.51}$$

$$\text{or } \dot{q}_{iR}(t) = 0 \tag{26.52}$$

$$= h_{iR} \text{ in } (t_1,\ t_{3i}) \tag{26.53}$$

$$= 0 \text{ in } (t_{3i},\ T) \tag{26.54}$$

with $q_{iM}(T) = 0, q_{iR}(T) = 0$.

Following the maximum principle, the Lagrangian is maximized at every point of time with respect to admissible controllable production function $U_i(t)$. This leads to the relation,

$$\begin{aligned}\frac{\partial L}{\partial U_i(t)} = s_i\delta_i - C_{ui} + (q_{iM}(t) - tr_{iM})(1 - \delta_i))\\ - \lambda_2 C_{ui} \text{ in } (0, t_1)\end{aligned} \tag{26.55}$$

$$\begin{aligned}= s_i\delta_i - C_{ui} + (q_{iR}(t) - tr_{iR})(1 - \delta_i)\\ - \lambda_2 C_{ui1} \text{ in } (t_1, t_{2i})\end{aligned} \tag{26.56}$$

$$= -\lambda_2 C_{ui1} \text{ in } (t_{2i},\ T) \tag{26.57}$$

$$q_{iM}(t) = q_{iM}(t_1) - e^{-d_{i1}(t_1-t)} + (p_i d_{i1} - \lambda_1 a_{i1j} - h_{iM})(\frac{1 - e^{-d_{i1}(t_1-t)}}{d_{i1}}), (0, t_1) \tag{26.58}$$

$$\begin{aligned}= q_{iM}(t_{2i}) + ((p_i + tr_{iR} - tr_{iM})d_{i1} - \lambda_1 a_{i1j} - h_{iM})(t_2 - t)\\ - \frac{d_{i1}h_{iR}}{2}((t_{3i} - t)^2 - (t_{2i} - t_{3i})^2), (t_1, t_{2i})\end{aligned} \tag{26.59}$$

$$\begin{aligned}= q_{iM}(t_{3i}) + ((p_i - tr_{iRM})d_{i1} - \lambda_1 a_{i1j} - h_{iM})(t_3 - t)\\ + \frac{d_{i1}h_{iR}}{2}(t_{3i} - t)^2, (t_{2i}, t_{3i})\end{aligned} \tag{26.60}$$

$$= (p_i d_{i1} - \lambda_1 a_{i1j} - h_{iM})\frac{1 - e^{-d_{i1}(T-t)}}{d_{i1}}, (t_{3i}, T) \tag{26.61}$$

Here three cases may aries,
Case-1: $\frac{\partial L}{\partial U_i(t)} > 0$
Case-2: $\frac{\partial L}{\partial U_i(t)} = 0$
Case-3: $\frac{\partial L}{\partial U_i(t)} < 0$

For Case-1, the Lagrangian function is a increasing function of production function, $U_i(t)$, for Case-2, the Lagrangian function is obviously maximized for some values of $U_i(t)$ (for $\lambda_2 < 1$) given that $\frac{\partial L}{\partial U_i(t)} = 0$ and for Case-3, the Lagrangian function is a decreasing function of production function. Using Mathematica 9.0.1 software, obtain the numerical result.

26.4.3 Numerical Illustration

The production inventory model is illustrated numerically for two items. The others input data and corresponding output result are given below.

26.4.3.1 Input Data

An inventory system of two ($n = 2$) items with a storage house of capacity $(M_1, M_2, M_3) = (80,\ 100,\ 120)$ sq mt., unit area $(\tilde{a}_1, \tilde{a}_2) = ((1.9, 2.0, 2.1), (2.1, 2.2, 2.3))$ sq mt. budget cost $(Z_1, Z_2, Z_3) = (1000\$, 1050\$, 1100\$)$, production costs $C_{u1} = 5\$, C_{u2} = 5.25\$, k = 1.5, ds_1 = 22$ units, $ds_2 = 30$ units, $set_1 = 40\$, set_2 = 20\$, T = 10$ units and $\eta_{11} = 0.1, \eta_{12} = 0.65, \eta_2 = 0.60$ are considered. Also the sales cost p_1 = 12\$, p_2 = 15\$, s_1 = 5.5\$ and s_1 = 6\$. The holding cost h_{1M} = 0.5\$, h_{2m} = 0.5\$, h_{1R1} = 0.2, h_{1R2} = 0.3\$, h_{2R2} = 0.21\$ and h_{2R2} = 0.3\$. The transportation cost tr_{1M} = 0.2\$, tr_{2M} = 0.3\$, tr_{1R1} = 0.1\$, tr_{1R2} = 0.01\$, tr = 0.11\$, tr_{2R2} = 0.01\$, tr_{1RM1} = 0.11\$, tr_{1RM2} = 0.01\$, tr_{2RM1} = 0.12\$ and tr_{2RM2} = 0.01\$. The imperfective rates $\delta_1 = 0.10$ and $\delta_2 = 0.11$. The demand coefficient $d_{10} = 5.0$, $d_{11} = 0.2$, $d_{20} = 4.0$ and $d_{21} = 0.3$. The upper bound of the production $u_1 = 25$ and $u_2 = 26$ are consider. Here demand function at MW is taken as $D_{iM}(X(t)) = d_{i0} + d_{i1}X_{iM}(t)$, i $= 1, 2$.

26.4.3.2 Results for Different Scenarios

Results of Scenario-1

Production rate $U_i(t)$, stock rate $X_{iM}(t), X_{iR}(t)$ and demand rate $D_{iM}(t)(= d_{i0} + d_{i1}X_{iM}(t))$, $i = 1, 2$ are given in Tables 26.2 and 26.3 and corresponding maximum value of objective function, PF = 623.24\$ and PF = 638.21\$ for Scenarios-1 and -2 respectively.

Maximum amount of space utilized is 98 sq mt.for Scenario-1.

These functions can be plotted for different values of t in $(0, T)$. Here, $X_{1M}(t)$, $X_{1R}(t)$, $U_1(t)$ and $D_{1M}(X(t))$ are depicted in Fig. 26.4. The curves for $X_{2M}(t)$, $X_{2R}(t)$ $U_2(t)$ and $D_{2M}(X(t))$ are exactly of similar nature.

26.5 A Three Layer Supply Chain Imperfect Production Inventory Model Under Permissible Delay in Payments in Uncertain Environment

A supply chain model (SCM) is a network of supplier, producer, retailer and customer which synchronizes a series of inter-related business process in order to have: (i) optimal procurement of raw materials from market; (ii) transportation of

Table 26.2 Values of $X_{iM}(t), X_{iR}(t), U_i(t)$ and $D_{iM}(X(t))$ (i = 1, 2) under scenario-1

t	0	1	1.5	2.5	3.65	4.65	6.5	7	8	9	10
$X_{iM}(t)$	0	15.86	23.45	23.45	23.45	23.45	23.45	19.37	11.73	5.51	0
	0	16.54	23.52	23.52	23.52	23.52	23.52	18.50	10.60	4.52	0
$X_{iR}(t)$	0	0	0.01	12.80	27.52	17.82	0.01	0	0	0	0
	0	0	0.02	12.09	25.99	18.96	1.02	0	0	0	0
$U_i(t)$	25	25	25	25	25	0	0	0	0	0	0
	26	26	26	26	26	0	0	0	0	0	0
$D_{iM}(X(t))$	5	8.17	9.7	9.7	9.7	9.7	9.7	8.81	7.32	6.1	5
	4	8.96	11.06	11.06	11.06	11.06	11.06	9.8	7.35	5.5	4

Table 26.3 Values of $X_{iM}(t), X_{iR}(t), U_i(t)$ and $D_{iM}(X(t))$(i = 1, 2) under scenario-2

t	0	1	1.6	2.6	3.72	4.72	6.3	7	8	9	10
$X_{iM}(t)$	0	15.86	25.7	25.7	25.7	25.7	25.7	19.39	11.86	5.56	0
	0	16.54	25.82	25.82	25.82	25.82	25.82	18.70	10.98	4.81	0
$X_{iR}(t)$	0	0	0.01	12.36	26.27	16.13	0.01	0	0	0	0
	0	0	0.02	11.69	24.65	18.30	1.04	0	0	0	0
$U_i(t)$	25	25	25	25	25	0	0	0	0	0	0
	26	26	26	26	26	0	0	0	0	0	0
$D_{iM}(X(t))$	5	8.17	10.14	10.14	10.14	10.14	10.14	8.83	7.33	6.13	5
	4	8.96	11.45	11.45	11.45	11.45	11.45	9.8	7.38	5.5	4

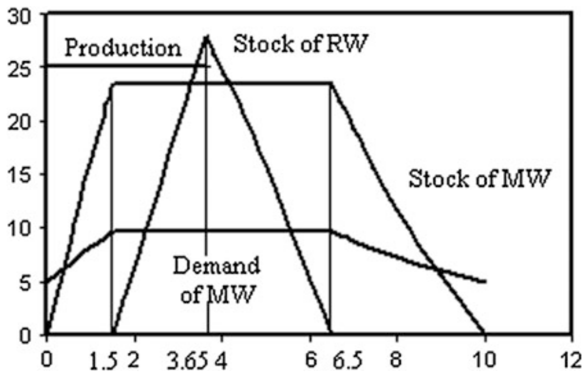

Fig. 26.4 Optimal production, stock level and demand for Scenario-1

raw-materials into warehouse; (iii) production of the goods in the production centre and (iv) distribution of these finished products to the retailer for sale to the customers. With a recent paradigm shift to the supply chain (SC), the ultimate success of a firm may depend on its ability to link supply chain members seamlessly.

Traditional definitions of SC and SCM have very little to do with what the product is going through after its delivery to customers. One of the earliest efforts to create an integrated SCM dates back to Bookbinder, Cachon and Zipkin (1999), Agarwal et al. (2004) and others. They developed a production, distribution and inventory (PDI) planning system that integrated three supply chain segments comprised of supply, storage/location and customer demand planning. The core of the PDI system was a network model and diagram that increased the decision maker's insights into supply chain connectivity. The model however was confined to a single-period and single-objective problem. Das et al. (2007) have been developed a Two Warehouse Supply-Chain Model Under Possibility/Necessity/Credibility Measures. Peidro et al. (2010) develops a fuzzy linear programming model for tactical supply chain planning in a multi-echelon, multi-product, multi-level, multi-period supply chain network in fuzzy environment. Krishnan and Winter (2010) developed an inventory dynamics and supply chain model. Chu (2011) developed the supply chain flexibility that has become increasingly important. This study thus builds a group decision-making structure model of flexibility in supply chain management development. Hoque (2011) have been developed an optimal solution technique to the single-vendor multi-buyer integrated inventory supply chain by incorporating some realistic factors. Kristianto et al. (2012) developed an adaptive fuzzy control application to support a vendor managed inventory (VMI). This paper also guides management in allocating inventory by coordinating suppliers and buyers to ensure minimum inventory levels across a supply chain. Jana et al. (Jana et al. 2014) developed a three layer supply chain production inventory model under permissible delay in payment in uncertain environment. Jonrinaldi (2013) developed an integrated supply chain production inventory model involving reverse logistics with finite horizon period. Recently, Maity (2014) developed a supply chain production inventory model with warehouse facility in fuzzy environment. A moment ago, Giri and Maiti (2013) developed a supply chain system in which the sole manufacturer supplies the same product to two retailers.

In this model, we developed three layer supply chain production inventory model (TLSCPIM) under fuzzy rough and Liu uncertain environment. Delay in payment is also considered. The suppliers collect the raw material (ore) and produce the raw material of actual manufacture. Then manufacturer produce the usable product to sale the retailer. Also using expectation of fuzzy rough number and Liu uncertain number, the fuzzy rough inventory parameters and Liu uncertain inventory parameters are converted into equivalent crisp problem. Then the problem is solved by Mathematica software 9.0. The model is illustrated through numerical examples and results are presented in tabular and graphical form.

26.6 Assumptions and Notations

The following assumption and notation are consider to develop the model.

26.6.1 Assumptions

(i) Model is developed for single item product.
(ii) Lead time is negligible.
(iii) Joint effect of supplier, manufacturer, retailer is consider in a supply chain management.
(iv) Supplier produced the item with constant rate p_s unit per unit time.
(v) Total production rate of manufacturer is equal to the demand rate of manufacturer which is decision variable.
(vi) The manufacturer give the opportunity to the retailer conditionally permissible delay in payment.
(vii) Idle cost of suppliers, manufacturer and retailer are taken into account.

26.6.2 Notations

p_s = collection rate of supplier.
p_m = supply rate of supplier (decision variable).

$\delta e^{(1-R)}$ = reliability dependent defective rate.
$(1-\beta)\delta\, e^{(1-R)} p_m$ = rework rate of manufacturer.
$\left(1-\beta\delta\, e^{(1-R)}\right) p_m$ = production rate of manufacturer (decision variable).
$\beta\delta\, e^{(1-R)}$ = reliability dependent disposal rate.
$D_R + \gamma\upsilon T_R$ = demand rate for the retailer which is advertisement dependent.
$D_c + \gamma\upsilon$ = demand rate of customer which is also advertisement dependent.
β = disposal rate which is constant.
C_s = collection cost of unit item of supplier.
C_{m0} = selling price of unit item of suppliers which is also purchase cost of manufacturer.
C_{rw} = rework cost of manufacturer.
$C_{m1}(R) = M_1 + N_1 e^{k\frac{(R-R_{min})}{R_{max}-R}}$, Development cost dependent on reliability parameter.
α = wear tear cost.
$C_m(R) = \left(C_{m0} + \frac{C_{m1}(R)}{p_m} + \alpha p_m\right)$ = unit production cost which depend on production rate, raw material cost, development cost and wear tear cost of manufacturer.
R = reliability parameter.
δ = imperfective parameter.
R_{min} = minimum value of the reliability parameter.
R_{max} = maximum value of the reliability parameter.
M_1 = the fixed cost like labor and energy costs which is independent of reliability factor R.
N_1 = the cost of technology, resource and design complexity for production when $R = R_{min}$.
c_υ = advertisement cost per unit per unit time.
υ = advertisement unit time.
C_r = selling price of unit item of manufacturer which is also purchase cost of retailer.
C_{r1} = selling price of retailer.
C_{rw} = rework cost per unit of manufacturer.
C_d = cost to dispose the disposal unit of manufacturer.
C_{co2} = cost due to equivalent c_{o_2} per unit quantity.
t_s = collection time of suppler.
T_s = cycle length of supplier.
T_R = length of each time period of retailer.
T' = last cycle length of the retailer.
T = total time for the integrated model.
$h_s, \tilde{\tilde{h}}_s$ *and* $\widehat{h_s}$ = holding cost per unit per unit time of supplier in crisp, fuzzy rough and Liu uncertain environment respectively.

h_m, $\tilde{\tilde{h}}_m$ *and* $\widehat{h_m}$ = holding cost per unit per unit time of manufacturer in crisp, fuzzy rough and Liu uncertain environment respectively.

h_r, $\tilde{\tilde{h}}_r$ *and* $\widehat{h_r}$ = holding cost per unit per unit time of retailer in crisp, fuzzy rough and Liu uncertain environment respectively.

h_m, $\tilde{\tilde{h}}_m$ *and* $\widehat{h_m}$ = ordering cost of supplier in crisp, fuzzy rough and Liu uncertain environment respectively.

A_m, $\tilde{\tilde{A}}_m$ *and* $\widehat{A_m}$ = ordering cost of manufacturer in crisp, fuzzy rough and Liu uncertain environment respectively.

A_r, $\tilde{\tilde{A}}_r$ *and* $\widehat{A_r}$ = ordering cost of retailer in crisp, fuzzy rough and Liu uncertain environment respectively.

id_s, $i\tilde{\tilde{d}}_s$ *and* $\widehat{id_s}$ = idle cost per unit time of supplier in crisp, fuzzy rough and Liu uncertain environment respectively.

id_m, $i\tilde{\tilde{d}}_m$ *and* $\widehat{id_m}$ = idle cost per unit time of manufacturer in crisp, fuzzy rough and Liu uncertain environment

id_r, $i\tilde{\tilde{d}}_r$ *and* $\widehat{id_r}$ = idle cost per unit time of retailer in crisp, fuzzy rough and Liu uncertain environment respectively.

n = number of cycle of retailer.

r = number of cycle where manufacturer stop the production.

M = retailers trade credit period offered by the manufacturer to the retailer in years.

I_p = interest payable to the manufacturer by the retailer.

I_{re} = interest earned by the retailer.

$q_s(t)$ = inventory level of suppliers in time [0, T].

$q_m(t)$ = inventory level of manufacturer in time [0, T].

$q_r(t)$ = inventory level of retailers in time [0, T].

ATP, $A\tilde{\tilde{T}}P$ average total profit of the integrated models in crisp, fuzzy rough environment respectively.

$\widehat{ATP}$ average total profit of the integrated models in Liu uncertain environment.

p_{m*} = optimum value of p_m of integrated models.

26.7 Model Description and Diagrammatic Representation

The logical flow of the TLSCPIM is depicted in Fig. 26.5 and mathematically the model shown in Fig. 26.6 starts with stock zero at $t = 0$. At that time the supplier starts his production with constant rate p_s unit per unit time and sales to the manufacturer at the rate p_m unit per unit time, when $t = t_s$ suppliers stop his production and at $t = T_s$ the inventory level of suppliers become zero. The total time of the integrated model is T, so the idle time for supplier is $T - T_s$. Similarly manufacturer starts his production at the same time $t = 0$ with production rate p_m unit per unit time and sales this production at the rate D_R unit per unit time to the retailer in the time gap T_R, which is the bulk pattern. At time $t = T_s$ manufacturer stop the production and at $t = (n+1)T_R$ $(n = [\frac{(1-\beta\delta e^{(1-R)})p_m T_s}{D_R+\gamma\upsilon T_R}])$ stock of manufacturer is zero. So idle period for manufacturer is $T - (n+1)T_R$. Retailer start his business of this production to the customer at time $t = T_R$ and end at $T = (n+1)T_R + \frac{(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}$. The idle period for retailer is T_R.

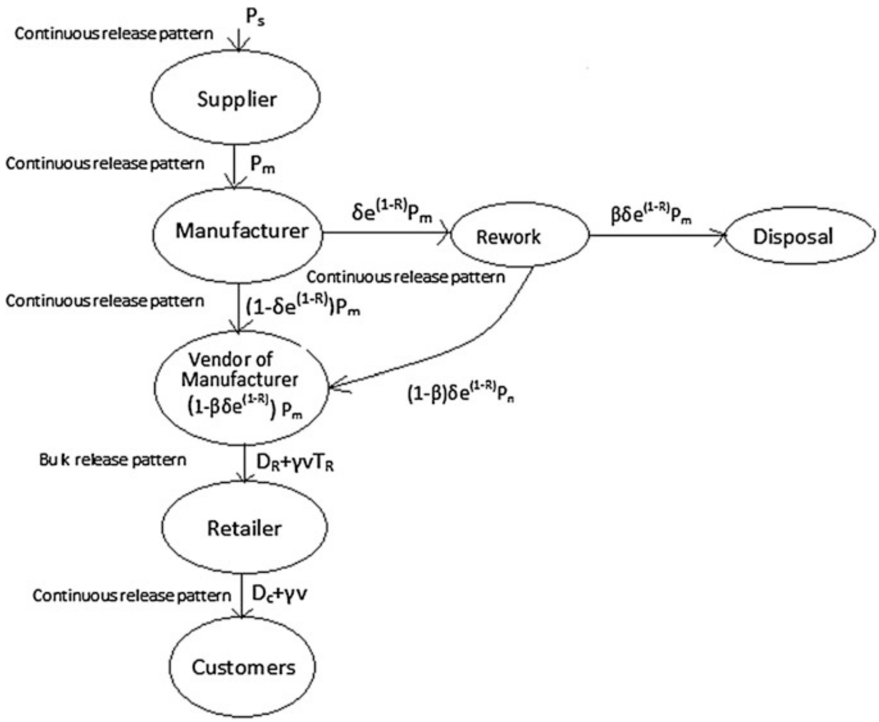

Fig. 26.5 Logical flow of TLSCPIM

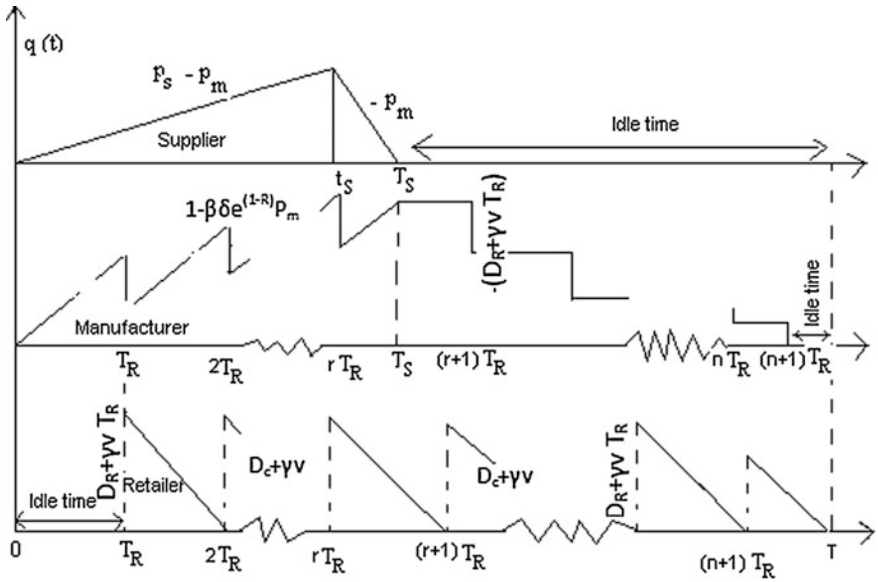

Fig. 26.6 Mathematical structure of the TLSCPIM

26.8 Mathematical Formulation of the Model

26.8.1 Formulation of Suppliers Individual Average Profit

Differential equation for the supplier in [0, T] is given by

$$\frac{dq_s}{dt} = \begin{cases} p_s - p_m, & 0 \le t \le t_s \\ -p_m, & t_s \le t \le T_s \\ 0, & T_s \le t \le T \end{cases}$$

with boundary condition $q_s(t) = 0, t = 0, T_s$. Solving the differential equation with boundary condition, we have

$$q_s(t) = \begin{cases} (p_s - p_m)t, & 0 \le t \le t_s \\ p_m(T_s - t) & t_s < t \le T_s \\ 0, & T_s < t \le T \end{cases} \tag{26.62}$$

by continuity at $t = t_s$, we get $p_m T_s = p_s t_s$ and total unit produced by the supplier in $[0, t_s]$ $Q_s = p_s t_s = p_m T_s$(= Total demand during $[0, T_s]$)

$$\begin{aligned} H_s &= \text{Holding cost of supplier} \\ &= h_s\left[\int_0^{t_s}(p_s - p_m)tdt + \int_{t_s}^{T_s} p_m(T_s - t)dt\right] \\ &= h_s\left[p_mT_s^2 - \frac{p_m^2T_s^2}{p_s}\right] \end{aligned}$$

The idle cost of supplier $= id_s[(n+1)T_R + \frac{(1-\beta\delta e^{(1-R)})p_mT_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s]$
Total purchase cost $= c_sp_mT_s$
Total selling price $= c_{m0}p_mT_s$
Ordering cost is $= A_s$

$$\begin{aligned} \text{APS} &= \text{Average profit of supplier} \\ &= \frac{1}{T}[\text{revenue from sale} - (\text{purchase} + \text{holding} + \text{idle} + \text{ordering})\text{ cost.}] \\ &= \frac{1}{T}\left[(c_m0 - c_s)p_st_s - h_s\left[p_mT_s^2 - \frac{p_m^2T_s^2}{p_s}\right] - id_s[(n+1)T_R\right. \\ &\quad \left. + \frac{(1-\beta\delta)p_mT_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - A_s\right] \end{aligned} \tag{26.63}$$

26.8.2 Formulation of Manufacturer Individual Average Profit

Inventory level of manufacturer in [0, T] is given by

$$q_m(t) = \begin{cases} \left(1-\beta\delta e^{(1-R)}\right)p_mt, & 0 \le t \le T_R \\ \left(1-\beta\delta e^{(1-R)}\right)p_mt - i(D_R+\gamma\upsilon T_R), & iT_R < t \le (i+1)T_R, \quad i = 1,2,\ldots,(r-1) \\ \left(1-\beta\delta e^{(1-R)}\right)p_mt - r(D_R+\gamma\upsilon T_R), & rT_R < t \le T_s \\ \left(1-\beta\delta e^{(1-R)}\right)p_mT_s - r(D_R+\gamma\upsilon T_R), & T_s < t \le (r+1)T_R \\ \left(1-\beta\delta e^{(1-R)}\right)p_mT_s - i(D_R+\gamma\upsilon T_R), & iT_R < t \le (i+1)T_R, \quad i = r+1,\ r+2,\ldots,n-1 \\ \left(1-\beta\delta e^{(1-R)}\right)p_mT_s - n(D_R+\gamma\upsilon T_R), & nT_R < t \le (n+1)T_R \\ 0, & (n+1)T_R \le t \le T \end{cases} \tag{26.64}$$

with boundary condition $q_m(0) = 0$, and $q_m(iT_R + 0) = q_m(iT_R) - D_R$

$H_m =$ Holding cost for manufacturer.

$$= h_m\Bigg[\int_0^{T_R}\left(1-\beta\delta^{(1-R)}\right)p_m t + \sum_1^{r-1}\int_{iT_R}^{(i+1)T_R}\left[(1-\beta\delta)e^{(1-R)}p_m t - i(D_R+\gamma\upsilon T_R)\right]dt$$

$$+ \int_{rT_R}^{(T_s}\left[\left(1-\beta\delta\, e^{(1-R)}\right)p_m t - r(D_R+\gamma\upsilon T_R)\right]dt + \int_{T_s}^{(r+1)T_R}\left[\left(1-\beta\delta\, e^{(1-R)}\right)p_m T_s\right.$$

$$\left.- r(D_R+\gamma\upsilon T_R)\right]dt + \sum_{r+1}^{n-1}\int_{iT_R}^{(i+1)T_R}\left[\left(1-\beta\delta\, e^{(1-R)}\right)p_m T_s - i(D_R+\gamma\upsilon T_R)\right]dt$$

$$+ \int_{nT_n}^{(n+1)T_R}\left[\left(1-\beta\delta\, e^{(1-R)}\right)p_m T_s - n(D_R+\gamma\upsilon T_R)\right]dt\Bigg]$$

$$= h_m\left[n\left(1-\beta\delta\, e^{(1-R)}\right)p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) - \frac{\left(1-\beta\delta^{(1-R)}\right)p_m T_s^2}{2}\right],$$

The idle cost of manufacturer $= id_m\left[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}\right]$,
Total purchase cost $= c_m(R)p_m T_s$,
Total selling price $= c_r(1-\beta\delta\, e^{(1-R)})p_m T_s$,
Total rework cost $= c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T$,
Total advertisement cost $= c_\upsilon(e^\upsilon - 1)T$,
Ordering cost $= A_m$.
Pollution control cost due to manufacturing of manufacturer $= c_{o_2}\epsilon_m p_m T_s$
And disposal cost = $c_d\beta\delta e^{(1-R)}p_m T_s$

26.8.2.1 Case-I (When $M \le T' \le T_R$)

$I_{em} = I_{pr} =$ Amount of interest earned by the manufacturer in [0, T] from retailer.
$=$ Amount of interest paid by the retailer to the manufacturer in [0, T].

$$= c_r i_p\Bigg[n\int_M^{T_R}[(D_R+\gamma\upsilon T_R)-(D_c+\gamma\upsilon)t]dt$$

$$+ \int_M^{T\prime}\left[\left(1-\beta\, e^{(1-R)}\right)p_m T_s - n(D_R+\gamma\upsilon T_R) - (D_c+\gamma\upsilon)t\right]dt\Bigg]$$

$$= \frac{nc_r i_p}{2}\left[T_R(D_R+\gamma\upsilon T_R) + (D_c+\gamma\upsilon)M^2 - 2M(D_R+\gamma\upsilon T_R)\right]$$

$$+ c_r i_p\Bigg[\frac{\left[\left(1-\beta\delta\, e^{(1-R)}\right)p_m T_s - n(D_R+\gamma\upsilon T_R)\right]^2}{2(D_c+\gamma\upsilon)}$$

$$+ \left[\left(1-\beta\delta^{(1-R)}\right)p_m T_s - n(D_R+\gamma\upsilon T_R)\right]m + \frac{(D_c+\gamma\upsilon)M^2}{2}\Bigg]$$

$$
\begin{aligned}
APM_1 &= \text{Average profit of Manufacturer.}\\
&= \frac{1}{T}[\text{revenue from sale-purchase cost-holding cost-idle cost}\\
&\quad + \text{ earned interest from retailers-advertisement cost-rework cost-disposal cost}\\
&\quad - \text{ ordering cost-pollution control cost}]\\
&= \frac{1}{T}\Big[\Big[c_r\Big(1-\beta\delta\, e^{(1-R)}\Big) - c_m(R)\Big]p_mT_s - h_m\Big[n\Big(1-\beta\delta\, e^{(1-R)}\Big)p_mT_sT_R\\
&\quad - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) - \frac{\big(1-\beta\delta\, e^{(1-R)}\big)p_mT_s^2}{2}\Big]\\
&\quad - id_m\left[\frac{\big(1-\beta\delta\, e^{(1-R)}p_mT_s\big)-n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}\right] + \frac{nc_ri_p}{2}\big[T_R(D_R+\gamma\upsilon T_R)+(D_c+\gamma\upsilon)M^2\\
&\quad - 2M(D_R+\gamma\upsilon T_R)\big] + c_ri_p\left(\frac{\big[\big(1-\beta\delta\, e^{(1-R)}\big)p_mT_s - n(D_R+\gamma\upsilon T_R)\big]^2}{2(D_c+\gamma\upsilon)}\right.\\
&\quad \left. + \Big[\Big(1-\beta\delta\, e^{(1-R)}\Big)p_mT_s - n(D_R+\gamma\upsilon T_R)\Big]M + \frac{(D_c+\gamma\upsilon)M^2}{2}\right)\\
&\quad - c_\upsilon(e^\upsilon-1)T - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_mT_s - c_d\beta\delta e^{(1-R)}p_mT_s - A_m - c_{o2}\epsilon_m p_mT_s\Big]
\end{aligned}
\tag{26.65}
$$

26.8.2.2 Case-II (When $T' \leq M \leq T_R$)

$$
\begin{aligned}
I_{em}I_{pr} &= \text{Amount of interest earned by the manufacturer in } [0, \text{T}] \text{ from retailer.}\\
&= \text{Amount of interest paid by the retailer to the manufacturer in } [0, \text{T}].\\
&= nc_ri_p\int_M^{T_R}[(D_R+\gamma\upsilon T_R)-(D_c+\gamma\upsilon)t]dt\\
&= \frac{nc_ri_p}{2}[(T_R-M)(2\gamma\upsilon T_R - M(D_c-\gamma\upsilon))]
\end{aligned}
$$

$$
\begin{aligned}
APM_2 &= \text{Average profit of Manufacturer.}\\
&= \frac{1}{T}[\text{revenue from sale-purchase cost-holding cost-idle cost}\\
&\quad + \text{ earned interest-advertisement cost-rework cost-disposal cost}\\
&\quad - \text{ ordering cost-pollution control cost.}]
\end{aligned}
$$

$$
\begin{aligned}
= \frac{1}{T}\Big[&[c_r(1-\beta\delta e^{(1-R)}) - c_m(R)]p_m T_s - h_m\Big[n(1-\beta\delta e^{(1-R)})p_m T_s T_R \\
&- \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) - \frac{(1-\beta\delta e^{(1-R)})p_m T_s^2}{2}\Big] \\
&- id_m[\frac{(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] \\
&+ \frac{nc_r i_p}{2}[(T_R-M)(2\gamma\upsilon T_R - M(D_c-\gamma\upsilon))] - c_\upsilon(e^\upsilon-1)T - c_{rw}(1-\beta)\delta e^{(1-R)}p_m T_s \\
&- c_d\beta\delta e^{(1-R)}p_m T_s - A_m - c_{o_2}\epsilon_m p_m T_s]
\end{aligned} \tag{26.66}
$$

26.8.2.3 Case-III (When $M \geq T_R$)

$$
\begin{aligned}
I_{em} = I_{pr} &= \text{Amount of interest earned by the manufacturer in [0, T] from retailer.} \\
&= \text{Amount of interest paid by the retailer to the manufacturer in [0, T].} \\
&= 0
\end{aligned}
$$

$$
\begin{aligned}
APM_3 &= \text{Average profit of Manufacturer.} \\
&= \frac{1}{T}[\text{revenue from sale-purchase cost-holding cost-idle cost} \\
&\quad + \text{earned interest-advertisement cost-rework cost-disposal cost} \\
&\quad - \text{ordering cost-pollution control cost.}] \\
&= \frac{1}{T}\Big[[c_r(1-\beta\delta e^{(1-R)}) - c_m(R)]p_m T_s - h_m\Big[n(1-\beta\delta e^{(1-R)})p_m T_s T_R \\
&\quad - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) - \frac{(1-\beta\delta e^{(1-R)})p_m T_s^2}{2}\Big] \\
&\quad - id_m[\frac{(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma v T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon-1)T \\
&\quad - c_{rw}(1-\beta)\delta e^{(1-R)}p_m T_s - c_d\beta\delta e^{(1-R)}p_m T_s - A_m \\
&\quad - c_{o_2}\epsilon_m p_m T_s\Big]
\end{aligned} \tag{26.67}
$$

26.8.3 *Formulation of Retailer Individual Average Profit*

Inventory level of retailer in [0,T] is given by

$$
q_r(t) = \begin{cases} (D_R+\gamma\upsilon T_R) - (D_c+\gamma\upsilon)t, & iT_R \leq t \leq (i+1)T_R \\ (1-\beta\delta)e^{(1-R)}p_m T_s - n(D_R+\gamma\upsilon T_R) - (D_c+\gamma\upsilon)t, & (n+1)T_R \leq t \leq T \end{cases} \tag{26.68}
$$

with boundary condition $q_r((n+1)T_R)=0$, and $q_r(T)=0$

$$H_r = \text{Holding cost of retailer.}$$
$$= nh_r\left[\int_0^{T_R}[(D_R+\gamma\upsilon T_R)-(D_c+\gamma\upsilon)t]dt+\int_0^{T'}[(1-\beta\delta e^{(1-R)})p_mT_s-n(D_R+\gamma\upsilon T_R)\right.$$
$$\left. -(D_c+\gamma\upsilon)t]dt\right]$$
$$=\frac{h_r}{2}\left[\frac{[(1-\beta\delta e^{(1-R)})p_m]^2T_s^2}{D_c+\gamma\upsilon}-2n(1-\beta\delta e^{(1-R)})p_mT_sT_R-(2n+1)T_R(D_R+\gamma\upsilon T_R)\right]$$

The idle cost of retailer $= id_rT_R$
Total purchase cost $= c_r(1-\beta\delta e^{(1-R)})p_mT_s$
Total selling price $= c_{r1}(1-\beta\delta e^{(1-R)})p_mT_s$
Ordering cost $= A_r$.

26.8.3.1 Case-I (When $M\le T'\le T_R$)

Interest earned by the retailers for $(n+1)$ cycle is given by

$$I_{er} = \text{Amount of interest earned by the retailer from Bank in (n + 1) cycle.}$$
$$= (n+1)c_{r_1}i_e\left[\int_0^M(M-t)(D_c+\gamma\upsilon)dt\right]$$
$$=\frac{(n+1)c_{r_1}i_e(D_c+\gamma\upsilon)M^2}{2},$$

$$I_{pr} = \text{Amount of interest paid by the retailer to the manufacturer in [0, T].}$$
$$= c_ri_p\left[n\int_M^{T_R}[(D_R+\gamma\upsilon T_R)-(D_c+\gamma\upsilon)t]dt\right.$$
$$\left.+\int_M^{T'}[(1-\beta\delta)e^{(1-R)}p_mT_s-n(D_R+\gamma\upsilon T_R)-(D_c+\gamma\upsilon)t]dt\right]$$
$$=\frac{nc_ri_p}{2}[T_R(D_R+\gamma\upsilon T_R)+(D_c+\gamma\upsilon)M^2-2M(D_R+\gamma\upsilon T_R)]$$
$$+c_ri_p[\frac{[(1-\beta\delta)e^{(1-R)}p_mT_s-n(D_R+\gamma\upsilon T_R)]^2}{2(D_c+\gamma\upsilon)}$$
$$+[(1-\beta\delta e^{(1-R)})p_mT_s-n(D_R+\gamma\upsilon T_R)]M+\frac{(D_c+\gamma\upsilon)M^2}{2}]$$

$$\begin{aligned}
APR_1 = &\ \text{Average profit of retailer.}\\
= &\ \frac{1}{T}[\text{revenue from sale-purchase cost-holding cost}\\
&+ \text{earned interest-payable interest-idle cost-ordering cost}]\\
= &\ \frac{1}{T}\Bigg[c_{r_1}(1-\beta\delta e^{(1-R)})p_m T_s - c_r(1-\beta\delta e^{(1-R)})p_m T_s - \frac{h_r}{2}\Bigg[\frac{[(1-\beta\delta e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon}\\
&- 2n(1-\beta\delta e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R)\Bigg] + \frac{(n+1)c_{r_1} i_e (D_c+\gamma\upsilon)M^2}{2}\\
&- \frac{nc_r i_p}{2}[T_R(D_R+\gamma\upsilon T_R) + (D_c+\gamma\upsilon)M^2 - 2M(D_R+\gamma\upsilon T_R)]\\
&- c_r i_p\Bigg[\frac{[(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)]^2}{2(D_c+\gamma\upsilon)}\\
&+ [(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)]M + \frac{(D_c+\gamma\upsilon)M^2}{2}\Bigg] - id_r T_R - A_r\Bigg]
\end{aligned} \tag{26.69}$$

26.8.3.2 Case-II (When $T' \le M \le T_R$)

Interest earned by the retailer for $(n+1)$ cycle

$$\begin{aligned}
I_{er} = &\ \text{Amount of interest earned by the retailer from Bank in n cycle.}\\
= &\ c_{r_1} i_e\Bigg[n\int_0^M (M-t)(D_c+\gamma\upsilon)dt + \int_0^{T'} (T'-t)(D_c+\gamma\upsilon)dt\\
&+ (M-T')[(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)]\Bigg]\\
= &\ \frac{nc_{r_1} i_e (D_c+\gamma\upsilon)M^2}{2} + \frac{c_{r_1} i_e}{2}[(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T')
\end{aligned}$$

Interest payable by the retailers for 1st n cycle is given by

$$\begin{aligned}
I_{pr} = &\ \text{Amount of interest paid by the retailer to the manufacturer in } [0, \mathrm{T}].\\
= &\ nc_r i_p \int_M^{T_R} [(D_R+\gamma\upsilon T_R) - (D_c+\gamma\upsilon)t]dt\\
= &\ \frac{nc_r i_p}{2}[(T_R-M)(2\gamma\upsilon T_R - M(D_c-\gamma\upsilon))]
\end{aligned}$$

$$
\begin{aligned}
APR_2 &= \text{Average profit for retailer.}\\
&= \frac{1}{T}[\text{revenue from sale-purchase cost-holding cost}\\
&\quad + \text{ earned interest-payable interest - idle cost-ordering cost}].\\
&= \frac{1}{T}\Bigg[c_{r_1}(1-\beta\delta e^{(1-R)})p_m T_s - c_r(1-\beta\delta e^{(1-R)})p_m T_s - \frac{h_r}{2}[\frac{[(1-\beta\delta e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon}\\
&\quad - 2n(1-\beta\delta e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R) + \frac{nc_{r_1}i_e(D_c+\gamma\upsilon)M^2}{2}\\
&\quad + \frac{c_{r_1}i_e}{2}[(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T')\\
&\quad - \frac{nc_r i_p}{2}[(T_r-M)(2\gamma\upsilon T_R - M(D_c+\gamma\upsilon))] - id_r T_R - A_r\Bigg]
\end{aligned}
\tag{26.70}
$$

26.8.3.3 Case-III (When $M \geq T_R$)

Interest earned by the retailer for $(n+1)$ cycle

$$
\begin{aligned}
I_{er} &= \text{Amount of interest earned by the retailer from Bank in (n + 1) cycle.}\\
&= c_{r_1}i_e\Bigg[n\int_0^{T_R}(T_R-t)(D_c+\gamma\upsilon)dt + n(M-T_R)(D_R+\gamma\upsilon T_R)\\
&\quad + \int_0^{T'}(T'-t)(D_c+\gamma\upsilon)dt + (M-T')[(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)]\Bigg]\\
&= \frac{nc_{r_1}i_e(D_c+\gamma\upsilon)T_R^2}{2} + nc_{r_1}i_e(M-T_R)(D_R+\gamma\upsilon T_R) + \frac{c_{r_1}i_e}{2}[(1-\beta\delta e^{(1-R)})p_m T_s\\
&\quad - n(D_R+\gamma\upsilon T_R)](2M-T')
\end{aligned}
$$

Interest payable by the retailers for 1st $(n+1)$ cycle is given by

$$
\begin{aligned}
I_{pr} &= \text{Amount of interest paid by the retailer to the manufacturer in } [0, \text{T}].\\
&= 0
\end{aligned}
$$

$$\begin{aligned}
APR_3 = & \text{ Average profit for retailer.} \\
= & \frac{1}{T}\ [\text{revenue from sale-purchase cost-holding cost} \\
& + \text{ earned interest-payable interest - idle cost-ordering cost}]. \\
= & \frac{1}{T}\left[c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{h_r}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} \right. \\
& - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R) + \frac{nc_{r_1} i_e (D_c+\gamma\upsilon)T_R^2}{2} \\
& + nc_{r_1} i_e (M-T_R)(D_R+\gamma\upsilon T_R) + \frac{c_{r_1} i_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T') \\
& \left. - id_r T_R - A_r \right]
\end{aligned} \tag{26.71}$$

26.9 Integrated Model

26.9.1 In Crisp Environment

26.9.1.1 Case-I (When $M \le T' \le T_R$)

$$\begin{aligned}
\text{Maximize}\, ATP_1 = & \text{ Total average profit for integrated model} \\
= & \ APS + APM_1 + APR_1 \\
= & \frac{1}{T}[(c_{m0}-c_s)p_s t_s - h_s[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - id_s[(n+1)T_R \\
& + \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - A_s + [c_r(1-\beta\delta\, e^{(1-R)}) - c_m(R)]p_m T_s \\
& - h_m\left[n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) - \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\right] \\
& - id_m[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T - c_{rw}(1-\beta)\delta\, e^{(1-R)} p_m T_s \\
& - c_d\beta\delta e^{(1-R)} p_m T_s - A_m - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s \\
& - \frac{h_r}{2}\left(\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R)\right) \\
& + \frac{(n+1)c_{r_1} i_e (D_c+\gamma\upsilon)M^2}{2} - id_r T_R - A_r \Big]
\end{aligned} \tag{26.72}$$

26.9.1.2 Case-II (When $T^{'} \leq M \leq T_R$)

$$\begin{aligned}
\text{Maximize } ATP_2 &= \text{Total average profit for integrated model} \\
&= APS + APM_2 + APR_2 \\
&= \frac{1}{T}\Bigg[(c_{m0}-c_s)p_s t_s - h_s[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - id_s[(n+1)T_R \\
&\quad + \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - A_s + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&\quad - c_m(R)\Bigg]p_m T_s - h_m\Bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
&\quad - \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg) - id_m[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T
\end{aligned}$$

$$\begin{aligned}
&- c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T_s - c_d\beta\delta e^{(1-R)}p_m T_s - A_m - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s \\
&- c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{h_r}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R \\
&- (2n+1)T_R(D_R+\gamma\upsilon T_R) + \frac{nc_{r_1}i_e(D_c+\gamma\upsilon)M^2}{2} + \frac{c_{r_1}i_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s \\
&- n(D_R+\gamma\upsilon T_R)](2M-T') - id_r T_R - A_r\Bigg]
\end{aligned} \tag{26.73}$$

26.9.1.3 Case-III (When $M \geq T_R$)

$$\begin{aligned}
\text{Maximize } ATP_3 &= \text{Total average profit for integrated model} \\
&= APS + APM_3 + APR_3 \\
&= \frac{1}{T}\Bigg[(c_{m0}-c_s)p_s t_s - h_s[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - id_s[(n+1)T_R \\
&\quad + \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - A_s + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&\quad - c_m(R)]p_m T_s - h_m\Bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
&\quad - \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg) - id_m[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T \\
&\quad - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T_s - c_d\beta\delta e^{(1-R)}p_m T_s - A_m - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s \\
&\quad - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{h_r}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R \\
&\quad - (2n+1)T_R(D_R+\gamma\upsilon T_R) + \frac{nc_{r_1}i_e(D_c+\gamma\upsilon)T_R^2}{2} + nc_{r_1}i_e(M-T_R)(D_R+\gamma\upsilon T_R) \\
&\quad + \frac{c_{r_1}i_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T') - id_r T_R - A_r\Bigg]
\end{aligned} \tag{26.74}$$

26.9.2 In Fuzzy Rough(Fu Ro) Environment

In this environment, we have considered all holding cost, idle cost and setup cost as fuzzy-rough parameters. Then the crisp model in Eqs. (26.72)–(26.74) becomes fuzzy-rough model and the corresponding fuzzy-rough objective function is

26.9.2.1 For Case-I $M \leq T' \leq T_R$

$$
\begin{aligned}
\text{Max}\,(A\tilde{\tilde{T}}P_1) = \frac{1}{T}\Bigg[& (c_{m0} - c_s)p_s t_s - \tilde{\tilde{h}}_s[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - i\tilde{\tilde{d}}_s[(n+1)T_R \\
& + \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R + \gamma\upsilon T_R)}{D_c + \gamma\upsilon} - T_s] - \tilde{\tilde{A}}_s + [c_r(1-\beta\delta\, e^{(1-R)}) - c_m(R)]p_m T_s \\
& - \tilde{\tilde{h}}_m\Bigg[n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R + \gamma\upsilon T_R) \\
& - \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg] - i\tilde{\tilde{d}}_m[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R + \gamma\upsilon T_R)}{D_c + \gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T \\
& - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - \tilde{\tilde{A}}_m - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s \\
& - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{\tilde{\tilde{h}}_r}{2}\Bigg(\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c + \gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R \\
& - (2n+1)T_R(D_R + \gamma\upsilon T_R)\Bigg) + \frac{(n+1)c_{r_1}I_e(D_c + \gamma\upsilon)M^2}{2} - i\tilde{\tilde{d}}_r T_R - \tilde{\tilde{A}}_r\Bigg]
\end{aligned}
\tag{26.75}
$$

where $p_m T_s = p_s t_s$.

26.9.2.2 For Case-II ($T' \leq M \leq T_R$)

$$
\begin{aligned}
Max(A\tilde{\tilde{T}}P_2) = \frac{1}{T}\Bigg[& (c_{m0} - c_s)p_s t_s - \tilde{\tilde{h}}_s[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - i\tilde{\tilde{d}}_s[(n+1)T_R \\
& + \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R + \gamma\upsilon T_R)}{D_c + \gamma v} - T_s] - \tilde{\tilde{A}}_s + [c_r(1-\beta\delta\, e^{(1-R)}) \\
& - c_m(R)]p_m T_s - \tilde{\tilde{h}}_m\Bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R + \gamma\upsilon T_R)
\end{aligned}
$$

$$- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}) - i\tilde{\tilde{d}}_m[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T$$
$$- c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - \tilde{\tilde{A}}_m - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s$$
$$- c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{\tilde{\tilde{h}}_r}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R$$
$$- (2n+1)T_R(D_R+\gamma\upsilon T_R)] + \frac{nc_{r_1}\tilde{I}_e(D_c+\gamma\upsilon)M^2}{2} + \frac{c_{r_1}I_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s$$
$$- n(D_R+\gamma\upsilon T_R)](2M-T') - i\tilde{\tilde{d}}_r T_R - \tilde{\tilde{A}}_r\Big] \tag{26.76}$$

26.9.2.3 For Case-III ($M \geq T_R$)

$$\text{Max}\,(A\tilde{\tilde{T}}P_2) = \frac{1}{T}\Big[(c_{m0}-c_s)p_s t_s - \tilde{\tilde{h}}_s[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - i\tilde{\tilde{d}}_s[(n+1)T_R$$
$$+ \frac{(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - \tilde{\tilde{A}}_s + [c_r(1-\beta\delta\, e^{(1-R)})$$
$$- c_m(R)]p_m T_s - \tilde{\tilde{h}}_m\Big(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R)$$
$$- \frac{(1-\beta\delta e^{(1-R)})p_m T_s^2}{2}\Big) - i\tilde{\tilde{d}}_m[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T$$
$$- c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - \tilde{\tilde{A}}_m - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s$$
$$- c_r(1-\beta\delta e^{(1-R)})p_m T_s - \frac{\tilde{\tilde{h}}_r}{2}[\frac{[(1-\beta\delta e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R$$
$$- (2n+1)T_R(D_R+\gamma\upsilon T_R)] + \frac{nc_{r_1}I_e(D_c+\gamma\upsilon)T_R^2}{2} + nc_{r_1}i_e(M-T_R)(D_R+\gamma\upsilon T_R)$$
$$+ \frac{c_{r_1}I_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T') - i\tilde{\tilde{d}}_r T_R - \tilde{\tilde{A}}_r\Big] \tag{26.77}$$

(here $\simeq$ denotes the fuzzy rough parameters).

Where fuzzy rough variables $\tilde{\tilde{h}}_s, \tilde{\tilde{h}}_m, \tilde{\tilde{h}}_r$, $\tilde{\tilde{i}}d_s, \tilde{\tilde{i}}d_m, \tilde{\tilde{i}}d_r\, \tilde{\tilde{A}}_s, \tilde{\tilde{A}}_m$, and $\tilde{\tilde{A}}_r$ are defined as follows,

$\tilde{\tilde{h}}_s = (\overline{h}_{s1}, \overline{h}_{s2}, \overline{h}_{s3}, \overline{h}_{s4})$ with $\overline{h}_{st} \vdash ([h_{st2}, h_{st3}], [h_{st1}, h_{st4}]),\ 0 \le h_{st1} \le h_{st2} < h_{st3} \le h_{st4},$
$\tilde{\tilde{h}}_m = (\overline{h}_{m1}, \overline{h}_{m2}, \overline{h}_{m3}, \overline{h}_{m4})$ with $\overline{h}_{mt} \vdash ([h_{mt2}, h_{mt3}], [h_{mt1}, h_{mt4}]),\ 0 \le h_{mt1} \le h_{mt2} < h_{mt3} \le h_{mt4}.$
$\tilde{\tilde{h}}_r = (\overline{h}_{r1}, \overline{h}_{r2}, \overline{h}_{r3}, \overline{h}_{r4})$ with $\overline{h}_{rt} \vdash ([h_{rt2}, h_{rt3}], [h_{rt1}, h_{rt4}]),\ 0 \le h_{rt1} \le h_{rt2} < h_{rt3} \le h_{rt4}.$
$\tilde{\tilde{id}}_s = (\overline{id}_{s1}, \overline{id}_{s2}, \overline{id}_{s3}, \overline{id}_{s4})$ with $\overline{id}_{st} \vdash ([id_{st2}, id_{st3}], [id_{st1}, id_{st4}]),\ 0 \le id_{st1} \le id_{st2} < id_{st3} \le id_{st4},$
$\tilde{\tilde{id}}_m = (\overline{id}_{m1}, \overline{id}_{m2}, \overline{id}_{m3}, \overline{id}_{m4})$ with $\overline{id}_{mt} \vdash ([id_{mt2}, id_{mt3}], [id_{mt1}, id_{mt4}]),\ 0 \le id_{mt1} \le id_{mt2} < id_{mt3} \le id_{mt4}.$
$\tilde{\tilde{id}}_r = (\overline{id}_{r1}, \overline{id}_{r2}, \overline{id}_{r3}, \overline{id}_{r4})$ with $\overline{id}_{rt} \vdash ([id_{rt2}, id_{rt3}], [id_{rt1}, id_{rt4}]),\ 0 \le id_{rt1} \le id_{rt2} < id_{rt3} \le id_{rt4}.$
$\tilde{\tilde{A}}_s = (\overline{A}_{s1}, \overline{A}_{s2}, \overline{A}_{s3}, \overline{A}_{s4})$ with $\overline{A}_{st} \vdash ([A_{st2}, A_{st3}], [A_{st1}, A_{st4}]),\ 0 \le A_{st1} \le A_{st2} < A_{st3} \le A_{st4},$
$\tilde{\tilde{A}}_m = (\overline{A}_{m1}, \overline{A}_{m2}, \overline{A}_{m3}, \overline{A}_{m4})$ with $\overline{A}_{mt} \vdash ([A_{mt2}, A_{mt3}], [A_{mt1}, A_{mt4}]),\ 0 \le A_{mt1} \le A_{mt2} < A_{mt3} \le A_{mt4}.$
$\tilde{\tilde{A}}_r = (\overline{A}_{r1}, \overline{A}_{r2}, \overline{A}_{r3}, \overline{A}_{r4})$ with $\overline{A}_{rt} \vdash ([A_{rt2}, A_{rt3}], [A_{rt1}, A_{rt4}]),\ 0 \le A_{rt1} \le A_{rt2} < A_{rt3} \le A_{rt4}.$
$\mathrm{t} = 1, 2, 3, 4.$

26.9.3 Equivalent Fuzzy Rough(Fu Ro) Model

Using Lemma 5 and Theorems 1 and 2, the fuzzy rough model in Eq. (26.75) becomes

26.9.3.1 For Case-I ($M \le T' \le T_R$)

$$\begin{aligned}
E[\mathrm{Max}\,(A\tilde{\tilde{T}}P_1)] = \frac{1}{T}\Bigg[& (c_{m0} - c_s)p_s t_s - E[\tilde{\tilde{h}}_s][p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - E[i\tilde{\tilde{d}}_s][(n+1)T_R \\
& + \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R + \gamma\upsilon T_R)}{D_c + \gamma\upsilon} - T_s] - E[\tilde{\tilde{A}}_s] + [c_r(1-\beta\delta\, e^{(1-R)}) \\
& - c_m(R)]p_m T_s - E[\tilde{\tilde{h}}_m]\Bigg[n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
& - \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg] - E[i\tilde{\tilde{d}}_m][\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] \\
& - c_\upsilon(e^\upsilon - 1)T - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - E[\tilde{\tilde{A}}_m] - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s \\
& + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{E[\tilde{\tilde{h}}_r]}{2}\Bigg(\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} \\
& - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R)\Bigg) + \frac{(n+1)c_{r_1}I_e(D_c+\gamma\upsilon)M^2}{2} \\
& - E[i\tilde{\tilde{d}}_r]T_R - E[\tilde{\tilde{A}}_r]\Bigg]
\end{aligned} \tag{26.78}$$

26.9.3.2 For Case-II ($T' \leq M \leq T_R$)

Using Lemma 7 and Theorems 1 and 2, the fuzzy rough model in Eq. (26.76) becomes

$$\begin{aligned}
E[\text{Max}\,(A\tilde{\tilde{T}}P_2)] = \frac{1}{T}\Bigg[&(c_{m0}-c_s)p_s t_s - E[\tilde{\tilde{h}}_s][p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - E[i\tilde{\tilde{d}}_s][(n+1)T_R \\
&+ \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - E[\tilde{\tilde{A}}_s] + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&- c_m(R)]p_m T_s - E[\tilde{\tilde{h}}_m]\Bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2} T_R(D_R+\gamma\upsilon T_R) \\
&- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg) - E[i\tilde{\tilde{d}}_m][\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] \\
&- c_\upsilon(e^\upsilon-1)T - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - E[\tilde{\tilde{A}}_m] - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s \\
&+ c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{E[\tilde{\tilde{h}}_r]}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} \\
&- 2n(1-\beta\delta e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R) + \frac{nc_{r_1}I_e(D_c+\gamma\upsilon)M^2}{2} \\
&+ \frac{c_{r_1}I_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T') - E[i\tilde{\tilde{d}}_r]T_R - E[\tilde{\tilde{A}}_r]\Bigg]
\end{aligned} \tag{26.79}$$

26.9.3.3 For Case-III ($M \geq T_R$)

Using Lemma 5 and Theorems 1 and 2, the fuzzy rough model in Eq. (26.77) becomes

$$\begin{aligned}
E[\text{Max}\,(A\tilde{\tilde{T}}P_2)] = \frac{w_1}{T}\Bigg[&(c_{m0}-c_s)p_s t_s - E[\tilde{\tilde{h}}_s][p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - E[i\tilde{\tilde{d}}_s][(n+1)T_R \\
&+ \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - E[\tilde{\tilde{A}}_s] + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&- c_m(R)]p_m T_s - E[\tilde{\tilde{h}}_m]\Bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2} T_R(D_R+\gamma\upsilon T_R) \\
&- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg) - E[i\tilde{\tilde{d}}_m][\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] \\
&- c_\upsilon(e^\upsilon-1)T - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - E[\tilde{\tilde{A}}_m] - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s \\
&+ c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{E[\tilde{\tilde{h}}_r]}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} \\
&- 2n(1-\beta\delta e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R) + \frac{nc_{r_1}I_e(D_c+\gamma\upsilon)T_R^2}{2} \\
&+ nc_{r_1}i_e(M-T_R)(D_R+\gamma\upsilon T_R) + \frac{c_{r_1}I_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T') \\
&-E[i\tilde{\tilde{d}}_r]T_R - E[\tilde{\tilde{A}}_r]\Bigg]
\end{aligned} \tag{26.80}$$

where

$$E[\tilde{\bar{h}}_s] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} h_{stk}, \quad E[\tilde{\bar{h}}_m] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} h_{mtk}, \quad E[\tilde{\bar{h}}_r] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} h_{rtk},$$
$$E[\tilde{\bar{id}}_s] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} id_{stk}, \quad E[\tilde{\bar{id}}_m] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} id_{mtk}, \quad E[\tilde{\bar{id}}_r] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} id_{rtk},$$
$$E[\tilde{\bar{A}}_s] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} A_{stk}, \quad E[\tilde{\bar{A}}_m] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} A_{mtk}, \quad E[\tilde{\bar{A}}_r] = \frac{1}{16}\sum_{t=1}^{4}\sum_{k=1}^{4} A_{rtk},$$

26.10 In Liu Uncertain Environment

In this environment, we have considered all holding cost, idle cost and setup cost as Zigzag Liu Uncertain parameters. Then the crisp model in Eqs. (26.72)–(26.74) becomes Liu Uncertain model and the corresponding Liu Uncertain objective function is

26.10.1 For Case-I $M \le T' \le T_R$

$$\begin{aligned}
\text{Max}\,(\widehat{ATP_1}) = \frac{1}{T}\Bigg[&(c_{m0} - c_s)p_s t_s - \widehat{h_s}[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - \widehat{id_s}[(n+1)T_R \\
&+ \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R + \gamma\upsilon T_R)}{D_c + \gamma\upsilon} - T_s] - \widehat{A_s} + [c_r(1-\beta\delta\, e^{(1-R)}) - c_m(R)]p_m T_s \\
&- \widehat{h_m}[n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
&- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}] - \widehat{id_m}[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T \\
&- c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - \widehat{A_m} - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s \\
&- c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{\widehat{h_r}}{2}\Bigg(\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R \\
&- (2n+1)T_R(D_R+\gamma\upsilon T_R)\Bigg) + \frac{(n+1)c_{r_1}I_e(D_c+\gamma\upsilon)M^2}{2} - \widehat{id_r}T_R - \widehat{A_r}\Bigg]
\end{aligned} \tag{26.81}$$

where $p_m T_s = p_s t_s$,

26.10.2 For Case-II ($T' \leq M \leq T_R$)

$$
\begin{aligned}
\text{Max }(\widehat{ATP_2}) =& \frac{1}{T}\Bigg[(c_{m0}-c_s)p_s t_s - \widehat{h_s}[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - \widehat{id_s}[(n+1)T_R \\
&+ \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - \widehat{A_s} + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&- c_m(R)]p_m T_s - \widehat{h_m}\Bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
&- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg) - \widehat{id_m}[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T \\
&- c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - \widehat{A_m} - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s \\
&- c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{\widehat{h_r}}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R \\
&- (2n+1)T_R(D_R+\gamma\upsilon T_R)] + \frac{nc_{r_1}I_e(D_c+\gamma\upsilon)M^2}{2} + \frac{c_{r_1}I_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s \\
&- n(D_R+\gamma\upsilon T_R)](2M-T') - \widehat{id_r}T_R - \widehat{A_r}\Bigg]
\end{aligned}
\tag{26.82}
$$

26.10.3 For Case-III ($M \geq T_R$)

$$
\begin{aligned}
\text{Max }(\widehat{ATP_2}) =& \frac{1}{T}\Bigg[(c_{m0}-c_s)p_s t_s - \widehat{h_s}[p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - \widehat{id_s}[(n+1)T_R \\
&+ \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - \widehat{A_s} + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&- c_m(R)]p_m T_s - \widehat{h_m}\Bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
&- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg) - \widehat{id_m}[\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] - c_\upsilon(e^\upsilon - 1)T \\
&- c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - \widehat{A_m} - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s + c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s \\
&- c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{\widehat{h_r}}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} - 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R \\
&- (2n+1)T_R(D_R+\gamma\upsilon T_R)] + \frac{nc_{r_1}I_e(D_c+\gamma\upsilon)T_R^2}{2} + nc_{r_1}i_e(M-T_R)(D_R+\gamma\upsilon T_R) \\
&+ \frac{c_{r_1}I_e}{2}[(1-\beta\delta e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T') - \widehat{id_r}T_R - \widehat{A_r}\Bigg]
\end{aligned}
\tag{26.83}
$$

26.10.4 Equivalent Crisp Model

Using Lemmas 5 and 6 and Theorems 3 and 4, the Liu uncertain model in Eq. (26.81) becomes

26.10.4.1 For Case-I ($M \le T' \le T_R$)

$$\begin{aligned}
E[Max\,(\widehat{ATP_1})] =& \frac{1}{T}\Bigg[(c_{m0}-c_s)p_s t_s - E[\widehat{h_s}][p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - E[\widehat{id_s}][(n+1)T_R \\
&+ \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - E[\widehat{A_s}] + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&- c_m(R)]p_m T_s - E[\widehat{h_m}]\Bigg[n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
&- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg] - E[\widehat{id_m}][\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] \\
&- c_\upsilon(e^\upsilon - 1)T - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - E[\widehat{A_m}] - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s \\
&+ c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{E[\widehat{h_r}]}{2}\Bigg(\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} \\
&- 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R)\Bigg) + \frac{(n+1)c_{r_1}I_e(D_c+\gamma\upsilon)M^2}{2} \\
&- E[\widehat{id_r}]T_R - E[\widehat{A_r}]\Bigg]
\end{aligned} \tag{26.84}$$

26.10.4.2 For Case-II ($T' \le M \le T_R$)

Using Lemmas 6 and 7 and Theorems 3 and 4, the fuzzy rough model in Eq. (26.82) becomes

$$\begin{aligned}
E[\mathrm{Max}\,(\widehat{ATP_2})] =& \frac{1}{T}\Bigg[(c_{m0}-c_s)p_s t_s - E[\widehat{h_s}][p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - E[\widehat{id_s}][(n+1)T_R \\
&+ \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon} - T_s] - E[\widehat{A_s}] + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&- c_m(R)]p_m T_s - E[\widehat{h_m}]\Bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
&- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\Bigg) - E[\widehat{id_m}][\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma v}] \\
&- c_\upsilon(e^\upsilon - 1)T - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - E[\widehat{A_m}] - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s \\
&+ c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{E[\widehat{h_r}]}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} \\
&- 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R) + \frac{nc_{r_1}I_e(D_c+\gamma\upsilon)M^2}{2} \\
&+ \frac{c_{r_1}I_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T') - E[\widehat{id_r}]T_R - E[\widehat{A_r}]\Bigg]
\end{aligned} \tag{26.85}$$

26.10.4.3 For Case-III ($M \geq T_R$)

Using Lemmas 6 and 7 and Theorems 3 and 4, the fuzzy rough model in Eq. (26.83) becomes

$$\begin{aligned}
E[\text{Max }(\widehat{ATP_2})] =& \frac{1}{T}\Bigg[(c_{m0} - c_s)p_s t_s - E[\widehat{h_s}][p_m T_s^2 - \frac{p_m^2 T_s^2}{p_s}] - E[\widehat{id_s}][(n+1)T_R \\
&+ \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R + \gamma\upsilon T_R)}{D_c + \gamma\upsilon} - T_s] - E[\widehat{A_s}] + [c_r(1-\beta\delta\, e^{(1-R)}) \\
&- c_m(R)]p_m T_s - E[\widehat{h_m}]\bigg(n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - \frac{n^2+n-2r-2}{2}T_R(D_R+\gamma\upsilon T_R) \\
&- \frac{(1-\beta\delta\, e^{(1-R)})p_m T_s^2}{2}\bigg) - E[\widehat{id_m}][\frac{(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)}{D_c+\gamma\upsilon}] \\
&- c_\upsilon(e^\upsilon - 1)T - c_{rw}(1-\beta)\delta\, e^{(1-R)}p_m T - E[\widehat{A_m}] - c_d\beta\delta e^{(1-R)}p_m T_s - c_{o_2}\epsilon_m p_m^2 T_s \\
&+ c_{r_1}(1-\beta\delta\, e^{(1-R)})p_m T_s - c_r(1-\beta\delta\, e^{(1-R)})p_m T_s - \frac{E[\widehat{h_r}]}{2}[\frac{[(1-\beta\delta\, e^{(1-R)})p_m]^2 T_s^2}{D_c+\gamma\upsilon} \\
&- 2n(1-\beta\delta\, e^{(1-R)})p_m T_s T_R - (2n+1)T_R(D_R+\gamma\upsilon T_R) + \frac{nc_{r_1}I_e(D_c+\gamma\upsilon)T_R^2}{2} \\
&+ nc_{r_1}i_e(M-T_R)(D_R+\gamma\upsilon T_R) + \frac{c_{r_1}I_e}{2}[(1-\beta\delta\, e^{(1-R)})p_m T_s - n(D_R+\gamma\upsilon T_R)](2M-T') \\
&- E[\widehat{id_r}]T_R - E[\widehat{A_r}]\Bigg]
\end{aligned} \tag{26.86}$$

26.11 Numerical Example

To illustrate the above multi-objective TLSCPIM numerically, we consider crisp and fuzzy-rough input datas. The following Table 26.4 is included the crisp datas in crisp environment and corresponding optimum result is given in Table 26.5. Tables 26.6 for fuzzy-rough input datas in fuzzy-rough environment and the corresponding optimum result is given in Table 26.7. Tables 26.8 for Liu Uncertain input datas in Liu Uncertain environment and the corresponding optimum result is given in Table 26.9. Also, Fig. 26.7 is shown the average profit versus supply rate of supplier's in Case-I,-II and -III.

26.11.1 Crisp Environment

26.11.2 Fuzzy-Rough and Equivalent Crisp Environment

Input data of crisp parameter in fuzzy-rough environment are same as Table 26.4 and remaining fuzzy-rough parameters are given in Table 26.6. Optimum result is given in Table 26.7.

Table 26.4 Input data of different parameter in crisp environment for Case-I, -II and -III

Parameter	Case-I	Case-II	Case-III	Parameter	Case-I	Case-II	Case-III
c_s	8	8	8	D_R	120	120	120
c_{m_0}	12	12	12	D_C	50	50	50
c_r	28	28	28	T_s	9	9	9
c_{r_1}	35	35	35	v	4	4	4
p_s	150	150	150	i_e	0.09	0.09	0.09
n	5	6	8	M	1.6	2	2.5
r	4	4	5	i_p	0.1	0.1	0.1
M_1	40	40	40	α	0.02	0.02	0.02
n_1	10	10	10	β	0.4	0.4	0.4
k	0.5	0.5	0.5	γ	0.1	0.1	0.1
R_{min}	0.5	0.5	0.5	δ	0.2	0.2	0.2
R_{max}	0.95	0.95	0.95	c_{rw}	4	4	4
c_d	1	1	1	ε_s	0.1	0.1	0.1
ε_m	0.2	0.2	0.2	ε_r	0.1	0.1	0.1
$C_{c_{o_2}}$	10	10	10	c_v	0.8	0.8	0.8
h_s	0.05	0.05	0.05	A_s	20	20	20
h_m	0.1	0.1	0.1	A_m	30	30	30
h_r	0.2	0.2	0.2	A_r	40	40	40
id_s	1	1	1	id_m	2	2	2
id_r	3	3	3				

26.11.3 Liu Uncertain and Equivalent Crisp Environment

Input data of crisp parameter in Liu Uncertain environment are same as Table 26.5 and remaining Liu uncertain data are given in Table 26.8. Optimum result is given in Table 26.9.

Table 26.5 Optimal values of objective and decision variable in crisp environment for case-I, -II and -III

Parameter	Case-I	Case-II	Case-III	Parameter	Case-I	Case-II	Case-III
ATP^*	1014.63	1082.91	1102.34	APS^*	238.28	243.92	246.32
p_m^*	68.43	72.37	73.69	APM^*	468.96	449.65	432.49
T'	2.32	1.71	1.68	APR^*	307.39	389.34	423.53
R^*	0.7431	0.7681	0.7992				

Table 26.6 Input data of fuzzy-rough parameters and equivalent crisp values for case-I, -II and -III

Fu-Ro parameters	Fu-Ro value	Input values	Expected value	Value
$\tilde{\tilde{h}}_s$	Near roughly(0.05)	$(\overline{0.044}, \overline{0.048}, \overline{0.5}, \overline{0.504})$ with $([-0.01, 0.01], [-0.02, 0.02])$	$E[\tilde{\tilde{h}}_s]$	0.04875
$\tilde{\tilde{h}}_m$	Near roughly(0.1)	$(\overline{0.094}, \overline{0.098}, \overline{0.1}, \overline{0.104})$ with $([-.01, .01], [-.02, .02])$	$E[\tilde{\tilde{h}}_m]$	0.09875
$\tilde{\tilde{h}}_r$	Near roughly(0.2)	$(\overline{0.194}, \overline{0.198}, \overline{0.2}, \overline{0.204})$ with $([-0.01, 0.01], [-0.02, 0.02])$	$E[\tilde{\tilde{h}}_{r_1}]$	0.19875
$\tilde{\tilde{id}}_s$	Near roughly(1)	$(\overline{0.96}, \overline{0.98}, \overline{1.02}, \overline{1.04})$ with $([-.02, .02], [-.04, .04])$	$E[\tilde{\tilde{id}}_s]$	0.9875
$\tilde{\tilde{id}}_m$	Near roughly(2)	$(\overline{1.96}, \overline{1.98}, \overline{2.02}, \overline{2.04})$ with $([-0.02, 0.02], [-0.04, 0.04])$	$E[\tilde{\tilde{id}}_m]$	1.9875
$\tilde{\tilde{id}}_m$	Near roughly(3)	$(\overline{2.96}, \overline{2.98}, \overline{3.02}, \overline{3.04})$ with $([-0.02, 0.02], [-0.04, 0.04])$	$E[\tilde{\tilde{id}}_r]$	2.9875
$\tilde{\tilde{A}}_s$	Near roughly(20)	$(\overline{18}, \overline{19}, \overline{23}, \overline{24})$ with $([-1, 1], [-2, 2])$	$E[\tilde{\tilde{A}}_{r_1}]$	22.5
$\tilde{\tilde{A}}_m$	Near roughly(30)	$(\overline{24}, \overline{29}, \overline{34}, \overline{39})$ with $([-2, 2], [-4, 4])$	$E[\tilde{\tilde{A}}_s]$	31.5
$\tilde{\tilde{A}}_r$	Near roughly(40)	$(\overline{34}, \overline{39}, \overline{44}, \overline{49})$ with $([-3, 3], [-4, 4])$	$E[\tilde{\tilde{A}}_m]$	41.5

Table 26.7 Optimal values of objective and decision variable in equivalent crisp environment for case-I,-II and -III

Parameter	Case-I	Case-II	Case-III	Parameter	Case-I	Case-II	Case-III
ATP^*	1019.56	1085.82	1105.64	APS^*	240.09	245.87	247.68
p_m^*	70.03	73.68	75.68	APM^*	487.91	450.06	433.31
T'	2.17	1.63	1.51	APR^*	291.56	289.89	424.65
R^*	0.7561	0.7638	0.7961				

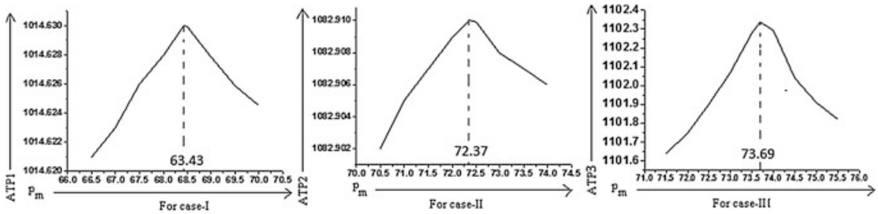

Fig. 26.7 Average profit versus supply rate of supplier's in case-I, -II and -III

Table 26.8 Input data of Liu Uncertain parameter and corresponding expectation for case-I, -II and -III

Uncertain parameters	Zigzag uncertain values ($, $)	Expectation of uncertain parameters $
$\widehat{h_s}$	$(0.04, 0.05, 0.07)$	0.0525
$\widehat{h_m}$	$(0.08, 0.1, 0.12)$	0.1
$\widehat{h_r}$	$(0.18, 0.2, 0.22)$	0.2
$\widehat{id_s}$	$(0.9, 1, 1.5)$	1.1
$\widehat{id_m}$	$(1.9, 2.1, 2.5)$	2.15
$\widehat{id_r}$	$(2.7, 3, 3.3)$	3
$\widehat{A_s}$	$(18, 20, 24)$	20.5
$\widehat{A_m}$	$(29, 31, 35)$	31.5
$\widehat{A_r}$	$(38, 40, 42)$	40

Table 26.9 Optimal values of objective and decision variable in equivalent crisp environment for case-I, -II and -III

Parameter	Case-I	Case-II	Case-III	Parameter	Case-I	Case-II	Case-III
ATP^*	1031.45	1099.56	1121.67	APS^*	242.55	249.87	252.30
p_m^*	71.05	74.78	76.93	APM^*	494.45	456.64	438.89
T'	2.19	1.72	1.63	APR^*	294.45	293.05	430.48
R^*	0.7691	0.7762	0.7986				

26.12 Conclusion

In the first model of this chapter, a multi-item dynamic system with imprecise resource constraints has been solved using optimal control theory, Kuhn-Tucker conditions and the imprecise constraints are defuzified by using necessity and possibility measures. The proposed model can be extended in several ways. First, we may extend the model to incorporate some more realistic features, such as quantity discount, the inventory holding cost and others are also fluctuating with time. Second, we could generalize the model under delay in payment in fuzzy-rough/bi-fuzzy environment.

In second model, we developed a three layers supply chain production inventory model under fuzzy rough and Liu uncertain environment. Here suppliers collect the raw material(ore) and produce the raw material of actual manufacture. For example, In petroleum industries suppliers collect the ore and produced the naphthalene, which is the raw material of manufacturer. Then manufacturer produce the usable product to sale the retailer. The chapter can be extended to imperfect production inventory system in different uncertain environment. Deterioration can be allowed for produced items of retailer, manufacturer and also in case of retailer.

In this chapter, two production control models have been developed in fuzzy/fuzzy-rough/Liu-uncertain environments. In addition, this chapter has also included several uncertain techniques/soft computing techniques which can be used in seminar classes in industry and teaching an introductory production planning and control or an operations management course for M.B.A. students.

References

Agrawal, S., Banerjee, S.: Papachristos, S., Inventory model with deteriorating items, ramp-type demand and partially backlogged shortages for a two warehouse system. Appl. Math. Model. **37**, 8912–8929 (2013)

Agarwal, V., Chao, X., Seshadri, S.: Dynamic balancing of inventory in supply chains. Eur. J. Oper. Res. **159**, 296–317 (2004)

Andrade, L.C., Miguez, C.G., Gomez, M.C.T., Bugallo, P.M.B.: Management strategy for hazardous waste from atomised SME: application to the printing industry. J. Clean. Prod. **35**, 214–229 (2012)

Benkherouf, L.: A deterministic order level inventory model for deteriorating items with two storage facilities. Int. J. Prod. Econ. **48**, 167–175 (1997)

Bhunia, A.K., Jaggi, C.K., Sharma, A., Sharma, R.: A two-warehouse inventory model for deteriorating items under permissible delay in payment with partial backlogging. Appl. Math. Comput. **232**, 1125–1137(2014)

Bhunia, A.K., Maiti, M.: A two warehouses inventory model for deteriorating items with a linear trend in demand and shortages. J. Oper. Res. Soc. **49**, 287–292 (1998)

Braschel, N., Posch, A.: A review of system boundaries of GHG emission inventories in waste management. J. Clean. Prod. **44**, 30–38 (2013)

Cachon, G.P., Zipkin, P.H.: Competitive and cooperative inventory policies in a two-stage supply chain. Manage. Sci. **45**, 936–953 (1999)

Chiu, Y.S.P., Chen, K.K., Cheng, F.T., Wu, M.F.: Optimization of the finite production rate model with scrap, rework and stochastic machine breakdown. Comput. Math Appl. **59**, 919–932 (2010)

Chu, S.J.: Interactive group decision-making using a fuzzy linguistic approach for evaluating the flexibility in a supply chain. Eur. J. Oper. Res. **213**, 279–289 (2011)

Chung, K.J., Huang, T.S.: The optimal retailers ordering policies for deteriorating items with limited storage capacity under trade credit financing. Int. J. Prod. Econ. **106**, 127–145 (2007)

Das, B., Maity, K., Maiti, M.: A two warehouse supply-chain model under possibility/necessity/credibility measures. Math. Comput. Model. **46**, 398–409 (2007)

Dey, J.K., Mondal, S.K., Maiti, M.: Two storage inventory problem with dynamic demand and interval valued lead-time over finite time horizon under inflation and time-value of money. Eur. J. Oper. Res. **185**, 170–194 (2008)

Demrc, M.: Genuine sets, various kinds of fuzzy sets and fuzzy rough sets. International Journal of Uncertainty. Fuzziness Knowl. Based Syst. **11**, 467–494 (2003)

Dubois, D., Prade, H.: Rough fuzzy sets and fuzzy rough sets. Int. J. Gen Syst **17**, 91–208 (1990)

Giri, B.C., Maiti, T.: Trade credit competition between two retailers in a supply chain under credit-linked retail price and market demand. Optim. Lett. (2013). doi:10.1007/s11590-013-0702-x

Glock, C.H., Schwindl, K., Jaber, M.Y.: An EOQ model with fuzzy demand and learning in fuzziness. Int. J. Serv. Oper. Manage. **12**, 90–100 (2012)

Gunasekaran, A., Ngai, E.W.T.: Information systems in supply chain integration and management. Eur. J. Oper. Res. **159**, 269–295 (2004)

Harris, F.: Operations and cost (Factory management series). A.W. Shaw co., Chicago (1915)

Hazari, S., Dey, J.K., Maity, K., Kar, S.: An interactive method for two-plants production inventory control with two-warehouse facility under imprecise environment. Int. J. Comput. Appl. **96**, 1–13 (2014a)

Hazari, S., Dey, J.K., Maity, K., Kar, S.: Advertisement policy and reliability dependent imperfect production inventory control problem in bi-fuzzy environment, Article in Press. Int. J. Oper. Res. (2014b)

Hazari, S., Dey, J.K., Maity, K., Kar, S.: Optimal dynamic production and pricing for reliability depended imperfect production with inventory-level-dependent demand in uncertain environment. J. Uncertainty Anal. Appl. **2**, 1–17 (2014b)

Hoque, M.A.: An optimal solution technique to the single-vendor multi-buyer integrated inventory supply chain by incorporating some realistic factors. Eur. J. Oper. Res. **215**, 80–88 (2011)

Huang, Y.F.: An inventory model under two levels of trade credit and limited storage space derived without derivatives. Appl. Math. Model. **30**, 418–436 (2006)

Islam, S., Roy, T.K.: Fuzzy multi-item economic production quantity model under space constraint: a geometric programming approach. Appl. Math. Comput. **184**, 326–335 (2007)

Jana, D.K., Maity, K., Roy, T.K.: Multi-item production inventory model with Fuzzy Rough coefficients via geometric programming approach. Opsearch **50**, 475–490 (2013a)

Jana, D.K., Maity, K., Roy, T.K.: A Bi-fuzzy production-recycling-disposal inventory problem with environment pollution cost via genetic algorithm. Int. J. Comput. Appl. **61**, 1–10 (2013b)

Jana, D.K., Maity, K., Roy, T.K.: A three layers supply chain production inventory model under permissible delay in payments in uncertain environment. J. Uncertainty Anal. Appl. **1**, 1–17 (2014)

Jonrinaldi, D.Z.: An integrated production and inventory model for a whole manufacturing supply chain involving reverse logistics with finite horizon period. Omega. **41**, 598–620 (2013)

Krishnan, H., Winter, R.A.: Inventory dynamics and supply chain coordination. Manage. Sci. **56**, 141–147 (2010)

Kristianto, Y., Helo, P., Jiao, J., Sandhu, M.: Adaptive fuzzy vendor managed inventory control for mitigating the Bullwhip effect in supply chains. Eur. J. Oper. Res. **216**, 346–355 (2012)

Lee, C.C.: Two-warehouse inventory model with deterioration under FIFO dispatching policy. Eur. J. Oper. Res. **174**, 861–873 (2006)

Liang, Y., Zhou, F.: A two-warehouse inventory model for deteriorating items under conditionally permissible delay in payment. Appl. Math. Model. **35**, 2221–2231 (2011)

Liao, J.J., Huang, K.N., Chung, K.J.: Lot-sizing decisions for deteriorating items with two warehouses under an order-size-dependent trade credit. Int. J. Prod. Econ. **137**, 102–115 (2012)

Liu, B., Iwamura, K.B.: Chance constraint Programming with fuzzy parameters. Fuzzy Sets Syst. **94**, 227–237 (1998)

Liu, B., Liu, Y.K.: Expected value of fuzzy variable and fuzzy expected value models. IEEE Trans. Fuzzy Syst. **10**, 445–450 (2002)

Lin, H.D., Chiu, Y.S.P., Ting, C.K.: A note on optimal replenishment policy for imperfect quality EMQ model with rework and backlogging. Comput. Math Appl. **56**, 2819–2824 (2008)

Liu, B.: Uncertainty Theory, 2nd edn. Springer, Berlin (2007)

Liu, B.: Fuzzy process, hybrid process and uncertain process. J. Uncertain Syst. **2**, 3–16 (2008)

Liu, B.: Some research problems in uncertainty theory. J. Uncertain Syst. **3**, 3–10 (2009)

Liu, B.: Uncertain risk analysis and uncertain reliability analysis. J. Uncertain Syst. **4**, 163–170 (2010)

Maity, K., Maiti, M.: Necessity constraint in two plant optimal production problem with imprecise parameters. Inf. Sci. **177**, 5739–5753 (2007)

Maity, K.: Possibility and Necessity representations of fuzzy inequality and its application to two warehouse production-inventory problem. Appl. Math. Model. **35**, 1252–1263 (2011)

Maity, K.: Advertisement policy, reliability dependent imperfect production and environmental pollution control problem in fuzzy-rough environment. Int. J. Uncertainty. Fuzziness and Knowl. Based Syst. **22**, 845–863 (2014)

Maity, K.: A supply-chain production inventory model with warehouse facilities under fuzzy environment. In: Kahraman, K., Oztaysi, B., (eds.) Supply Chain Management Under Fuzziness. Springer, Heidelberg (2014) (**312**, 517–551)

Mettas, A.: Reliability Allocation and Optimization for Complex System. Reliability and Maintainability Symposium. Relia Soft Corporation, Los Angeles (2000)

Naddor, E.: Inventory Systems. Wiley, New York (1966)

Panda, D., Kar, S., Maity, K., Maiti, M.: A single period inventory model with imperfect production and stochastic demand under chance and imprecise constraints. Eur. J. Oper. Res. **188**, 121–139 (2008)

Panda, D., Maiti, M.: Multi-item inventory models with price dependent demand under flexibility and reliability consideration and imprecise space constraint: a geometric programming approach. Math. Comput. Model. **49**, 1733–1749 (2009)

Pawlak, Z.: Rough sets. Int. J. Comput. Inform. Sci. **11**, 341–356 (1982)

Peidro, D., Mula, J., Jimenez, M., Botella, M.M.: A fuzzy linear programming based approach for tactical supply chain planning in an uncertainty environment. Eur. J. Oper. Res. **205**, 65–80 (2010)

Pontryagin, L.S., Boltyanski, V.S., Gamkrelidze, R.V., Mischenko, E.F.: The Mathematical Theory of Optimal Process. Wiley, New York (1962)

Porteus, E.L.: Optimal lot sizing, process quality improvement and setup cost reduction. Oper. Res. **34**, 137–144 (1986)

Roy, A., Maity, K., Kar, S., Maiti, M.: A production-inventory model with remanufacturing for defective and usable items in fuzzy-environment. Comput. Ind. Eng. **56**, 87–96 (2009)

Rong, M., Mahapatra, N.K., Maiti, M.: A two warehouse inventory model for a deteriorating item with partially/fully backlogged shortage and fuzzy lead time. Eur. J. Oper. Res. **189**, 59–75 (2008)

Sarma, K.V.S.: A deterministic order level inventory model for deteriorating items with two storage facilities. Eur. J. Oper. Res. **29**, 70–73 (1987)

Sarma, K.V.S.: A deterministic inventory model with two levels of storage and an optimum release rule. Opsearch **20**, 175–180 (1983)

Sarma, K.V.S.: On the K-release rule for an inventory system with two warehouses. Opsearch **21**, 38–40 (1984)

Salameh, M.K., Jaber, M.Y.: Economic Production quantity model for items with imperfect quality. Int. J. Prod. Econ. **64**, 59–64 (2000)

Sarkar, B.: An inventory model with reliability in an imperfect production process. Appl. Math. Comput. **218**, 4881–4891 (2012)

Selçuk, B., Agrali, S.: Joint spare parts inventory and reliability decisions under a service constraint. J. Oper. Res. Soc. **64**, 446–458 (2012)

You, C.: Some convergence theorems of uncertain sequences. Math. Comput. Model. **49**, 482–487 (2009)

Xu, J., Zhao, L.: A multi-objective decision-making model with fuzzy rough coefficients and its application to the inventory problem. Inf. Sci. **180**, 679–696 (2010)

Xu, J., Zhou, X.: fuzzy link multiple-objective decision making. Springer, Berlin (2009)

Yang, H.L.: Two-warehouse inventory models for deteriorating items with shortages under inflation. Eur. J. Oper. Res. **157**, 344–356 (2004)

Yang, H.L.: Two-warehouse partial backlogging inventory models for deteriorating items under inflation. Int. J. Prod. Econ. **103**, 362–370 (2006)

Zhou, Y.W., Yang, S.L.: A two-warehouse inventory model for items with stock-leveldependent demand rate. Int. J. Prod. Econ. **95**, 215–228 (2005)

Chapter 27
Application of Alternative Multi-criteria Decision Making Approaches to Supplier Selection Process

Vinod Yadav and Milind Kumar Sharma

Abstract In today's highly competitive and turbulent business environment, selection of reliable and high quality suppliers has become the most important purchasing decision in order to reduce the production cost while maintaining the product quality and customer satisfaction simultaneously. The problem of supplier selection gets complicated further when a company looks for various criteria to evaluate different suppliers that lead it to become a multi-criteria decision making (MCDM) problem. This work reviews supplier selection models based on both individual and hybrid MCDM methodologies. A case study of an automobile company is presented to illustrate and propose three alternative supplier selection models based on analytic hierarchy process (AHP) as an individual MCDM methodology and data envelopment analytic hierarchy process (DEAHP) and fuzzy analytic hierarchy process (FAHP) as hybrid MCDM methodologies.

Keywords Supplier selection process · Multi-Criteria decision making (MCDM) · Analytic hierarchy process (AHP) · Data envelopment analytic hierarchy process (DEAHP) · Fuzzy analytic hierarchy process (FAHP)

27.1 Introduction and Theoretical Background

In today's era of intelligent manufacturing where the application of production technology that can automatically adapt to fast changing business environment and varying process needs, with the capability of producing different products with minimum human intervention has paved the way for competitive manufacturing. Hence, due to global competition, for a manufacturing organization it is challenging

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to produce high quality products whilst offering competitive prices to the customers. Having reliable and competent supplier base has become one of the critical success factors for modern engineering management. The key objective of the purchasing department in any organization is to source the right quality of material in the right size from the right source at the right time and also at reasonable price (Boran et al. 2009). In competitive environment, the manufacturing organizations pay particular attention to the selection of alternative supply sources. Hence, supplier selection process has become the most significant variable in the modern supply chain management (Shaw et al. 2012; Arikan 2013; Pitchipoo et al. 2013; Yu and Wong 2014) as it helps in achieving high quality products and customer satisfaction (Gonzaile et al. 2004; Deng et al. 2014). Effective supplier selection needs robust analytic methods and decision support systems that are able to deal with multiple criteria (Ni et al. 2007; Chen and Chao 2012). Supplier selection assumes very important role in any manufacturing organization as the cost and quality of goods and services sold are directly related to the cost and quality of goods and services purchased. However, it becomes a complex issue to address for manufacturing firms when it considers multiple subjective and objective criteria. Criteria may vary depending on the type of product or industry being considered and include many qualitative factors in addition to the quantitative criteria (Vokurka et al. 1996). An efficient supplier selection process is capable to handle the complexity of the current business scenario.

Supplier selection gets complicated due to consideration of various criteria and sub criteria in decision making. Every buyer has different expectations from the suppliers. Different companies may have different organizational and cultural backgrounds, which may also affect the supplier selection process. The selection criteria may vary from industry to industry. The single criterion approach of the lowest cost supplier is no more accepted in this challenging and continuously changing environment (Agarwal et al. 2011). Quality, delivery performance, services, etc. need to be considered by the manufacturing firms. Dickson (1966) identified 23 criteria for supplier selection based on the survey of 273 purchasing managers. In a survey, Weber et al. (1991) classified all published papers (from 1967 to 1990) according to the studied criteria and they identified quality, cost and on-time delivery as the most important supplier selection criteria in the evaluation of supplier performance. After scanning a plethora of literatures Jain et al. (2009) grouped all criteria into six categories i.e. cost, quality, cycle time, service, relationship and organizational profile. Hence, it is imperative to devise an intelligent system for engineering management of business enterprises that may help decision makers to choose suppliers when it becomes a multi-criteria decision making (MCDM) problem. Multi-criteria decision-making approaches are formal methods to structure the decision problems with multiple and conflicting criteria or goals. MCDM methods have been widely used in many research fields. Supplier selection is basically, a multiple criteria decision-making problem. Broadly, the numerous multi-criteria decision-making approaches suggested in the literature to solve the supplier selection problem may be classified into individual approaches and integrated ones (Ho et al. 2010). The most widespread individual approaches are: the data envelopment analysis (DEA), mathematical programming, the analytic hierarchy process (AHP), the analytic network process (ANP), Neural networks, Structural equation modeling, Multi Attribute Utility Theory (MAUT), Dimensional analysis (DA), fuzzy decision making, genetic algorithms, the simple multi-attribute rating technique (SMART) and many more. The integrated approaches join together different techniques (e.g. integrated AHP and DEA, integrated AHP and goal programming, etc.). Different types of supplier selection approaches reported in the literature are shown in Table 27.1.

Table 27.1 Supplier selection approaches

Approaches	Authors
Data envelopment analysis	• Liu et al. (2000) • Forker and Mendez (2001) • Garfamy (2006) • Seydel (2006) • Wu et al. (2007) • Songhori et al. (2011) • Dotoli and Falagario (2012) • Partovi (2013)
Analytic hierarchy process	• Muralidharan et al. (2002) • Hou and Su (2007) • Chan and Chan (2010) • Kumar and Roy (2011) • Bruno et al. (2012)
Analytic network process	• Gencer and Gurpinar (2007) • Bayazit (2006) • Sarkis and Talluri (2002)
Fuzzy set theory	• Chen et al. (2006) • Florez-Lopez (2007) • Chang et al. (2011) • Jiang and Chan (2011) • Ahmady et al. (2013) • Ghorbani et al. (2013)
Linear programming	• Talluri and Narasimhan (2003) • Talluri and Narasimhan (2005) • Ng (2008)
Integer programming	• Talluri (2002) • Hong et al. (2005)
Goal programming	• Karpak et al. (2001)
Data envelopment analytic hierarchy process	• Sevkli et al. (2007) • Zhang et al. (2011) • Yadav and Sharma (2015a, b)
Integrated AHP-GP	• Cebi and Bayraktar (2003) • Percin (2006) • Kull and Talluri (2008) • Mendoza et al. (2008)
Integrated fuzzy-AHP	• Kahraman et al. (2003) • Kahraman et al. (2004) • Chan and Kumar (2007) • Tas (2012) • Yadav and Sharma (2015a, b)

Data Envelopment Analysis (DEA) is a widely recognized approach (Songhori et al. 2011; Dotoli and Falagario 2012; Partovi 2013) for evaluating the efficiencies of decision making units (suppliers). Because of its easy and successful application and case studies, DEA has gained too much attention and widespread use by business and academy researchers. Many researchers (Hou and Su 2007; Chan and Chan 2010; Kumar and Roy 2011) have concluded that analytic hierarchy process (AHP) is a useful, practical and systematic method for supplier selection. The AHP methodology, which was developed by Saaty (1980), is a powerful tool in solving complex decision problems. Fuzzy set theory has proven advantages within vague, imprecise and uncertain contexts and it resembles human reasoning in its use of approximate information and uncertainty to generate decisions for supplier selection (Jiang and Chan 2011; Chang et al. 2011; Ghorbani et al. 2013; Ahmady et al. 2013). In order to deal with uncertainties of the decision problem and eliminate the disadvantages of AHP, fuzzy AHP is preferred in supplier selection studies (Chan and Kumar 2007; Kilincci and Onal 2011; Tas 2012).

Kahraman et al. (2003) used fuzzy AHP technique to select the best supplier providing the most satisfaction for the three criteria (and 11 sub-criteria) determined in the white good sector. Kahraman et al. (2004) also proposed a fuzzy AHP based model to select a best catering Turkish firm providing the most customer satisfaction. Sevkli et al. (2007) applied an integrated AHP–DEA approach for supplier selection. In the approach, AHP was used to derive local weights from a given pair wise comparison matrix, and aggregate local weights to yield overall weights. Each row and column of the matrix was assumed as a decision making unit (DMU) and an output, respectively. A dummy input that had a value of one for all DMUs was deployed in DEA to calculate the efficiency scores of all suppliers. However, the authors pointed out that the approach was relatively more cumbersome to apply than the individual AHP. Aydin and Kahraman (2010) proposed a fuzzy analytic hierarchy process based methodology in the supplier selection of an air conditioner firm. Chang et al. (2011) proposed fuzzy decision making trial and evaluation laboratory (DEMATEL) method to effectively find evaluation factors for supplier selection. This method was based on practical approach of finding key factors to improve supplier performance through different questionnaire. Jiang and Chan (2011) proposed a methodology with the application of fuzzy set theory (FST), based on twenty criteria to deal with supplier evaluation and selection problem. They used the Dempster Shafer theory (DST) to combine the criterion data to calculate the final scores of the suppliers. Kumar and Roy (2011) proposed a rule based model with the application of AHP to aid the decision makers in vendor evaluation and selection taking a case from a power transmission industry. The article presented a three-step model to calculate the performance scores of various vendors and select the best vendor. The researchers also validated the proposed model taking the data from a multinational transformer company. Songhori et al. (2011) presented a structured framework to help decision makers in selecting the best supplier for a firm using DEA approach. Zhang et al. (2011) developed a hybrid methodology combining the data envelopment analytic hierarchy process (DEAHP) and activity-based costing (ABC). Using this hybrid model, decisions on supplier selection and order quantity could easily be made within an integrated single objective function which was based on consideration of the budget of the buyer and of the capacity of the suppliers. Bruno et al. (2012) proposed a hierarchical model for supplier selection in corporate environment. In this model twelve sub-criteria were considered under four criteria i.e. process and product quality, service level, management and innovation and financial position. The analysis of the implementation process of the methodology allowed the identification of strengths and weaknesses of using formalized supplier selection models to tackle the supplier evaluation problem, also highlighted potential barriers preventing firms to adopt such methods. Dotoli and Falagario (2012) proposed modified DEA approach which was used to evaluate the efficiency of each supplier according to some criteria proposed by the buyer. Ahmady et al. (2013) developed a novel fuzzy DEA approach with double frontiers for supplier selection. Compared with the traditional DEA, the DEA approach with double frontiers can identify the best supplier appropriately and easily without the need to impose any weight restriction or the need to calculate the cross-efficiency matrix, which requires a large number of computations and may also result in inconsistent conclusions. Ghorbani et al. (2013) proposed a three-phase approach for supplier selection based on the Kano model and fuzzy Multi Criteria Decision-Making. Initially, the importance weight of the criteria had been calculated using a fuzzy Kano questionnaire and fuzzy analytic hierarchy process. In the second phase, the Fuzzy TOPSIS technique was used to screen out incapable suppliers. Finally, in the third phase, the filtered suppliers which were qualified, once again evaluated by the same approach for the final ranking. This approach had also been examined in a case study. Partovi (2013) developed a quantitative methodology based on data envelopment analysis (DEA), including the constraint of 'self-efficiency' for supplier selection.

However, after scanning a plethora of literatures, following gaps are observed in it:

- The literature lacks the comparative studies of different MCDM approaches for supplier selection problem.
- Alternative MCDM methodologies for a supplier selection problem do not seem to receive adequate attention of the researchers.
- It is further observed that very less articles have proposed MCDM approach based on DEAHP methodology for supplier selection despite of the fact that this approach offers various benefits over other approaches.
- The literature lacks the case application in developing countries setting such as India.
- Very few researchers reported on flexibility criteria, one of the most crucial factors in today's competitive manufacturing environment, for supplier selection.
- The literature lacks essential elements to recognize some of the elements of long term relationships between buyer and supplier.

On the basis of above, it is felt appropriate to propose supplier selection model based on some alternative MCDM approaches to provide different perspectives. At the same time, a need is also felt to suggest an intelligent system for supplier selection which uses an individual and hybrid MCDM approaches simultaneously to give valuable insights into it. Hence, in this work, an attempt is made to propose supplier selection model based on AHP methodology, an individual MCDM approach and DEAHP and FAHP methodologies as hybrid MCDM approaches. An automobile company from Indian context is chosen for the study.

The rest of the chapter is organized as follow: Sect. 27.2 discusses about the supplier selection problem of the company. The application of analytic hierarchy process (AHP), data envelopment analytic hierarchy process (DEAHP) and fuzzy analytic hierarchy process (FAHP) are reported in Sects. 27.3, 27.4 and 27.5 respectively. Finally last section concludes the chapter and presents the limitation and direction for future research.

27.2 Problem Identification

One of the leading car and truck manufacturing company in India wants to select the best supplier for one of its critical components used in truck. The company providing the context for this application is a manufacturer of automobile, motor vehicles and internal combustion engines founded in 1926 and entered in the Indian market to built medium and heavy duty commercial vehicles in 2008. It is a leading car and truck manufacturing company. Besides, it manufactures buses and provides financial services through its sister concern. It set up a manufacturing plant for trucks in India. Initial production capacity at the plant in 28,000 units per year and expanded to 60,000 units per year by start of next year. The company chosen in the study is new in this market and trying to increase its customer base. The purchasing managers have acknowledged the fact that their suppliers have a major influence on customers' satisfaction level, and it is strongly desired to purchase the right quality of product in the right quantity from the right source at the right time. Therefore, the company decided to develop an effective supplier selection policy for the responsive market. The managers of the company recognized that a wide range of factors must be considered in the supplier selection process and the selection decisions should not be made merely on the basis of price related factors alone. Hence, in order to address this problem, a hierarchy is structured on the basis of identified supplier selection criteria in the literature and evidence found in the company as shown in Fig. 27.1.

In order to maintain the confidentiality of the supplier companies, the suppliers are identified as S1, S2 and S3 in the chapter.

27.3 AHP Model for Supplier Selection

The analytic hierarchy process (AHP) methodology, which was developed by Saaty (1980), is a powerful decision making tool in solving complex multiple criteria problems. In the AHP approach, the problem is structured hierarchically at different

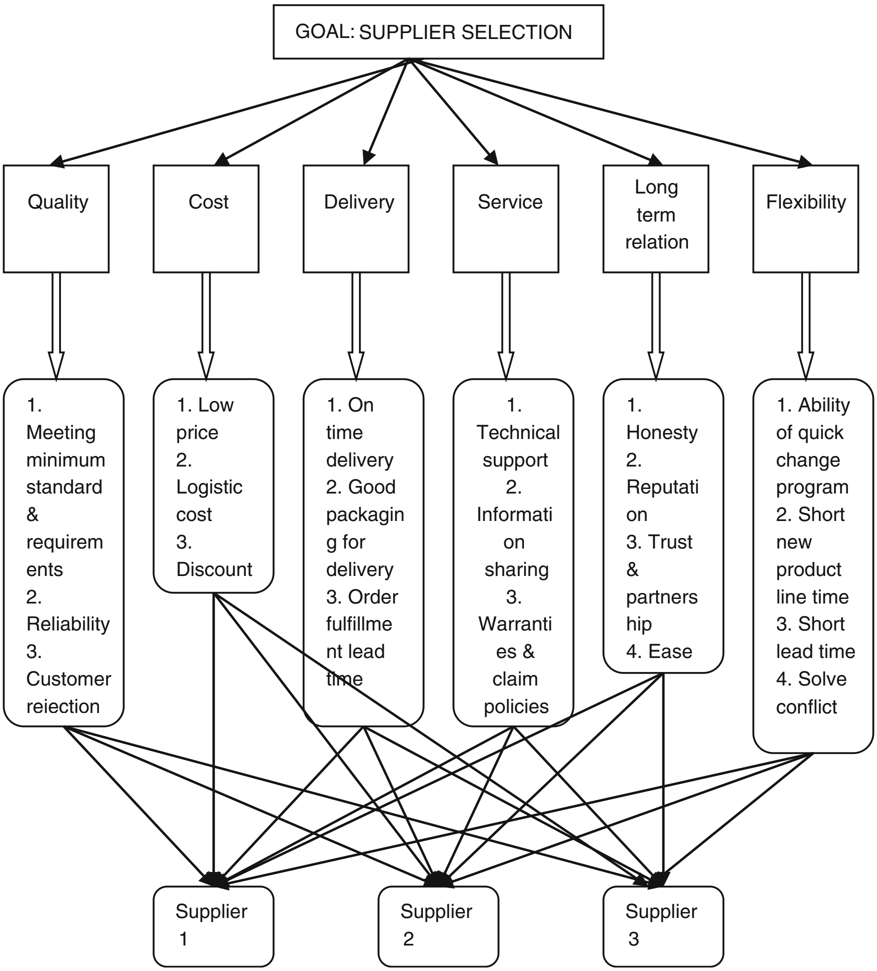


Fig. 27.1 Problem hierarchy

levels with each level consisting of a finite number of decision elements. The upper level of the hierarchy represents the overall goal, while the lower level consists of all possible alternatives. One or more intermediate levels embody the decision criteria and sub-criteria as shown in Fig. 27.1.

Pair wise comparisons are formulated to include all the combinations of criteria, sub-criteria and alternative relationships. The inputs of the pair wise comparison matrix are mangers preferences of the criterion, sub-criteria and alternative over other. The AHP priorities are computed with the help of computer software 'Expert Choice'. These priorities as shown in Table 27.2.

After deriving the priorities of criteria, sub-criteria and alternatives through pair wise comparison, these derived priorities were synthesized to get overall priorities

Table 27.2 AHP priorities for criteria, sub-criteria and alternatives

Goal		S_1	S_2	S_3
Quality (0.420)	MMSR (0.462)	0.218	0.691	0.091
	Reliability (0.103)	0.528	0.333	0.140
	CR (0.134)	0.122	0.320	0.558
	DR (0.301)	0.243	0.088	0.669
Cost (0.243)	LP (0.271)	0.320	0.558	0.122
	LC (0.085)	0.528	0.140	0.333
	Discount (0.644)	0.320	0.558	0.122
Delivery (0.093)	OTD (0.661)	0.493	0.196	0.311
	GP (0.131)	0.333	0.140	0.528
	OFLT (0.208)	0.345	0.547	0.109
Service (0.126)	TS (0.242)	0.320	0.122	0.558
	IS (0.084)	0.309	0.109	0.582
	WCP (0.502)	0.323	0.588	0.089
	Capabilities (0.172)	0.250	0.095	0.655
Long term relationship (0.051)	Honesty (0.556)	0.540	0.297	0.163
	Reputation (0.249)	0.200	0.683	0.117
	TP (0.115)	0.167	0.094	0.740
	EC (0.081)	0.320	0.588	0.122
Flexibility (0.068)	AQCP (0.142)	0.200	0.177	0.683
	SNPLT (0.327)	0.540	0.297	0.163
	SLT (0.095)	0.333	0.097	0.570
	SC (0.436)	0.200	0.683	0.117

of suppliers. Equations (27.1) and (27.2) are used to synthesize the priorities and the overall priorities of suppliers are shown in Table 27.3.

$$\text{Second level priority of supplier } S_i = \sum \{(\text{local weight of } S_i \text{ w.r.t. sub-criteria } SC_j) \times (\text{local weight of } SC_j)\} \tag{27.1}$$

$$\text{First level priority of supplier } S_i = \sum \{(\text{second level weight of } S_i \text{ w.r.t. criteria } C_j) \times (\text{local weight of } C_j)\} \tag{27.2}$$

Table 27.3 Overall AHP priorities

Suppliers	Final priorities
S_1	0.306
S_2	0.421
S_3	0.273

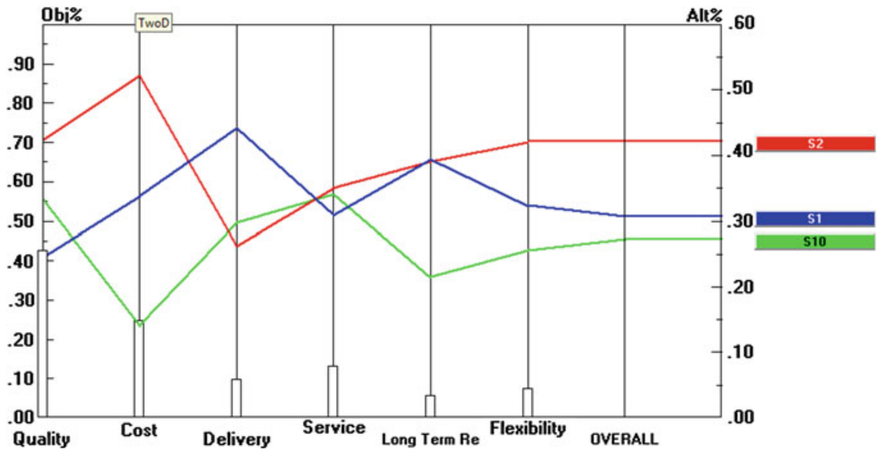


Fig. 27.2 Sensitivity analysis graph for AHP

It may be seen from the Table 27.3 that the supplier 2 (S_2) has got highest priority (0.421) and hence may be selected by the company. Supplier 3 (S_3) has the lowest priority as 0.273 while supplier 1 (S_1) has priority of 0.306. It is worth to notice that the relative score difference between the first and the last supplier in the ranking is quite limited ((0.421 − 0.273)/0.421 = 35.15 %). Therefore, slight variation in managers' judgment can modify the final ranking.

However, the evaluation of supplier based on each criterion is also an important issue to address. Therefore, it is not necessary that overall highest ranked supplier will have highest rank with respect to all individual criterion also. Some interesting insights are obtained in the sensitivity analysis, as shown in Fig. 27.2.

Sensitivity graph with respect to goal is shown in Fig. 27.2. It is clearly seen from the graph that supplier 2 has highest priority with respect to four criteria i.e. quality, cost, service and flexibility while it has lowest priority with respect to delivery criterion. Therefore, in special case where delivery will be a critical criterion, the supplier 2 should be replaced by supplier 1. Supplier 1 has highest priority with respect to delivery and long term relationship while it has lowest priority with respect to the criteria quality and service. Supplier 3 doesn't get highest priority with respect to any criterion so it may be recommended to eliminate it from further analysis.

It is noteworthy to mention here that the local weights of the elements are calculated from the judgment matrices using the eigenvector method (EVM) in AHP. The normalized eigenvector corresponding to the principal eigen value of the judgment matrix provides the weights of the corresponding elements. The ranking of alternatives determined by the traditional AHP may be altered by any addition or deletion of another alternative for consideration. Hence, hybrid use of AHP with another methodology, such as data envelopment analysis (DEA) may overcome this limitation and pave the way for more useful results.

27.4 Hybrid DEAHP Model for Supplier Selection

Ramanathan (2006) first proposed the data envelopment analytic hierarchy process (DEAHP) methodology, in which DEA method is embedded into AHP method. The structure of DEAHP is the same as AHP structure; the upper level of the hierarchy represents the overall goal, while the lower level consists of all possible alternatives. One or more intermediate levels embody the decision criteria and sub-criteria. In this methodology, each row of the pair wise matrix is assumed as Decision Making Unit (DMU) and each column is assumed as output. However, according to DEA method, the efficiency scores of each DMU cannot be calculated entirely with outputs and required at least one input. So, a dummy inputs for all the DMU's is employed, this dummy input has a value of 1. In DEAHP methodology, the efficiency scores are calculated using the DEA method for each pair-wise comparison matrix and could be interpreted as a local weights of the DMUs. Once the local weights of DMUs are calculated the next step is to aggregates the local weights to get overall weights. Again, the DEA method is used to drive the overall weights from the local weights. Ramanathan (2006) proves that DEA method correctly drives the weights for consistent judgment matrix. Sevkli et al. (2007) and Zhang et al. (2011) applied this approach for supplier selection problem. Hence, it is imperative to use an integrated DEAHP approach for the present study also.

Pair wise comparison matrixes are prepared through interviews conducted with the managerial staff employed in the purchase department of the company. In order to derive the local priority for a consistent pair wise matrix DEA methodology is used. For example, to derive the local priority for criterion 'meeting minimum standard and requirements' for Table 27.4 the following model is used.

$$\begin{aligned}
&\textbf{Objective function}: \ \textbf{Maximization Z} = \mathbf{1y_{11} + 3y_{12} + 4y_{13} + 2y_{14}}\\
&\textbf{Subject to}:\\
&\mathbf{x_{11} = 1},\\
&\mathbf{1y_{11} + 3y_{12} + 4y_{13} + 2y_{14} \le 0},\\
&\mathbf{1/3y}_{11} \mathbf{+ 1y_{12} + 1/2y_{13} + 1/3y_{14} \le 0},\\
&\mathbf{1/3y_{11} + 1y_{12} + 1/2y_{13} + 1/3y_{14} \le 0},\\
&\mathbf{1/4y_{11} + 2y_{12} + 1y_{13} + 1/3y_{14} \le 0},\\
&\mathbf{1/2y_{11} + 3y_{12} + 3y_{13} + 1y_{14} \le 0},\\
&\mathbf{y_{11}, y_{12}, y_{13}, y_{14}, x_{11}, x_{12}, x_{13}, x_{14} \ge 0}.
\end{aligned}$$

Similarly, to obtain the local weights for other criteria, similar models are used by changing the objective functions in following manner-

Table 27.4 Evaluation of sub-criteria with respect to QUALITY for DEAHP

DMU	Output 1	Output 2	Output 3	Output 4	Input	AHP	DEAHP
Meeting minimum standard and requirements	1	3	4	2	1	0.462	1.000
Reliability	1/3	1	1/2	1/3	1	0.103	0.333
Customer rejection	¼	2	1	1/3	1	0.134	0.666
Defect rate	½	3	3	1	1	0.301	1.000

$$\textbf{Maximization Z} = \mathbf{1/3y_{11} + 1y_{12} + 1/2y_{13} + 1/3y_{14}} \text{ (for reliability)}$$
$$\textbf{Maximization Z} = \mathbf{1/4y_{11} + 2y_{12} + 1y_{13} + 1/3y_{14}} \text{ (for customer rejection)}$$
$$\textbf{Maximization Z} = \mathbf{1/2y_{11} + 3y_{12} + 3y_{13} + 1y_{14}} \text{ (for defect rate)}$$

The local weights of decision making units may be seen in Table 27.5. Once local weights of suppliers are obtained, then next step is to aggregate the local weights of suppliers in order to obtain overall weights of the decision alternatives.

Table 27.5 DEAHP priorities for criteria, sub-criteria and alternatives

Goal		S_1	S_2	S_3
Quality (1.000)	MMSR (1.000)	0.500	1.000	0.167
	Reliability (0.333)	1.000	1.000	0.333
	CR (0.666)	0.250	0.750	1.000
	DR (1.000)	0.428	0.142	1.000
Cost (0.800)	LP (0.667)	0.750	1.000	0.250
	LC (0.167)	1.000	0.333	1.000
	Discount (1.000)	0.750	1.000	0.250
Delivery (0.400)	OTD (1.000)	1.000	0.500	1.000
	GP (0.250)	1.000	0.333	1.000
	OFLT (0.500)	1.000	1.000	0.250
Service (0.600)	TS (0.750)	0.750	0.250	1.000
	IS (0.250)	0.600	0.200	1.000
	WCP (1.000)	0.667	1.000	0.167
	Capabilities (0.750)	0.500	0.167	1.000
Long term relationship (0.200)	Honesty (1.000)	1.000	0.666	0.333
	Reputation (0.600)	0.400	1.000	0.200
	TP (0.600)	0.285	0.142	1.000
	EC (0.200)	0.750	1.000	0.250
Flexibility (0.400)	AQCP (0.667)	0.400	0.200	1.000
	SNPLT (1.333)	1.000	0.666	0.333
	SLT (0.333)	0.800	0.200	1.000
	SC (1.000)	0.400	1.000	0.200

Table 27.6 Overall DEAHP priorities of suppliers

DMU	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Input	AHP	DEAHP
S_1	0.722	0.822	1.000	1.287	1.000	1.084	1	0.306	0.981
S_2	1.000	1.000	0.619	1.000	0.994	1.000	1	0.421	1.000
S_3	0.984	0.338	0.785	1.406	0.706	0.786	1	0.273	0.883
y11 = 5/4y12 = 5/2y13 = 5/3y14 = 5y15 = 5/2y16									

The calculations for aggregation are same as of local weights but the only difference is to include additional constraints that are related to the local weights of criteria. The overall priorities for alternative suppliers are shown in Table 27.6.

The final results of the model are illustrated in Table 27.6, due to the maximum overall weight supplier 2 is ranked as number 1 as obtained from both methodologies (i.e. AHP and DEAHP) and suppliers 1 and 3 are ranked as number 2 and number 3 respectively from both methodologies, so in this model, results obtained from both methodologies are same. Therefore, supplier 2 is recommended to be selected.

However, the evaluation of suppliers based on each criterion also provides interesting insights. Figure 27.3 shows the sensitivity graph with respect to the goal. It is clearly seen from the graph that supplier 1 has been ranked as number 1 with respect to criteria delivery, service, long-term relationship and flexibility whilst, supplier 2 is ranked as number 1 with respect to criteria quality and cost.

In DEAHP, the weights of alternatives (i.e., the efficiency scores) are calculated separately for each alternative using a separate linear programming model. However, in AHP weights of all the alternatives are derived simultaneously with the help of EVM. In addition to it, while traditional AHP uses arithmetic normalization, no such normalization is done in case of DEAHP. Further, the DEAHP weights are calculated relative to the weight of the best rated alternative. Efficient alternatives are interpreted as relevant alternatives because they play an important role in the rank ordering of all the alternatives. In case the alternative other than the best one is eliminated from the model, then the new ranking calculated will again be relative to

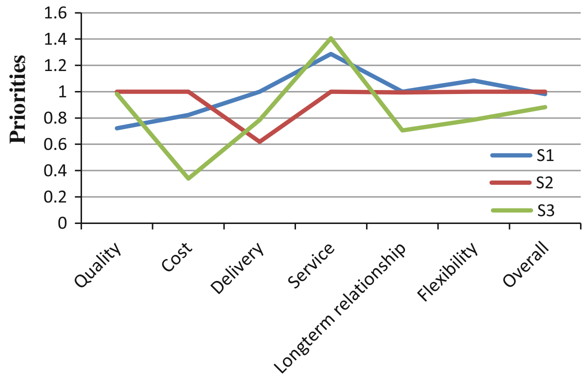


Fig. 27.3 Sensitivity analysis graph for DEAHP

the highest ranked one alternative, and the ordering of alternatives will not change. But the common problem in both the methodologies is inconsistency in the pair wise comparison.

27.5 FAHP Model for Supplier Selection

In order to deal with uncertainties in the decision making problem and overcome the limitations of AHP and DEAHP, another MCDM approach known as fuzzy AHP is preferred in supplier selection studies. It proposes an intelligent supplier selection model which may help decision makers to choose suppliers based on the different criteria. Fuzzy-AHP was introduced by Van laarhoven and Pedrycz in 1983. Basically, fuzzy analytic hierarchy process (FAHP) is an integrated approach, which consist fuzzy sets theory and analytic hierarchy process. Fuzzy sets theory resembles the human reasoning and mathematically represents the uncertainty and vagueness. In this study Chang's extent analysis method is used to select the best supplier among the number of alternative supplier available. Chang (1996) used triangular fuzzy numbers (TFN) for the pair-wise comparison in AHP. Chang's approach is less time taking and less computational expense than many other FAHP approaches.

Let $\mathrm{X} = \{\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3, \ldots, \mathrm{x}_\mathrm{n}\}$ be an object set, and $\mathrm{U} = \{\mathrm{u}_1, \mathrm{u}_2, \mathrm{u}_3, \ldots, \mathrm{u}_\mathrm{m}$ be a goal set. According to the method of Chang's extent analysis, each object is taken and extent analysis for each goal, g_i, is performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^1, M_{gi}^2, M_{gi}^3, \ldots\ldots, M_{gi}^m; \quad \mathrm{i} = 1, 2, 3, \ldots, \mathrm{n}$$

Where all M_{gi}^j are TFN; j = 1, 2, 3,…..,m

The steps of Chang's (1996) extent analysis can be given as in the following:

Step 1: The fuzzy synthetic extent with respect to *i*th object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1} \tag{27.1}$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$ the fuzzy addition operation of m extent analysis values for a particular matrix is performed such that

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j \sum_{j=1}^{m} u_j\right) \tag{27.2}$$

and to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1}$ the fuzzy addition operator of M_{gi}^j values is performed such that

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (27.3)$$

and then inverse of the vector of computed, such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (27.4)$$

Step 2: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ can be defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x}[\min(\mu_{M1}(x), \mu_{M2}(y))] \quad (27.5)$$

Equation (27.5) can be expressed as follows:

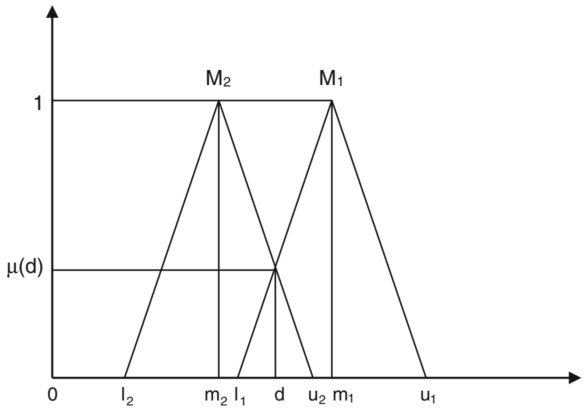
$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2} = \begin{bmatrix} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{bmatrix} \quad (27.6)$$

where d is the ordinate of the highest intersection point D between μ_{M1} and μ_{M2}. In Fig. 27.4, the intersection between M_1 and M_2 can be seen. To compare M_1 and M_2, both the values of $V(M_1 \geq M_2)$ and $V(M_1 \leq M_2)$ are needed.

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i (i = 1, 2, \ldots, k)$ can be defined by

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots \text{ and } (M \geq M_k)] = \min V(M \geq M_i)$$

Fig. 27.4 Intersection of M_1 and M_2



Assume that

$$d'(A_i) = \min V(S_i \geq S_k) \tag{27.8}$$

For $k = 1, 2, \ldots\ldots, n;\ k \neq i$, weight vector is given by Eq. (27.9)

$$W' = (d'(A_1),\ d'(A_2),\ \ldots,\ d'(A_n))^T \tag{27.9}$$

where $A_i (i = 1, 2, \ldots, n)$ are n elements.

Step 4: After normalization, the normalized weight vectors are:

$$W = (d(A_1),\ d(A_2),\ \ldots,\ d(A_n))^T \tag{27.10}$$

where W is a non-fuzzy number.

First the managers compared the criteria with respect to the goal; then compared the sub-criteria with respect to the main criteria. Finally the managers compared the supplier with respect to each sub-criterion. The linguistic variables were used to make the pair-wise comparisons. Then the linguistic variables were converted to triangular fuzzy numbers. In order to find the priority weights of the decision variables (criteria, sub-criteria and alternatives) the fuzzy extent analysis is used. The local priorities of decision variables are shown in Table 27.7. At last the local priorities of decision variables are synthesized into overall priorities which are shown in Table 27.8.

According to the final scores as shown in Table 27.8, S_3 (supplier 3) has been found as the most preferred choice due to its highest priority weight. S_1 is the next recommended alternative followed by S_2. The difference between priority weights of S_1 and S_3 is very high, so, it is strongly recommended to select the alternative S_3 over other options.

27.6 Conclusion

On the basis of the existing literature it may be concluded that the supplier selection process is one of the most critical issues within the supply chain management. It becomes more important in the context of an automobile industry. A typical manufacturer spends 60 % of its total sales on purchased items such as raw materials, parts, subassemblies components etc. (Krajewski and Ritzman 1996). In automotive industries, these costs may be more than 50 % of the total revenues. That can go up to 80 % of the total product costs for high technology firms (Weber et al. 1991). Selection of the best suppliers significantly reduces the purchasing costs and improves corporate competitiveness.

In this study three multi-criteria decision making (MCDM) approaches are used to address the supplier selection problem of an automobile company. Six decision criteria are identified by an extensive review of literature and subsequently held

Table 27.7 FAHP priorities for criteria, sub-criteria and alternatives

Goal		S_1	S_2	S_3
Quality (0.41)	MMSR (0.50)	0.26	0.65	0.09
	Reliability (0.10)	0.45	0.03	0.52
	CR (0.00)	0.00	0.96	0.04
	DR (0.40)	0.00	0.14	0.86
Cost (0.25)	LP (0.68)	0.45	0.03	0.52
	LC (0.27)	0.44	0.20	0.36
	Discount (0.05)	0.43	0.57	0.00
Delivery (0.11)	OTD (1.00)	0.33	0.33	0.33
	GP (0.00)	0.47	0.06	0.47
	OFLT (0.00)	0.46	0.21	0.33
Service (0.11)	TS (0.27)	0.45	0.52	0.03
	IS (0.015)	0.44	0.36	0.20
	WCP (0.29)	0.56	0.00	0.44
	Capabilities (0.29)	0.36	0.20	0.44
Long term relationship (0.06)	Honesty (0.53)	0.45	0.03	0.52
	Reputation (0.36)	0.03	0.52	0.45
	TP (0.11)	0.00	0.35	0.65
	EC (0.00)	0.43	0.57	0.00
Flexibility (0.06)	AQCP (0.00)	0.03	0.45	0.52
	SNPLT (0.55)	0.44	0.33	0.23
	SLT (0.00	0.68	0.27	0.05
	SC (0.45)	0.03	0.52	0.45

Table 27.8 Overall priority weights with respect to goal

Goal	Quality	Cost	Delivery	Service	Long term relationship	Flexibility	Priority weights
Weights →	0.41	0.25	0.11	0.11	0.06	0.06	
S_1	0.175	0.4395	0.33	0.4543	0.2493	0.2555	0.299
S_2	0.384	0.1029	0.33	0.2524	0.2416	0.4155	0.287
S_3	0.441	0.4576	0.33	0.2933	0.5091	0.3290	0.414

interviews with the company management to evaluate the suppliers. Firstly, AHP approach is used to rank the available supplier with respect to identified criteria. Further DEAHP approach is employed to validate the outcomes of AHP model. And finally a fuzzy AHP model is developed to deal with the problem of uncertainty or inconsistency in the previous models.

The results of all three models are shown in Table 27.9. It may be clearly seen from the second and third column of Table 27.9 that top priority has been assigned to supplier 2 followed by supplier 1 and supplier 3 as suggested by AHP and

Table 27.9 Overall priorities of suppliers

	AHP	DEAHP	FAHP
S_1	0.306	0.981	0.299
S_2	0.421	1.000	0.287
S_3	0.273	0.883	0.414

Table 27.10 Overall priorities of criteria

Criteria	AHP	DEAHP	FAHP
Quality	0.420	1.000	0.410
Cost	0.243	0.800	0.250
Delivery	0.093	0.400	0.110
Service	0.126	0.600	0.110
LTR	0.051	0.200	0.060
Flexibility	0.068	0.400	0.060

DEAHP analysis. Hence it may be concluded that results of AHP and DEAHP models are similar for the problem in question. However, the results of FAHP model are different from other models as shown in last column of Table 27.9. According to it, top priority has been assigned to supplier 3 followed by supplier 1 and supplier 2.

It is worth to notice that the relative score difference between the first and the last supplier in the ranking is quite limited ((0.421–0.273)/0.421 = 35.15 %). Therefore, slight variation in managers' judgment can modify the final ranking.

It can be concluded from this study that quality and cost are the most crucial criteria for the automobile company. Other researchers also identified quality (Bruno et al. 2012; Zhang et al. 2011; Sen et al. 2010) and cost (Zhang et al. 2011; Sevkli et al. 2007) as key criteria for supplier selection problem. Priorities given to the quality criterion by AHP, DEAHP and FAHP are 0.420, 1.000 and 0.410 respectively as shown in Table 27.10. Hence quality criterion is the top priority criterion among the other criteria. However, the cost criterion from AHP, DEAHP and FAHP are 0.243, 0800 and 0.25 respectively. Table 27.10 provides priorities to other criteria also in the similar fashion.

This study has contributed important findings of supplier selection process in following ways:

- It contributes to supplier selection process and points out the importance of supplier selection.
- This study proposes an intelligent supplier selection model for an automobile industry which often faces heterogeneous supply environments.
- The models provide key criteria for supplier selection in Indian context.
- It provides case applications of AHP, DEAHP and FAHP models for supplier selection problem.
- This study further provides useful insights in the dynamics of the supplier selection process by varying the selection criteria by conducting sensitivity analysis.

- The findings provide important directions and guidelines in choosing appropriate suppliers in dynamic situations in order to enhance long term relationship with them.

However this study should be viewed in the light of some limitations. As this analysis and findings are based on only one case study of an Indian automobile company, and this necessitates caution in interpreting the results. The limited number of interviewed managers in a company restricts the generalizability of the results. Though the company selected for this study is typical of developing country businesses, the findings of the study may not be readily extensible to other companies. Future research could examine these results using a larger sample set or field surveys in developing country settings. Secondly, this study used retrospective settings, based on the interviewed feedback after the events had occurred. This method naturally poses limitations due to respondent recall and the accuracy of information provided. Thirdly, the problem chosen for this study is based in a single country context and further additional research will be required to examine if the findings could be extended to other automobile companies in other developing nations. Fourthly, this study can be extended to add more supplier alternatives, which encompass both domestic and international suppliers; however, it may increase computational complexities and efforts.

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References

Agarwal, P., Sahai, M., Mishra, V., Bag, M., Singh, V.: A review of multi-criteria decision making techniques for supplier evaluation and selection. Int. J. Ind. Eng. Comput. **2**(4), 801–810 (2011)

Ahmady, N., Azadi, M., Sadeghi, S.A.H., Saen, R.F.: A novel fuzzy data envelopment analysis model with double frontiers for supplier selection. Int. J. Logistic Res. Appl. Lead. J. Supply Chain Manage. **16**(2), 87–98 (2013)

Arikan, F.: A fuzzy solution approach for multi objective supplier selection. Expert Syst. Appl. **40** (3), 947–952 (2013)

Aydin, S., Kahraman, C.: Multiattribute supplier selection using fuzzy analytic hierarchy process. Int. J. Comput. Intell. Syst. **3**(5), 553–565 (2010)

Bayazit, O.: Use of analytic network process in vendor selection decisions. Benchmarking Int. J. **13**(5), 566–579 (2006)

Boran, F.E., Genc, S., Kurt, M., Akay, D.: A multi criteria intuitionistic fuzzy group decision making fir supplier selection with TOPSIS method. Expert Syst. Appl. **36**(8), 11363–11368 (2009)

Bruno, G., Esposito, E., Genovese, A., Passaro, R.: AHP-based approaches for supplier evaluation: problems and perspectives. J. Purchasing Supply Manage. **18**(3), 159–172 (2012)

Cebi, F., Bayraktar, D.: An integrated approach for supplier selection. Logistics Inf. Manage. **16** (6), 395–400 (2003)

Chan, F.T.S., Chan, H.K.: An AHP model for selection of suppliers in the fast changing fashion market. Int. J. Adv. Manuf. Technol. **51**(4), 1195–1207 (2010)

Chan, F.T.S., Kumar, N.: Global supplier development considering risk factors using fuzzy extended AHP-based approach. OMEGA—Int. J. Manage. Sci. **35**(4), 417–431 (2007)
Chang, B., Chang, C., Wu, C.: Fuzzy DEMATEL method for developing supplier selection criteria. Expert Syst. Appl. **38**(3), 1850–1858 (2011)
Chang, D.Y.: Applications of the extent analysis method on fuzzy AHP. Eur. J. Oper. Res. **95**(3), 649–655 (1996)
Chen, C.T., Lin, C.T., Huang, S.F.: A fuzzy approach for supplier evaluation and selection in supply chain management. Int. J. Prod. Econ. **102**(2), 289–301 (2006)
Chen, Y.H., Chao, R.H.: Supplier selection using consistent fuzzy preference relations. Expert Syst. Appl. **39**(3), 3233–3240 (2012)
Deng, X., Hu, Y., Deng, Y., Mahadevan, S.: Supplier selection using AHP methodology extended by D numbers. Expert syst. Appl. **41**(1), 156–167 (2014)
Dickson, G.W.: An analysis of vendor selection systems and decisions. J Purchasing **2**(1), 5–17 (1966)
Dotoli, M., Falagario, M.: A hierarchical model for optimal supplier selection in multiple sourcing contexts. Int. J. Prod. Res. **50**(11), 2953–2967 (2012)
Florez-Lopez, R.: Strategic supplier selection in the added-value perspective: a CI approach. Inf. Sci. **177**(5), 1169–1179 (2007)
Forker, L.B., Mendez, D.: An analytical method for benchmarking best peer suppliers. Int. J. Oper. Prod. Manage. **21**(1–2), 195–209 (2001)
Garfamy, R.M.: A data envelopment analysis approach based on total cost of ownership for supplier selection. J. Enterp. Inf. Manage. **19**(6), 662–678 (2006)
Gencer, C., Gurpinar, D.: Analytic network process in supplier selection: a case study in an electronic firm. Appl. Math. Model. **31**(11), 2475–2486 (2007)
Ghorbani, M., Arabzad, S.M., Shahin, A.: A novel approach for supplier selection based on the Kano model and fuzzy MCDM. Int. J. Prod. Res. **51**(8), 5469–5484 (2013)
Gonzailez, M.E., Quesada, G., Monge, C.A.M.: Determining the importance of the supplier selection process in manufacturing: a case study. Int. J. Phys. Distrib. Logistics Manage. **34**(6), 492–504 (2004)
Ho, W., Xu, X., Dey, P.K.: Multi-criteria decision making approaches for supplier evaluation and selection: a literature review. Eur. J. Oper. Res. **202**(1), 16–24 (2010)
Hong, G.H., Park, S.C., Jang, D.S., Rho, H.M.: An effective supplier selection method for constructing a competitive supply-relationship. Expert Syst. Appl. **28**(4), 629–639 (2005)
Hou, J., Su, D.: EJB–MVC oriented supplier selection system for mass customization. J. Manuf. Technol. Manage. **18**(1), 54–71 (2007)
Jain, V., Wadhwa, S., Deshmukh, S.G.: Select supplier-related issues in modelling a dynamic supply chain: potential, challenges and direction for future research. Int. J. Prod. Res. **47**(11), 3013–3039 (2009)
Jiang, W., Chan, F.T.S.: A new fuzzy dempster MCDM method and its application in supplier selection. Expert Syst. Appl. **38**(8), 9854–9861 (2011)
Kahraman, C., Cebeci, U., Ulukan, Z.: Multi-criteria supplier selection using fuzzy AHP. Logistics Inf. Manage. **16**(6), 382–394 (2003)
Kahraman, C., Cebeci, U., Ruan, D.: Multi-attribute comparison of catering service companies using fuzzy AHP: the case of Turkey. Int. J. Prod. Econ. **87**(2), 171–184 (2004)
Karpak, B., Kumcu, E., Kasuganti, R.R.: Purchasing materials in the supply chain: managing a multi-objective task. Eur. J. Purchasing Supply Manage. **7**(3), 209–216 (2001)
Kilincci, O., Onal, S.A.: Fuzzy AHP approach for supplier selection in a washing machine company. Expert Syst. Appl. **38**(8), 9656–9664 (2011)
Krajewski, L.J., Ritzman, L.P.: Operations Management Strategy and Analysis. Addison-Wesley Publishing Co., London (1996)
Kull, T.J., Talluri, S.: A supply-risk reduction model using integrated multicriteria decision making. IEEE Trans. Eng. Manage. **55**(3), 409–419 (2008)

Kumar, J., Roy, N.: Analytic hierarchy process (AHP) for a power transmission industry to vendor selection decisions. Int. J Comput Appl. **12**(11), 26–30 (2011)

Liu, F., Ding, F.Y., Lall, V.: Using data envelopment analysis to compare suppliers for supplier selection and performance improvement. Int. J. Supply Chain Manage. **18**(6), 143–150 (2000)

Mendoza, A., Santiago, E., Ravindran, A.R.: A three-phase multicriteria method to the supplier selection problem. Int. J. Ind. Eng. **15**(2), 195–210 (2008)

Muralidharan, C., Anantharaman, N., Deshmukh, S.G.: A multi-criteria group decision-making model for supplier rating. J. Supply Chain Manage. **2**(45), 22–33 (2002)

Ng, W.L.: An efficient and simple model for multiple criteria supplier selection problem. Eur. J. Oper. Res. **186**(3), 1059–1067 (2008)

Ni, M., Xu, X., Deng, S.: Extended QFD and data-mining-based methods for supplier selection in mass customization. Int. J. Comput. Integr. Manuf. **20**(2–3), 280–291 (2007)

Partovi, F.Y.: Selecting suppliers for a long-term relationship. Int. J. Manage. Sci. Eng. Manage. **8** (2), 109–116 (2013)

Percin, S.: An application of the integrated AHP–PGP model in supplier selection. Measuring Bus. Excellence **10**(4), 34–49 (2006)

Pitchipoo, P., Venkumar, P., Rajakarunakaran, S.: Fuzzy hybrid decision model for supplier evaluation and selection. Int. J. Prod. Res. **51**(13), 3903–3919 (2013)

Ramanathan, R.: Data envelopment analysis for weight derivation and aggregation in the analytic hierarchy process. Comput. Oper. Res. **33**(5), 1289–1307 (2006)

Saaty, T.L.: The Analytic Hierarchy Process. McGraw-Hill Book Co., New York (1980)

Sarkis, J., Talluri, S.: A model for strategic supplier selection. J. Supply Chain Manage. **38**(1), 18–28 (2002)

Sen, C.G., Sen, S., Baslıgil, H.: Pre-selection of suppliers through an integrated fuzzy analytic hierarchy process and max-min methodology. Int. J. Prod. Res. **48**(6), 1603–1625 (2010)

Sevkli, M., Koh, S.C.L., Zaim, S., Demirbag, M., Tatoglu, E.: An application of data envelopment analytic hierarchy process for supplier selection: a case study of BEKO in Turkey. Int. J. Prod. Res. **45**(9), 1973–2003 (2007)

Seydel, J.: Data envelopment analysis for decision support. Ind. Manage. Data Syst. **106**(1), 81–95 (2006)

Shaw, K., Shankar, R., Yadav, S.S., Thakur, L.S.: Supplier selection using fuzzy AHP and fuzzy multi-objective linear programming for developing low carbon supply chain. Expert Syst. Appl. **39**(9), 8182–8192 (2012)

Songhori, M.J., Tavana, M., Azadeh, A., Khakbaz, M.H.: A supplier selection and order allocation model with multiple transportation alternatives. Int. J. Adv. Manuf. Technol. **52**(1–4), 365–376 (2011)

Talluri, S.: A buyer–seller game model for selection and negotiation of purchasing bids. Eur. J. Oper. Res. **143**(1), 171–180 (2002)

Talluri, S., Narasimhan, R.: Vendor evaluation with performance variability: a max min approach. Eur. J. Oper. Res. **146**(3), 543–552 (2003)

Talluri, S., Narasimhan, R.: A note on a methodology for supply base optimization. IEEE Trans. Eng. Manage. **52**(1), 130–139 (2005)

Tas, A.: A Fuzzy AHP approach for selecting a global supplier in pharmaceutical industry. Afr. J. Bus. Manage. **6**(14), 5073–5084 (2012)

Vokurka, R.J., Choobineh, J., Vadi, L.: A prototype expert system for the evaluation and selection of potential suppliers. Int. J. Oper. Prod. Manage. **16**(12), 106–127 (1996)

Weber, C.A., Current, J.R., Benton, W.C.: Vendor selection criteria and methods. Eur. J. Oper. Res. **50**(1), 2–18 (1991)

Wu, T., Shunk, D., Blackhurst, J., Appalla, R.: AIDEA: A methodology for supplier evaluation and selection in a supplier-based manufacturing environment. Int. J. Manuf. Technol. Manage. **11**(2), 174–192 (2007)

Yadav, V., Sharma, M.K.: An application of hybrid data envelopment analytical hierarchy process approach for supplier selection, J. Enterprise Inf. Manage. **28**(1 or 2) (2015a) (In press)

Yadav, V., Sharma, M.K.: Multi-criteria decision making for supplier selection using fuzzy AHP approach. Benchmarking Int. J. **22**(7) (2015a) (In press)

Yu, C., Wong, T.N.: A supplier pre-selection model for multiple products with synergy effect. Int. J. Prod. Res. (2014). doi:10.1080/00207543.2014.900199

Zhang, X., Lee, C.K.M., Chen, S.: Supplier evaluation and selection: a hybrid model based on DEAHP and ABC. Int. J. Prod. Res. **50**(7), 1–13 (2011)

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