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Efficient Decision Support Systems

Practice and Challenges in Multidisciplinary Domains

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EFFICIENT DECISION SUPPORT SYSTEMS – PRACTICE AND CHALLENGES IN MULTIDISCIPLINARY DOMAINS

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http://dx.doi.org/10.5772/911
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First published in Croatia, 2011 by INTECH d.o.o.
eBook (PDF) Published by IN TECH d.o.o.
Place and year of publication of eBook (PDF): Rijeka, 2019.
IntechOpen is the global imprint of IN TECH d.o.o.
Printed in Croatia

Legal deposit, Croatia: National and University Library in Zagreb

Additional hard and PDF copies can be obtained from orders@intechopen.com

Efficient Decision Support Systems - Practice and Challenges in Multidisciplinary Domains
Edited by Chiang Jao

p. cm.

ISBN 978-953-307-441-2

eBook (PDF) ISBN 978-953-51-5557-7

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Meet the editor

Chiang S. Jao, Ph.D., is chief biomedical informaticist with Tranformation Inc. based in Maryland. He has been involved medical informatics since coming to University of Illinois at Chicago in 1992 to work on clinical decision support systems. His research was awarded the grant from National Patient Safety Foundation in investigating the matching of prescribing medications and clinical problems in electronic heath records. He was the visiting scholar in the Lister Hill National Center for Biomedical Communications, National Library of Medicine and built a standard drug-problem database based on authoritative information from approved drug package inserts. He has extensive experience as a software consultant to healthcare institutions. He is a senior member of the Institute of Electrical and Electronic Engineers (IEEE) and the American Medical Informatics Association (AMIA).

Contents

Preface

Series Preface

This series is directed to diverse managerial professionals who are leading the transformation of individual domains by using expert information and domain knowledge to drive decision support systems (DSSs). The series offers a broad range of subjects addressed in specific areas such as health care, business management, banking, agriculture, environmental improvement, natural resource and spatial management, aviation administration, and hybrid applications of information technology aimed to interdisciplinary issues.

This book series is composed of three volumes: Volume 1 consists of general concepts and methodology of DSSs; Volume 2 consists of applications of DSSs in the biomedical domain; Volume 3 consists of hybrid applications of DSSs in multidisciplinary domains. The book is shaped decision support strategies in the new infrastructure that assists the readers in full use of the creative technology to manipulate input data and to transform information into useful decisions for decision makers. This book series is dedicated to support professionals and series readers in the emerging field of DSS.

Preface

Book Volume 2 extends the applications of decision support systems (DSSs) to regulate various resources in dealing with business, water resource, agriculture, space, risks/crisis, and other interdisciplinary issues. Design and development of such hybrid types of DSSs need to integrate interdisciplinary knowledge, resource data, as well as a variety of surrounding interdisciplinary parameters (for example behavioral-, economic-, environmental-, and social-related factors) and to effectively improve resource management. This book can be used in case-study courses related to decision support systems (DSSs). It may be used by both undergraduate senior and graduate students from diverse computer-related fields. After reading this book, the readers should be able to draw a clear picture about how to apply DSSs in multidisciplinary fields. It will also assist professionals in business, spatial, agricultural, aviation and other non-biomedical fields for self-study or reference.

Section 1, including Chapter 1 through 9, illustrates several applications of intelligent DSSs for business purposes. Chapter 1 focuses on customer relationship management and its adoption in banking industry. Chapter 2 focuses on the improvement of modern production and trade management using intelligent agent technologies. Chapter 3 presents a novel DSS performed to analyze stocks, calling market turns and making recommendations by combining knowledge-based problem solving with case-based reasoning and fuzzy logic inference. Chapter 4 presents an efficient business DSS, integrated with the configuration management database, to reduce operational cost expenses and promote the satisfactory level of client expectations. Chapter 5 focuses on enhancing decision making for managers to re-engineer existing business processes and enterprise activity analysis. Chapter 6 presents an intelligent DSS that assists managers in improving customer needs who are using e-commerce systems based on collected data relating to their behavior. Chapter 7 presents another intelligent DSS that provides quick responses in a continuous replenishment program to reduce the stock level throughout the supply chain. Chapter 8 presents a semi-automated DSS protocol for collaborative decision making in managing virtual enterprises with business globalization and sharing supply chains. Chapter 9 presents a lean balanced scorecard method to enhance the organization's competitive advantages for decision making in its financial dimension.

Section 2, including Chapter 10 through 13, presents a set of DSSs aimed to water resource management and planning issues. Chapter 10 focuses on improving water delivery operations in irrigation systems through the innovative use of water DSSs. Chapter 11 uses one of the latest biophysical watershed level modeling tools to estimate the effects of land use change in water quality. Chapter 12 presents a flood prediction model with visual representation for decision making in early flood warning and impact analysis. Chapter 13 presents an integrated sustainability analysis model that provides holistic decision evaluation and support addressed the environmental and social issues in green operations management.

Section 3, including Chapter 14 through 15, presents two DSSs applied in the agricultural domain. Chapter 14 integrates agricultural knowledge and data representation using fuzzy logic methodology that generalizes decision tree algorithms when an uncertainty (missing data) is existed. Chapter 15 presents Web-based DSS models in respectively dealing with surface irrigation and sustainable pest management in the agricultural domain.

Section 4, including Chapter 16 through 17, illustrates two spatial DSSs applied to multidisciplinary areas. Chapter 16 presents the DSS for location decisions of taxicab stands in an urban area with the assistance of geographical information system (GIS) and fuzzy logic techniques. Chapter 17 presents the spatial DSS integrated with GIS data to assist managers identifying and managing impending crisis situations.

Section 5, including Chapter 18 and 19, emphasizes the importance of DSS applications in risk analysis and crisis management. In a world experiencing recurrent risks and crises, it is essential to establish intelligent risk and crisis management systems at the managerial level that supports appropriate decision making strategies and reduces the occurrence of uncertainty factors. Chapter 18 illustrates the DSS for industrial managers to support risk analysis and prediction of critical resource distribution and infrastructure protection. Chapter 19 focuses on the use of the hybrid DSS in improving critical decision making process for treating extreme risk and crisis event management.

This book concludes in Section 6 that covers a set of DSS applications adopted in aviation, power management, warehousing, and climate monitoring respectively. Chapter 20 presents an aviation maintenance DSS to promote the levels of airworthiness, safety and reliability of aircrafts and to reduce indirect costs due to frequent maintenance.Chapter 21 introduces a fuzzy logic DSS to assist decision makers in better rankings of power consumption in rock sawing process. Chapter 22 presents a DSS for efficient storage allocation purpose that integrates management decisions in a warehousing system. Chapter 23 investigates challenges in climate-driven DSS in forestry. By including prior damage data and forest management activities caused by changes in weather and forest structure, a DSS model is presents to assist forest managers in assessing the damage and projecting future risk factors in monitoring the climate change.

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Part 1

Applications in Business

1

Application of Decision Support System in Improving Customer Loyalty: From the Banking Perspectives

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1. Introduction

The focus of this research is on customer relationship management (CRM) and its adoption in Taiwan's banking industry. The concept of CRM and its benefits have been widely acknowledged. Kincaid (2003, p. 47) said, "CRM deliver value because it focuses on lengthening the duration of the relationship (loyalty)." Motley (2005) found that satisfiers keep customers with the bank while dissatisfiers eventually chase them out. Earley (2003) pointed out the necessity of holistic CRM strategies for every company because today even the most established brands no longer secure lasting customer loyalty. It seems clear that customer relationship management is critical for all service firms, including the banks.

1.1 Research motivations

Nowadays, for banking industry, one way to keep being profitable is to retain the existing customers, and one way to keep existing customers is to satisfy them. According to the 80/20 rule in marketing, 80% of sales comes from 20% customers. In addition, Peppers and Rogers (1993) pointed out that the cost of discovering new customers is six to nine time higher than that of keeping existing customers. Thus, it is critical to maintain customer loyalty. According to Lu (2000), through the adoption of CRM systems, companies could (1) find the best customers, (2) keep existing customers, (3) maximize customer value, and (4) develop effective risk management. In addition, successful CRM will create huge values for companies through improved customer retention rate. Therefore, it is worthwhile to conduct an empirical study on the adoption of CRM systems in Taiwan's banking industry.

1.2 Statement of problems

A major challenge banks are facing today is to implement new technology solutions that will provide more responsiveness and flexibility to their business clients. Many corporations are now conducting their transactions with fewer banks. Dobbins (2006, p. 1) said, "The challenge for all banks, large and small, is not only to create a centre of excellence with established international standards of communication, but also to reconstruct and automate their business processes to maximize efficiency."In addition, a number of researchers found that implementation of technology such as CRM do not guarantee that the expected results will be achieved. In fact, a number of studies indicate that firms have suffered failures organizational problems (53%) or an inability to access the most relevant information technologies (40%) (Ernst & Young, 2001). In Taiwan's banking industry, there is also a CRM adoption issue. Most banks do not quite understand CRM. F. H. Lin and P. Y. Lin (2002, p. 528) said that according to a CRM-application survey of Taiwan's industries by ARC Consulting, 90% of the industry (most of which consists of banks) knew about CRM while only 64% understood the intension of CRM. Furthermore, only 10% of Taiwan's industries have already established the CRM systems. Hence, there is still much room for improving when it comes to CRM adoption in Taiwan's banking industry. Huang and Lu (2003, p. 115) noted that recently, the competition in local banking industry has become more acute as branches of banks are multiplying and as Taiwan has become a member of World Trade Organization (WTO). Given these environmental changes, implementing a CRM system is becoming a pressing item on local banks' agendas. At this juncture, then, addressing the importance of CRM adoption in Taiwan's banking industry is indeed a worthy cause. Huang and Lu (2003) further suggested that Taiwan's financial institutions, in this customer-oriented age, should not be limited to operational strategies that are product-oriented. Instead, according to these authors, they need to gauge customers' favorites accurately and find out the potential needs of their customers. Only by doing so, they would be able to promote their financial products with their customers. In the future, the focus of core competitive strategies in Taiwan's banking industry will shift from "products" to "customers." Thus, integrating front and back processes and understanding the intension and implementation of CRM have become an urgent task for Taiwan's banking industry. Therefore, it is imperative to explore the factors that would affect CRM adoption in Taiwan's banking industry and to solve the problems arising therein.

2. Literature review

A body of previous studies on this topic lends a solid basis to the present investigation. This literature covers the following sub-areas: (1) introduction of customer relatioship management, (2) measurement of success with CRM, (3) CRM technologies and success with CRM.

2.1 Introduction of Customer Relationship Management

Customer relationship management (CRM) is now a major component of many organizations' E-commerce strategy. Trepper (2000) thought that CRM could classified as (1) operational (e.g., for improving customer service, for online marketing, and for automating the sales force), (2) analytical (e.g., for building a CRM data warehouse, analyzing customer and sales data, and continuously improving customer relationships), or (3) collaborative (e.g., for building Web and online communities, business-to-business customer exchanges and personalized services).

2.2 Measurement of success with CRM

Every bank, regardless of its size, would pride itself on providing high-quality customer service. However, the challenge is that the benchmarks for high-quality customer services are changing dramatically, to the extent that yesterday's standards will not enable a bank to win today's customers. Shermach (2006) considered identifying customer expectation lines and reaching those lines the most important tasks for the banking industry. Sheshunoff (1999) likewise argued that banks will need to develop new tools and strategies in an effort to maintain their reputation and that those tools and strategies will likely involve CRM.

Once a CRM system has been implemented, an ultimate question arises. That is, whether the CRM adoption can be considered a success. Since there exist many measures to assess IT adoption success, care must be taken when selecting the appropriate approach for analyzing CRM implementations with banks. In the present study, the author chose to determine CRM implementation by process efficiency and IT product quality. These approaches make it possible to highlight the goals that need to be managed more actively during the CRM introduction process to make the adoption of CRM systems a success.

2.2.1 Process efficiency

Levitt (1960) believed that customer satisfaction is the ultimate goal for every business because, for most industries, unsatisfied customers will eventually leave. To the same effect, Motley (1999, p.44) said, "In most industries, unhappy customers turn to competitors who promise more. This also happens in banking; it just takes longer." Cambell (1999, p. 40) said, "As the competition in banking and financial services industries continues to increase, achieving the highest possible levels of customer satisfaction will be critical to continued success." Along this line of thinking, Jutla and Bodorik (2001) have suggested that three customer metrics – customer retention, customer satisfaction, and customer profitability—could be used to measure CRM performance. These assertions have been corroborated by similar studies conducted in Taiwan. For instance, according to F. H. Lin and P. Y. Lin. (2002), with CRM systems, businesses could gain higher customer loyalty and higher customer value. Lu, Hsu and Hsu (2002) also argued that Taiwan's banking industry should utilize customer data analyses and multiple communication channels to increase customer satisfaction. In addition to customer satisfaction, process efficiency has been considered a norm for successful CRM adoption. Burnett (2004) stated that real-time assessment to CRM could increase efficiency, responsiveness, and customer loyalty, because it could make customer information available anytime and anywhere. As long as people continue to believe that CRM is equal to process efficiency, the real benefits of CRM will stay beyond reach. Baldock (2001) suggested that banks need to implement additional software that could do two things: (1) deciding what product or message should be offered to which customer and (2) delivering these product recommendations in real-time through all of the bank's channels allowing CRM to combine efficiency and effectiveness. The relationships that customers have with banks are becoming increasingly complex, so complex that the data that a customer's profile is based on needs to be updated continually, in real time. Luo, Ye, and Chio (2003) felt that businesses in Taiwan could involve customers in CRM by one-on-one marketing through Internet. By doing so, businesses could (1) achieve accuracy of information, (2) increase information value, (3) lower work-force demands, and (4) increase process efficiency. Chang and Chiu (2006, p. 634) also claimed that "it is also very meaningful to investigate factors influencing the efficiency of Taiwan banks." It seems clear, then, that for Taiwan's banking industry process efficiency is an important variable in determining the success of CRM.

2.2.2 Product quality

Research on software engineering has identified certain IT product-quality dimensions, such as human engineering, portability, reliability, maintainability, and efficiency. A variety of metrics to assess these dimensions of CRM system quality has also been developed and validated. As this stream of research continues to evolve, its emphasis has been on the engineering characteristics of the CRM system while limited attention has been paid to assessing and enhancing users' subjective evaluations of the system (Yahaya, Deraman, and Hamdan, 2008; Ortega, Perez, and Rojas, 2003). A key management objective when dealing with information products is to understand the value placed by users on these IT products. In contrast to the technical focus of CRM system's quality assurance research, customer satisfaction is an important objective of TQM (total quality management) initiatives. Customers have specific requirements, and products/services that effectively meet these requirements are perceived to be of higher quality (Deming, 1986; Juran, 1986). A similar perspective is evident in the IS management studies, where significant attention has been paid to understanding user requirements and satisfying them. Research has focused on identifying the dimensions of developing reliable and valid instruments for the measurement of this construct (Bailey and Pearson, 1983; Galletta and Lederer, 1989; Ives, Olson, and Baroudi, 1983). It seems clear that, for Taiwan's banking industry, product quality is an important variable in determining the success of CRM.

2.3 CRM technologies and success with CRM

This section presents an exploration of the applications of certain technologies and their effects on CRM adoption in Taiwan's banking industry.

2.3.1 Developing information technologies in the banking industry

Chowdhury (2003) stated that banks are widely acknowledged to be heavily dependent on information technologies. This is so especially in the United States, where banking is considered a most IT-intensive industry. Such dependence is readily evidenced by the proportion of computer equipment and software employed by the U.S. banks in their day-to-day operation. Some researchers found that for the banks the IT spendings were as high as 8% of the industry's average revenue, with the average ratio of IT spending to revenue being approximately 2 to 3% for other industries. In addition, IT spendings represent about one third of the average operating expenses (Berensmann, 2005; Rebouillon and Muller, 2005). Furthermore, this pattern of extensive IT usage in banking is assumed to be similar across countries (Zhu, Kraemer, Xu, and Dedrick, 2004). However, this high level of IT has turned out to be a problem for many banks. Banks have traditionally relied on in-house development since the early days of electronic data processing. However, the emergent applications in the 1970s are conceived of as legacy applications today (Moormann, 1998). These legacy systems have historically been built around the banks' product lines, e.g., loans, deposits and securities, with very limited cross-functional information flow (Chowdhury, 2003). It is well known that in banking there have been substantial IT-driven business innovations which not only boost bank efficiency but also benefited the consumers. Automated teller machines and electronic fund transfer are among these innovations (Dos Santos and Peffers, 1995). Because of these cutting-edge innovations, banks have not been motivated to redesign their IT infrastructure in a modular, integrated and more flexible manner (Betsch, 2005). Consequently, most banks tend to use a number of isolated solutions to perform even standard business activities, such as loan application processing, instead of seamlessly integrating business processes and the underlying information systems. Nevertheless, prevailing legacy systems create problems not merely in data processing. They are also a major cost driver, as approximately two thirds of a bank's IT budget typically goes into the maintenance of legacy applications (Rebouillon & Muller, 2005). Therefore, existing IT infrastructures in banks are often obstacles to efficiently running a bank, in spite of a heavy investment in IT. Veitinger and Loschenkohl (2005) asserted that modular and flexible CRM/ERP systems could mitigate some of the legacy-application problems with the banks since CRM/ERP systems may enable the banks to align their business processes more efficiently. Although the CRM systems are able to provide huge direct and indirect benefits, potential disadvantages, e.g., lack of appropriate CRM/ERP package, can be enormous and can even negatively affect a bank's Success with CRM adoption. Scott and Kaindl (2000) found that approximately 20% of functionalities/modules needed are not even included in the systems. This rate may arguably be even higher in banking, possibly creating the impression that CRM/ERP systems with appropriate functionality coverage are not available at all. In addition to the system package, the pressure from CRM/ERP vendors to upgrade is an issue. This pressure has become a problem due to recent architectural changes that systems of major CRM/ERP vendors face. That is, with the announcement of mySAP CRM as the successor of SAP R/3 and its arrival in 2004, SAP's maintenance strategy has been extensively discussed while users fear a strong pressure to upgrade (Davenport, 2000; Shang & Seddon, 2002).

2.3.2 Customization of CRM functions/modules

Chang and Liu (2005) believed that customization is a key to gaining the emotional promises from the customers in Taiwan's banking industry and that such promises can increase customer loyalty (i.e., decreasing customer churn rate). Due to the fast-changing financial environment, competition and high customer churn rates, Taiwan's banking industry should focus on long-term customer relationships and strive to raise the customer retention rate. Li (2003) found that, in order to enhance customer services, the CRM systems should be adjusted when a company adopts them. In other words, companies should "customize" their CRM systems according to the demands of their own customers. If the customization of the CRM system cannot satisfy the customers, companies could further consider "personalizing" their CRM systems. Chang and Liu (2005, p. 510) stated that if a bank has effective ability to deal with a contingency or emergency and could provide professional financial plans as well as innovative services with its financial products, these customization functions could help increase the reorganization of customer values. Liao (2003) suggested that companies, when adopting CRM systems, should emphasize customer differentiation, customer loyalty, customer lifetime values, one-on-one marketing, and customization. Born (2003, p. 1) argued that "the greater the CRM functionality, the less customization of the CRM system required." Huang (2004, p. 104) also said, "When the goal of implementing CRM is to improve operational efficiency, the management should try to minimize the customization of a CRM system." Obviously, there is a difference in customization in the banking industry between the United Sates and Taiwan. Companies in Taiwan would more likely customize their CRM systems in order to satisfy their customers' needs. In U.S., though, customization is not as widespread. A main goal of the present study is to explore the relationship between customization of CRM functions/modules and the adoption of CRM's in Taiwan's banking industry.

2.3.3 Selecting the CRM vendors

Once a company starts to implement a CRM system, it will look to the CRM vendors as a barometer of their CRM system's health. However, at any given point in time, one may choose from a host of CRM vendors (e.g., Oracle/People Soft, Siebel, Broadvision, NetSuite 10, SAP, E.pipjany, Rightnow CRM 7.0, Salesforce.com, Salesnet.com, and Microsoft).

According to Hsu and Rogero (2003), in Taiwan, the major CRM vendors are the well-known brand names, such as IBM, Oracle, Heart-CRM, and SAP. Confronted with so many vendors, organizations that wish to implement a CRM system will need to choose wisely.It has been recognized that the service ability of vendors would affect the adoption of information technologies (Thong and Yap, 1996). Lu (2000) posited that the better the training programs and technical support supplied by a CRM vendor, the lower the failure rate will be in adopting a CRM system. It is generally believed that CRM vendors should emphasize a bank's CRM adoption factors such as costs, sales, competitors, expertise of CRM vendors, managers' support, and operational efficiency (H. P. Lu, Hsu & Hsu, 2002). For banks that have not yet established a CRM system, CRM vendors should not only convince them to install CRM systems, but also supply omnifarious solutions and complete consulting services. For those banks that have already established a CRM system, in addition to enhancing after-sales services, the CRM vendors should strive to integrate the CRM systems into the legacy information systems.When companies choose their CRM vendors, they face many alternatives (Tehrani, 2005). Borck (2005) believed that the current trend among CRM vendors is moving toward producing tools that satisfy the basic needs of sales and customer support. The ultimate goal of a bank in choosing a CRM vendor is to enable the IT application intelligence to drive the revenues to the top line. Based on these views, it may be concluded that choosing a reputable CRM vendor and benefiting from its expertise are prerequisite for a successful CRM adoption in Taiwan's banking industry.

2.3.4 Conducting DSS (Decision Support System)

Since a bank offers countless daily services — offering credit cards, loans, mortgages — it is very risky for it to offer such services to customers they know nothing about. It is generally acknowledged that banks need to ensure the reliability of their customers (Hormazi & Giles, 2004). The concept here is simple: the banking industry has a need to reduce the risks from issuing credit cards or loans to customers who are likely to default. An example, given by Cocheo (2005), is of a bank that found a borrower appealing until receiving a court notice saying the customer had filed a bankruptcy. As a solution to problems such as this, the artificial neural network (ANN) has been widely adopted. According to Fadlalla and Lin (2001), an ANN is a technology using a pattern-recognition approach that has established itself in many business applications, including those in the U.S. banking industry**.** According to Turban, Aronson, and Liang (2004), an ANN is able to learn patterns in the data presented during training and will automatically apply what it has learned to new cases. One important application of ANN is in bank loan approvals because an ANN can learn to identify potential loan defaulters from the ascertained patterns. Turban et al. (2004) further observed that one of the most successful applications of ANN is in detecting unusual credit spending patterns, thereby exposing fraudulent charges. Therefore, conducting DSS systems, such as ANN technology, to analyze the customer data should be a critical step toward CRM adoption in Taiwan's banking industry.

2.4 Summary

In conclusion, this author, based on the previous studies, would like to test the relationship between CRM technologies and success with CRM. Table 1 sums up the factors selected from the literature review to be tested in the present study.

	Factors
Measurements of CRM success	A. CRM deployment. B. Process efficiency. C. Product quality.
CT1	Conducting the decision support system (DSS)s
CT2	Customizing CRM functions/modules.
CT3	Choosing reputed CRM vendors.
CT4	Drawing on the expertise of CRM vendors.
CT5	Pressure from CRM(ERP) vendor to upgrade.
CT6	Non-availability of appropriate CRM(ERP) packages.

Table 1. A Summary of Variables Included in the Present Study

3. Research methodology

The objective of this study is to examine the impact of a variety of relevant factors on the CRM success in Taiwan's banking industry. This section presents the research question, hypothesis, and statistical techniques for hypothesis testing.

3.1 The research question and the hypothesis

Since the challenges that the banks are facing today are to implement and support new technological solutions that will enable them to be more responsive and flexible to their business clients, the present study seeks to answer the following research question:
Research Question: What are the critical factors that explain the degree of success in the adoption of a CRM system in Taiwan's banking industry?
The hypothesis derived from this research question is displayed in the following:
H_1: The CRM technology will be positively associated with successful CRM adoption in Taiwan's Banking industry.

3.2 Research design

First, based on the findings from the literature review, an exploratory study (i.e., focus group interviews) was conducted to discover the nature of the problems and to generate possible solutions to the research question. Second, on the basis of the findings from the focus group interviews, a quantitative analysis was conducted using survey and statistical methods to identify possible answers to the research question.

3.2.1 Research population and samples

The population for the present survey consists of the local banking industry in Taiwan, including domestic banks and local branches of foreign banks. The information about these banks came from the official website of Financial Supervisory Commission, Executive Yuan in Taiwan. There are 37 domestic banks and 31 local branches of foreign banks in Taiwan. The research samples are the CRM users in IT or Customer-Service departments in those banks.

3.3 Statistical methods

Two statistical methods were conducted in this present study: (1) EFA (exploratory factor analysis) and (2) SEM (structural equation modeling).

3.3.1 Introduction

Figure 1 summaries the processes of two statistical methods in the present study.

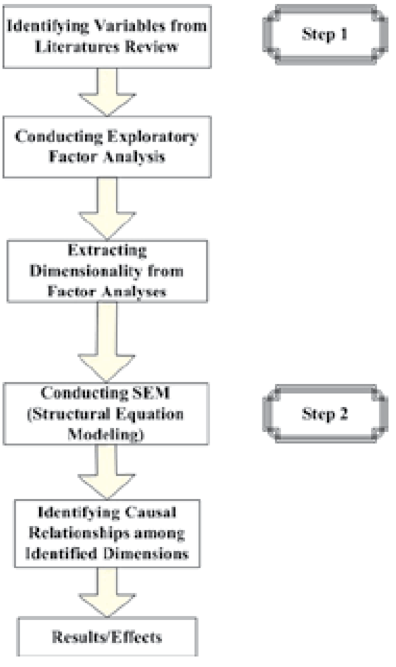


Fig. 1. A Summary of Statistical Methods

4. Results

In the present study, this author would like to test the causal relationship between CRM technologies and success with CRM. The hypothesis of the study, the variables involved and the statistical methods are described in the following.

Tested hypothesis: H_1: The CRM technology will be positively associated with successful CRM adoption in Taiwan's Banking industry

Observed variables: CT1 (Conducting the decision support system), CT2 (Customizing CRM functions/modules), CT3 (Choosing reputed CRM vendors), CT4 (Drawing on the expertise of CRM vendors), CT5 (Pressure from CRM/ERP package), CT6 (Non-availability of appropriate CRM/ERP packages), CRM deployment, Process efficiency, and Product quality

Latent variables: CRM technologies; success with CRM

Statistical method: Structural-equation modeling

The writing in the remaining part of this section is organized into the following subsections: (a) offending estimates, (b) construct reliability and average variance extracted and (c) goodness-of-fit.

a. Offending Estimates
As shown in Table 1, the standard error ranges from 0.001 to 0.006. There is no negative standard error in this model.

	Estimate	*S.E.*	*C.R.*	*P*
CRM technologies	.016	**.003**	4.481	***
e10	.036	**.006**	6.453	***
e1	.034	**.003**	10.318	***
e2	.031	**.003**	10.202	***
e3	.013	**.001**	9.132	***
e4	.002	**.001**	2.015	.044*
e5	.011	**.001**	8.380	***
e6	.025	**.003**	9.803	***
e7	.025	**.003**	7.263	***
e8	.016	**.004**	3.952	***
e9	.029	**.003**	8.350	***

*Note: Estimate = Unstandardized Coefficients; SE = Standard Error; C.R. = Critical Ration; P = Significance: *p<0.05, **p<0.01, ***p<0.001*

Table 1. Variances: Default model

Also, in Table 2, the standardized regression weight ranges from 0.381 to 0.983. All of the standardized regression weights are below 1.0. Thus, it is clear that the offending estimates do not occur in this model.

			Estimate
Success with CRM	<---	CRM technologies	.381
CT1	<---	CRM technologies	.563
CT2	<---	CRM technologies	.665
CT3	<---	CRM technologies	.863
CT4	<---	CRM technologies	.983
CT5	<---	CRM technologies	.892
CT6	<---	CRM technologies	.774
CRM Deployment	<---	Success with CRM	.791
Process Efficiency	<---	Success with CRM	.895
Product Quality	<---	Success with CRM	.738

Note: Estimate = Standardized Coefficients

Table 2. Standardized Regression Weights: Default model

b. Construct reliability and Average variance extracted
Construct reliability of CRM Technologies was calculated (with a suggested lower limit of 0.70) by using this formula:

$$\rho_{c1} = \frac{\Sigma(\lambda_1)^2}{[\Sigma(\lambda_1)^2 + \Sigma(\theta_1)]} \quad (1)$$

ρ_{c1} is the construct reliability of CRM technologies. Let λ_1 be the standardized loadings (or the standardized coefficients) for CRM Technologies. Let θ_1 be the error variance for CRM Technologies. Based on the data in Table 3, the construct reliability of *CRM technologies* is:

$$\rho_{c1} = \frac{(0.563+0.665+0.863+0.983+0.892+0.774)^2}{(0.563+0.665+0.863+0.983+0.892+0.774)^2+(0.034+0.031+0.013+0.002+0.011+0.025)} \quad (2)$$

$$= \mathbf{0.9863}$$

Construct reliability of success with CRM in this model was calculated (with a suggested lower limit of 0.70) by using this formula:

$$\rho_{c2} = \frac{\Sigma(\lambda_2)^2}{[\Sigma(\lambda_2)^2+\Sigma(\theta_2)]} \quad (3)$$

ρ_{c2} is the construct reliability of success with CRM. Let λ_2 be the standardized loadings (or the standardized coefficients) for success with CRM. Let θ_2 be the error variance for success with CRM. Based on the data in Table 3, the construct reliability of success with CRM in this model is:

$$\rho_{c2} = \frac{(0.791+0.895+0.738)^2}{(0.791+0.895+0.738)^2+(0.025+0.016+0.029)} = \mathbf{0.9882} \quad (4)$$

The average variance extracted of *CRM Technologies* was calculated (with a suggested lower limit of 0.50) by using this formula:

$$\rho_{v1} = \frac{\Sigma({\lambda_1}^2)}{[\Sigma({\lambda_1}^2)+\Sigma(\theta_1)]} \quad (5)$$

ρ_{v1} is the average variance extracted of CRM Technologies. Based on the data in Table 3, the average variance extracted of CRM Technologies is:

$$\rho_{v1} = \frac{[(0.563)^2+(0.665)^2+(0.863)^2+(0.983)^2+(0.892)^2+(0.774)^2]}{[(0.563)^2+(0.665)^2+(0.863)^2+(0.983)^2+(0.892)^2+(0.774)^2]+(0.034+0.031+0.013+0.002+0.011+0.025)} \quad (6)$$

$$= \mathbf{0.9708}$$

The average variance extracted of success with CRM in this model was calculated (with a suggested lower limit of 0.50) by using this formula:

$$\rho_{v2} = \frac{\Sigma({\lambda_2}^2)}{[\Sigma({\lambda_2}^2)+\Sigma(\theta_2)]} \quad (7)$$

ρ_{v2} is the average variance extracted of success with CRM. Based on the data in Table 3, the average variance extracted of success with CRM is:

$$\rho_{v2} = \frac{[(0.791)^2+(0.895)^2+(0.738)^2]}{[(0.791)^2+(0.895)^2+(0.738)^2]+(0.025+0.016+0.029)} = \mathbf{0.9657} \quad (8)$$

To sum up, the construct reliability and average variance extracted in this model are considered acceptable as all of them are much higher than suggested values (0.70 and 0.50). This means, the inner quality of this model is acceptable and deserves further analyses.

c. Goodness-of-fit

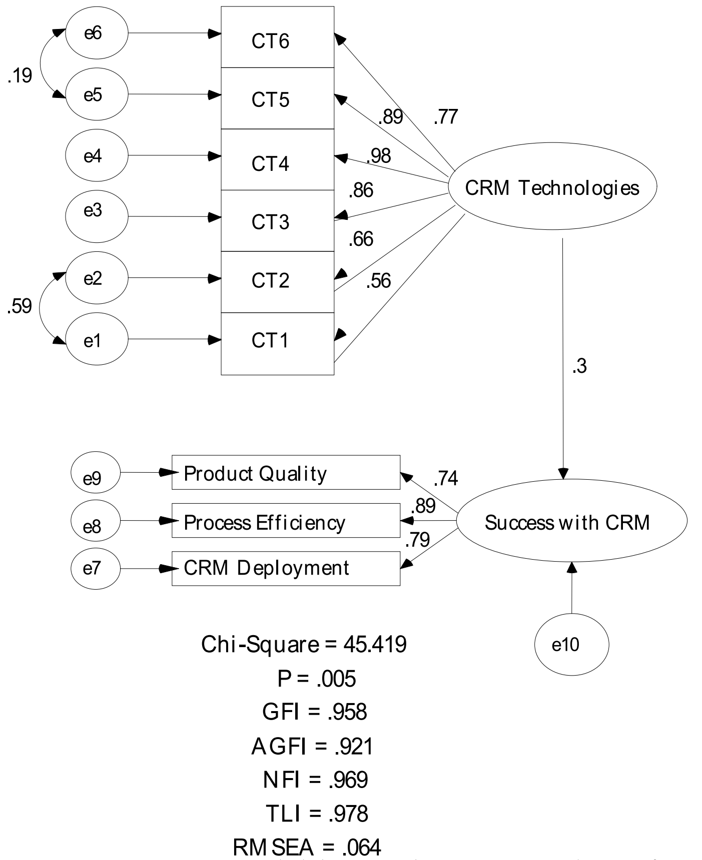
	Factor loadings	*Error variances*
Latent Variable: CRM technologies		
Observed Variables: CT1	0.563	0.034
Observed Variables: CT2	0.665	0.031
Observed Variables: CT3	0.863	0.013
Observed Variables: CT4	0.983	0.002
Observed Variables: CT5	0.892	0.011
Observed Variables: CT6	0.774	0.025
Latent Variable: Success with CRM		
Observed Variables: CRM deployment	0.791	0.025
Observed Variables: Process efficiency	0.895	0.016
Observed Variables: Product quality	0.738	0.029

Table 3. Factor Loadings and Error Variances: Default model

Figure 2 is a graphical representation of this model. With 45 distinct sample moments and 21 distinct parameters to be estimated, the total number of degrees of freedom is 24 (45 - 21). This model fits the hypothesized data structure well. The chi-square is 45.419 with 24 degrees of freedom, and p =. 005. Although the p-value is below 0.05, all other critical fit index values are above the recommended critical value of .90 (GFI =.958, AGFI =.921, NFI = .969, TLI = .978) with RMSEA = .064<0.10.

Moreover, a few more findings came out of the testing of this model:

i. The analyzed data in Table 4 indicate that CRM technology has a significant influence over success with CRM (p<0.001).
ii. The assumption that the six observed variables (i.e., CT1 ~ CT6) would be positively influenced by CRM technologies was proved. The data in Table 4 indicate that the relationships between all of the six observed variables and CRM technologies were significant (p<0.001).
iii. The assumption that three observed variables (i.e., CRM deployment, process efficiency and product quality) would be positively influenced by success with CRM was proved. The data in Table 4 indicate the relationships between all of the three observed variables on the one hand and success with CRM on the other hand were significant (p<0.001).
iv. According to the standard regression weights in Table 2, the relationships among the variables in this model could displayed with the formulas listed below:
    a. $\eta_{\text{(Success with CRM)}} = 0.38\xi_{\text{(CRM technologies)}} + e10$
    b. $Y_{1\text{(CRM development)}} = 0.79\eta_{\text{(Success with CRM)}} + e7$
    c. $Y_{2\text{(Process efficiency)}} = 0.89\eta_{\text{(Success with CRM)}} + e8$
    d. $Y_{3\text{(Product Quality)}} = 0.74\eta_{\text{(Success with CRM)}} + e9$
    e. $CT6 = 0.77\xi_{\text{(CRM technologies)}} + e6$
    f. $CT5 = 0.89\xi_{\text{(CRM technologies)}} + e5$
    g. $CT4 = 0.98\xi_{\text{(CRM technologies)}} + e4$
    h. $CT3 = 0.86\xi_{\text{(CRM Technologies)}} + e3$
    i. $CT2 = 0.66\xi_{\text{(CRM technologies)}} + e2$
    j. $CT1 = 0.56\xi_{\text{(CRM technologies)}} + e1$
v. The covariances in Table 5 indicate that the two-way relationships between the errors of CT5 & CT6 and CT1 & CT2 should be created. These relationships have statistical significance.



Note: Chi-Square =Discrepancy; P = Probability Levels; GFI = Goodness of Fit Index; AGFI = Adjusted Goodness of Fit Index; NFI = Normed Fit Index; TLI = Tucker-Lewis Index; RMSEA = Root Mean Square Error of Approximation

Fig. 2. Path Diagram

vi. Based on the findings described above, it seems clear that H_1 – *The CRM technology will be positively associated with successful CRM adoption in Taiwan's Banking industry* — is accepted, and the null hypothesis is rejected.

4.1 Further discussion

As the coefficient weights in Figure 2 suggest, the variables containing special (high or negative) correlation coefficient weights need to be singled out as they are worthy of further discussion. This section will present reasons and descriptions for the phenomenon behind the correlation between these variables.

4.1.1 Conducting the decision support system (DSS)

The coefficient weight between CT1 (conducting the decision support system) and CT2 (customizing CRM functions/modules) is significantly high (0.59). This result indicates that when banks in Taiwan try to a deploy a CRM project, they might need to conduct the decision support system as one of the customized CRM functions/modules. From the literature review of the present study, a difference in customization of a CRM system

			Estimate	*S.E.*	*C.R.*	*P*
Success with CRM	<---	CRM technologies	.627	.134	4.679	***
CT1	<---	CRM technologies	1.000			
CT2	<---	CRM technologies	1.250	.104	11.962	***
CT3	<---	CRM technologies	1.584	.172	9.223	***
CT4	<---	CRM technologies	1.756	.180	9.761	***
CT5	<---	CRM technologies	1.647	.175	9.385	***
CT6	<---	CRM technologies	1.539	.177	8.672	***
CRM Deployment	<---	Success with CRM	1.000			
Process Efficiency	<---	Success with CRM	1.216	.099	12.260	***
Product Quality	<---	Success with CRM	.911	.082	11.113	***

*Note: Estimate = Unstandardized Coefficients; SE = Standard Error; C.R. = Critical Ration; P = Significance: *p<0.05, **p<0.01, ***p<0.001*

Table 4. Regression Weights: Default model

			Estimate	*S.E.*	*C.R.*	*P*
CT5	<-->	CT6	.003	.001	2.279	.023*
CT1	<-->	CT2	.019	.003	7.306	***

*Note: Estimate = Unstandardized Coefficients; SE = Standard Error; C.R. = Critical Ration; P = Significance: *p<0.05, **p<0.01, ***p<0.001*

Table 5. Covariances: Default model

between the United Sates and Taiwan was discussed. In the United States, customization is not widely applied while companies in Taiwan are more likely to customize their CRM systems in order to satisfy their customers' needs. Chang (2003) believes that project managers, when adopting business intelligence systems such as CRM, should customize the systems, complete interface requirements, and conduct data conversion . Chang (p. 99) also suggests that companies establish stable and long-term relationships with their customers through customization software. Moreover, Lai (2006) argues that CRM systems should gather and analyze customer related information, develop forecasting models, provide real-time responses, and effectively customize communication channels by integrating well-established information technologies in financial service firms. Those discussions echo the statistical results from the present study. In addition, Turban, Aronson and Liang (2004, p. 457) consider CRM a fundamentally enterprise-level DSS. In the present study, this author defined CRM as a philosophy to understand and influence customers, to gain new customers, to retain existing customers, and to enhance the profits provided by customers in the banking industry. The subsequent empirical investigation makes it clear that a customer relationship management (CRM) system will provide the technology to do so. Corporations that are able to achieve high customer retention and high customer profitability are those that are able to provide the right product (or service), to the right customers, at the right price, at the right time, through the right channel (see Swift, 2001). Such is the main goal of CRM. The rise of "E-commerce" has affected the need for quality (product and service) and accurate customer analysis (Berkowitz, 2001; Kohli et al., 2001). Chou (2006) takes artificial neural network (ANN) technology as one of the most popular methods on evaluation of credit-card loan decisions in Taiwan's banking industry. Support vector machine (SVM), an ANN technology, is singled out. Chou (2006) took artificial neural network (ANN) technology as one of the most popular methods for evaluating credit-card loan decisions in Taiwan's banking industry. Support vector machine (SVM), an ANN technology, was singled out by Chou. Both Chou (2006) and Hung (2005) held the predicting power of the support vector machine as being better than that of the other tools. Not only does it outplay the traditional statistical approach in precision, it also achieves better results than the neural network. With the incorporation of a support-vector machine (SVM) into individual credit-card loan systems, the banks will be to render a highly effective evaluation of customers credit conditions while decreasing the probability of bad debts. Equipped with complete mathematical theories, SVM can comply with the principle of risk minimization and deliver better performance. It is anticipated that properly applying the SVM theory to loaning decisions of a bank will be a great asset. Clearly, conducting decision support systems could help Taiwan's banking industry analyze its customers more accurately. CRM gathers customer data while tracking the customers. What's important here is using data to effectively manage customer relations. The foregoing discussions, in fact, resonate with the statistical results of the present study. Clearly, conducting decision support systems could help Taiwan's banking industry analyze its customers more accurately. CRM gathers customer data while tracking the customers. What's important here is use data to effectively manage customer relations. These further discussion resonate the statistical results of the present study.

5. Conclusion

In the present study, CRM technologies, containing six observed variables ([i.e., CT1 (conducting the decision support system), CT2 (customizing CRM functions/modules), CT3 (choosing reputed CRM vendors), CT4 (drawing on the expertise of CRM vendors), CT5 (pressure from CRM/ERP packages), and CT6 (non-availability of appropriate CRM/ERP packages)], indeed help CRM adoption in Taiwan's banking industry. Moreover, as mentioned in the research result, four variables contain special (high or negative) correlation coefficients need to be singled out. They are CT1 (conducting the decision support system) and CT2 (customizing CRM functions/modules), both with a high coefficient weight (0.59). Thus, if the banks in Taiwan wish to deploy a CRM program, they should consider the following suggestion:

Conducting the decision support systems (DSS): If the goal of implementing a CRM system is to improve the process efficiency and IT product quality, managers in Taiwan's banking industry should emphasize more on conducting the decision support systems (DSS) (e.g., artificial neural network (ANN) technology) as one of the customized module in the whole CRM system.

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2

Intelligent Agent Technology in Modern Production and Trade Management

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1. Introduction

The technological progress is constantly evolving and each year presents new growth opportunities for different people and companies. Modern production and trade management are processing terabytes of gathered statistical data to gain useful information for different management tasks. Most common tasks that have arisen for solving are forecasting the demand for a new product, knowing only the product descriptive data and creating a production plan for a product on different product life cycle phases. As the amount of data grows, it becomes impossible to analyse it without using modern intelligent technologies.
Trade management is strictly connected with sales forecasting. Achieving accurate sales forecasting will always remain on the top of the most important tasks. Due to that different solutions are introduced each year in order to overcome the efficiency of the traditional sales forecasting methods. Let us discuss several possible solutions recently introduced. A sales forecasting model based on clustering methods and fuzzy neural networks was proposed by (Chang et al., 2009). The model groups demand time series applying clustering algorithms, then a fuzzy neural network is created for each cluster and used to forecast sales of a new product. Another interesting solution for sales forecasting was proposed by (Ni & Fan, 2011). The model combines the Auto-Regressive trees and artificial neural networks to dynamically forecast a demand for a new product, using historical data. Both models apply modern intelligent information technologies and, as authors state, are more efficient and accurate comparing to traditional forecasting methods. Nevertheless, the models preserve that a product is already introduced on the market and some sales data are already available. This rises a question that may be important for retailers, supplying market with items, but not producing them personally. The question may be stated as "How to forecast a demand for a product before purchasing it for resale?". A system, capable of making such forecasts, will bring to retailers a useful and valuable information, enabling them to create a list of stock products before any investments are made. A possible solution to such task was proposed by (Thomassey & Fioraliso, 2006). The authors proposed a hybrid sales forecasting system based on a combination of clustering and classification methods. The system applies clustering methods to gain product demand profiles from historical data, then, using product descriptive data, a classifier is built and used to forecast a sales curve for a new product, for which only descriptive data are available. The system was tested on textile item sales and, as authors state, the results were relatively good. Authors continued their research and in (Thomassey & Happiette, 2007) a new system based on idea of combining clustering and classification methods was introduced. Authors used Artificial Neural Networks technologies to cluster

and classify sales time series. As they state, the proposed system increases accuracy of mid-term forecasting in comparison with the mean sales profile predictor.

The production management itself combines several tasks of forecasting and planning, one of which is a product life cycle (PLC) management. A product life cycle is a time of product existence on the market and can be viewed as a sequence of known phases with bounds. Each PLC phase differs by sales profiles, due to what different production planning strategies are used and what is more important - different advertising strategies are applied. Traditionally a product life cycle has four phases, namely "Growth", "Introduction", "Maturity" and "End-of-Life". The models with a larger number of phases are also possible and are used (Aitken et al., 2003). For products with a significantly long PLC, growth and introduction phases can be merged into one phase - "Introduction". This PLC phase imply high investments in advertising, as potential customers need to know about the new product. This gives rise to the task of defining bounds for the PLC phases, which to be one of the important tasks in the PLC management. Let us discuss several possible solutions introduced for this task. Most of the solutions concentrate around the idea of forecasting the sales curve for a product and then defining in which particular PLC phase product currently is. Often the *Bass* diffusion model or its modifications are used to forecast sales, as it was proposed by (Chien et al., 2010). Authors present a demand forecasting framework for accurately forecasting product demand, thus providing valuable information to assist managers in decision-making regarding capacity planning. The framework is based on the diffusion model and, as authors state, has a practical viability to forecast demands and provide valuable forecasting information for supporting capacity planning decisions and manufacturing strategies. Other researchers (Venkatesan & Kumar, 2002) applied a genetic algorithm to estimate the *Bass* diffusion model and forecast sales for products, when only a few data points are available. Both solutions make accurate forecasts in the scope of the tasks solved, but still give an answer to what the demand will be, but not to when the PLC phase will be changed. To answer that, the forecasted sales curves need to be analysed by a manager, who will set PLC phase bounds, using his personal experience. Due to that, the efficiency of the discussed models may fall as the amount of monitored products growths.

The present research is oriented towards bringing intelligent agent technology for supporting manager's decisions in such tasks as forecasting demand for a new product and defining the end of the introduction/beginning of the maturity PLC phase for the monitored products. The chapter proposes two multi-agent systems designed directly for solving the tasks defined. Intelligent agent technology was chosen as it gives a new modern look at the forecasting and planning tasks and brings new possibilities in designing solutions to support modern production and trade management.

The conceptual and functional aspects of the proposed systems are revealed in Sections 2 and 3, but first, some agent terminology needs to be defined to eliminate possible misunderstandings. There are no unified definitions of what an agent is (Wooldridge, 2005). One of the reasons for that is that agents are mostly defined as a task specific concept. Nevertheless, some definitions are useful (Weiss, 1999; Wooldridge, 2005) and also applicable to present research:

- Agent is a computer program that exists in some environment and is capable of performing an autonomous activity in order to gain its desired objectives.
- Intelligent agent is an agent capable of learning, capable of mining and storing knowledge about the environment it is situated in.
- Multi-agent system contains agents and intelligent agents capable of interaction through an information exchange.

- Agent community is an indivisible unit of agents with similar attributes, abilities and behaviour, aimed at gaining the desired objectives. It differs from a Multi-agent system in that agents are not interacting with one another.

The proposed definitions are task specific and are oriented to making the ideas proposed in the multi-agent systems simple and clear.

2. Agent Technology in PLC Management

The product life cycle management, as it was stated in the introduction, is an important objective for company growth, as most of the decisions taken are dependent on the current demand. A proper product life cycle management strategy gives opportunities for precise resource planning, lessening expanses and negative profit.

The present section reveals the concepts of the proposed PLC management support multi-agent system, and describes both structural and functional aspects of it. An analysis of the obtained experimental results concludes this section.

The main task of the proposed system is to forecast a period - transition point, when a product will change an introduction phase to maturity phase. A specific feature of the system is that the forecast is made having only the first several data points, and a scalar value - period, is forecasted. From the viewpoint of Data Mining this task is a classification task and formally can be stated as follows. Assume that the available sales data is a dataset $D = \{d_1, \ldots, d_i, \ldots, d_n\}$, where each record $d = \{x_1, \ldots, x_j, \ldots, x_l\}$ is a discrete time series with l periods, representing a sales profile of a specific product during the defined phase of a product life cycle. The length of a time series l is not a constant value. It may take a finite number of values defined by the set L, $l \in L = \{l_1, \ldots, l_h, \ldots, l_s\}$ and may vary from record to record.

Each record $d_i \in D$ has a specific marker p containing the number of a period after which a PLC phase, represented by record d_i, was finished. Marker p may take a finite number of values defined by the set P, $p \in P = \{p_1, \ldots, p_k, \ldots, p_m\}$. Having such assumptions the forecasting of a transition point for a specific new product $d' \notin D$ should start with building a model of an implication between datasets D and P, $f : D \to P$, representing relations between sales profiles and the value of a specified marker. As the model is built, it may be applied to forecast a transition point for a new record, when it reaches the minimal length $l_{min} \in L$.

2.1 Structure of the proposed system

The proposed product life cycle management support multi-agent system is displayed in Figure 1. The system contains three interacting agents, namely Data Management Agent, Data Mining Agent and Decision Support Agent. The Data Management Agent was included as the system should be capable of processing a large amount of sales data. This condition asks for an agent capable of autonomously performing general and specific operations with data, one of which is pre-processing. As it was stated before, first, the model of the relations between the sales profiles and a target attribute should be made. The Data Mining Agent implements an intelligent data processing methods and is capable of autonomously creating a knowledge base with desired relations. The application of the knowledge base to the forecasting of a transition point for a new product is designated to the Decision Support Agent.

2.1.1 Data Management Agent

The Data Management Agent is an agent as it uses a predefined logic and cannot change it over time. The agent handles several data management tasks, including data cleaning, normalization and preparing datasets. The environment the Data Management Agent is

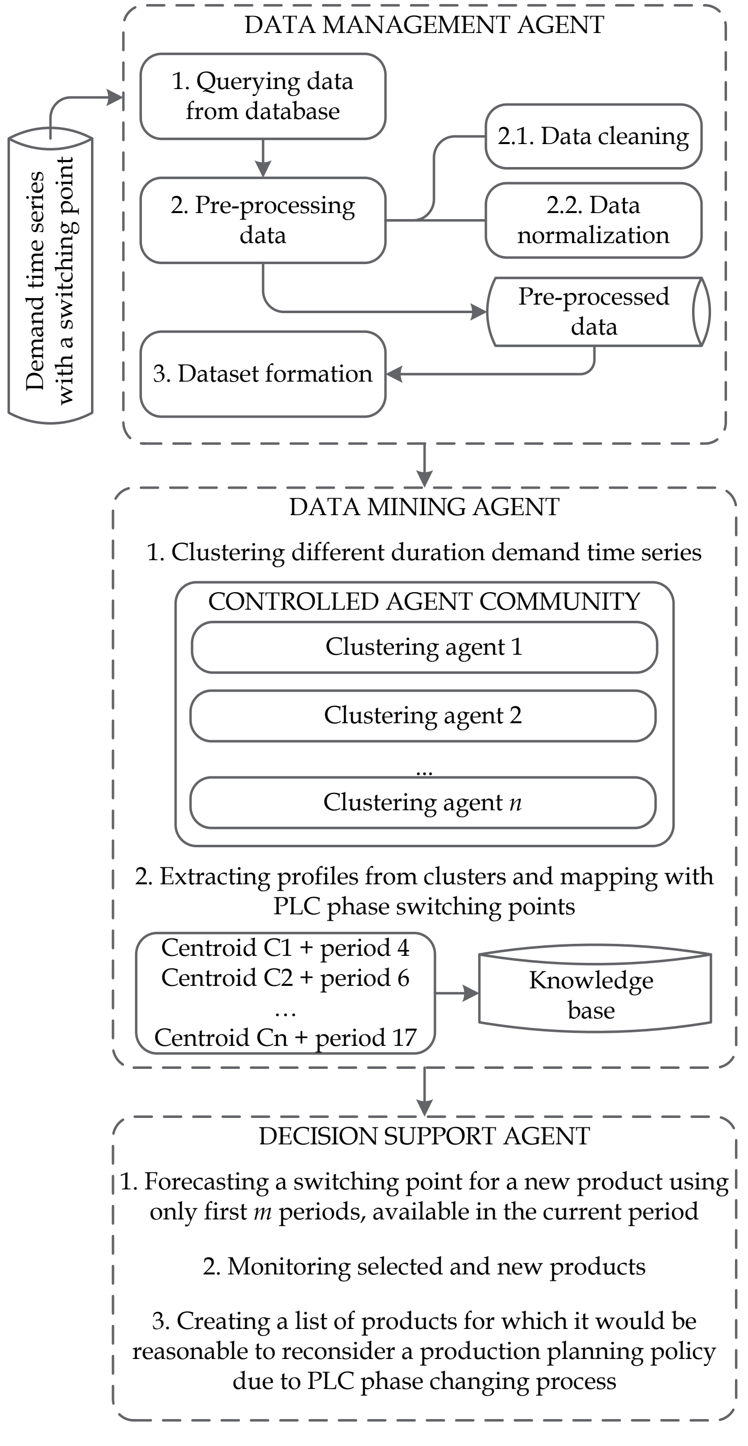


Fig. 1. PLC Management Support Multi-Agent System

situated in is a raw data repository. The environment affects the agent with new data, forcing the Data Management Agent to perform the data pre-processing actions. By performing those actions, the agent affects the environment by changing the raw data to the pre-processed data. The agent functioning algorithm, displayed in Figure 1, contains three main processes - first get data from a database, then pre-process it and prepare datasets for system training and testing. The first two processes are performed in the autonomous mode, the actions in the third process are performed reactively by responding to the Data Mining Agent's requests.
The data repository contains data of the unique structure that may not fit the desired data format. The processes in the first block of an Data Management Agent algorithm return the set of sales data, obtained during a specified product life cycle phase, as a time series, summing sales by each period (day, week, month), which is defined by the user. For each sales time series a value of a target attribute (transition point) is supplied, excluding the new data, for what the information on the transition point is not available yet. The next step is pre-processing, it becomes necessary as the raw data may contain noise, missing or conflicting data. The defined task speaks for performing several steps of data pre-processing:

- **Excluding the outliers.** The definition of an outlier is dynamic and changes according to the desired tasks. This makes the step of outlier exclusion highly task specific. The present research foresees the following actions to be completed. The time series with the number of periods (length) less than the user defined minimum l_{min} or with missing values to be excluded from the raw dataset.
- **Data normalization.** This step is performed in order to bring sales time series to one level, lessening possible domination occurrences. One of the normalization methods that suites the sales time series normalization is the *Z-score* normalization with standard deviation method. To calculate the normalized value $x_i^{'}$ for i-th period of a time series X, Equation 1 is used, where $\overline{X}$ is the average of an X.

$$x_i^{'} = \frac{x_i - \overline{X}}{s_x} \tag{1}$$

  To calculate the standard deviation s_x, Equation 2 is used. As the number of periods in the normalized sales time series is not large, it is recommended to use the $(n-1)$ as a denominator in order to obtain an unbiased standard deviation. As an option, the standard deviation can be replaced with a mean absolute deviation.

$$s_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{2}$$

- **Imitation of a data flow.** The sales data become available over time and this moment should be taken into account in order to obtain an accurate transition point forecast. This step is very important as the proposed system will be limited to forecast a binary result - either the transition is occurred or not, if the data flow imitation will not be performed. The imitation of the data flow process ensures that the proposed system will be able to forecast transition points in different time periods having only first l_{min} periods available.

2.1.2 Data Mining Agent

The Data Mining Agent (see Fig. 1) is an intelligent agent that performs an intellectual data processing with data mining methods. The environment the agent is situated in is the datasets created by the Data Management Agent. This environment is highly dynamic as it changes

each time a new data is obtained. The agent itself may induce changes in the environment by requesting the Data Management Agent to produce new datasets. The Data Mining Agent changes the environment by creating the knowledge base, that contains relations between the sales time series and transition point values. The proposed structure of a Data Mining Agent contains two main steps - first clustering the time series with different duration and then extracting profiles from clusters and mapping profiles with PLC phase switching points.
The time series clustering is performed by the clustering agents in the agent community controlled by the Data Mining Agent (see Fig. 1). Each clustering agent implements a clustering algorithm and processes a defined part of the input data. The number of the clustering agents as well as the part of dataset it will process, is defined by the parameter Q called the load of a clustering agent. It is an integer parameter containing a number of different time series lengths $l_i \in L$ each clustering agent can handle. The set L contains all possible lengths of the time series in the input data, as it was defined in the task statement at the beginning of this section. For example, assume that $l_{min} = 4$ periods and $Q = 3$, then the first clustering agent will handle the part of an input data with 4, 5 and 6 periods long time series. The load of a clustering agent is defined by the user and is also used for calculating n_{ca} - the number of the clustering agents in the Controlled Agent Community (CAC). Equation 3 is used for obtaining the value of n_{ca}.

$$n_{ca} = Roundup\left(\frac{|L|}{Q}\right) \tag{3}$$

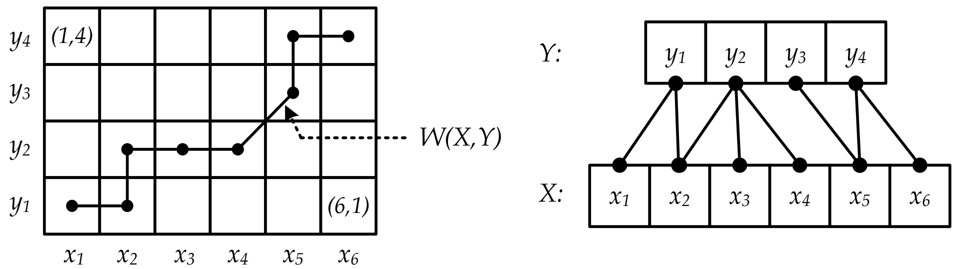
The input data is distributed among n_{ca} clustering agents $ca_i \in CAC$ according to the defined value of Q. Given a uniform clustering agent load distribution, Equation 4 can be used for splitting the input data among clustering agents.

$$\begin{cases} i = 1, & l_{i,min} = l_{min} \\ i > 1, & l_{i,min} = l_{i-1,max} + 1 \end{cases}$$
$$l_{i,max} = l_{i,min} + Q - 1 \tag{4}$$

where the l_{min} and l_{max} are the bounds for the number of periods in the time series the clustering agent ca_i will process. One of the proposed system objectives is to support clustering of time series with different number of periods. A number of clustering methods exist, but majority use an Euclidean distance to calculate the similarity of two objects. The simple Euclidean distance will not allow a clustering agent to process time series with different number of periods, but still may be applied while $Q = 1$. Two clustering methods - *Self Organising Maps* (SOM) (Kohonen, 2001) and *Gravitational Clustering algorithm* (GC) (Gomez et al., 2003; Wright, 1977), were chosen to support the data mining process. To gain an ability to cluster time series with different duration we suggest using different distance measures in each of the methods. The proposed system implements two different distance measures - *Dynamic Time Warping* (DTW) (Keogh & Pazzani, 2001; Salvador & Chan, 2007) and a modified Euclidean distance *MEuclidean*.

2.1.2.1 Distance measures

The *DTW* creates a warping path $W(X,Y)$ between two time series X and Y and uses it to calculate the distance, which occurs as follows. Let X and Y have durations equal to n and m periods, respectively. First a distance matrix $n \times m$ is created, where each cell (i,j) contains distance $d(x_i, y_j)$ between two points x_i and y_j (Keogh & Pazzani, 2001). The warping path $W(X,Y)$ is a sequence of the steps w_k in the distance matrix starting with a cell $(1,1)$ and ending in (n, m). Each time performing a new step w_k, a direction with minimal distance is chosen. Other strategies for choosing the next step are possible and widely used (Salvador & Chan, 2007). An example of a warping path is graphically displayed in Figure 2.



(a) Warping path in the distance matrix

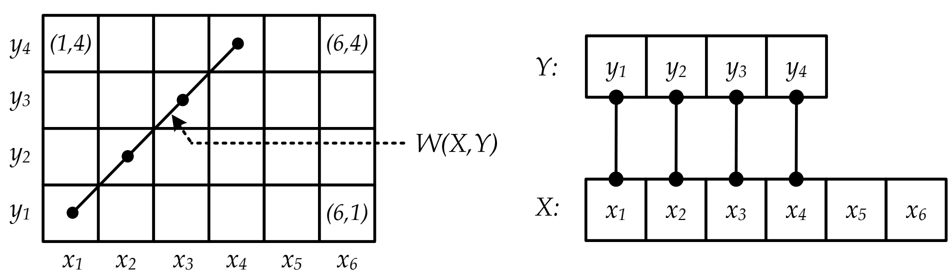
(b) A warping map *M*

Fig. 2. Example of a *DTW* warping path $W(X, Y)$

The total path distance $d(X, Y)$ between two time series X and Y using the Dynamic Time Warping is calculated as shown in Equation 5. The denominator K representing the total number of steps w_k in the warping path $W(X, Y)$ is used in order to calculate the distance proportionally for one step w_k, as the number of steps may be different in different warping paths.

$$d(X, Y) = \frac{\sqrt{\sum_{k=1}^{K} w_k^2}}{K} \tag{5}$$

The second proposed distance measure is *MEuclidean* - Modified Euclidean. The concept of this measure is to calculate the distance $d(X, Y)$ between two time series $X = x_1, \ldots, x_i, \ldots, x_n$ and $Y = y_1, \ldots, y_j, \ldots, y_m$ only by first z periods of each time series, where $z = min\{n, m\}$. Speaking in the terminology of *DTW*, the warping path $W(X, Y)$ in the case of *MEuclidean* will always begin in the cell $(1, 1)$ and will always end in the cell (z, z). The example of a warping path for a distance measure *MEuclidean* is displayed in Figure 3.



(a) Warping path in the distance matrix

(b) A warping map *M*

Fig. 3. Example of a *MEuclidean* warping path $W(X, Y)$

The total path distance $d(X, Y)$ between two time series X and Y using the *MEuclidean* distance measure is calculated using Equation 6.

$$d(X, Y) = \sqrt{\sum_{i=1}^{z} (x_i - y_i)^2} \tag{6}$$

2.1.2.2 Clustering algorithms

The *SOM* model introduced by T.Kohonen is one of the vector-coding algorithms, whose main objective is to transform an input data into a discrete map of neurons. The *SOM* algorithm contains four main steps - network initialization, neuron competition, neuron cooperation and synoptic adaptation (Kohonen, 2001). Executing the initialization,weights of each neuron are assigned random values small enough to eliminate any possible organization in the network at the beginning of the system training.
During the neuron competition step, for each time series in the input dataset the winning neuron, as the one with most similar vector of weights, is defined. This is where the proposed distance measures are applied to find the winning neuron, which will be set as the centre of the topological neighbourhood in order to perform the neuron cooperation step. The cooperating neurons are neurons that are stimulated by the activity in the winning neuron. Executing the cooperation step each neuron in the *SOM* is assigned a neighbourhood level, using the neighbourhood function $h_{j,i(X)}$, where $i(X)$ is the index of a winning neuron for a time series X and j is an index of a cooperating neuron. The neighbourhood level is also affected by the chosen neural network topology. The classical *SOM* algorithm uses Equation 7 for synoptic adaptation of weights.

$$W_j(n+1) = W_j(n) + \eta(n) \cdot h_{j,i(X)}(n) \cdot (X - W_j(n))\,, \tag{7}$$

where n is the iteration number; $W(n)$ - vector of weights of a j-th neuron; η is a learning coefficient.
The learning coefficient decreases over time, but remains higher than a defined minimal value η_{min}. This can be reached by using Equation 8 (Kohonen, 2001), where τ_2 is a time constant, which can be assigned total iterations number. The value of a topological neighbourhood function $h_{j,i(X)}(n)$ at the moment n is calculated by Equation 9.

$$\eta(n) = \eta_0 \cdot exp\left(-\frac{n}{\tau_2}\right) \tag{8}$$

$$h_{j,i(X)}(n) = exp\left(-\frac{d^2_{j,i(X)}}{2\sigma^2(n)}\right), \tag{9}$$

where d is the lateral distance between the j-th neuron and the winning neuron; parameter σ defines the width of a topological neighbourhood function.
In Subsection 2.1.2.1 it was shown that both of the proposed distance measures can produce a warping path in order to compare two time series. If a distance measure *MEuclidean* is used, then Equation 7 is modified and Equation 10 is used for synoptic adaptation of neuron weights.

$$\forall w_k \in W_j,\;\; k \le l_{min}:\; w_k\,(n+1) = w_k\,(n) + \eta\,(n) \cdot h_{j,i(X)}(n) \cdot (x_k - w_k\,(n))\,, \tag{10}$$

where W_j is the weight vector of a j-th neuron and $l_{min} = min(l_X, l_W)$.
Using distance measure *MEucliden* two cases during weight adaptation are possible:

1. The length l_W of a weight vector W_j of the j-th neuron is less or equal to the l_X - the length of a time series X. In this case all weights of the j-th neuron will be changed according to the warping map M, example of which is shown in Figure 3.b.

2. The length l_W of a weight vector W_j of the j-th neuron is greater than the l_X - the length of a time series X. In this case only the first l_X weights $w_k \in W_j$ will be adopted according to the warping map M. The rest of neuron weights will remain unchanged.

If the distance measure DTW is used, then cases are possible, when one weight w_k should be adopted to several values of a time series X. An example of this case is shown in Figure 2.b. Assuming that Y is a weight vector, the weights y_1, y_2 and y_4 must be adopted to two or three different values at one time. In this case each of the mentioned weights will be adopted to the average of all time series X values it must be adopted to, according to the warping map M.
This concludes the modifications of a *SOM* algorithm, the rest part of the subsection is devoted to the second chosen clustering algorithm - gravitational clustering algorithm. This algorithm is an unsupervised clustering algorithm (Gomez et al., 2003; Wright, 1977). Each clustering agent in the *CAC* represents a multidimensional space, where each time series from the input dataset is represented as an object in the n-dimensional space, where each object can be moved by the gravitational force of the other objects. If two or more objects are close enough, that is distance d between them is less or equal to the d_{max}, then those objects are merged into the cumulative object. By default, masses of all non-cumulative objects are equal to 1. Depending on user choice, masses of the merged objects can be summed or remain equal to 1. A movement of an object X, induced by the gravitational force of an object Y at the time moment t, can be calculated by Equation 11.

$$X(t+\Delta t) = X(t) + v(t)\cdot \Delta t + \vec{d(t)} \cdot \frac{G\cdot m_Y \cdot \Delta t^2}{2\cdot \left\| \vec{d(t)} \right\|^3}\ , \tag{11}$$

where $v(t)$ is the object velocity; G - gravitational constant, which can also be set by the user; m_Y - the mass of an object Y; vector $\vec{d(t)}$ represents the direction of a gravity force, induced by the object Y and is calculated as $\vec{d(t)} = X(t) - Y(t)$.
Setting velocity $v(t)$ as a null vector and having $\Delta t = 1$, Equation 11 can be simplified as shown in Equation 12.

$$X(t+\Delta t) = X(t) + \vec{d(t)} \cdot \frac{G\cdot m_Y}{2\cdot \left\| \vec{d(t)} \right\|^3}\ , \tag{12}$$

The *GC* uses the *Euclidean* distance to measure spacing between to objects. The support of clustering of time series with different number of periods can be gained by using the distance measures, proposed in Subsection 2.1.2.1, but the first of the gravitational clustering algorithm concepts should be redefined. In the classical algorithm this concept is defined as follows: "In the n-dimensional space all objects have values in all n dimensions". The proposed redefined version is "In the n-dimensional space can exist m-dimensional objects, where $m \leq n$". This means that in a 10-dimensional space can exist an object with four dimensions, which will be present only in the first four dimensions.
In the case of using the distance measure *MEuclidean* two possible cases can occur while calculating the induced gravitational force:

1. The number of the object's X dimensions n_X is less or equal to the number of the inducting object's Y dimensions n_Y. In this case the gravitational force is calculated for all dimensions of an object X and it is moved according to the calculated gravitational force.

2. The number of the object's X dimensions n_X is greater than the number of the inducting object's Y dimensions n_Y. In this case the gravitational force for X is calculated only for the first n_Y dimensions of the X. The object X is moved only in those dimensions for which the gravitational force was calculated.

Using the dynamic time warping, an m-dimensional object X will always be moved in all m dimensions. Situations, when for some dimension x_i a gravitational force should be calculated using several dimensions of an object Y, may take place. This is similar to the case with *SOM* when a single weight should be adopted to multiple time series values. Having a such situation, the gravitational force, induced by the object Y, is calculated using an average from all y_j dimensions inducing gravitational force to the object's X dimension x_i.

2.1.2.3 Creating a knowledge base

The knowledge base contains a model, representing the connections between sales profiles and the transition points, induced from the input data. The knowledge base is level-structured, the number of levels coincides with the number of the clustering agents in the clustering agent community. Each level contains clusters from a corresponding clustering agent. Let us define the meaning of a cluster for each of a clustering algorithm described in the previous subsection.
The cluster extraction in the *SOM* algorithm begins after network organisation and convergence processes are finished, and contains next three steps:

1. Each record X from a training set is sent to the system.
2. The winning neuron for each record X is found. For each winning neuron a transition point statistics S_j is collected, containing a transition point value and frequency of it's appearing in this neuron, which is used as a rank of a transition point.
3. The cluster is a neuron that at least once became a winning neuron during the cluster extraction process. The weight vector of a neuron is taken as a centroid of a cluster.

For the gravitational clustering algorithm a cluster is defined as follows: "The cluster is a cumulative object having at least two objects merged". Using the merged objects, a transition point statistics S_j is collected for each cluster c_j. Each transition point, included in S_j, is assigned a rank as the frequency of it's appearing in the cluster c_j. The centroid of a cluster is set as a position of a cumulative object in the clustering space at the moment of cluster extraction.

2.1.3 Decision Support Agent

The Decision Support Agent is an agent that forecasts a transition point value for a new data, monitors selected and new products and creates a list of the products, for which it would be reasonable to reconsider a production planning and advertising policies. The DSA can perform its actions either by receiving a request from a user, or in autonomous mode, with defined interval of time (at the end of each period) reporting the decision analysis results.
The transition point for a new data is forecasted by using the data from a cluster, best-matching the new time series. The best-matching cluster is obtained by sending an appropriate request to the Data Mining Agent, which finds the closest cluster in the knowledge base. The transition point with a higher rank is taken as the value that will be forecasted for the new time series. If several transition points have equal rank, then the minimal transition point is chosen.
The list of the noteworthy products (LNP) is created by applying this strategy:

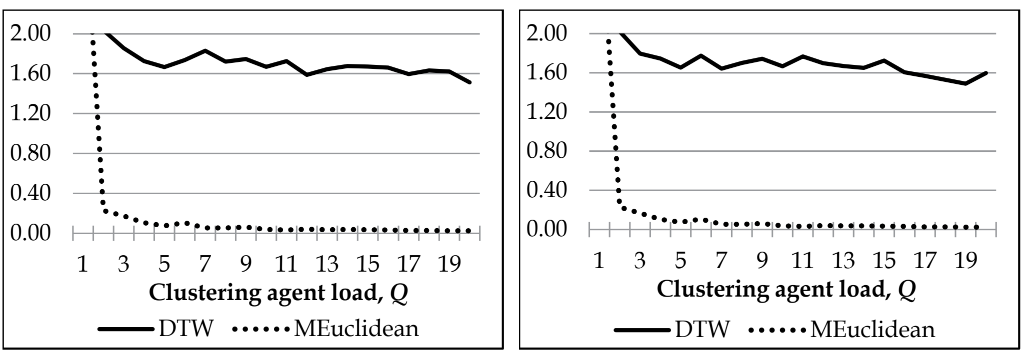
1. If $l < p$ and $p - l > \theta$ Then: Product remains monitored and is not included in the LNP;

2. If $l < p$ and $p - l \leq \theta$ Then: Product is included in the LNP;
3. If $l \geq p$ Then: Product is included in the LNP.

where l is the duration of the demand time series in periods; p - a forecasted transition point; and variable θ stores the minimal threshold of interest for either including the product in the list of the noteworthy products or not.

2.2 Experimental results

The proposed product life cycle management support system was trained and tested on a dataset, received within the international project *ECLIPS*. The dataset contains sales profiles of different products during the PLC introduction phase. For each record in the dataset a transition point value is supplied. The length of a time series in the dataset varies from 4 to 23 periods, giving 20 possible values for a clustering agent load Q parameter, $Q = \{1, 2, \ldots, q_i, \ldots, 20\}$. The dataset was pre-processed according to the steps described in Subsection 2.1.1 and normalized by the *Z-score* normalization method.
The precision of the proposed system is measured, using the *Mean Absolute Error*, measured in periods. To measure the precision of the system, first the learning error for all combinations of the proposed clustering methods and distance measures was measured. The system with gravitational clustering algorithm was tested with both options for calculating the mass of a cumulative object after merging two or more other objects. The obtained results are displayed in Figure 4.



(a) Masses are summed (b) Object mass remains equal to 1

Fig. 4. Learning error (MAE) in periods for the system with gravitational clustering algorithm

As may be seen from Figure 4, the results, received using the distance measure *MEuclidean*, are more precise than those obtained with the *DTW*. The *MEuclidean* dominates *DTW* within all possible Q values, and that is the reason to exclude the *DTW* distance measure from further experiments with testing the system with gravitational clustering algorithm. As can also be seen, the results, obtained using *MEuclidean* in Figures 4.a and 4.b, are close to be equal. This indicates that both strategies for calculating the mass of a cumulative object are equal. However the strategy, where masses are summed after merging the objects, has a weakness. Merging the objects results in the growth of a mass of a cumulative object, consequently increasing the gravity force of that object. This could lead to the situation, when merging of objects will be affected more by the masses of an objects either by the closeness of those objects.

This could be the reason for that some potentially good combinations of clusters will not appear during the clustering process. Due to that, the strategy with summing objects masses will not be used in further experiments while using the gravitational clustering algorithm.
The transition point forecast error (using *MEuclidean*) decreases while the clustering agent load increases. This is the reason for performing further experiments by using only five values of Q that returned the smallest learning error. Those values of a clustering agent load are 16, 17, 18, 19 and 20, that is $Q = \{16, 17, 18, 19, 20\}$.
The system with *SOM* algorithm was tested using three neural network topologies - quadratic topology with eight neighbours in the first lateral level, cross-type topology with four neighbours and linear topology with two neighbours. The neural network contained 100 neurons, organized as a matrix 10×10 neurons for quadratic and cross-type topologies and as a one-dimensional line for the linear topology. The obtained results with learning error for each topology and distance measure *MEuclidean* are displayed in Figure 5.

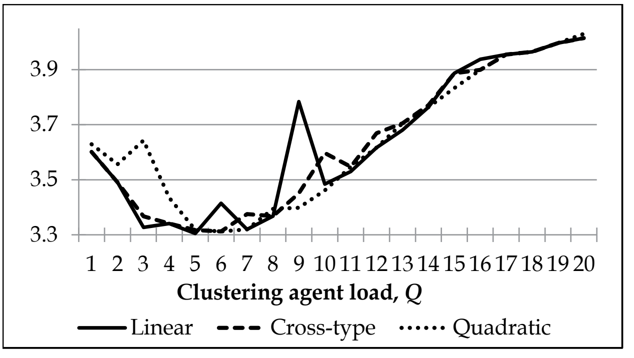


Fig. 5. Learning error (MAE) in periods for the system with *SOM* algorithm, using *MEuclidean*

The *SOM* algorithm returned a much larger learning error than the gravitational clustering algorithm. Due to that, only three values of Q, $Q = \{5, 6, 7\}$ will be used in further experiments. Table 1 contains the learning error obtained with *SOM* algorithm while using *DTW* and selected Q values.

	$Q = 5$	$Q = 6$	$Q = 7$
Linear	3.381	3.320	3.323
Cross-type	3.366	3.317	3.323
Quadratic	3.354	3.317	3.323

Table 1. Learning error (MAE) in periods for *SOM* algorithm, using *DTW*

Comparing the efficiency of the chosen topologies (see Figure 5) it may be concluded that none of three topologies dominates the others two. For further experiments with *SOM* algorithm all three topologies were chosen.
The learning error evaluation was used to lessen the number of experiments needed for system strong evaluation. To evaluate systems the 10-fold crossvalidation method was applied. The proposed system with gravitational clustering was tested, applying only the *MEuclidean* distance measure and using the five values of the clustering agent load, selected at the beginning of this section, while evaluating the system learning error. Table 2 shows the obtained system testing results, each cell contains a 10-fold average *Mean Absolute Error* in periods. Figure 6 displays the data from Table 2.

	Q = 16	*Q = 17*	*Q = 18*	*Q = 19*	*Q = 20*
MAE	2.021	**1.995**	2.026	2.019	2.010

Table 2. Mean absolute error in periods for the system with *GC* algorithm

As can be seen, the error remains at the level of two periods, the best result was gained with the clustering agent load *Q = 17* and is 1.995 periods.

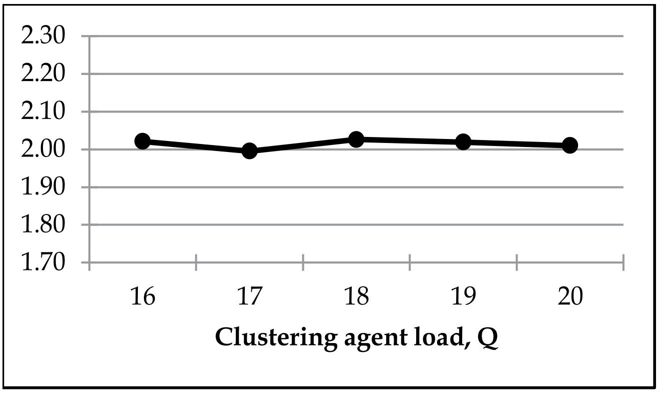


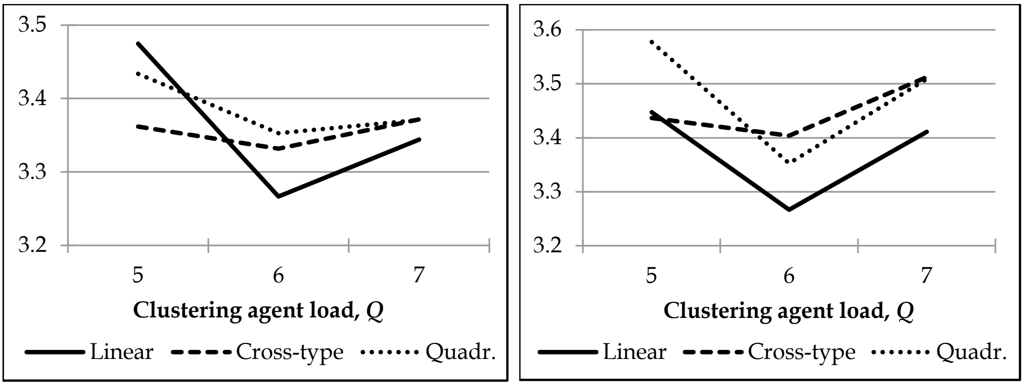
Fig. 6. MAE in periods for system with gravitational clustering, using *MEuclidean*

The same testing method and data were used for testing the system with *SOM* algorithm. While testing the system, all three neural network topologies - linear, cross-type and quadratic, were applied, combining with two proposed distance measures (see Subsection 2.1.2.1). The system with *SOM* was tested by using only three clustering agent load values - $Q = \{5, 6, 7\}$, selected while evaluating the learning error. Table 3 summarises the obtained testing results and Figure 7 displays them.

Q	**Linear topology**		**Cross-type topology**		**Quadratic topology**	
	DTW	*MEuclidean*	*DTW*	*MEuclidean*	*DTW*	*MEuclidean*
5	3.475	3.447	3.362	3.437	3.434	3.578
6	**3.267**	**3.267**	**3.332**	3.404	**3.353**	**3.353**
7	3.344	3.411	3.372	3.513	3.371	3.509

Table 3. Mean absolute error in periods for the system with *SOM* algorithm

The best results for all three topologies were obtained while testing the system with clustering agent load *Q = 6* and remains equal about 3.3 periods. That supports the conclusion, stated while evaluating the learning error that none of three topologies dominates other two. The best result was obtained while using the linear topology and is equal to 3.267 periods. Comparing the efficiency of applied distance measures we may conclude that for the proposed system with *SOM* algorithm it is not crucial whether to choose *DTW* or *MEuclidean* distance measure, as the *DTW* returned better result only once, using the cross-type topology. For other topologies both distance measures returned equal results.



(a) Using distance measure *DTW* (b) Using distance measure *MEuclidean*

Fig. 7. Test error in periods for system with *SOM* algorithm

2.3 Results analysis and summary

Analysing the obtained results it may be concluded that for the task of forecasting the period when the product will change its PLC phase, the efficiency of the hierarchical clustering algorithms, a part of which is the gravitational clustering algorithm, comparing to the self-organising maps. Comparing the learning and test errors for both of clustering algorithms, it can be seen that the *GC* test error (1.995 periods) is about 10 times greater than the learning error (0.2 periods), but the *SOM* learning and test errors remain on the same level of 3.3. From that it may be concluded that the gravitational clustering algorithm is less robust to the noise in data than the *SOM* algorithm.

The smallest transition point forecasting error - 1.995 periods, was gained by the multi-agent system with the gravitational clustering algorithm, while using the distance measure *MEuclidean*. The test error of two periods may be taken as a relatively high, but, viewing it from the position of the end user, the ability of gaining the additional useful information about the bounds of a PLC phase, makes this error level acceptable.

3. Intelligent Sales Forecasting

Traditional forecasting is mostly based on finding relations in time series, representing changes in economic indexes, system technical parameters etc. It is assumed that relations are mined from a stationary time series and the longer it is, the higher is the probability to find some relations in it (Armstrong et al., 2005). However, in most of real-life tasks the length of a time series is relatively short and mining relations will not bring the desired results. An example of such task is a textile sales analysis and forecasting, which is the main task the proposed system was designed for. As it was stated, clustering textile sales short time series will return sales profiles, but how precise they will be? An additional information can be gained from a descriptive data of each textile product. This sets a task of combinations of several data mining methods - cluster analysis and classification, in order to obtain an additional useful information.

The proposed system is aimed at forecasting textile product sales profiles using only descriptive data, such as price, size, colour, type etc. Subsection 3.1 reveals the structure and conceptual aspects of the proposed system. Figure 8 displays the proposed system.

3.1 Concepts of Sales Forecasting Multi-Agent System

The proposed sales forecasting multi-agent system contains three agents - Data Management Agent, Data Mining Agent and the Sales Forecasting Agent. The Data Management Agent supports receiving data from a data repository and data preparation for further analysis. The Data Mining Agent mines relations from sales data, merging those with product descriptive data and inducing classification rules that are included in the knowledge base. The Sales Forecasting Agent uses the knowledge base to forecast a sales profile for a new product, having only descriptive data available.

3.1.1 Data Management Agent

The Data Management Agent is an agent that is similar to the one described in Subsection 2.1.2. It receives raw data from a data repository, each record containing product descriptive data and one year sales data, and performs data pre-processing - this two steps are performed in the autonomous mode. The Data Management Agent cleans the uninformative profiles like those containing one or two sales facts during all 12 months or have a large number of missing values. The rest of sales profiles that were not excluded, are normalized with *life curve* normalization method (Thomassey & Fioraliso, 2006). Normalizing by the life curve, the new value $x_i^{'}$ of each period of a time series $X = x_1, \ldots, x_i, \ldots, x_n$ is calculated by Equation 13.

$$x_i^{'} = \frac{x_i}{\sum_{j=1}^{n} x_j} \tag{13}$$

The third step of pre-processing is feature selection. During this process a set of the attributes with descriptive data is produced as a an aggregation of available attributes. The objective of this process is to lessen the attributes negative impact to the classification results (Thomassey & Fioraliso, 2006). Attributes can be selected using the information gain or by simple choosing based on user experience. The third - Dataset formation, process is performed reactively by responding to the Data Mining Agent's requests.

3.1.2 Data Mining Agent

The Data Mining Agent is an intelligent agent. The environment it is situated in is the data from the datasets received from the Data Management Agent. The Data Mining Agent performs data clustering and creates classification models, changing the environment into the classification rule sets. The processes in the Data Mining Agent are divided into two main steps - data clustering and the classification rules induction.

The *k-means* algorithm (Tan et al., 2006) was chosen to support the data clustering, though other clustering algorithms can also be applied. The *k-means* is a simple and easy-to-understand algorithm, but it has a sufficient weakness - the number of clusters must be defined before the clustering process begins. Due to that, the clustering process should be repeated several times with different number of clusters and the best number of clusters may be chosen by the smallest clustering error. To lessen the time of searching for the appropriate number of clusters an assumption that the maximal number of clusters should be less or equal to the $\sqrt{n}$, where n is the number of records in the dataset, can be used (Tan et al., 2006). The *k-means* algorithm is executed as follows:

1. The number of clusters m is defined, for each cluster centroid random values are assigned.
2. By using a distance measure (the *Euclidean* distance is used by default) each record in the dataset is assigned to the closest cluster. If none of records changed its cluster, then the clustering process finishes.

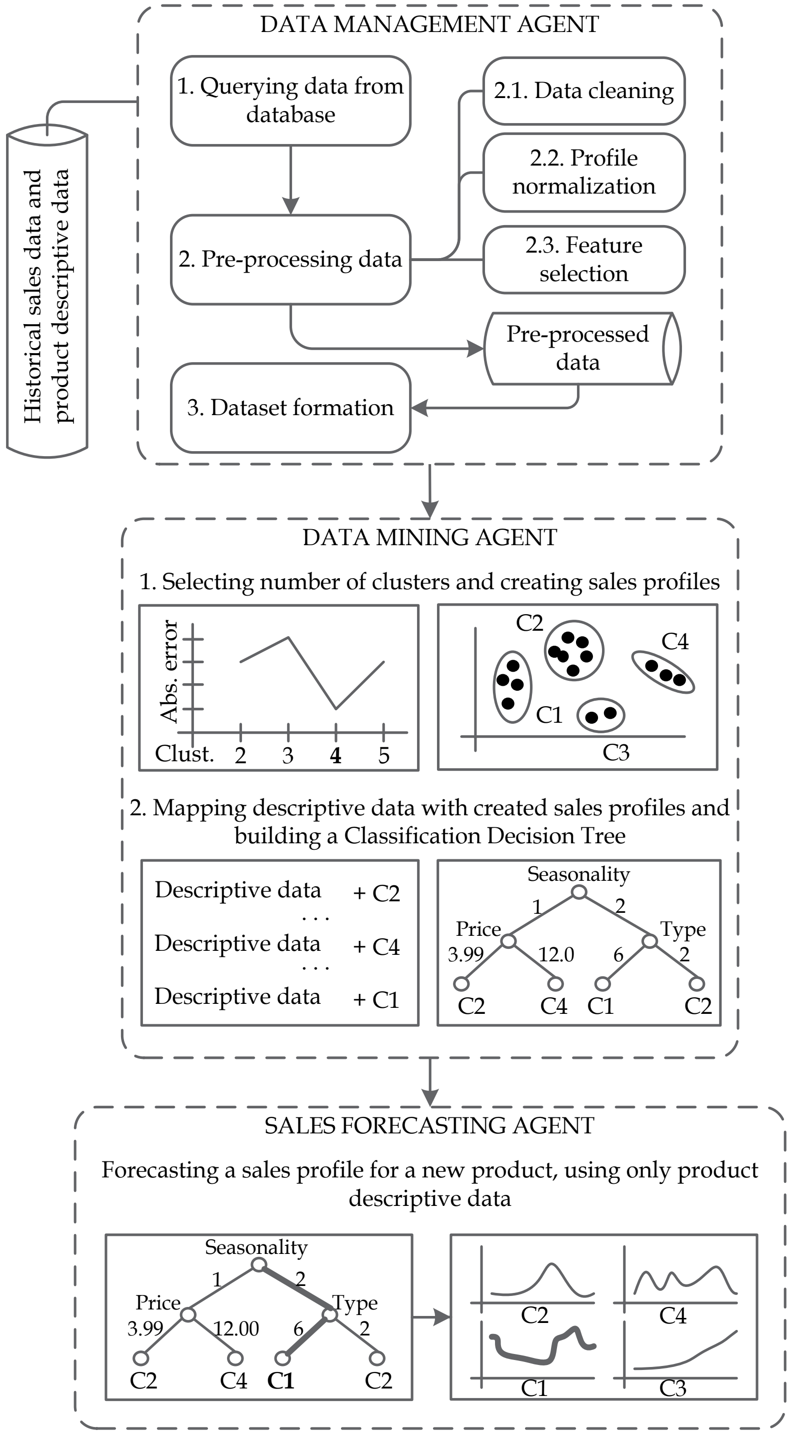


Fig. 8. Multi-Agent System for Sales Forecasting

3. Cluster centroids are recalculated using the records in the appropriate cluster. Then the algorithm returns to Step 2.

Having all data distributed among the defined number of clusters, the clustering error should be calculated in order to show the efficiency of the chosen number of clusters. The clustering error is calculated as a mean absolute error. First, Equation 14 is used to calculate the absolute error AE_i for each cluster c_i. Then the mean absolute error is calculated by Equation 15.

$$AE_i = \frac{1}{n(c_i)} \cdot \sum_{j=1}^{n(c_i)} d_j \ , \tag{14}$$

where $n(c_i)$ is the number of records in the cluster c_i; d_j - the absolute distance between j-th record in the cluster c_i and the centroid of this cluster.

$$MAE = \frac{1}{m} \cdot \sum_{i=1}^{m} AE_i \tag{15}$$

The result of clustering the sales data is the set P, containing a number of sales profiles - cluster centroids, example of which is displayed in Figure 9, where the centroid is marked with a bold line. Each sales profile p is assigned a unique identification number, which will be used in the classification rule set induction step. The data clustering step finishes with the

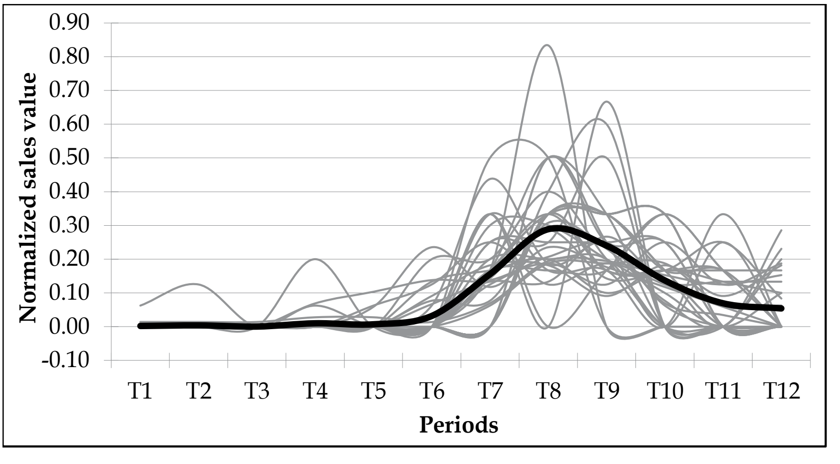


Fig. 9. An example of a cluster and a centroid

process of merging the descriptive data with found sales profiles. During this process each record is merged with an identification number of a closest sales profile. In other words - each record is assigned an appropriate target attribute value.
In order to forecast a sales curve for a product by having only descriptive data, a model of the relations between found sales profiles and descriptive data must be created. Assuming that each sales profile $p \in P$ is a class, the classification methods can be applied for building the desired model. A number of classification methods exist, each having its positive and negative sights. The proposed sales forecasting system applies the inductive decision trees for building the classification model. The decision trees not only create a classification model, which can be represented as a rule set, but also support a graphical tree-like representation of a model, which makes it more understandable for a user.

The Data Mining Agent builds the inductive decision tree using the training dataset, merged with found sales profiles. It uses the C4.5 classification algorithm (Quinlan, 1993). The C4.5 algorithm is able to proceed with discrete and numeric attributes and to handle the missing values. The decision tree built is the model representing the relations between descriptive attributes and the sales profiles. The internal nodes represent the descriptive attributes and leafs are pointing to one of sales profiles found.

3.1.3 Sales Forecasting Agent

The Sales Forecasting Agent is an agent that uses the model (knowledge base) created by the Data Mining Agent. The environment the Sales Forecasting Agent is situated in is the set of new data, containing only descriptive attributes. The environment may include the records from a test set that have the sales profile attached, while the system is in the evaluation stage. The Sales Forecasting Agent changes the environment by forecasting a sales profile for the new data, using the product descriptive data and the model built by the Data Mining Agent. The sales profile forecasting process can be described as a sequence of the next steps:

1. Chose a record X, containing the descriptive data of a new product.
2. By following the structure of the classification tree, created by the Data Mining Agent, find a tree leaf l_j for the record X_i.
3. Take the sales profile p_k, represented by the determined leaf l_j, as a forecasted one for the record X_i.

Figure 10 displays a part of the classification tree and shows the path to the leaf for a record with the following descriptive data: *Kind = 2*, *Type = 1* and *Price = 65.4*.

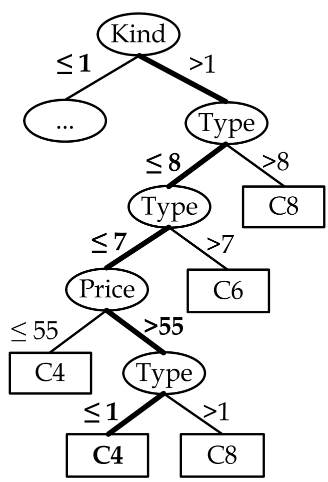


Fig. 10. Example of a classification decision tree

3.2 Experimental results

The proposed sales forecasting system was trained using sales data of a local retailer of textile products, gathered in the year 2005. After all necessary pre-processing steps were finished, the dataset contained 423 records. The 149 sales records from the year 2006 were used for system

testing. As a descriptive data, the following three parameters were chosen: *Kind*, showing either the product is seasonal or not, the *Price* of the product and the *Type*, showing what the product actually is - jeans, t-shirt, bag, shorts, belt etc.
The data clustering was powered by the *k-means* algorithm and the number of clusters was chosen by evaluating clustering error with different cluster number starting with two and continuing till 21, as the square root of 423 records is approximately equal to 20.57. Figure 11 shows the results of clustering error evaluation with different number of clusters. The

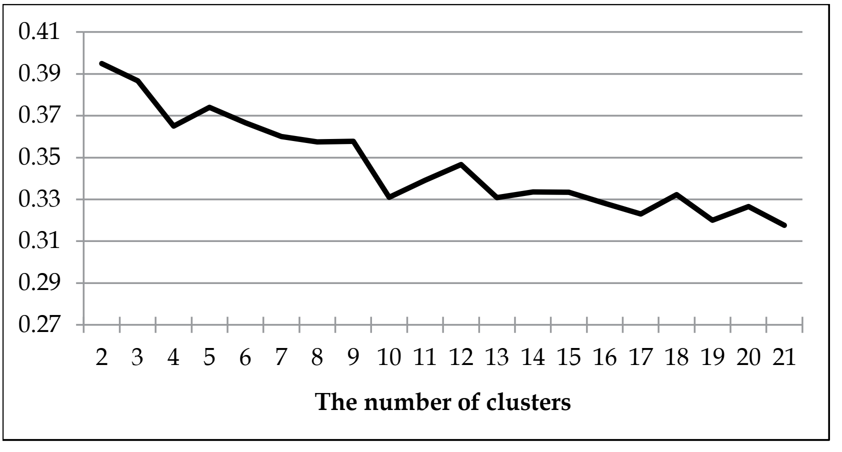


Fig. 11. The clustering error for different number of clusters

first noteworthy improvement in clustering error was while using 10 clusters. For larger numbers of clusters the clustering error was not sufficiently improving, comparing to the result with 10 clusters. Taking this into account, the number of clusters was set to 10 for all further experiments.
For building the classification model, the C4.5 classification algorithm was chosen among other classification methods by comparing six classifiers using such measures as *Root Mean Square Error - RMSE* (see Equation 16) and the *Mean Absolute Error - MAE* (see Equation 17). The *RMSE* and *MAE* were used to measure an error between the forecasted sales profile and the actual sales profile.

$$RMSE = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (f_i - x_i)^2} \tag{16}$$

$$MAE = \frac{1}{n} \cdot \sum_{i=1}^{n} |f_i - x_i| \ , \tag{17}$$

where n is the number of periods in the forecasted sales profile F and also in the actual sales profile X.
Figure 12 displays the classification tree that was built by the C4.5 classification algorithm. Table 4 shows the results of different classifier evaluation. As can be seen, the C4.5 decision tree algorithm dominates others in both error measures.

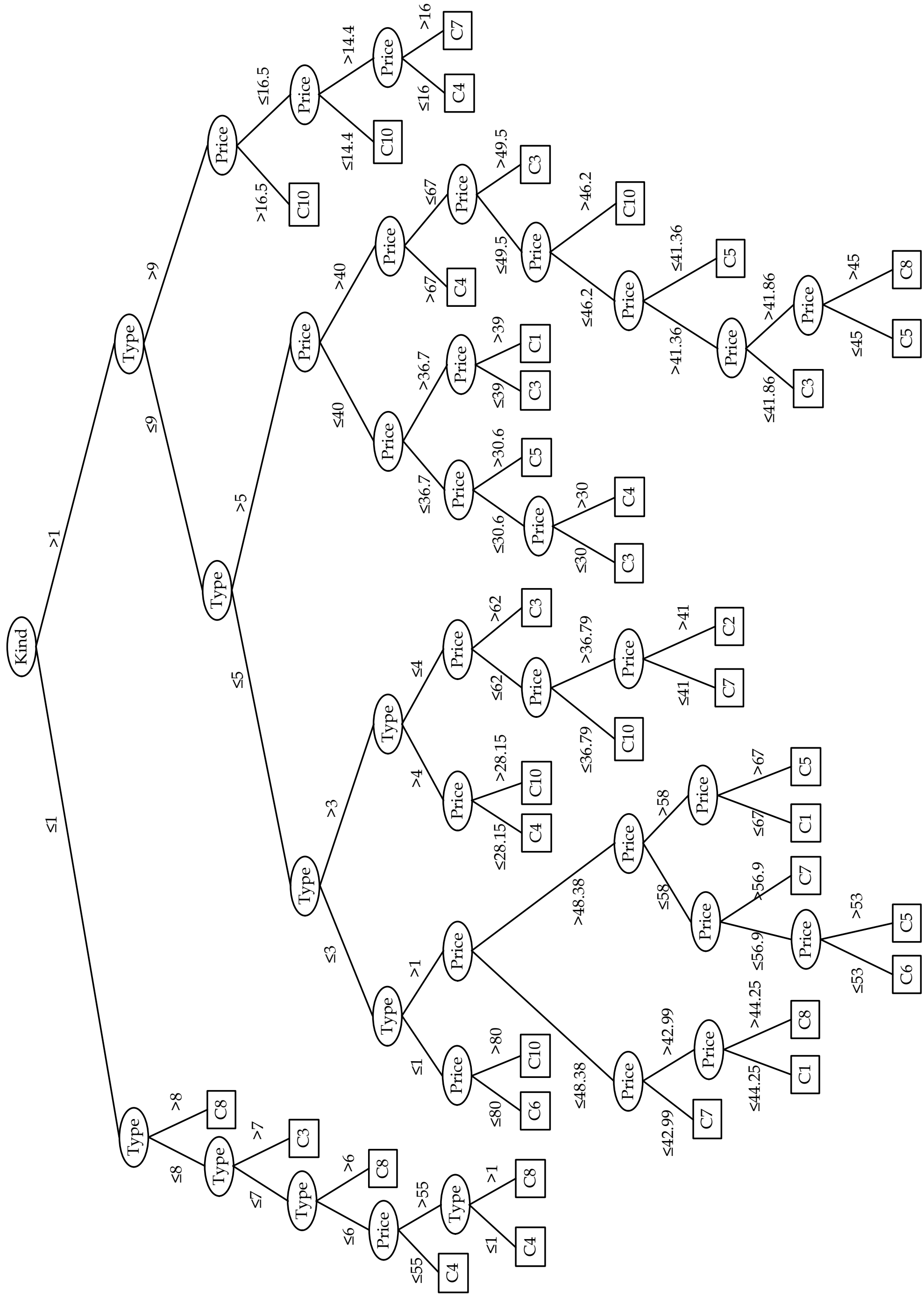


Fig. 12. Decision tree for sales profile forecasting

Error measures	Classifiers					
	ZeroR	*OneR*	*JRip*	*Naive Bayes*	*IBk*	*C4.5*
RMSE	0.295	0.375	0.284	0.282	0.298	**0.264**
MAE	0.174	0.141	0.161	0.156	0.160	**0.129**

Table 4. Error measures for various classification methods

3.3 Results analysis and summary

The results obtained while testing the proposed multi-agent sales forecasting system show that a combination of the intelligent agent technology and the data mining methods - clustering and classification, can be efficiently used for solving such task as the sales forecasting. The system showed good results in clustering the sales data and building the decision tree for forecasting a sales profiles for new products, having only descriptive data available, which is important for retailers while planning the investments for the new stock products. One of the advances of the system is that a user is able to personally view the model - classification decision tree that was used for forecasting to find the relations between the sales profile and the descriptive data, which makes the model more understandable. Using the intelligent agent technology, the system was made modular, which simplifies the implementation of new clustering and classification methods.

4. Conclusions

The modern production and trade management remains a complicated research field and as technology is evolving, becomes even more complicated. This field combines different tasks of forecasting, planning, management etc. In the present research two of them - PLC management and sales forecasting, were discussed and possible solutions proposed. Looking back in time, those tasks were efficiently solved by standard statistical methods and a single user was able to perform that. Today the level of technological evolution, the amount of gathered data and complicated planning objectives require the solutions that are able to lessen the human's load and are capable to perform different data analysis tasks in the autonomous mode. In order to gain the above possibilities, the agent technology and combinations of the intelligent data analysis methods were chosen as the basis. Using the mentioned technologies, the structures of the PLC management support multi-agent system and the multi-agent sales forecasting system were proposed and the concepts of each system were described and discussed. The structures of the proposed systems were intentionally made general in order to demonstrate the advances of the agent technology. The modularity of the proposed systems allows one to adapt individual processes to the specific field of application, without breaking the structure of the system.

Both systems were tested using the real-life data and the results obtained show the effectiveness of the proposed multi-agent systems and the technologies, chosen for creating those systems. The conclusion of the present research is that the intelligent agent technology and other intelligent data analysis technologies can be efficiently applied in tasks connected with supporting the modern production and trade management. The two proposed multi-agent systems give an example of such applications.

5. Acknowledgement

This work has been supported by the European Social Fund within the project "Support for the implementation of doctoral studies at Riga Technical University".

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3

Modeling Stock Analysts Decision Making: An Intelligent Decision Support System

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1. Introduction

Over 60% of the families in the United States have billions of dollars invested in mutual funds. Consequently portfolio managers are under tremendous pressure to make critical investment decisions in dynamically changing financial markets. Experts have been forecasting and trading financial markets for decades, using their knowledge and expertise in recognizing patterns and interpreting current financial data. This paper describes a knowledge based decision support system with the analogical and fuzzy reasoning capabilities to be used in financial forecasting and trading. In an attempt to maximize a portfolio's return and avoid costly losses, the portfolio manager must decide when to enter trades as well as when to exit and thus, must predict the duration as well as the direction of stock price movement. A portfolio manager is faced with a daunting information management task and voluminous amounts of rapidly changing data. It is simply an impossible task to manually and simultaneously follow many investment vehicles, stocks and market moves effectively.

To assist portfolio managers' decision making processes, tens of millions of dollars are spent every year on Wall Street to automate the process of stock analysis and selection. Many attempts have been made at building decision support systems by employing mathematical models and databases(Liu et al, 2010; Tan 2010). These traditional decision support systems are composed of three components: a database, a user interface, and a model base. The user interface allows the end user (in most cases, a manager) to select appropriate data and models to perform an analysis for a given stock. The database contains data necessary to perform the analysis, such as market capitalization, shares outstanding, price ratio, return on equity, and price to book ratio. The model base consists of mathematical models to deal with the present value of expected future payoffs from owning the stock, such as the dividend discount model, price-to-earning ratio(P/E) models, and their variants. Standard decision support systems employ quantitative approaches to decision making. Specific quantities in the form of payoffs and probabilities are used to arrive at a quantitative expected value. The decision maker simply selects the alternative that has the highest expected value. Despite the mathematical soundness and systematic approach of traditional decision support systems, researchers have discovered compelling reasons for developing qualitative approaches in decision making. It is inappropriate to suggest that people reason about decisions in a purely quantitative fashion. In the domain of security analysis and trading, if we expect a stock to go up in value, we are likely to invest in the stock despite not knowing quantitatively how much or how soon a stock will rise. A qualitative analysis of a decision problem is usually logically prior to a quantitative analysis(Sen, 2009).

In order to develop a decision support system with the capabilities of qualitative analysis, considerable progress has been made toward developing "knowledge-based decision support systems", sometimes known as expert systems (Silverman, 1992). An expert system designed in the domain of security analysis is an intelligent decision support system whose behavior duplicates, in some sense, the ability of security analysts. Expert systems are computer programs with characteristics that include the ability to perform at an expert level, representing domain-specific knowledge and incorporating an explanation of conclusions reached. Traditional expert systems consist of five major components: an end user interface, an inference engine, a working memory, a knowledge base, and an explanation mechanism. The interface allows the end user to input data to and receive explanations or conclusions from the expert system. The working memory keeps track of specific data, facts and inferences relevant to the current status of the problem solving. The knowledge base contains problem-solving knowledge of a particular domain collected from an expert. The inference engine matches data in the working memory with knowledge in the knowledge base, and acts as the interpreter for the knowledge base. By combining the five components together, an expert system is able to act as a knowledgeable assistant and provide "expert quality" advice to a decision maker in a specific domain.

Despite the impressive performance of expert systems, they have a number of inherent flaws, especially when operating in a dynamically changing environment. An expert system solves problems by taking input specifications and then "chaining" together an appropriate set of rules from the knowledge base to arrive at a solution. Given exactly the same problem situation, the system will go through the same amount of work to come up with a solution. In addition, traditional expert systems are "brittle" in the sense that they require substantial human intervention to compensate for even slight variations in descriptions, and break down easily when they reach the edge of their knowledge(Zhou, 1999).

In response to weaknesses associated with traditional decision support systems and expert systems, this paper presents a knowledge-based and case-based intelligent decision support system with fuzzy reasoning capabilities called TradeExpert, designed for assisting portfolio managers to make investment decisions based not only mathematical models, but also facts, knowledge, experiences, and prior episodes.

2. Efficient market hypotheses and trading opportunities

Since the 1960's, the theory of Efficient Market Hypothesis (EMH) has been popular and well-known in the investment community(Eugene,1965; Malkiel, 1987). The basic idea behind EMH is that at any point in time, prices of stocks in an efficient market reflect the information from a variety of sources available to all investors involved in the market. According to EMH, past stock prices, movements, and patterns provide little or no guidance as to the direction of future prices. EMH asserts that stock markets are "informationally efficient". That is, one cannot consistently achieve returns in excess of average market returns on a risk-adjusted basis, given the information publicly available at the time the investment is made. The validity of the hypothesis has been questioned by critics who blame the belief in rational markets for much of the financial crisis of 2007–2010(Fox, 2009; Nocera, 2009). Since the 1980's, there was a resurgence of interest in questions of the accuracy of

EMH. A variety of empirical tests developed new and often elaborate theories that sought to explain subtle security-pricing irregularities and other anomalies. Market strategist Jeremy Grantham has stated flatly that the EMH is responsible for the current financial crisis, claiming that belief in the hypothesis caused financial leaders to have a "chronic underestimation of the dangers of asset bubbles breaking"(Nocera, 2009).

More recently, institutional investors and computer-driven trading program appeared to be resulting in more anomalies. Anomalies may also arise from the market's incomplete assimilation of news about particular securities, lack of attention by market participants, difference of opinion about the meaning and significance of available data, response inertia and methodological flaws in valuation(Robertson & Wolff, 2006). Findings like the preceding suggest that the EMH is not perfect representation of market realities that behave as complex systems. Because security markets are complex, time-variant, and probably nonlinear dynamic systems, one simple theory cannot adequately represent their behavior; From time to time there may arise anomalies that are exploitable. In the design of TradeExpert, technical analysis rules, trend analysis rules, and fundamental analysis rules are used to exploit whatever inefficiencies may exist and unearth profitable situations.

Technical analysis is the systematic evaluation of price, volume and patterns for price forecasting(Wilder 1978). There are hundreds of thousands of market participants buying and selling securities for a wide variety of reasons: hope of gain, fear of loss, tax consequences, short-covering, hedging, stop-loss triggers, price target triggers, broker recommendations and a few dozen more. Trying to figure out why participants are buying and selling can be a daunting process. Technical analysis puts all buying and selling into perspective by consolidating the forces of supply and demand into a concise picture. As a complete pictorial record of all trading, technical analysis provides a framework to analyze the battle raging between bulls and bears. More importantly, it can help determine who is winning the battle and allow traders and investors to position themselves accordingly. Technical analysis uses trading indicators and stock trading prices to analyze the stock trend. Trading indicators, e.g. Moving Average, Bollinger Bands, Relative Strength Index, and Stochastic Oscillator, provide trading signals which can be used to determine when to trade stocks.

Trend analysis, also known as Momentum Trading(Simple, 2003), is the process by which major and minor trends in security prices are identified over time. The exact process of trend analysis provides investors with the ability to identify possible changes in price trends. As securities prices change over time it will exhibit one of three states: uptrend, downtrend or sideways consolidation. It is the job of the technical analyst to identify when a security may change from one trend to another as these may provide valid trading signals. Trend analysis uses a fixed trading mechanism in order to take advantages from long-term market moves without regards to past price performance. Trend analysis is a simplistic trading strategy that tries to take advantage of stock price movements that seem to play out in various markets. Trend analysis aims to work on the market trend mechanism and take benefits from both sides of the market. It gains profits from ups and downs of the stock market. Traders who use this approach can use current market price calculation, moving averages and channel breakouts to determine the general direction of the market and to generate trade signals.

Fundamental analysis maintains that markets may misprice a security in the short run but that the "correct" price will eventually be reached. Profits can be made by trading the mispriced security and then waiting for the market to recognize its "mistake" and reprice the security. One of the most important areas for any investor to look when researching a company is the financial statement of that company. Fundamental analysis is a technique that attempts to determine a security's value by focusing on underlying factors that affect a company's actual business and its future price.

To summarize, technical analysis, fundamental analysis, and trend analysis do not really follow the theory of Efficient Market hypothesis. They attribute the imperfections in financial markets to a combination of cognitive biases such as overconfidence, overreaction, representative bias, information bias, and various other predictable human errors in reasoning and information processing.

3. System architecture

TradeExpert is a hybrid system that uses both quantitative and qualitative analysis to exploit changing market conditions and to grind through mountains of economic, technical and fundamental data on the market and on individual stocks. Furthermore, TradeExpert incorporates the mechanism of case-based reasoning which enables it to recall similar episodes from the past trading experience, and the consequences of that action. The goal, of course, is to ferret out patterns from which future price action can be deduced, to meaningfully assimilate vast quantities of information automatically, and to provide support intelligently for portfolio managers in a convenient, timely and cost-effective manner.

TradeExpert assumes the role of a hypothetical securities analyst who makes a recommendation for a particular stock in terms of *strong buy, buy, hold, sell* and *strong sell* based on chart reading, fundamental analysis, investment climate, and historical performance. TradeExpert is designed and implemented based on principles consistent with those used by a securities analyst(Kaufman 2005). It is capable of reasoning, analyzing, explaining, and drawing inferences. In terms of system architecture, TradeExpert consists of the following major components: a user interface, databases, knowledge bases, a case base, a similarity evaluator, an explanation synthesizer, a working memory, and an inference engine, shown in the following diagram 1. The user interface provides communication between the user and the system. Input data from the user to the system contains the parameters of a stock under consideration, such as Yield, Growth rate, P/E, Return on net worth, Industry sector, Profit margins, Shares outstanding, Estimated earning per share, Price to book ratio, Market capital, Five-year dividend growth rate, Five-year EPS growth rate, and Cash flow per share. If a stock being analyzed is already stored in the database, TradeExpert retrieves data and fills in the parameter fields on the input screen automatically. The fuzzy inference component employs fuzzy logic and reasoning to measure partial truth values of matched rules and data. It makes reasoning processes more robust and accurate. The output from the system is a trading recommendation with a list of reasons justifying the conclusion. With human expertise in the knowledge base, past trading experience in the case base, and stock's data in the database, TradeExpert is capable of analyzing a stock, forecasting future price movements, and justifying the conclusion reached.

4. Knowledge bases and organization

The knowledge bases capture the knowledge of human securities analysts in the form of If-Then rules. In the design of TradeExpert, the knowledge base is divided into three separate knowledge bases: technical analysis knowledge base, fundamental analysis knowledge base and trend analysis knowledge base. TradeExpert can use any or all of these different but somewhat complementary methods for stock picking. For example it uses technical analysis for deciding entry and exit points, uses trend analysis for deciding the timing of a trade, and uses fundamental analysis for limiting its universe of possible stock to solid companies. As a justification of the expert system serving as a model of human thought processes, it is believed that a single rule corresponds to a unit of human knowledge. In the design of an intelligent decision support system, knowledge representation for human problem solving expertise is a critical and complex task.

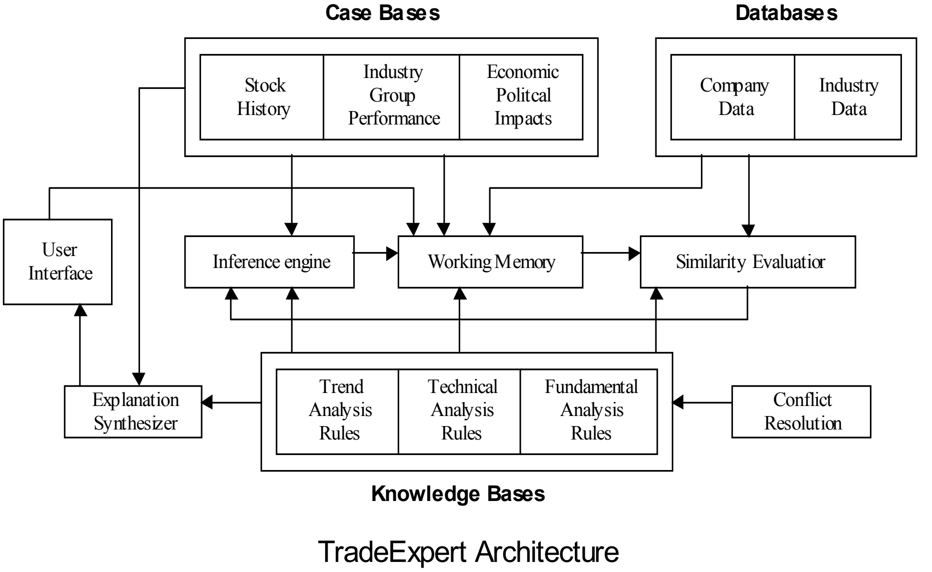


Fig. 1.

In what follows, the knowledge representation of stock analysis and selection in TradeExpert is described along with a rule frame as an example (Trippi & Lee 1992).

RULE <ID>
(INVESTMENT HORIZON: <statement>)
(ASSUMPTION: <statement>)
(INVESTMENT OBJECTIVES: <statement>)
(IF <statement> <statement> ..... <statement>)
THEN <statement>)
(REASONS: <statement>)
(UNLESS: <statement>)
(CERTAINTY FACTOR: <real number>)

The key word INVESTMENT HORIZON designates the period of the investment: day trading, short term or long term. The key word INVESTMENT OBJECTIVES indicates the investment objective of the user, such as trading for profits, income, and capital appreciation. The key word REASONS provides justifications and explanations of how a rule arrives at a conclusion. The key word UNLESS excludes the stock even when the hypothesis(condition) part of a rule is satisfied. The key word CERTAINTY FACTOR contains a real number in the range of (0..1) measuring the strength of evidence in support of the rule's hypothesis. In order to invoke a rule, both the hypothesis part and the ASSUMPTION part must be met. Given a situation, investors may reach different conclusions and select different trading strategies based on different assumptions. Some examples are: "Can the Asian financial crisis be over in the next 12 months?", "Will the U.S. dollar be stronger or weaker over the next 3 months?", or "Will the FED cut interest rates at its next meeting?" Of course, different answers to these questions lead to different trading strategies. Since investing is a subjective process, TradeExpert allows the user to determine the future direction of financial markets and then select stocks accordingly. One of the rules in the knowledge bases is listed below:

RULE <31>
(INVESTMENT HORIZON: <day trading>)
(ASSUMPTION: <*bull market*>)
(INVESTMENT OBJECTIVES: <*trading profits*>)
(IF
<*Company is in internet-sector*> AND
<*internet-sector = Hot*> AND
<Avg-peer-earnings = beat the estimate> AND
<*estimated EPS = increase over last two months*> AND
<*product = high demand*> AND
<*average-daily-volume* >= *1.5 average)* AND
< price-range = new 52-week high> AND
< liquidity = good>
THEN <*Short term Strong Buy*> *)*
(REASONS:
<*technical analysis signals a new high*> AND
<*price movement trend is favorable*> AND
<*stock momentum carries over*> AND
<*small number of outstanding shares*> AND
<*history performance of hot stocks*> *)*
(UNLESS:
<*downgrades-by-analysts* > *2 in last 5 days*> OR
<*earning-warning-by-peers* > *1 in last 5 days*>*)*
(CERTAINTY-FACTOR: *0.85*)

With a set of reasons associated with the conclusion of a rule, TradeExpert is able to justify its reasoning by providing evidence and rational of its conclusion in addition to a certainty factor. In order to retrieve appropriate rules efficiently, the rules in TradeExpert are organized in a hierarchical structure. They are classified in terms of their scope and attributes. One rule designed for day trading may not be important at all for long-term investment and vice versa. A technical break out of stock price and daily price fluctuation may not have impact on long-holding investors. Classifying rules into different categories makes logical sense in terms of knowledge retrieval and maintenance. Of course, one rule may be indexed by multiple categories so that the match and evaluation steps during the inference process can be completed efficiently. Another factor for consideration is an investor's subjective judgmental call, such as the assessment and long term view of a particular market. Given current economic data and political environment, different investors market be up or down over the next 6 months?" will definitely elicit several answers from the investor community. A partial diagram that shows the knowledge organization (Trippi & Lee 1992) in TradeExpert is presented in figure 2.

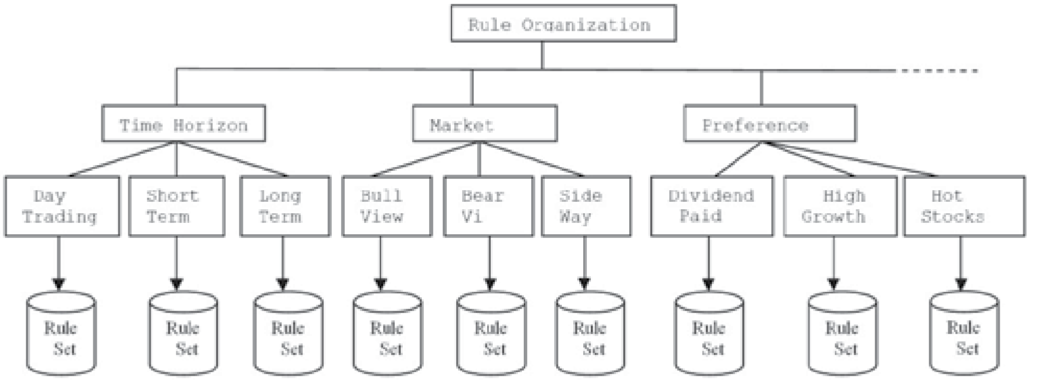


Fig. 2. Knowledge Organization

It is worth noting the above diagram is a simplified version, many levels and branches of indices have been left out. Hot stocks that satisfy certain criteria such as high daily trading volume, large percentage price gain and belonging to a best-performing industrial sector are identified and collected daily.

4.1 Fundamental analysis knowledge base

There are two models of investing: growth-oriented and value-based. Growth-oriented investing seeks companies that show consistent earnings and sales growth, usually 20% or more per annum for the past three to five years. These stocks usually carry a high PE and have a record of better-than-average earnings growth. They usually beat analyst estimates by a large percentage quarter after quarter. Acceleration in earning growth often indicates the future upward price movements of a stock. Value-based investing looks for bargains and gravitates to stocks with a low price/ratio(P/E) and a low price-to-book value. As a foundation of growth-oriented and value-based investing, fundamental analysis relies on the following factors to make an evaluation: P/E, price-to-cash flow, market value-to-book, sales-to-price, debt ratios, yield, and projected earnings. It is a method of evaluating securities that attempts to measure intrinsic values by examining related economic, financial and other qualitative and quantitative factors. Fundamental analysis views the stock market as a relatively ordered system and each company is represented by factors such as financial ratios and performance measures, which are used to draw inferences. The rules in the fundamental analysis knowledge base are concerned with analysis of the company itself and deriving estimates of net worth per share, current assets, future earnings and dividends, and other related measures of value. The fundamental analysis rules attempt to estimate the future earning of a stock and therefore define a stock's true value. It performs analysis on industries or the economy as a whole. The term refers to the analysis of the economic well-being of a financial entity as opposed to its price movements. It does not pay attention to daily price movements and short term fluctuations. The investment horizon is often in the range of multiple years, not days and weeks.

Fundamental analysis serves to answer questions, such as:

- Is the company's revenue growing?
- Is it actually making profits?
- Is it in a strong-enough position to beat out its competitors in the future?
- Is it able to repay its debts?

One of the rules in the fundamental knowledge base is listed below:

```
RULE   <16>
    (INVESTMENT HORIZON: <long term>)
    (ASSUMPTION: <bull or bear market>)
    (INVESTMENT OBJECTIVES: <return on capital>)
    (IF
        <PE < similar_stock_average>                     AND
        <earning_history = stable>               AND
        <dividend pay-out history = consistent>          AND
        <market_value_to_book < 1.05>            AND
        <Company is believed to be profitable>           AND
        <credit-rating > A or better>                    AND
        <debt rations = low>                             AND
    THEN <Long term Strong Buy> )
    (REASONS:
        <good credit rating>                             AND
        <its intrinsic value = attractive>               AND
        <consistent dividend payout>
    (UNLESS:
        <law suit = pending>                     OR
        <In the middle of financial_scandal>     OR
    < Bankruptcy = likely>
    (CERTAINTY-FACTOR: 0.73)
```

Fundamental analysis is a technique that attempts to determine a security's value by focusing on underlying factors that affect a company's *actual* business and its future prospects. It believes that the intrinsic value of the stock eventually drives long-term stock prices. It looks at revenue, expenses, assets, liabilities and all the other financial aspects of a company to gain insight on a company's future performance and therefore, the stock's future price.

4.2 Technical analysis knowledge base

Fundamental analysis tells us what stocks are capable of but does not tell us just how high or low stock prices will go or when they will peak or bottom out. Technical analysis works in opposite principle of the fundamental analysis(Edwards & Magee, 1992). The underlying philosophy for this approach is that market prices well reflect all known factors at all times. So the price is already a solid performance indicator as a result of the supply and demand for that particular stock. Therefore technical analysis evaluates solely on market prices themselves rather than on any fundamental factor outside the market. The rules in the technical analysis knowledge base are concerned with studies of supply and demand for a stock and statistics which are related to price and volume. Technical indicators are tools invented on concept of technical analysis. There are many kinds of technical indicators that have been developed to gain insight about the market behavior. Each of them may have different concept about when to buy and sell (trading signals). Some well-known and widely used technical indicators are listed below briefly. **Moving Average (MA)** is used to remove market noise and find the direction of prices. It is calculated by sum up the stock prices over n days divided by n. **Relative Strength Index (RSI)** compares the magnitude of the stock's recent gains to the recent losses then turns into the number ranged from 0 to 100. It compares the magnitude of recent gains to recent losses in an attempt to determine overbought and oversold conditions of an asset. It is calculated using the following formula: **RSI** = 100 - 100/(1 + RS*), where RS = Average of x days' up closes / Average of x days' down closes. If RSI is less than 30, it shows an oversold market condition. **Stochastic Oscillator (SO)** is an oscillator that measures the relative position of the closing price within a past high-low range. **Volatility Index(VIX)** is derived from the prices of ALL near-term at-the-money call and out-of-the-money call and put options. It is a measure of fear and optimism among option writers and buyers. When a large number of traders become fearful, then the VIX rises. Conversely, when complacency reigns, the VIX falls. The VIX is sometimes used as a contrarian indicator and therefore can be used as a measurement of how oversold or overbought the market is. Usually it increases as the market decreases. Its usefulness is in showing when a trend reversal is about to take place.

One popular form of technical analysis is charting, in which the graphic display of past price performance, moving-average trends, cycles, and intro or inter-day stock price ranges are studied in an attempt to discern cues for profitable trading. Stock price pattern analysis is the basis of the technical analysis of stocks. It relies on the interpretation of some typical configurations of the ups and downs of price movements like "head and shoulders", "top and bottom formations" or resistance lines. Stock price pattern analysis comes down to comparing known patterns with what is evolving on the chart. Charting makes use of techniques such as moving indices, trend analysis, turning-point indicators, cyclical spectral analysis, and the recognition of various formations or patterns in prices in order to forecast subsequent price behavior. Some examples of patterns are assigned names such as "flag", "triangle", "double bottom or top", "symmetrical triangles", and "head-and-shoulders".

The rules in the technical analysis knowledge base represent the expertise of chart reading without concerning the fundamentals of a company. By analyzing MA, RSI, SO, VIX, and trading volumes of a stock, the technical analysis rules suggest entry points as well as exit points, taking advantage of market fluctuations instead of being victimized by them. One technical analysis rule used by TradeExpert is presented below:

RULE <92>
(INVESTMENT HORIZON: <short term>)
(ASSUMPTION: <*bull market*>)
(INVESTMENT OBJECTIVES: <*trading for profits*>)
(IF
<**RSI** < 35> AND
<10_day **MA** > 30_day **MA**> AND
<**VIX** > 70) AND
< Chart reading shows a near complete **W** shape> AND
<*average-daily-volume* >= *1.5 average*)
THEN <*Short term Strong Buy*>)
(REASONS:

<*price moving average shows an uptrend direction*> *AND*
<*technical analysis signals a breakout*> AND
< Volatility index shows a reversal is imminent> AND
<stock relative strength shows the market is oversold> AND
<Daily volume > daily average>
)
(UNLESS:
<Overall market is extremely weak> OR
<down_grades > 2 in last 7 days>)
(CERTAINTY-FACTOR: *0.75*)

Technical analysis maintains that all information is reflected in the stock price. Trends 'are your friend' and sentiment changes predate and predict trend changes. Investors' emotional responses to price movements lead to recognizable price chart patterns. Technical analysis does not care what the 'value' of a stock is. Their price predictions are only extrapolations from historical price patterns. Like x-rays and brain scans are used to diagnose diseases and seismic data is used to exploit oil, technical analysis is used to help determine the behavior and future price movements of a stock. TradeExpert as well as investors can use technical analysis to buy stocks and sell stocks at the most advantageous and profitable prices.

4.3 Trend analysis knowledge base

Instead of striving to predict a market direction, Trend analysis, also known as Momentum Trading, reacts to the market's movements whenever they occur(Eng 1993). It responds meticulously to what has recently happened and what is currently happening, rather than anticipating what will happen.
Unlike the strategy "buy low and sell high" often employed in value-based investing, the trend analysis rules are based on a different approach: "buy high and sell higher." The basic rational behind this approach is based on the well known Wall Street statement: "go with the tape". That is, if you try to short a stock in an up trend, you will get killed. The same is true if you try to go long on a stock in a down trend. Since investing is an art not a science, a reasonable guess is that tomorrow will likely follow the trend established over the past few days. The stocks which have been strong relative to all other stocks should continue to be relatively stronger in the near future. Trend analysis rules reflect and implement this idea in TradeExpert. The rules in the trend analysis knowledge are designed and selected to recognize some short-term persistence in markets and to identify the stocks that may generate significant returns in a short period of time. Fortunes are made by those who recognize trends and ride them. In the period of 1997-1998, the internet sector was white hot. A company would have done much better if it could create a website than buying back its own stock to pop up its stock's price. The trend then was internet-related stocks. For example, the 400 plus percentage gain of Amazon and Yahoo, the gravity-defying internet stocks, was made in the first 10 months of 1998. These rules attempt to unearth stocks whose prices move far beyond any reasonable estimate of intrinsic value and often outperform the market index averages by a big margin in a short period of time.
In what follows, one formula used in trend analysis rules and momentum trading is presented (Schulmeister, 2002). It consists of a short-term moving average (MAS_j) and a long-term moving average (MAL_k) of past prices. The length j of MAS usually varies between 1 day (in this case the original price series serves as the shortest possible MAS) and

10 days, the length k of MAL usually lies between 10 and 30 days. (if one uses 30 minutes data, then Buy (go long) when the short-term (faster) moving average crosses the long-term (slower) moving average from below and sell (go short) when the converse occurs. Or equivalently: Open a long position when the difference (MAS_j-MAL_k) becomes positive, otherwise open a short position. If one expresses this difference as percentage of MAL_k one gets the moving average oscillator:

$$MONTENTUM(j,k)_t = [(MAS_{j,t} - MAL_{k,t}) / MAL_{k,t}] * 100$$

This type of representation facilitates a (graphical) comparison of the signal generation between moving average models and momentum models. Another way to express the basic trading rule is then: Hold a long position when MONTENTUM is positive, hold a short position when MONTENTUM is negative. The second type of model works with the relative difference (rate of change in %) between the current price and that i days ago:

$$M(i) = (Pt_{current} - Pt_i)$$

The basic trading rule of momentum models is as follows(Carter, 2006):
Buy (go long) when the momentum M(i) turns from negative into positive and sell (go short) in the opposite case. Or equivalently: Hold a long position when M is positive, hold a short position when M is negative. The variables MONMENTUM(j,k) or M(i) are called "oscillators" because they fluctuate around zero. The basic trading rule of moving average models and momentum models is trend-following since $MONMENTUM(j,k)_t$ and $M(i)_t$, respectively, are positive (negative) only if an upward (downward) price movement has persisted for some days (or some 30 minutes intervals). When and how often $MONMENTUM(j,k)_t$ and $M(i)_t$, respectively, cross the zero line depends not only on the persistence of recent price movements but also on the lengths of moving averages and the time span i in the case of momentum models, respectively.
As an example, a rule in the trend analysis knowledge base is presented below:

RULE <45>
(ASSUMPTION: <*bull market*>)
(INVESTMENT OBJECTIVES: <*trading for profits*>)
(IF
<*growth_rate* > **PE**> AND
<Momentum > 0) AND
<*the industrial sector = Hot*> AND
<reported-peer-earnings = beat the estimate> AND
<*floating-shares = small*> AND
<*estimated EPS = increase over last two months*> AND
<*earning_release_day* < *5 days*> AND
<*average-daily-volume* >= *1.5 average)*
THEN <*Short term Strong Buy*>)
(REASONS:
<*possible short squeeze*> AND
<Stock price is on uptrend> AND
<*momentum before earning release*> AND
<*expectation of good earning report*> AND
<*historical performance of hot stocks before earning*>)

(UNLESS:
<*downgrades-by-analysts > 2 in last 5 days*> OR
<*earning-warning-by-peers > 1 in last 5 days*>)
(CERTAINTY-FACTOR: *0.78*)

Trend analysis observes a security price movement, times an exit and entry point, analyzes price change directions, and jumps on a trend and rides it for the purpose of making quick profits. It tries to profitably exploit the frequent occurrence of asset price trends ("the trend is your friend").Hence, this trading technique derives buy and sell signals from the most recent price movements which indicate the continuation of a trend or its reversal.

5. Object-oriented databases

The objected-oriented database contains financial data of industries and companies, such as the company name, debt ratio, price-earning ratio, annual sales, value to book value and projected earnings(Trippi & Lee 1992). An object in the database is defined by a vector of three components: <I, P, M>. The component I is a unique ID or name for the object, which may represent an industry or a company. The component P is a set of properties belonging to an object represented as a vector. The vector characterizes an object in terms of its attributes. The component M is a set of methods implemented by member functions. In addition to direct input, these functions are the only means of accessing and changing the attributes of objects. There are two kinds of objects in our database: industry-based objects and company-based objects. The company-based objects contain company-specific data, such as P/E ratio, projected growth rate, debt ratio, and annual sales. The industry-based objects contain data and information related to a specific industry, such as tax benefits, stage of life cycle, sensitivity to interest rates, legal liability, and industry strength.
Examples of such objects are shown below:
An industry-based object:

(<ID> :- industry-name (xyz))
(<ATTIBUTES> :-
(Tax-Benefits: (direct-input))
(Stage-in-life-cycle:(direct-input))
(total-sales: (**method1**))
(daily-volumes: (**method2**))
(Sensitivity-to-interest-rate: (direct-input))
(Potential-legal-liability: (direct-input))
(industry-strength: (**method3**))
(<METHODS> :-
(method1: sum up sales from companies)
(method2: sum up from related stocks)
(method3: average up from companies)
))
A company-based object:
{(<ID> :- company-name <abc>)
(<Attributes> :-
(Sales: <database retrieval>)
(Sales-growth-rate: <database retrieval>)

(Debt-ratio: <database retrieval>)
(Tax-benefits: <inherit from industry>)
(High/low price: **method1**)
(daily volume: **method2**)
(industry-strength: <inherit from industry>)
(number-shares-outstanding: <database retrieval>)
(shares-sold-by-insiders-recently: <database retrieval>)
(relative-strength: **method3**)
(gross-margin-on-sales: <database retrieval>)
(<Methods> :-
(**method1**: update-daily-price)
(**method2**: update-daily-volume)
(**method3**: calculate-average-strength)
)}

In the object-oriented database, company objects and industry objects are organized in a hierarchy where industry objects are at higher levels and related company objects are considered subclasses. Each object represents either an industry sector or a company. Specific objects have descriptive attributes and methods that they can invoke to perform certain tasks. These attributes and methods are inherited from super classes to subclasses. Thus, the principles of inheritance, average up, and sum up will apply. For example, to obtain the total sales figure, the function Sum-up-sales-from-companies would be invoked to calculate the total sales from all companies indexed by the industry object. On the other hand, all the indexed company objects would inherit the parent object's attributes, such as industry-strength, tax-benefits, and sensitivity-to-interest-rate which are applicable to every company within the same industry sector.

6. Case base and case-based reasoning

The process of developing an effective trading system must take into consideration the current situation and past data. History often repeats itself. Similar behaviors may occur again despite not being in the same domain or industry. Lessons learned in the past can provide useful guidance in terms of a stock price changes over time. The difference between a recent business school graduate and a seasoned securities analyst is that the former has learned everything from textbooks and knows the rules of securities analysis and trading, while the latter knows all this but in addition, has experienced up markets as well down markets. Therefore, the seasoned analyst has witnessed thousands of trading episodes which supply a rich context for recognizing and analyzing new problems. TradeExpert employing case-based reasoning(CBR) provides a contrast to traditional expert systems and is analogous to comparing an experienced analyst to a new MBA. Being a cognitive model of human securities analysts, TradeExpert is capable of recalling similar cases seen in the past, retrieving and modifying the results of those cases and then deducing the reasoning behind those results(Kolodner 1983). If no solution is found, TradeExpert does not give up like a traditional expert system, instead it employs a heuristic approach in which reasoning can be guided, past experiences can be recalled, and solutions to new and similar problems can be constructed.

A case in the case base can be described as follows:

Case base {C}	$:= \{<C_1><C_2> \ldots <C_i> \ldots <C_p>\}$
Case C_i	$:= \{<A_i><R_i><P_i><J_i><M_i>\}$
Attributes A_i	$:= \{<a_{i1}><a_{i2}> \ldots <a_{ij}> \ldots <a_{im}>\}$
Recommendation Ri	:= {<strong-buy>, <buy>, <hold>, <sell>, <strong-sell>}
Performance P_i	:= {<direction> <percentage> <time-frame>}
Justification J_i	$:= \{<J_{i1}><J_{i2}> \ldots <J_{ij}> \ldots <J_{is}>\}$
Method M_i	$:= \{<m_{i1}><m_{i2}> \ldots <m_{ij}> \ldots <m_{ik}>\}$

A case C_i represented by an object consists of a set of attributes A_i, a recommendation R_i made by a security analyst, a performance figure P_i that measures the security's performance after the recommendation, and a list of methods that perform related computation. The attributes vector A_i represents financial data and characteristics of the security under consideration. The performance value P_i measures the performance of the security after recommendation in terms of the price change percentage. A methods M_i is implemented by a function that provides means to access databases or updates the data of the case. The justification J_i lists reasons and explanations on how and why the analyst arrived at the recommendation.

Analogical problem solving is one of the most complex techniques in human cognition. Yet, people have no difficulties in recalling similar episodes as new problems occur and applying them where appropriate. The design of similarity evaluation in TradeExpert is psychologically motivated and experimentally tested. The similarity evaluator, as shown in the system architecture diagram, consists of two parts: an external impact evaluator and a feature evaluator. The external impact evaluator is concerned with the impact of external forces on the performance of stocks and is not directly related to the fundamentals of companies, such as political pressures from the federal government, international events, or economical conditions. An example of the cases in the case base is presented below:

CASE 24:
(
{ATTRIBUTES:
<time-frame: 1962>
<industry-sector: steel makers>
<R/D spending: insignificant>
<price-competition: fierce>
<long-term growth rate: < 10% >
<management/worker-relation: intense>
.
.
}
{RECOMMENDATION: Sell}
{PERFORMANCE: down 50% on average in 6 months}
{JUSTIFICATIONS: Caused by JFK's policy}
{METHODS: calculating industry-related data}
)

In 1962, President John Kennedy declared war on steel companies blaming the higher labor cost and management. The sudden change of federal policy caused the steel stock prices to drop more than 50% in a very short period of time and remained low for months to come. This case remembers the consequences of an unfavorable drastic change in federal policy toward a particular industrial sector, and the dramatic price decline in the months ahead. In 1992, President Bill Clinton proposed a reform to national healthcare widely seen as criticism of pharmaceutical industry's practice and pricing. Consider the following pairs: presidents(John Kennedy, Bill Clinton) federal policies(against the steel industry, against the pharmaceutical industry), one could easily see the consequence of political pressure on the price of affected stocks. When given a drug manufacturer's stock, TradeExpert is able to draw inferences from its past experience and to make a SELL recommendation based on the historical lessons learned. The days that follow show the significant price decline of all pharmaceutical stocks in the next 12 to 18 months. Without the case-based reasoning mechanism, a decision support system would not be able to make such a predication since these two industry sectors are very different in terms of basic attributes, such as industry-sector, R/D spending, price-competition and long-term growth rate.

In addition to the external impact evaluator, TradeExpert also employs a feature matching process. The similarity score is determined by a combination of features in common and the relative importance, expressed by weights, of these features(Simpson, 1985). Formally, the feature evaluator can be described as follows.

Let N be a case with m features:

$$N = \{n_1\ n_2\ ..\ n_m\}$$

and O is an old case with k features:

$$O = \{o_1\ o_2\ ..\ o_k\}$$

CF denotes a common feature set

$$CF = \{c1\ c2\ ..\ ct\}$$

More specifically,

$$CF = \{\ c \in CF \quad \text{where}\ \ c \in N \wedge c \in O\ \}$$

Thus, a similarity score, S(N,O), of a new case N with respect to an old case O is given as:

$$S(N,O) = \frac{\left[\sum_{i=1}^{k} \lambda i \times ci\right] \times k}{m} \qquad 1 \le i \le k$$

where λ_i is a weight assigned to the i^{th} feature of a case.

With the case-based reasoning mechanism built in, TradeExpert is able to accumulate vast and specialized expertise in the domain of stock analysis and trading, and to apply it to new situations.

A case in point is the similar price movements of casino stocks in the early 90's and internet stocks from the period of 1997-2000. Both sectors have many attributes in common, such as expected high growth rates, high P/E, daily volumes far exceeding average trading volumes, a record of better-than-average earnings, and investors' favorable sentiments. By employing the feature similarity evaluator, TradeExpert is able to identify the upward price movements of internet-related stocks, while ignoring unbelievably high P/Es associated with them. As hot stocks in different periods of 90's, many stocks in these two sectors generated 3-digit returns in a matter of 12 months. Another example of analogical reasoning can be found in the banking sectors both in Great Depression of 30's and in Great Recession of 2007-2010. During these years, the stocks of all banks went down and stayed low for a long period of time. With regard to particular stocks, let us consider the examples of Google (GOOG) and Baidu (BIDU), a Chinese search engine. Having observed an impressive run by GOOG, it can be predicated with confidence that an IPO of BIDU would do very well considering the dominant market presence and the customer base. Indeed, Bidu actually went from $12(split adjusted) in 2005 to a high of $118 in 2011.

In general, given a stock, TradeExpert searches for similar cases in the case base, establishes correspondence between past experience and the stock currently under consideration, and then transforms related experience to a recommendation for the stock.

7. Fuzzy reasoning and inference

Many decision-making tasks of investors are too complex to be understood quantitatively. However, humans succeed by using knowledge that is imprecise rather than precise. Fuzzy logic refers to a logic system which represents knowledge and reasons in an imprecise or fuzzy manner for reasoning under uncertainty (Baldwin, 1981). Unlike classical logic which requires a deep understanding of a system, exact equations, and precise numeric values, fuzzy logic incorporates an *alternative way of thinking*, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience. Fuzzy systems, including fuzzy logic and fuzzy set theory, provide a rich and meaningful addition to standard logic(Zadeh,1963). The applications which may be generated from or adapted to fuzzy logic are wide-ranging, and provide the opportunity for modeling of conditions which are inherently imprecisely defined. TradeExpert with fuzzy reasoning capabilities allows expressing this knowledge through subjective concepts such as *very expensive* and a *significant below the market average* which are mapped into exact numeric ranges. Since knowledge can be expressed more naturally by using fuzzy sets, many decision making problems can be greatly simplified. *Fuzzy logic* provides an inference morphology that enables approximate human reasoning capabilities to be applied to knowledge-based systems. The theory of fuzzy logic provides mathematical strength to capture the uncertainties associated with human cognitive processes, such as thinking and reasoning. The conventional approaches to knowledge representation lack the means for representing the meaning of fuzzy concepts. As a consequence, approaches based on first order logic do not provide an appropriate conceptual framework for dealing with the representation of commonsense knowledge, since such knowledge is by its nature both lexically imprecise and non categorical. The development of fuzzy logic was motivated in large measure by the need for a conceptual framework which can address the issue of lexical imprecision. Decision support systems have been the most obvious recipients of the benefits of fuzzy logic, since their domain is often inherently fuzzy.

To summarize, in fuzzy logic:

- exact reasoning is viewed as a limiting case of approximate reasoning.
- everything is a matter of degree.
- knowledge is interpreted a collection of elastic or, equivalently, fuzzy constraint on a collection of variables.
- Inference is viewed as a process of propagation of elastic constraints.
- Any logical system can be fuzzified.

7.1 Fuzzy logic and degree of truth

English abounds with vague and imprecise concepts, such as "The p/e(ratio of price and earning per share) of this stock is low" or "The outstanding share of this company is small." Such statements are difficult to translate into more precise language without losing some of their semantic value: for example, the statement "p/e is 6.9." does not explicitly state that the stock is traded at a cheap price. It is fraught with difficulties. Let us assume the average p/e of all public traded stocks is 20. The p/e of 5 is considered low and the p/e of 40 is high. How would a stock with the p/e of 16 be ranked? What about a stock with the p/e of 25? The use of fuzzy logic allows for more gradual changes between categories and allows for a representation of certainty in the rule consequence through the ability to fire rules with varying strength dependent on the antecedents. One of the major tasks in the design of TradeExpert is to codify the investor's decision-making process. Exact reasoning strategies that make use of standard probability theory. A common approach is the certainty factor(CF) in rule-based systems. CF has a value between -1 and +1, representing 100% false and 100% true respectively. Degrees of truth are often confused with probabilities. However, they are conceptually distinct; fuzzy truth represents membership in vaguely defined sets, not the likelihood of some event or condition. Approximate reasoning is needed when the assumptions necessary to apply a probability based approach cannot be met. Fuzzy reasoning uses a collection of fuzzy membership functions and rules (instead of Boolean logic) to reason about data.

There is an important distinction between fuzzy logic and probability. Both operate over the same numeric range, and at first glance both have similar values: 0.0 representing False (or non-membership), and 1.0 representing True (or membership). However, there is a distinction to be made between the two statements: The probabilistic approach yields the natural-language statement, "There is an 80% chance that the stock looks attractive" while the fuzzy terminology corresponds to "The stock's degree of membership within the set of attractiveness is 0.80." The semantic difference is significant: the first view supposes that the stock is attractive or not; it is just that we only have an 80% chance of knowing it. By contrast, fuzzy terminology supposes that the stock is "more or less" attractive, or some other term corresponding to the value of 0.80. Further distinctions arising out of the operations will be noted below.

For independent events, the probabilistic operation for AND is multiplication, which (it can be argued) is counterintuitive for fuzzy systems. For example, let us presume that x is a company, S is the fuzzy set of high_p/e companies, and T is the fuzzy set of investor-preferred companies. Then, if $S(x) = 0.90$ and $T(x) = 0.90$, the probabilistic result would be:

$$S(x) * T(x) = 0.81$$

whereas the fuzzy result would be:

$$\text{MIN}\{S(x), T(x)\} = 0.90$$

The probabilistic calculation yields a result that is lower than either of the two initial values, which when viewed as "the chance of knowing" makes good sense.

However, in fuzzy terms the two membership functions would read something like "x is a high-growth company" and "x is an investor-preferred company." If we presume for the sake of argument that "very" is a stronger term than "fairly," and that we would correlate "fairly" with the value 0.81, then the semantic difference becomes obvious. The probabilistic calculation would yield the statement

*If x is a high-growth company and x is an investor-preferred company, then x is a **fairly** high-growth, investor-preferred company.*

The fuzzy calculation, however, would yield

*If x is a high-growth company and x is an investor-preferred company, then x is a **very** high-growth, investor-preferred company.*

Another problem arises as we incorporate more factors into our equations (such as the fuzzy set of actively-traded companies, etc.). We find that the ultimate result of a series of AND's approaches 0.0, even if all factors are initially high. Fuzzy theorists argue that this is wrong: that five factors of the value 0.90 (let us say, "very") AND'ed together, should yield a value of 0.90 (again, "very"), not 0.59 (perhaps equivalent to "somewhat").

Similarly, the probabilistic version of A OR B is (A+B - A*B), which approaches 1.0 as additional factors are considered. Fuzzy theorists argue that a sting of low membership grades should not produce a high membership grade. Instead, the limit of the resultant membership grade should be the strongest membership value in the collection.

Another important feature of fuzzy systems is the ability to define "hedges," or modifier of fuzzy values(Radecki, 1982). These operations are provided in an effort to maintain close ties to natural language, and to allow for the generation of fuzzy statements through mathematical calculations. As such, the initial definition of hedges and operations upon them will be a subjective process and may vary from one statement to another. Nonetheless, the system ultimately derived operates with the same formality as classic logic.

For example, let us assume x is a company. To transform the statement "x is an expensive company in terms of its p/e" to the statement "x is a very expensive company in terms of its p/e. The hedge "very" can be defined as follows:

"very"A(x) = A(x)^2

Thus, if Expensive(x) = 0.8, then Very_Expensive(x) = 0.64. Similarly, the word "more or less" can be defined as Sqrt(Expensive(x)). Other common hedges such as "somewhat," "rather," and "sort of," can be done in a similar way. Again, their definition is entirely subjective, but their operation is consistent: they serve to transform membership/truth values in a systematic manner according to standard mathematical functions. From the above discussion, it is clear that fuzzy logic can describe the investor's decision making process in a more natural and accurate way than the probability theory.

7.2 Fuzzy linguistic variables and membership

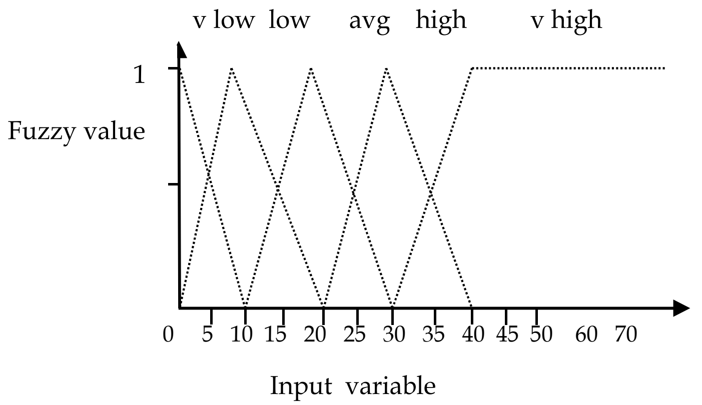
Fuzzy logic allows for set membership values to range (inclusively) between 0 and 1, and anything in between representing linguistic and imprecise terms like "slightly", "quite" and "very". Specifically, it allows partial membership in a set. It is related to fuzzy sets and possibility theory. Fuzzy logic is a form of multi-valued logic derived from

$$PE_{verylow}(x) = \begin{cases} \frac{10-x}{10} & 0 < x < 10 \\ 0 & 0 \geq 10 \end{cases} \qquad PE_{low}(x) = \begin{cases} \frac{x}{10} & 0 < x < 10 \\ \frac{20-x}{10} & 10 < x < 20 \\ 0 & x \geq 20 \end{cases}$$

$$PE_{avg}(x) = \begin{cases} 0 & x \le 10 \\ \frac{x-10}{10} & 10 < x \le 20 \\ \frac{30-x}{10} & 20 < x < 30 \\ 0 & x \ge 30 \end{cases} \qquad PE_{high}(x) = \begin{cases} 0 & x \le 20 \\ \frac{x-20}{10} & 20 < x \le 30 \\ \frac{40-x}{10} & 30 < x < 40 \\ 0 & x \ge 40 \end{cases}$$

$$PE_{veryhign}(x) = \begin{cases} 0 & x \le 30 \\ \frac{x-30}{10} & 30 < x < 40 \\ 1 & x \ge 40 \end{cases}$$

The memberships of the above formulas can be shown below:



Fuzzy logic is a form of mathematics that let computers deal with shades of gray. It handles the concept of partial truth – truth values between completely true and completely false. As an example, consider a p/e of 17, it yields the following fuzzy values:

$$PE_{low}(17) = 0.3 \quad \text{and } PE_{avg}(17) = 0.7$$

A p/e of 17 is considered 30% in the low range and 70% in the middle range. It shows a linguistic term can simultaneously belong to more than one category while exhibiting different degrees. By converting linguistic terms into numerical values, it permits TradeExpert to conduct reasoning and inference quantitatively, and to allow conflicting rules to be fired jointly.

Fuzzy set theory provides a host of attractive aggregation connectives for integrating membership values representing uncertain information. These connectives can be categorized into the following three classes *union, intersection* and *complement* connectives. Union produces a high output whenever any one of the input values representing degrees of satisfaction of different features or criteria is high. Intersection connectives produce a high output only when all of the inputs have high values. Complement connectives are defined as 1 minus the fuzzy value of its argument. More formally, these three basic fuzzy operators are defined below:

$$\textit{Not}\ F(x) = (1 - F(x))$$

$$F(x)\ \textit{And}\ F(y) = \text{minimum}(F(x), F(y))$$

$$F(x) \textit{ Or } F(y) = \text{maximum}(F(x), F(y))$$

Some of these operators provide compensation that has the property in which a higher degree of satisfaction of one criterion can compensate for a lower degree of satisfaction of another criterion to a certain extent. In that sense, union connectives provide full compensation and intersection connectives provide no compensation. In a decision process the idea of *trade-offs* corresponds to viewing the global evaluation of an action as lying between the *worst* and the *best* local ratings. This occurs in the presence of conflicting goals when compensation between the corresponding compatibilities is allowed. More operators known as *Contain*, *Empty* and *Equal* are listed below:

$F(x)$ is *Empty* if and only if for all x, $A(x) = 0.0$.

$F_a(x)$ *Equal* $F_b(x)$ if and only if for all x: $F_a(x) = F_b(x)$

$F_a(x)$ *is Contained* in $F_b(x)$ if and only if for all x: $F_a(x) <= F_b(x)$.

With these fuzzy operators, a decision support system can provide structured ways of handling uncertainties, ambiguities, and contradictions.

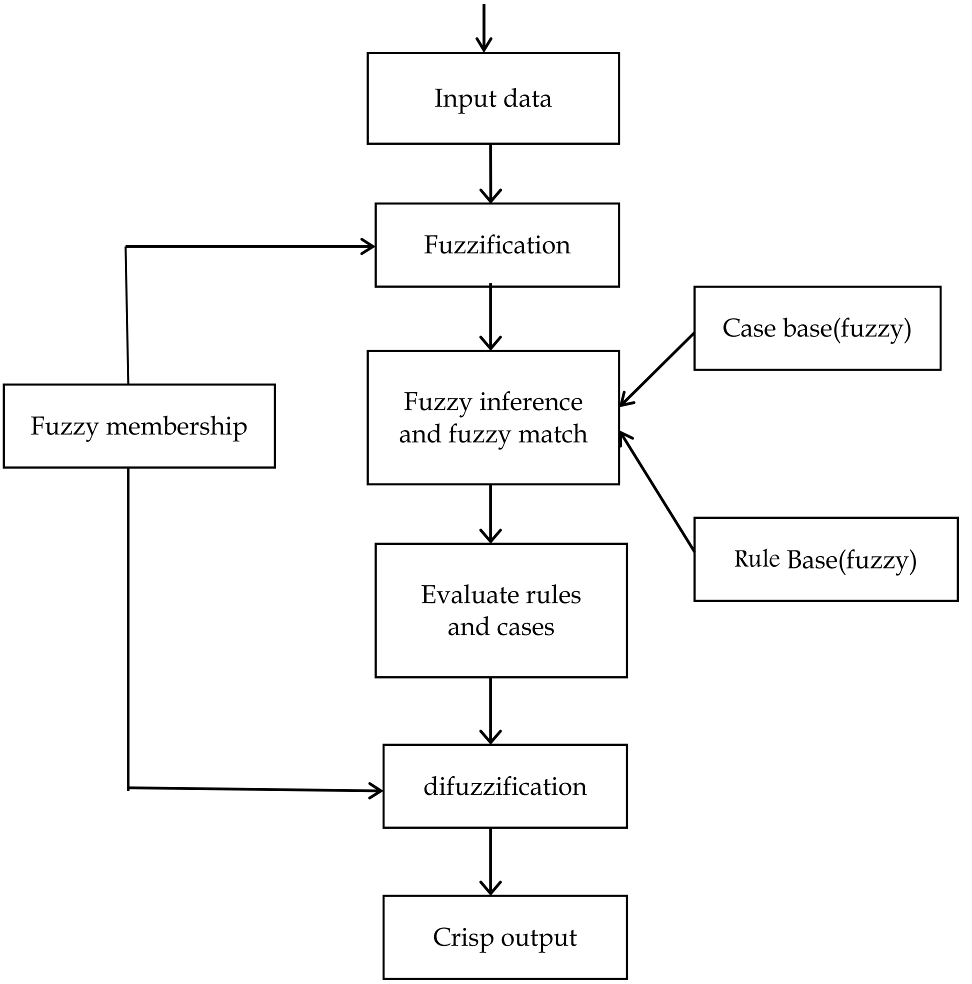
7.3 Fuzzy rule reasoning and deduction

TradeExpert is a rule-based decision support system that uses a collection of fuzzy sets and rules for the reasoning of data. Fuzzy logic in TradeExpert allows conclusion(s) to be reached from premise(s) with a gradation of truth. The rule's premises describe to what degree the rule applies while the conclusion assigns a membership function to each of one or more output variables. Compared to standard rule-bases systems, it allows multiple rules to be fired jointly as long as they exceed the predetermined threshold. When TradeExpert is used to solve real problems, the following steps are generally followed:
First, one needs to provide investment parameters, such as objectives, assumption, investment horizon and etc in a linguistic or mathematical form.

- Under FUZZIFICATION, Convert numeric data to literate words using fuzzy membership functions, and determine the degree of truth for the word. It calculates the degree to which the input data match the condition of the fuzzy rules.
- Under INFERENCE, the truth value for the condition of each rule is computed using AND, NOT or OR, and applied to the conclusion part of each rule. The result is one fuzzy subset to be assigned to the output variable for each rule. The output of each rule is scaled by the rule condition's computed degree of truth.
- Under COMPOSITION, all of the fuzzy subsets assigned to the output variable are combined together to form a single fuzzy. The operation SUM takes the point wise sum over all of the fuzzy subsets.
- DEFUZZIFICATION: convert the fuzzy output set to a numeric value. TradeExpert uses the MAXIMUM method. It selects the maximum value of the fuzzy sets as the crisp value for the output variable.

Unlike most rule-based systems, threshold values define the minimum required membership of the premises an investor would expect for that particular rule to be fired. The minimum requirements are generally defined by subjective criteria. With fuzzy

functions, it is possible that several rules may be fired concurrently with different certainty factors.
The following diagram shows how the fuzzy reasoning component works in TradeExpert:



To illustrate this process, let us consider the following simplified rules stored in the fundamental knowledge base and the fuzzy functions PE(x) as described before and Yield(x) which is defined below:

Rule 1: IF	p/e is low	AND	yield is high	THEN	strong buy
Rule 2: IF	p/e is high	AND	yield is low	THEN	strong sell
Rule 3: IF	*p/e is average*	AND	*yield is high*	THEN	*buy*
Rule 4: IF	p/e is *high*	AND	*yield is average*	THEN	*hold*

$$\text{Yield}_{\text{low}}(x)\begin{cases}\frac{1.5-x}{1.5} & 0 < x < 1.5\\ 0 & 0 \geq 1.5\end{cases}$$

$$\text{Yield}_{avg}(x) = \begin{cases} \frac{x}{1.5} & 0 < x < 1.5 \\ \frac{3-x}{1.5} & 1.5 < x < 3 \\ 0 & x \geq 3 \end{cases}$$

$$\text{Yield}_{high}(x) = \begin{cases} 0 & x \leq 1.5 \\ \frac{x-1.5}{1.5} & 1.5 < x < 3 \\ 1 & x \geq 3 \end{cases}$$

Given a stock with a p/e of 13 and dividend yield of 2.7%, the following membership functions return non-zero values in the process of fuzzification:

$$\text{Yield}_{avg}(2.7) = 0.2$$

$$\text{Yield}_{high}(2.7) = 0.8$$

$$\text{P/E}_{low}(13) = 0.7$$

$$\text{P/E}_{avg}(13) = 0.3$$

TradeExpert believes that the yield of the given stock is considered 20% in the average range and 80% in the high range compared to all publicly traded stocks. Its P/E is ranked 70% in the low range and 30% in the average range. By matching these words to the rules listed above and applying the operator AND, the non-zero truth value of each rule is listed below: Rule 1 has the truth value of 0.7 and Rule 3 has a truth value of 0.3. In other words, TradeExpert would issue a Strong Buy recommendation with a 70% certainty based on the experts' opinions and expertise stored in the fundamental knowledge base. Rule 3 was fired too but its conclusion had not been accepted due to a predetermined minimal threshold of 55%.

8. Conclusion

The development of TradeExpert demonstrates the effectiveness and value of using analogy in an intelligent decision support system, particularly in situations of imprecision, dynamics, or lack of perfectly-matched knowledge. TradeExpert shows its ability to manipulate two kinds of knowledge over time: episodic information and evolving experience. The system becomes "wiser" as more cases are added to the case base. With a research area as new as case-based reasoning in intelligent decision support systems, it often raises more questions than answers. Future research includes but is not limited to the following topics: how to dynamically adjust the weights associated with the features of cases, how to automatically index and store cases to facilitate efficient retrievals and searches, and how to modify the rules in knowledge bases with minimal intervention from human experts. In conclusion, the work reported in this paper discussed several important issues in the design of intelligent decision support systems, proposed and implemented solutions to these problems, and demonstrated the usefulness and feasibility of these solutions through the design of TradeExpert.

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4

Business Intelligence – CDMB – Implementing BI-CMDB to Lower Operation Cost Expenses and Satisfy Increasing User Expectations

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1. Introduction

Since the beginning of *Decision Support Systems* (DSS), benchmarks published by hardware and software vendors show that DSS technologies are more efficient by offering better performance for a stable cost and are aiming at lowering operations costs with resources mutualisation functionalities. Nevertheless, as a paradox, whereas data quality and company politics improves significantly, user dissatisfaction with poor performances increases constantly (Pendse, 2007).

In reality, this surprising result points the difficulties in globally defining the efficiency of a DSS. As a matter of fact, we see that whereas a "performance/cost" ratio is good for a technician, from the user perspective the "real performance/ expected performance" ratio is bad. Therefore, efficient may mean all or nothing, due to the characteristic of user perspective: a DSS may be very efficient for a developers needs, and completely inefficient for production objectives.

In order to improve the global DSS efficiency, companies can act upon (i) cost and/or (ii) expectations. They must be capable of well defining and exhaustively taking into account the costs and expectations relative to their DSS.

Concerning the first aspect of cost, the *Total Cost of Ownership* (TCO) provides a good assessment. It contains two principal aspects: hardware/software costs and cost of operations. With hardware/software, companies are limited by market offers and technological evolutions. The cost of operations, in addition to the potential gain by resource mutualisation, strongly influences the organization costs in rapport with its pertinence. Over this problematic, companies have implemented rationalization based on best practice guidelines, such as the *Information Technology Integration Library* (ITIL). Nevertheless, an internal study we have conducted at SP2 Solutions in 2007 showed that these guidelines are little or not-known to the DSS experts within or outside company IT departments. Our experience shows that this hasn't changed almost at all since then.

Relating with the second aspect, we state that user expectations cannot be ignored when evaluating the efficiency of a DSS. We estimate that the expected results must be based on the *Quality of Service* (QoS) and not on the raw technical performances. This way we define the DSS efficiency as a ratio between the DSS QoS and the DSS TCO, which is the foundation of our propositions.

Having described the context in which we position ourselves, we have developed and we offer several solutions to improve the DSS efficiency.

(1) First, we note that an improvement process cannot exist without a prior monitoring process. We propose to adapt and apply best practices, already deployed for operational systems, by implementing a system which permits the measuring of the DSS efficiency. Following ITIL guidelines, this kind of system is known as the *Configuration Management Data Base* (CMDB), and relates with ITIL specifications for: (i) service support and (ii) service offering (Dumont, 2007). The CMDB integrates all the information required to manage an information system. This information varies from incidents and known problems, configuration and change management, to management of availability, capacity, continuity and levels of service.

(2) Second, we show the necessity of taking into account DSS specifics (in contrast with operational systems), with the purpose of elaborating the right measures for the efficiency of a DSS. These measures are different from the ones used with operational systems, which focus on the problematic of real time utilization. DSS are often defined in comparison with operational information systems as the distinction between *On-Line Analytical Processing* (OLAP) and *On-Line Transaction Processing* (OLTP) shows it (Inmon, 2005), (Inmon, 2010). The two are part of fundamentally different worlds over aspects such as: the contained data (raw/aggregated), data organization (data bases/data warehouses), orientation (application/subject) or utilization (continuous/periods of utilization). DSS are classically aimed at managers and rely on analytical data, which is derived from the primitive data provided by operational systems.

Our major proposition presented here is the elaboration of the ***Business Intelligence CMDB (BI-CMDB)*** for the supervision of a DSS. It serves as a "decisional of the decisional" solution, and, to our knowledge and experience, it has never been approached so far with an integrated proposition. The BI-CMDB follows the principles of ITIL's CMDB and contains all the elements required for managing the DSS: architecture, configuration, performances, service levels, known problems, best practices etc. It integrates information both structured (e.g. configuration) and non-structured (e.g. best practices). With the help of the BI-CMDB, SLA/Os (Service Level Agreements / Objectives) are taken into account when computing performance, thus focusing on improving user satisfaction over technical performance.

Following this, a second contribution is to optimize the value offered by the CMDB. We combine BI, OLAP and semantic web technologies in order to improve DSS Management efficiency, while offering autonomic self management capabilities with references from (Nicolicin-Georgescu et al., 2009).

The chapter is organized as follows. Section 2 presents how monitoring of the DSS is done so far and what elements are followed in concordance with the ITIL guidelines. In Section 3 we focus on the description of the DSS specifics in comparison with the operational systems, and how performance measurement changes with these specifics. The subjective aspect of user perceived performance is equally discussed. Further, we present our proposition, the BI-CMDB, in Section 4. The A-CMDB and the integrated monitoring and analysis solutions for DSS management are some of the described elements. We equally note that the presented work has already been implemented and the solutions area available for use (SP2 Solutions, 2010). Section 5 consists of a series of possible shortcomings and limitations of the BI-CMDB, so we can conclude in Section 6 with an overview of the chapter and the future doors that BI-CMDB opens for DSS management.

2. Monitoring Decision Support Systems

As with any type of system, prior to any analysis and assessment, monitoring of the interesting elements is required. "You can't manage what you don't measure" is an old well known management adage, which seems to apply more than ever nowadays.

2.1 Monitoring challenges and guidelines

There are two challenges with monitoring, particularly underlined by the DSS: (i) getting some data and (ii) getting the right data.

The first aspect is obvious, and challenges here usually relate with technical barriers. For example, consider an interactive reporting application, which builds reports based on data from various data warehouses. If we are interested in the functioning of this application, we need to trace its running, usually from application and operation system logs (files, data bases etc.). The organization of these sources is usually very specific and requires specialized Extraction Transform Load (ETL) software. Therefore, the process is purely technical.

The second aspect of getting the interesting data proves to be much more subjective-oriented, as a natural question arises: Who needs this data? Continuing with our example, if the interesting party is a technician, he will most likely want to know if the available resources are enough for the application to work properly. If the interesting party is a business department responsible, he is more likely interested in knowing how often the application is used and if it offers any added value to the business process. Choosing the right data based on the specific needs is either done directly when monitoring is performed (i.e. gather only the interesting data), or is filtered afterwards from a pool of potentially interesting data.

Getting the right data to the right party is strongly related with the elaborated SLAs. In the context of information systems, an SLA is defined as a compact between a customer and a provider of an IT service that specifies the levels of availability, serviceability, performance, reporting, security or other attributes of a service, often established via negotiation from the two parts. It basically identifies the client's needs. IT organizations are measured on end-to-end business system response times, the degree of efficiency with which the system is used, and their ability to adapt to dynamic workloads (Ganek & Corbi, 2003). Breaking the SLAs may lead to financial and even legal problems, hence the need of their integration with the monitoring processes.

A very clear and detailed example of this aspect is shown by (Agrwala et al., 2006). The authors explain that Quality of Service is a particular concern for enterprise monitoring, exemplifying with an online airplane booking system. Formally, the QoS is defined as the level of current obtained data (usually performance) in rapport with what is expected. They describe QMON a QoS-capable monitoring system, which acts upon the system according to the importance of the monitored elements, importance expressed through the SLAs. The provided conclusion underlines the fact that QoS should be dynamically configurable and supported at monitoring level, allowing balance between monitoring overheads and improvement in application utility.

With DSSs, integration of SLAs and elaboration of QoS metrics is a central focus point. Unfortunately, best practices and guidelines to do so are not that elaborated as they are for operational system. One of the common mistakes done when managing a DSS is to use existing practices for operational systems and adopt them for DSSs without taking into account their particularities (Inmon, 2005). Nevertheless, ITIL provides a good foundation with the CMDB over service sustainability and offering (Dumont, 2007).

Service sustainability corresponds to the interface between the service user and the system providing the service. The CMDB integrates monitored data from: incidents, known problems and errors, configuration elements, changing and new versions. Each of the five data types corresponds to a management module (e.g. incident management, configuration management etc.). In turn, each of the management modules is retaken by the user to ensure service maintenance.

Service offering formalizes the interface between the clients and the system. This time, it refers to offering new services in rapport with the defined policies. Starting from management and infrastructure software (like the CMDB), the service levels are assessed based on SLA/Os. Elaboration of these agreements and objectives include availability management, capacity management, financial service management, service continuity, management of the levels of service and the assurance of a high QoS.

2.2 Monitoring solutions with DSS software

The described ITIL CMDB is general for an IS. As DSSs lack proper monitoring, elaborating a CMDB for a DSS is the first step towards a more efficient DSS. At this point a discussion is required over how monitoring is achieved with various DSS software solutions. The three most common ways are: (i) logging files, (ii) logging databases and (iii) console specific commands.

Logging files are the most used source of monitoring information. They contain all messages regarding the functioning of the DSS. For example, IBM's Cognos 8 Financial Performance Management (IBM, 2011) solutions offer a list of various log files and tracking levels by purpose. These include: the transfer log file for recording activity from the installation wizard with the transferred files; the startup configuration file for logging configuration choices; the run-time log for tracking all events from the server while at run time. The information from the logging files is normally semi-structured, and in order to be useful, additional parsing and analysis must be performed.

Logging databases are preferred over log files as they provide a better information structure, but are equally harder to implement. A good example of this is the audit data base (the Audit_event table) from the Business Objects Enterprise solution (Business Objects, 2008). The table contains information about run time events, such as the event id, the name of the user, the timestamp etc. Logging of these events can be activated or deactivated by the user, as it slightly affects performance. This also comes from the fact that the audit table is constructed by accessing a list of services provided by the BO server.

Console specific commands are especially used when recovering data concerning configuration parameters, which are isolated within logs, rendering them harder to identify. Sometimes, they are even impossible to recover, if the respective log that contains the last parameter modification has been archived and is no longer part of the current logs. To exemplify, the Oracle Hyperion Essbase solution employs a specific command line utility console, the "essmsh", to retrieve information such as the file sizes of the data marts or the cache memory configuration parameters (Oracle, 2010). Even if this solution is the hardest to use, from the monitoring point of view, it proves useful in situations such as above.

Either of the data sources used, the monitored data is usually raw basic data. Nevertheless, a distinction is done with this data at a first level of analysis which results in a combined monitored data. Some of the solutions, such as the BO monitoring data bases, offer a list of combined data parameters. To provide with a very simple example, consider that a data mart with two size indicators: the index file size and the size of the data file. We can obtain the two separately, but we have no indicator of the total size of the data mart. This is obtained by adding the two and 'creating' a new combined monitored indicator.

3. Intelligent performance with DSS specifics

Having the monitored data, the next natural phase is to use it in order to measure the performance levels of the DSS, consequently allowing the assessment of its efficiency. There are several particularities that render the process more delicate than for operational systems.

3.1 DSS specifics

We make a presentation of the most notable DSS particularities, as taken from (Inmon, 2005).

The data warehouse is the heart of a DSS, and represents the architecture used for storing the analytical data. The core of data warehouses is the data mart, which is a repository of data gathered with the help of ETL software from operational data and other sources, with the purpose of serving a particular community of knowledge workers (SAP, 2010). Metaphorically speaking, data marts are the bricks that are used to construct the data warehouse building. Inmon identifies four main considerations for making the separation between the analytical and operational data: (i) analysis data is physically different from operational data, (ii) the technology used for operational systems is fundamentally different from the one used with DSS, (iii) the processing characteristics for the two are different and (iv) the analytical and operational communities are two different worlds.

DSS are *subject oriented*, with the goal towards business objectives, whereas operational systems are application specific focusing on application requirements. That is why measuring the performance of a DSS is harder as it is based on user expectations.

The *resource utilization patterns* of DSS are completely different from the ones of operational systems. There is a notion of time relaxation, as data warehouses are not used constantly with the same load. There are periods of maximum load, which are also known as critical periods and periods of small load or inactivity. For example, a budget planning application will only be used the first week at the beginning of each month, thus requiring the maximum of available resources during this period only. The other three weeks, it can function with the minimum needed resources. We identify two major criteria for the distinction of the utilization patterns: (i) *the utilization periods* and (iii) *the utilization purpose*.

The utilization periods reflect the critical periods and are usually specified with the SLAs. The performance objectives per utilization period and per user type, alongside the specification of the critical functioning periods, are regular elements of the agreement documents.

The utilization purpose formalizes the two main data cycles of the data warehouse: (i) the usage of the data for the generation of reports, and, (ii) the recalculation of the data for data warehouse update. They are also known as the day (production) and the night (batch) usage. During day, users access the various data from the data warehouses in order to build analysis reports, which help them with the process of decision making. The data warehouses are exposed to intense data retrieval operations. Even if the response times are very small (e.g. 80% of OLAP queries must be under a second (Codd et al., 1993)) the user activity is very high (even thousands of users). During night, batch operations are executed to integrate the new operational data (from the day that has just passed) into the data warehouse. The executed calculation and restructuration operations are very resource and time consuming. Moreover, the new data must be integrated before the start of the next day in order for the users to have the correct reports.

One last DSS characteristic we want to discuss here is the motto of the decision expert: *"Give me what I say I want, so I can tell you what I really want"* (Inmon et al., 1999). This expresses the fact that data warehouse users access a large variety of data from the data warehouse, always being in search of explanations over the observed reports. Therefore anticipation and prediction of the requested data, data usage or system charge is very hard to implement, leading to (not necessarily a good thing) more relaxed performance requirements.

3.2 Performance

Performance measurement with DSSs brings into discussion, along the technical aspect (from operational systems), the user satisfaction aspect (form the business objective oriented point of view of analytical systems). There are two main types of performance (Agarwala et al., 2006):

Raw technical performance – related to the technical indicators for measuring system performance (such as response times for recovering data from the data warehouse, report generation, data calculation etc.)

Objective performances – relating to user expectations. These measures are based on predefined policies and rules that indicate weather or not satisfactory levels are achieved by the system (e.g. response time relative to the importance of the data warehouse or with the user activity).

Retaking the example shown by the authors of (Agarwala et al., 2006), a detailing of the QoS formula is shown below.

$$QoS = \frac{MonitoredValue}{ObjectiveValue} \tag{1}$$

and

$$QoS_{global} = \frac{\sum_{1}^{n} QoS_i * ScalingFactor_i}{\sum_{1}^{n} ScalingFactor_i} \tag{2}$$

The basic single parameter QoS is computed by the ratio between the monitored values and the specified expected values. If several parameters are responsible for a global QoS, then a scaling factor is multiplied with each individual QoS, and, in the end, an average of all the scaled QoS is computed to obtain the overall system QoS value.

The data warehouse quality model is goal oriented and roots from the goal-question-metric model. Whether metrics satisfy or not the goal determinates the quality of the data warehouse (Vassiliadis et al., 1999). Data warehouses must provide high QoS, translated into features such as coherency, accessibility and performance, by building a quality meta-model and establishing goal metrics through quality questions. The main advantage of a quality driven model is the increase in the service levels offered to the user and implicitly increase in the user satisfaction. QoS specifications are usually described by the SLAs and the SLOs.

We have seen what SLAs stand for. In a similar manner, SLOs describe service objectives, but on a more specific levels. For example, a SLA would describe that an application is critical on the first week of each month, whereas the SLO would state that during critical periods the query response time on the data marts used by the application should not be greater than 1s.

With DSSs and data warehouses, one important area where service levels are crucial is the utilization periods, in direct link with the answer to the question: *what is used, by whom and when*? Data warehouse high charge periods are specified with SLAs. When building a new DSS and putting in place the data warehouse architecture, the utilization periods are specified for the various applications. To paraphrase a study from Oracle, *the key to enterprise performance management is to identify an organization's value drivers, focus on them, and align the organization to drive results* (Oracle, 2008).

4. The BI-CMDB

In this section we present, in an exhaustively manner, our view and proposition for building a CMDB adapted to decisional systems, which we consequently call the BI-CMDB. In order to understand how this is built, we present a schema of the data flow and the organization of five modules that are part of our approach.

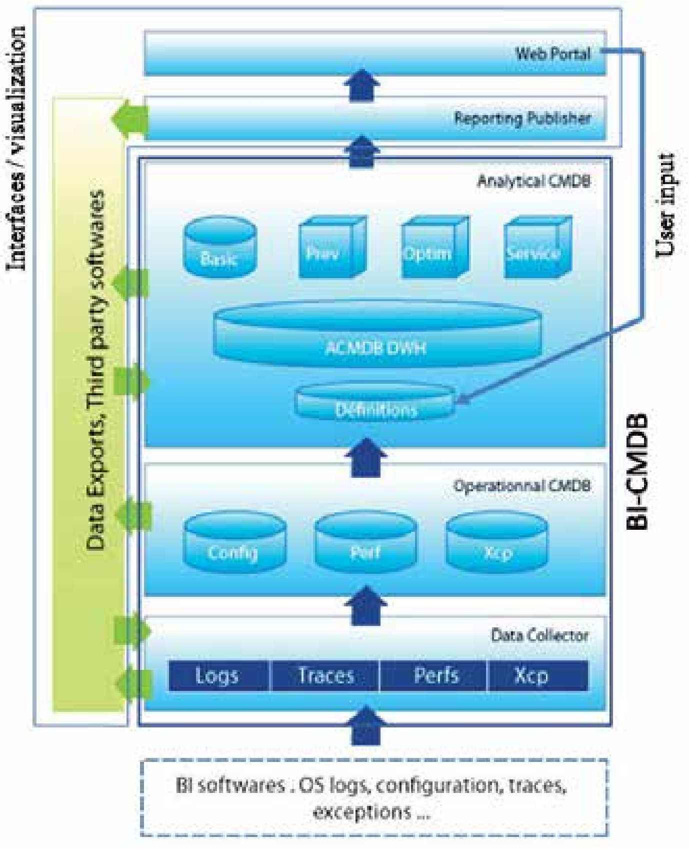

Fig. 1. The SP2 BI-CMDB simplified schema

On the bottom level we have the *data sources* that provide the monitored data. As mentioned, these are distributed, non-centralized and under different formats. Next, there is a *data collector* module, which gathers and archives the data sources. This is the first level of centralization while greatly reducing the size of this data by archiving. Following, an *Operational CMDB* is build with the data collector centralized information. It is the first level of filtering (parsing and interpretation) of the monitored data, which allows to keep only the interesting data for further analysis.

Analysis of the O-CMDB is brought climbing up to the *Analytical CMDB*, which builds a data warehouse architecture, by specific objective data marts, with the data from the O-CMDB. We note that the elements of the O-CMDB and of the A-CMDB correspond to ITIL's guidelines, with the addition of elements that correspond to the specifics of DSS. Once the A-CMDB has been constructed, two more levels of information access (by user) are added, with a module for *publishing the reports* built on the A-CMDB data warehouse and a *Web Portal* for consulting these reports and for dynamically exploring the data from the CMDBs. These last two are not of interest for this chapter, but equally make a challenge, from the study of computer-human interaction and GUI design.

A detailed description of the first three modules that are interesting to the BI-CMDB is done in the following. Examples for each of them are provided, in the light of the differences with the traditional CMDB and on the characteristics of DSS.

4.1 The data collector

The data collector is the first module in the data flow towards the construction of the BI CMDB. Its main objective is to gather and archive the various interesting monitoring information.

The core of the data collector architecture is the *connector*. A connector represents a generic interface for defining the elements that allow the gathering of information from a data source and the methods used for this process. The parameters of a connector allow him to connect to a target machine (i.e. name of the machine, connection port, data source location and type etc.), recover and archive the data from the sources and send these archives via ftp connections to the machine which is in charge of archive analysis and construction of the O-CMDB. Depending of the target machine installed BI software solution, various implementations of the generic connector are required (e.g. an Oracle Hyperion Essabse connector or a BO connector).

As we have seen previously in the monitoring section, there are three types of data sources: logging files, logging databases and specific console commands. A connector can specify any (or all) of these types.

Following the ITIL guidelines, a separation of the *data fluxes* is done for each connector (where possible). There are five types of data fluxes: (i) logging (*log*), (ii) exception (*xcp*), (iii) parameters (*param*), (iv) performance (*perf*) and (v) errors (*err*). This separation persists further on with the construction of both the O-CDMB and the A-CMDB. Another argument for this split is the fact that some solutions use different data sources for different fluxes. For instance, with Essbase, the monitored information is usually stored in plain text files (.log and .xcp). These files allow the identification of all the required data with the exception of the configuration parameters. Due to the fact that they change rarely, their identification through log files is very difficult or even impossible. This is why for this task, specific console commands are used for the *param* flux.

Example. We show below an example of data collection for a connector implementation for the Oracle Hyperion Essbase server, with the various connector data fluxes.
The Essbase server log files are under the */log* repository of the Essbase installation. The connector will specify the machine and port (for connection to the Essbase server) and the place of the Essbase installation (e.g. *C:/Hyperion/logs/essbase*). This repository contains a suite of *.log* and *.xcp* files, that are organized by application (here the term application indicates the regrouping several data marts which suit the same business objective)
The *.log* file contains various information about the application and its data marts, which is interesting for the *log*, *perf* and *err* data fluxes. An extract of the file is shown below for a data retrieval operation on a data mart from the application:
[Mon Jan 31 17:57:51 2011]Local/budgetApplication///Info(1013210)
User [admin] set active on database [budDM]
[Mon Jan 31 17:57:51 2011]Local/budgetApplication/budDM/admin/Info(1013164)
Received Command [Report] from user [admin]
[Mon Jan 31 17:58:21 2011]Local/budgetApplication/budDM/admin/Info(1001065)
Regular Extractor Elapsed Time : [29.64] seconds
These lines permit to identify that there was an Essbase report request (data retrieval) on the budDM data mart, part of the budget application on the on 31st of January at 17:57:51 from the admin user, which lasted 29.64 seconds. These elements represent the interesting monitored information, and are recovered from the last four lines. The first two lines are useless. This filtering process is done at the construction of the O-CMDB.
The *.xcp* file contains the information needed for the *xcp* data flux, logging the fatal crashes of the Essbase server. An extract of this file could be:
Current Date & Time: Fri Sep 19 11:29:01 2008
Application Name: budgetApplication
Exception Log File: /app/hyp/Hyperion/AnalyticServices/app/budgetApplication/log00001.xcp
Current Thread Id: 2
Signal Number: 0x15=Termination By Kill
Last, in order to get the configuration parameters of the application data marts, the esscmd command line console is used (i.e. GETDBINFO, GETAPPINFO etc.). The results of these commands are written into customized text files, which assure the *perf* data flux.
The role of the example was to show that the monitored information is very different, and data sources and formats vary even within the same implementation. The data collector has the role of assuring a first centralized level of information, with no data analysis intelligence. The only intelligence in the module allows an incremental data collection, such that data is not redundant (e.g. if data is monitored once each day, each collection takes only the information from the logs corresponding to the last past day). The following levels of information centralization are shown next with the construction of the O-CMDB and the A-CMDB.

4.2 The O-CMDB

The Operational CMDB is the first intelligent unification of the DSS information. It suits the role of an Operational Data Store (ODS), and it is build from the data collected by the data collector, by a series of filtering and analysis operations. The O-CMDB contains only the interesting information, rejecting any other unrequited data from the collector archives (as exemplified earlier with the Essbase report generation).
At first glance, the O-CMDB may seem as a simple log analyzer. This cannot be further from the truth. In reality, the process of building the O-CMDB makes a sweep of the information

available, holding only the useful one (through interpretation of the log data), and constructing a series of purpose objective data stores with this filtered data. The organization of the data stores retakes the main ITIL groups for the CMDB and continues in the line of the data collector connector data fluxes. Technically, our implementation of these data stores is via relational databases, for both the O and the A CMDB, term which we will further use for a better understanding.

The following O-CMDB databases are constructed.

The *CI (Configuration Items)* tables, holding information about the architectural organization of the target decision system. These tables are different by construction, as they are not built with the data recovered from the data collector, but they have as source specific defined files or databases which we use with our system to let the user 'complete' his DSS architecture. In specific cases some of the CIs can be automatically built from the data from the logs. This operation of DSS entity specification must be performed before the construction of the O-CMDB and is compulsory, as the rest of the tables are based on the DSS entities.

In our conception, we identify six levels of vertical hierarchy: (i) the entire DSS, (ii) the physical servers, (iii) the logical servers, (iv) the applications, (v) the bases and (vi) the programs. In order to keep this as generic as possible we note that depending on the specific BI software implementation, some of these levels disappear or are remapped (e.g. an application for Essbase is well defined with its own parameters while for a BO solution it becomes a report folder as a logical organization of BO reports).

The *PARAM* tables contain information about the configuration indicators. This is raw data, organized by indicator type and by CI type. A reference measure table (configuration and performance), lists the interesting monitored indicators. The data collector archives are analyzed for patterns that allow the identification of these indicators, and then extracted and written in the O-CMDB *PARAM* table. An example is shown in Table 1. We have mentioned that the data contained here is raw data, meaning that there is no treatment done on it. This is what we have earlier seen as basic monitored structured information. However an exception from this rule is done with combined monitored configuration indicators (i.e. deduced from existing indicators). The given example was on the size of an Essbase data mart. There are two basic configuration indicators (data file size and index size) which are extracted directly from the data collector archives and stored in the O-CMDB. Yet, an interesting measure is the total size of the data mart, which expresses as the sum of the two indicators. In this case, when constructing the O-CMDB a second passage is made to compute these combined indicators.

Data collector archive	***O-CMDB CONFIG table extract***		
	Field name	***Field Type***	***Data value***
[Tue May 11 17:57:51 2010] Local/budgetApplication/budDM Index Cache Size : [100] Mo	***CI_CODE***	INT	2
	MEASURE_CODE	INT	10
	MEASURE_VALUE	VARCHAR	100
	MEASURE_TYPE	VARCHAR	Mo
	DATE_CHANGE	DATE	11/05/2010

Table 1. O-CMDG PARAM table extract

The *PERF* tables are similar to the *PARAM* tables with the difference that the contained indicators express performance measures. The distinction between the two is made for the further analytical purposes, and in concordance with ITIL guidelines. Still, a series of conceptual differences are identified, mainly related to the timeline intervals. Configuration indicators are recorded in relation with the date at which they last change, operations that are rare. On the other hand, performance indicators have a high apparition frequency, and depend on several factors (from the network lag to the machine processor charge). On busy periods, we have met up to several of tens of thousands performance entries in the log files, which is a totally different scale from the configuration case.

In addition to these three 'main' tables, a series of additional tables are build, such as the *XCP* tables with data concerning fatal crashes, the *ERR* tables with data from (non-lethal) warnings and errors or the *MSG* tables with the various functioning messages.

One of the biggest benefits of constructing the O-CMDB is the reduction of the size of the monitored information. By comparing the size of the initial raw monitored data sources with the size of the O-CMDB database after integration of the data from those sources, we have obtained a gain of 1 to 99 (i.e. for each 99Mb of raw data we have an equivalent of 1Mb of integrated interesting data). In addition, this reduction allows keeping track of the data for both short and medium time periods (even long in some cases), which permits further prediction and tendency assessment.

4.3 The A-CDMB

The Analytical CMDB is the third and most advanced level of data integration. Unlike the O-CMDB which contained only raw data, the information in the A-CMDB is derived from this data. It represents the data warehouse of the O-CMDB, with analytical data suitable to business objectives. Considering the fact that the data from the O-CMDB regards a DSS implementation, we call the A-CMDB as the data warehouse of the DSS, or the support for 'the decisional of the decisional'.

The A-CMDB consists of tables (i.e. *AGG_PERF, AGG_PARAM*) which aggregate the O-CMDB tables on several axes of analysis. These axes are the fundamental characteristic of the A-CMDB, and reflect the characteristics of a DSS while suiting the DSS user needs. The main analysis axes are: (i) temporal intervals, (ii) utilization periods, (iii) utilization purpose, (iv) user type, (v) SLA/SLO and, obviously, (vi) the CIs. Data is aggregated on each of these axes, and their intersection provides the DSS user with any valuable information that he requires. We detail each of these axes, as they represent key points of our proposition.

The *CIs* represent the first implicit analysis axis, as it provides the vertical aggregation on the DSS hierarchy. Aggregation operations can either be averages, sums, standard deviations or min/max (e.g. the total size occupied by the entire DSS, the sum of all sizes of its data warehouses and the correspondent data marts, the maximum response time etc.).

Temporal intervals are the correspondent to the fundamental characteristic of the data warehouse, the time aggregation of the operational data. In the same manner, when building the O-CMDB we make a separation of six time intervals: year, month, weak, day, hour, min:sec. Buy using these six pivots, the A-CMDB aggregates the averages over each of them (e.g. the average response time for each week for a specific CI). The CI axis is the base axis which is always found in the aggregation for any of the rest of the axes.

Utilization periods are integrated in the A-CMDB in concordance with the specified data warehouse functioning patterns. By using the temporal intervals we are able to deduce if a specific CI is in its utilization period. The integration of the utilization periods in the *AGG_* tables will further be used for the assessment of the level of user satisfaction and the computation of the Quality of Service, in rapport with the given performance objectives.

Usage purposes are similar to the utilization periods, and are formalized under the same form. By using the hour time axis, the day and night intervals are defined (i.e. from 6:00 to 22:00 there is day, from 22:01 to 05:59 is night). Integrating this axis allows the user to identify or not whether a certain performance analysis is pertinent (i.e. following the restitution times during night periods makes little sense).

The *user type* axis represents the main focus axis when assessing user satisfaction. A response time that is acceptable for the developer who is testing the data warehouse can be completely unacceptable for a DSS user who wants his rapport as soon as possible. In the O-CDMB, the tables have columns which specify the user who triggered the actions (e.g. the user who asked for a report, the user that modified the configuration parameters etc.). When integrated in the A-CMDB, users are organized logically by areas of interest, such as: (i) data warehouse administrator, developer or user; (ii) area of responsibility (entire system, department, application); (iii) type of responsibility (technical, business objective). By intersecting these axes, the A-CMDB can rapidly respond at any questions concerning the user activity, thus covering a total 'surveillance' of *who is using what and when*.

Lastly, the *SLA/SLO* axis integrates all the elements related to business / technical objectives. For instance, defining the time intervals for the utilization and usage periods as business objectives and specifying the performance thresholds for each of these periods as technical objectives. By having these values we can afterwards compute the QoS indicators, with regards to any intersection of the analysis axes, as the A-CMDB offers all the data required to do so. The SLA and SLO data are not obtained from the O-CMDB and are not part of the data recovered by the data collector. They are usually integrated when building the A-CMDB, either by being manually specified or by using ETLs to load them from the source where they are specified. Even it may seem a paradox, in many enterprises today SLAs and SLOs are specified in semi-formatted documents (e.g. word documents) and their integration is only possible manually. This represents a big drawback for automatic integration, and by respecting the A-CMDB specifications, enterprises are 'forced' to render these elements into formats that allow automatic manipulation (such as spreadsheets, .xml or even data bases). Even if this alignment operation poses an effort in start, the return over investment makes its implementation worth.

We provide an example with an extract of some of the columns from the AGG_PERF table, which aggregates the O-CMDB performance tables.

Field name (Field type)	*CI_CODE (INT)*	*YEAR (INT)*	*WEEK (INT)*	*MEAS_CODE (INT)*
Data value	5	2010	23	15
Field name (Field type)	*USER (VARCHAR)*	*USAGE (VARCHAR)*	*SLO_OBJECTIVE (FLOAT) (user specified)*	*QOS (FLOAT)*
Data value	admin	Day	3	0.56
Field name (Field type)	*AGG_VALUE (FLOAT)*	*AGG_TYPE (VARCHAR)*	*UTILIZATION (VARCHAR)*	
Data value	5.3	avg	high	

Table 2. AGG_PERF tables extract

The table shows the fact that for the CI with code 5 (e.g. is an Essbase logical server), during the 23rd week of 2010, the measure response time (code = 15), has an average of 5.3 seconds.

Moreover, this average is computed for the admin user, during a high utilization periods and during day usage. Finally, there is an SLO objective of 3 seconds for the admin user under the same conditions, which leads to a quality of service of 0.56 (=3 / 5.3), meaning that the admin user is only 56% satisfied with the logical server response times. If we consider that under a level of satisfaction of 80%, more details are required, automatically we have the need to drill into the data in order to know exactly what are the applications and further the bases and the programs that generate this dissatisfaction. This functioning is characteristic for any data warehouse (from the DSS user motto).

Therefore, the A-CMDB contains all the information needed for the analysis of the functioning of the DSS. It is a question of vision and development of the ITIL's CMDB as a decisional component. Moreover, it is about applying the specific DSS characteristics for its construction, such that the relevant measures and indicators are well defined and that DSS supervisors have a very clear view over the performance of their system from the perspective of user and their satisfaction levels when using the DSS.

4.4 Advanced practices for the evolution of the BI-CMDB

Having seen how the BI-CMDB is built by processes from data collection, to construction of the operational CMDB and finally of the analytical CMDB, a series of advanced practices and topics are presented next, most of which open doors to future evolution of the model.

The benefice of the BI-CMDB is that it allows a complete (on every level) view of the functioning of an enterprise DSS.

One first very good application of this view is prediction and prevention. Using prediction algorithms and analyzing the data from the A-CMDB, we can see the potential bad tendencies of a DSS. For instance a slow but constant higher memory usage can lead to a system crash when the RAM memory is no longer sufficient. Moreover, by looking at past evolutions, prevention can be enabled by avoiding the previously done 'mistakes'. For example, modifying the available cache values of a data mart which leads to disastrous results can be avoided from repeating itself.

The aspects of prediction and prevention lead to a second application case, which is *change impact analysis*. What happens to my DSS if I change this or that parameter, if I buy additional resources, if I change the version of my BI software solution etc.? are commonly asked questions. So far, answers to these questions were practically impossible to provide specifically. With the help of the BI-CMDB detail levels, impact analysis can be rapidly performed by comparing the various situations and intersecting the analysis axes (e.g. the average response times per logical servers with different data mart cache values and different RAM memory available on the server). By intersecting the various configuration axes of the A-CMDB with the performance axis, one can isolate and explain performance variations. Moreover, by building a knowledge base around the BI-CMDB, the question of change management and migration can be responded with the integration of all the external 'meta' knowledge regarding the DSS management.

This is where the third advanced topic is discussed: providing meta-data and semantics with the BI-CMDB. For example, integrating all the information from the release Readme documents of the software, in order to identify the editor specified known and solved bugs or software compatibilities. When performing a migration such information is vital, and having it integrated with the BI-CMDB under a unified machine understandable form would simplify a lot the processes. In order to achieve this, solutions that imply the usage of web semantic technologies, specifically ontologies (Gruber, 1992), have been recently proposed for exploration (Nicolicin-Georgescu et al., 2010), and have been the result of our work over the last years. Using ontologies to formalize the DSS management aspects (such as best practices, subjective quality measurement, business rules etc.) go hand in hand with the BI-CMDB elaboration. Moreover, by using ontologies, it is possible to specify horizontal relations between the CI, as an addition to the hierarchical vertical relations of the DSS architecture, thus allowing a full description of the elements and their connections.

Last, but not least, having a complete integrated view of the data and information describing the DSS, automatic behaviors can be adopted, such that the DSS human expert is helped with managing his system. To this end, solutions as the Autonomic Computing (IBM, 2006) have been developed, with the declared purpose of helping IT professionals with low level, repetitive tasks, so they can focus on high level, business objectives. Inspired by the functioning of the human body, this autonomy model proposes four principles to assure that a system can function by 'itself', self: configuration, healing, optimization and protection. An intelligent control loop implemented by several Autonomic Computing Managers, assure these functions. It has four phases, which correspond to a self sufficient process: monitor, analyze, plan and execute, all around a central knowledge base.

The problem with autonomic computing is that it has been elaborated with the real time operational systems as targets. In order to apply the autonomic model for DSS, similar to the passage from the CMDB to the BI-CMDB, the characteristics of DSS must be taken into consideration. The works of (Nicolicin-Georgescu et al., 2009) have shown an example of optimizing shared resources allocations with data warehouses, by focusing on the data warehouse importance and priority to the user rather then on raw technical indicators. Moreover, to comply with the DSS functioning, changes in the traditional loop functioning were proposed, via the description of heuristics targeted at the SLAs and the improvement of the QoS.

5. Possible limitations and shortcomings

Before concluding this chapter, an overview of the limitations and shortcomings of the BI-CMDB is done. We note that with some of them we have already been confronted, whereas others are presented only as possible to arrive.

The first limitation when building the BI-CMDB is *generics*, specifically the difference between CI modeling of the different BI software solutions. As presented, the CI tables in the O-CMDB consist of six hierarchy levels, which were thought to fit a maximum number of software implementations. Yet, with every one of them, the connotations of a specific CI table change (e.g. a base table in the case of OLAP software becomes a report table in the case of reporting software). Moreover, the elements composing the DSS are not always logically organized hierarchically (not on all levels). For instance the reports and data fluxes with BO, are related through horizontal links. So vertically aggregating on the CI hierarchic sometimes doesn't make sense. Nevertheless, what is important is that the model offers the specification capacity, thus finally generics is assured through small (of semantic nature) changes.

Another limitation of the solution is related to the construction process time of the O and A CMDBs. One may object the fact that due to the times needed to build these databases, real time analysis cannot be achieved. Yet, is there a real need for real time? The answer may be yes in the case of technical alerts (which simplifies a lot the processes), but no in the case of DSS analysis. In this case, the 'standard' time interval is an operational day, following the DSS usage purpose characteristic (i.e. the day/night usage cycles). At the end of each operational day, the data collector recovers the new information via the configured connectors, archives it and passes it for integration into the O-CMDB. This interval evidently is configurable, based on the specific needs (e.g. once each week, once each 3 days etc.), and user needs for this interval are mostly higher than the time needed to integrate the data into the BI-CMDB.

Following, one shortcoming may be the unpredictability of usage of the system, which makes scaling effects harder to measure. We have here a decisional of the decisional solution, which metaphorically is like doubling the DSS expert motto. A user of the BI-CMDB will constantly require new rapports and find new analysis axes to intersect. This means, that alongside the list of the main analysis axis that are implemented, depending on the users needs and objectives a series of new analysis pivots are described. As these needs vary from case to case, it is hard to asses the usage process of the BI-CMDB. Its performances depend strongly on the chosen client implementation. Moreover, through the web portal interface the user has the liberty to define his custom queries towards the BI-CMDB, a liberty which can make the system overcharge (similar to the data warehouse user freedom problematic).

Also, as we have spoken of the combination of the BI-CMDB with ontologies, this is regarded as a future evolution. For now, assuring model consistency and completeness (from the contained data point of view) is done 'semi-manually', after the report generation (therefore at the final stage). We try to move this verification at database construction level, as to avoid any unnecessary report generation (or worst give the bad report to the bad receiver). Implementing an ontology model and by benefitting from the inference engines capacities, such verifications can be done at the construction stage, before any utilization of the BI-CMDB data. A classic example is the mixing of the CIs from the hierarchy. The CI specification is build from the manual user specification of his system, thus is prone to human error. A physical server which becomes an application by accident would lead to completely incorrect rapports (from what the user was expecting).

Finally, we note that semantic and autonomic evolutions of the BI-CMDB arise a series of questions, from knowledge integration to supervision of autonomic behaviors and rule consistency.

6. Conclusion

We have detailed in this chapter an implementation of the Business Intelligence – CMDB, with the purpose of improving the efficiency of a DSS. Based on the fact that despite the technological advancements, user satisfaction with DSS performance keeps decreasing, we have isolated some of the elements that are responsible for this paradox, among which the Quality of Service, the Total Cost of Ownership and the integration of Service Level Agreements policies when computing DSS performance. We state that user perception is a vital factor that cannot be ignored in the detriment of the raw technical performance indicators.

In conclusion, implementing the BI-CMDB for DSS offers a series of elements we consider compulsory to an efficient DSSs: a CMDB for DSS, a complete TCO, an integration of the SLA/Os, an adoption of ITIL guidelines and best practices, all these with lower costs and the improvement of the user's satisfaction levels. The BI-CMDB proposition for the 'decisional of the decisional', integrated with cutting edge semantic and autonomic technologies opens the doors to a whole new area of research towards the future of efficient DSS.

Nevertheless, developing the BI-CMDB is a first successful step towards the future of DSS. With the development of semantics and autonomic technologies, we strongly believe that future steps include these aspects, towards the development of a complete BI-CMDB, integrated with all pieces of knowledge required for managing a DSS. The ultimate *autonomic semantic based BI-CMDB* for DSS is a planet which seems “light years” away, but currently technology evolution speeds rapidly approach it.

7. Acknowledgment

We would like to thank Mr. Eng. Adrien Letournel and Mr. Eng. Guillaume St-Criq, both employees of SP2 Solutions, for their support with providing the data and the elements for the examples and for their feedback and support with this chapter.

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5

Decision Support Systems Application to Business Processes at Enterprises in Russia

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1. Introduction

The chapter focuses on one of possible approaches to decision support problem, which is based on multi-agent simulation modelling. Most decision support cases generally consist of a set of available alternatives definition, estimation and selection of the best one. When choosing a solution one needs to consider a large number of conflicting objectives and, thus, to estimate possible solutions on multiple criteria.

System analysis and synthesis constitute a management aid, targeting more effective system organization considering its limitations and objectives. In the limits of decision support process, analysis and synthesis methods are used for forecast and estimation of the consequences of taken decision. In such case available situation development scenarios are designed and analysed, scenario synthesis is performed, results are being evaluated in order to develop the policy for the most desired results. Computer aid for analysis and synthesis problems provides the most perspective and rational system development strategy making.

Formalized analysis and synthesis problems solving might be interesting from the point of view of workflow automation for analysts and decision making people.

The following analysis and synthesis problems of business systems are discussed further: virtual enterprise establishment; business process re-engineering; business process benchmarking (improvement and enhancement). In Russia major research relates to business systems analysis. This concept includes business processes, management, production and manufacture, logistics, technological processes and decision making. The task of virtual enterprise establishment (Andreichikov & Andreichikova, 2004) relates to a class of complex systems structural synthesis tasks. The main objective of virtual enterprise establishment is cooperation of legally independent companies and individuals, manufacturing certain product or providing services in common business process. Main goal of business processes re-engineering is reorganization of material, financial and informational flows, targeting organizational structure simplification; resource use redistribution and minimization; client needs satisfaction time decrease; quality of client service improvement.

Business process re-engineering offers solution for the following tasks: existing business process and enterprise activity analysis, decomposition to sub-processes; analysis of bottlenecks in business processes structure, e.g. related to resources underload or overload, queuing; business process re-organization (synthesis) for elimination of problems and reach of set effectiveness criteria; design and development of information system for business process support. Problem of business process structure bottlenecks analysis can be solved with aid of static or dynamic modeling methods. Static modeling implies definition and analysis of business process structure, as well as cost analysis of process functions, identification of the most demanding and unprofitable functions, or those ones with low coefficient of resource use. Dynamic simulation modeling allows implementation of multiple business process operations in continuous period of time, offering statistics gathering of process operation and identification of bottlenecks in their structure. Business process re-organization relying on static modeling is based on heuristic approach and demands high qualification and experience from analyst. Simulation modeling in business processes re-engineering allows automation of re-engineering rules and their application.

Business process benchmarking closely relates to re-engineering. Main goal of benchmarking is business process re-organization in accordance with master model. Master model is based on a combination of best business processes of various enterprises, identified with comparative analysis.

The main idea of the chapter is situational, multi-agent, simulation and expert modeling methods and tools integration in order to increase the decision support effectiveness in situational control of resource conversion.

Practical application of business process re-engineering approaches as management tools has its limitations: need for a highly qualified analyst, his deep understanding of problem domain; unavailability of synthesis of business process re-engineering decisions and check of computed solutions on real management object. Simulation and AI methods applied to automation of business process re-engineering allow to: 1. Reduce demand for analyst experience in system analysis and synthesis by using formalized expert knowledge and applying mathematical modelling methods; 2. Estimate computed re-engineering solutions and select the most effective solution on management object model.

Use of multi-agent approach on stage of business process model formalization is caused by the presence of decision making people in the system; their behaviour is motivated, they cooperate with each other, accumulate knowledge of problem domain and management tasks solution scenarios. Intelligent agent model provides design of decision making person model, which is the basis of information technology implementation for model analysis and decision making.

2. Analysis of business processes multi-agent dynamic models

Consider the problem of business process formalization model selection. The following models support agent representation of business processes: Gaia model, Bugaichenko's model, Masloboev's model, simulation model of intelligent agents interaction (SMIAI), Resource-Activity-Operation model (RAO), multi-agent resource conversion processes model (MRCP).

Gaia model of multi-agent system was offered by Michael Wooldridge and Nicholas Jennings (Wooldridge et al., 2000). It defines a system as an artificial structure that consists of heterogeneous agents, interacting with each other in order to achieve common goal that in turn consists of agents' sub-goals. Note that authors do not consider agents behaviour in situations with competitive goals.

The most abstract entity in concepts hierarchy of Gaia model is a system. Next hierarchy level contains roles (Fig. 1). Model design begins with analysis stage.

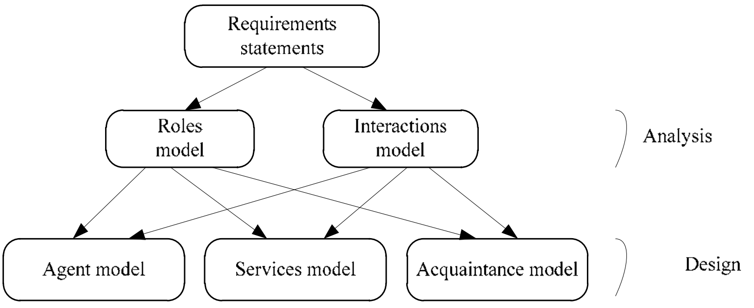

Fig. 1. Gaia methodology base concepts

A role has 4 attributes (Fig. 2) (Wooldridge et. Al, 2000): *Responsibility* determines functionality of role and can be divided into 2 kinds – *Liveliness properties* contain system reaction to external exposure (reactive component) and can be defined with temporal logic that has activity and role protocols as arguments; *Safety properties* define a set of activities that should not occur during role functioning. *Permissions* include rights associated with a role, for resources that are available. Resources in Gaia model may include information objects that may be used in ways of generation, reading and modification. *Activities* are computations to be carried out by the agents. These computations are carried out without interactions with other roles. Ways of interaction with other roes are defined by *Protocols*.

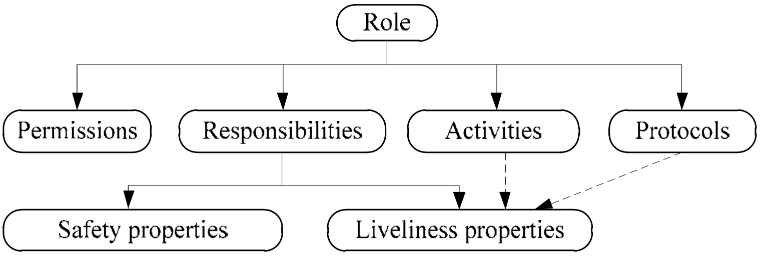

Fig. 2. Role attributes in Gaia model

Interactions model includes definition of the attributes of interaction protocols: interaction goal, interaction initiator role, interaction respondent role, interaction input and output resources and text definition of interaction process. Authors imply limitation of system structure being static in frames of roles interaction model definition.

Design phase starts with *agent model* definition. This incudes system agents types definition and agent types correlation with defined roles. During simulation a defined number of agent instances, in accordance with instance generation rules, are dynamically created for each type.

Services model is provided for agent fuctionality definition, when each agent service is mapped to a role defined on role activity analysis phase. Service has information inputs and outputs (corresponding to attributes of roles interaction protocol), as well as start and finish conditions in form of role safety properties. Here service represents a resource convertor, active when input resources are present and start condition is fulfilled; it generates output resources when finish condition is fulfilled.

Acquaintance model represents a directed graph with agent types as graph nodes and communications between agent types as arcs.

Bugaichenko's model (Bugaichenko, 2007) defines intelligent agents with mental (Belief-Desire-Intention, BDI) architecture. Multi-agent system properties are defined with aid of developed formal logic – MASL – multi-agent systems logical specification method with time limitations; these systems are considered to be capable of experience accumulation and analysis.
Multi-agent system model is represented with a triplet:

$$MAS=(S, AG, env)\text{, where}$$

S – finite collection of external environment states;
$AG=\{ag_1,\ldots,ag_n\}$ – finite collection of agents;
env – function, defining a possible reaction of external environment to activity of all system agents.
Each agent is represented with a collection:

$$ag=(S, A, env, see, Ib, bel, brf, ID, des, drf, filter, plan, prf)\text{, where}$$

A – nonempty finite collection of agent activities;
env – external environment behavior function, correlating a collection of next possible states of external environment to the current state of external environment and selected action of an agent;
see – correct perception of external environment states by an agent, setting collection *P* of equivalence classes on *S*;
Ib – collection of agent beliefs, dependent on agent perception of external environment and his own activity;
bel – collection of current agent beliefs;
brf – beliefs update function;
ID – collection of agent desires; depends on goals (criteria functions);
des – collection of current agent desires;
drf – agent desires update function;
filter – agent desires filtration function;
plan – current agent plan, represented by finite state machine with input alphabet P, output alphabet A, states set Ipln, transition relation σpln and initial state of ipln,0;
prf – plan update function.
Bugaichenko's agent has mental (BDI) architecture, featuring three components: beliefs, desires and intentions (Bugaichenko, 2005).
Beliefs contain information about regularities and current state of external environment of an agent. This information may be erroneous or incomplete, thus it may be considered as belief, not as reliable knowledge. Note that prognosis function is also considered an agent belief.
Agent desires make up a collection of all agent goals. It is unlikely that an agent, limited with resources, will be able to achieve all his goals.
Intentions make up a collection of goals that an agent decided to achieve. Satisfiability of intentions (in case of planning agent) may be defined as possession of a plan, leading to goal achievement.
One of the most complex stages of decision support process is selection (planning) of activities for goals achievement. Bugaichenko offers agent plans representation in form of a network of interacting finite state machines (Bugaichenko, 2007).
Problems of accumulating experience by the system and agent self-prognosis of own activity within Bugaichenko model are also solved with use of symbolic data representation in form of resolving diagrams.

Multi-agent system properties are described with aid of developed formal logic MASL – method for logical specification of multi-agent systems with time limitations; these systems are considered to be capable of experience accumulation and analysis. MASL logic is the interconnection of capabilities of the following temporal logics: Propositional Dynamic Logic PDL, Real-Time Computation Tree Logic RTCTL and Alternating-Time Temporal Logic ATL (Bugaichenko, 2006). Adaptation of these logics for specification of properties of multi-agent system mathematical model allowed Bugaichenko formalize definition of cooperation and agent competitiveness, define nondeterministic behaviour of external environment, extend expressive power of specification language.

Key concept of agent interaction modeling is *coalition*. According to Bugaichenko, coalition C is a certain subset of system agents that act together in order to achieve personal and common goals. Agents of the coalition trust each other, exchange information and coordinate activities. At the same time they do not trust the agents for outside the coalition, and do not affect their behavior. So, formally, coalition may be considered a single intelligent agent, that may have sense of external environment and mental behavior defined as a combination of senses and mental states of coalition agents.

Masloboev's multi-agent model (Masloboev, 2008) was developed for information support of innovative activity in the region together with support and estimation of potentially effective innovative structures.

Innovative activity subjects are represented in form of software agents, operating and interacting with each other in common information environment (virtual business environment, VBE) for the benefit of their owners, forming an open multi-agent system with decentralized architrecture.

According to Masloboev (Masloboev, 2008), VBE model has the form of

$$E_{VBE}=\{S, P, I, A, R, Atr\}, \text{ where}$$

S – collection of business process subjects;
P – collection of business processes;
I – set of relations on object models (business process subjects);
A – collection of agents;
$R=\{BI, BPL\}$ – collection of innovation resources, incuding business ideas (BI) and business plans (BPL);
Atr – collection of model objects attributes.
Agent model has the form of:

$$A=\{S, BI, ORG_A, C_A\}, \text{ where}$$

ORG_A – agent organizational structure,
C_A – agent inner structure.
Organizational structure is defined in form:

$$ORG_A=\{G, RL, CP, ACT, STR, L, ST, SL, T\}, \text{ where}$$

G – agent goals tree;
RL – collection of agent roles that it needs to operate in order to achieve the goals;
CP – collection of agent skills and capabilities that it needs to possess in order to operate the roles;
ACT – collection of actions;

STR – collection of agent behavior strategies for goal achievement;
L – collection of languages, including agents interaction language, local planning language, and execution level language, defined by used network services;
ST – set of agent states;
SL – collection of agent operation rules;
T – general transfer function on multitudes *ST*, *SL* and *ACT* (Masloboev, 2009).
Agent inner structure defines its functional design:

$$C_A=\{K_A, M_A, P_A, R_A, I_A, C_A\}, \text{ where}$$

K_A – mental subsystem;
M_A – modeling subsystem;
P_A – analysis and planning sybsystem;
R_A – reactive subsystem;
I_A – coordination and interaction subsystem;
C_A – communication subsystem (Masloboev, 2009).
Masloboev's hybrid agent architecture is an extension of existing InteRRaP architecture with problem-oriented sybsystem of continuous simulation modeling (system dynamics models complex), used by the agents for simulation of single innovation projects development scenarios, and behavior of companions and competitors on innovative services market. Thus, use of simulation apparatus lets the agent forecast the results of its activity (risks and economical effect of investments into innovations). Hybrid architecture consists of these elements:

- *Knowledge control subsystem*, based on descriptive logic, provides temporal reasoning and some other processing mechanisms. Three levels of knowledge play key role in agent architecture: problem domain knowledge, interaction knowledge (general declarative behavior rules together with rules for problem domain knowledge replenishment and update), and control knowledge (knowledge, applying interaction knowledge to problem domain knowledge for replenishing and update of operational memory).
- *Operational memory* is used as a temporary data storage for control subsystem knowledge, user or communication control data. Operates in form global message board.
- *Decision support system* is implemented on the basis of OLAP technology.
- *Communications control module* compiles and sends messages to other agents, also receives message delivery confirmations. ACL (agent communication language), based on theory of speech activity, is used for agent interaction.

Masloboev's model is designed for creation of virtual enterprise for innovation project implementation by selecting the most effective one (from the point of view of innovation project investments) and its correlation with the most advantageous business structures capable of project implementation. Innovation project is selected on the basis of effectiveness criteria mathematical models (Masloboev, 2008), including such project indicators as economical effectiveness, estimated project implementation time, partners reliability (competence).
Business structures within the model are implemented as agent coalitions with common goals of corresponding business ideas implementation. Business ideas are used for automatic generation of agent coalition on the basis of semantic matchmaking of corresponding business idea parameters.

Model of intelligent agent with simulation apparatus is implemented in multi-agent system of innovation activity information support, providing joint use of innovation portals information databases during automated generation of potentially effective business structures, targeting innovation projects implementation.

Simulation model of intelligent agents interaction (SMIAI) was developed by Rybina and Paronjanov with the purpose of formalizing communicative activity of intelligent agents by modelling separate communication components: interaction participants, communicative environment, problem region, interaction language, dialog scenarios (Rybina & Paronjanov, 2008a).

Model of intelligent agents interaction is defined in form (Rybina & Paronjanov, 2008a):

$$MI=\{SA, SE, SP, DI, L, SRA\}, \text{ where}$$

SA – collection of agents *Ai*;

SE – collection of communicative environments *Ek*;

SP – collection of problem regions, set by problem domains *PR* (collections of classes, their instances and relations between them), collection of current tasks *ST* (represented with five typical tasks: diagnostic, engineering, planning, control and study) and relations of compliance of elements *PR* with current tasks from collection *ST*;

DI – collection of dialog scenarios between interaction participants within multi-agent system;

L – interaction language, represented with lexical, syntactical and semantical components;

SRA – collection of relations, indicating possibility of interaction between a pair of interaction participants *Aj* and *Ai* in environment *Ek*.

Intelligent agent model was received by adaptation of Cetnorovich's model *K* with a purpose of having intelligent agents as participants of interaction (Rybina & Paronjanov, 2008a):

$$A=\{M, Q, R, P, Eff, MI, Plan, Aim, Time\}, \text{ where}$$

M – collection of environment models, available to the agent;

Q – collection of agent goals;

R – collection of actions, acceptable for the agent;

P – collection of tasks decomposition options (partial plans library);

Eff – collection of acceptable impacts on the agent from environment;

MI – agents communication model;

Plan – function of agent activity plan generation based on current goal and environment model;

Aim – agent goal-setting mechanism based on external impacts;

Time – collection of activities reflection into their duration based on environment state.

Interacting agents must have knowledge of communication language and problem domain that have to be the same for each agent or at least have common areas (Rybina & Paronjanov, 2008b).

Interation of intelligent agents in SMIAI model is performed in form of a dialog (polidialog), including global structure, dependent only on goals of interaction participants, thematical structure, dependent only on the the current problem, and local structure, used for representation of communication actions sequence on local level (Rybina & Paronjanov, 2008b). Authors offer use of painted Petri nets for local interaction steps definition (i.e. actions and reactions of partner agents on each step of interaction).

Model of dialog local structure has finite set of dialog states (P_i positions) and finite set of transfers t_j, each of which has a corresponding expression (transfer condition) in interaction language *L*.Model makes use of KIF and KQML languages for language interaction. The main concept here is speech acts theory, which is the basis of KQML language, as well as large amount of problem domains, defined on the basis of KIF language.
Graphical notation of local structure model for agents dialog is presented on Fig. 3.

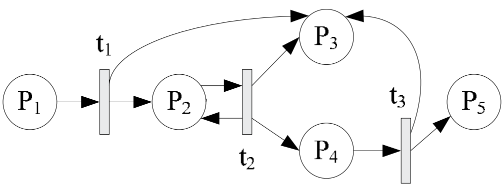

Fig. 3. Graphical notation of local structure model for agents dialog

Each dialog position is defined in form:

$$P = \left\{ agent\_state \begin{bmatrix} execut\_action \\ expec\_reactions \\ end\_of\_dialog \end{bmatrix}, color\_position, actions\_collection \right\}$$

Each dialog transfer has a structure like:

$$t = \{P_{i-1}, P_i, transfer\_condition(painting\_P_{i-1}), actions\_with\_colors\}$$, where

$$actions\_with\_colors = \begin{bmatrix} Delk = \{position\_with\_deleted\_color; deleted\_color\}, \\ Addk = \{position\_with\_added\_color; added\_color\}. \end{bmatrix}$$

Sequece of agents communicative actions is defined on the Petri net by output track analysis, determination of passed positions and inclusion of those actions into final sequence that are defined in actions list for current position.
General model of intelligent agents interaction is implemented in SMIAI, developed with aid of Gensym Corp. G2 and Microsoft Visual Studio. System has been tested in problem domains of online billing, investment projects management, control of state for chemically-dangerous objects anf other (Rybina & Paronjanov, 2009).
Resource-Activity-Operation model (RAO) is used for definition of complex discrete systems (CDS) and activities within these systems in order to study static and dynamic features of events and activities (Emelyanov & Yasinovskiy, 1998). System distrecity is defined with two properties:

- CDS content may be defined with countable set of resources, each of which relates to certain type;
- CDS state changes occur in countable moments of time (events) and $C^{+}_{e_i} = C^{-}_{e_{i+1}}$ (system state after e_i event is identical to system state before e_{i+1} event).

Conceptually CDS may be represented with a set of *resources*, that have certain parameters. Parameter structure is inherited from resource type. Resource state is defined with a vector of all its parameter values. System state is defined with all its resource parameter values.

There are two types of resources – permanent (always exist during model simulation) and temporary (dynamically created and destroyed during model simulation). By analogy with GPSS language, RAO resources may be called transacts, that are dynamically generated in certain model object, pass the other objects and are finally destroyed. Note that resource database in RAO is implemented on the basis of queueing system apparatus, having automatic support of system operation statistic gathering: average value of examined indicator, minimum and maximum values, standard deviation.

Resources perform specific *activities* by interacting with each other. Activities are defined with events of activity start and activity end, the event in general is considered a signal, transferring data (control) about certain CDS state for certain activity. All events are divided into regular and irregular. Regular events reflect logic of resource interaction between each other (interaction sequence). Irregular events define changes of the system, unpredictable in production model. Thus, CDS operation may be considered as timely sequence of activities and interrupting irregular events.

Activities are defined with *operations*, that are basically modified production rules that consider timely relations:

IF (condition) THEN1 (event1) WAIT (timely interval) THEN2 (event2).

Operation defines pre-conditions (operation resources state should fulfill those) and state change rules for resources in the beginning and end of corresponding activity. Operation with temporal interval of 0 in RAO model is considered a *decision point*, and is a usual production rule. RAO decision points are equivalent to reactive agents that store environment response data in knowledge base.

Intelligent modeling system RAO-simulator has been developed, its structure is shown on Fig. 4.

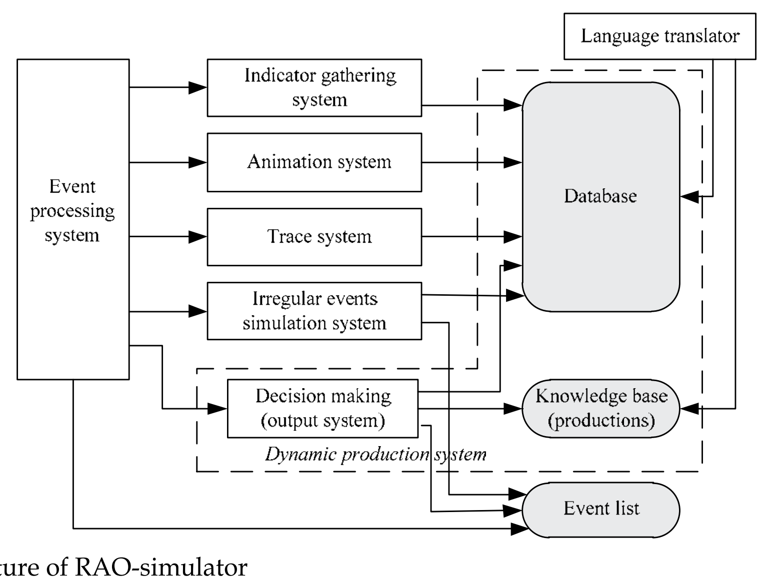

Fig. 4. Structure of RAO-simulator

Main elements of RAO-simulator include dynamic production system and events apparatus. During simulation system state changes in accordance with irregular event definition or activity that started or ended. Output system is called after each state change. It scans knowledge base for all operations and checks pre-conditions for availability of operation start. If located, the start events are raised for corresponding actions. Trace system displays detailed information on events to dedicated file, which is further processed for process detailed analysis and information representation in convenient form.

Dynamic model of multi-agent resource conversion processes (MRCP) (Aksyonov & Goncharova, 2006) was developed on the basis of resource conversion process (RCP) model (Aksyonov, 2003) and targets modeling of business processes and decision support for management and control pricesses.

Multi-agent resource conversion process model was developed on the basis of several approaches integration: simulation and situational modeling, expert and multi-agent systems, object-oriented approach.

Key concept of the RCP model is a resource convertor that has input, launch condition, conversion, control, output. Launch condition defines a moment in time when a convertor starts activity on the basis of such factors as state of conversion process, state of input/output resources, control commands, tools for conversion process and other events in external environment. Conversion duration is defined immediately before conversion based on control command parameters and active resource limitations.

MRCP model may be considered an extension to base RCP model, adding functionality of intelligent agents.

The main objects of discrete Multi-agent RCP are: operations (*Op*), resources (*Res*), control commands (*U*), conversion devices (*Mech*), processes (*PR*), sources (*Sender*) and resource receivers (*Receiver*), junctions (*Junction*), parameters (*P*), agents (*Agent*) and coalitions (*C*). Process parameters are set by the object characteristics function. Relations between resources and conversion device are set by link object (*Relation*). The agents and coalitions existence resumes availability of the situations (Situation) and decisions (action plan) (*Decision*).

MRCP model has hierarchical structure, defined with system graphs of high-level integration.

Agents control the RCP objects. There is a model of the decision-making person for every agent. An agent (software or hardware entity) is defined as an autonomous artificial object, demonstrating active motivated behavior and capable of interaction with other objects in dynamic virtual environment. In every point of system time a modeled agent performs the following operations (Aksyonov & Goncharova, 2006): environment (current system state) analysis; state diagnosis; knowledge base access (knowledge base (KB) and data base (DB) interaction); decision-making. Thus the functions of analysis, situations structuring and abstraction, as well as resource conversion process control commands generation are performed by agents.

Coalition is generated consequently after several agents union. Agent coalition has the following structure:

$$C = \langle Name, \{A1,\ldots,Am\}, GC, KBC, M\_In, M\_Out, SPC, Control\_O \rangle, \text{ where}$$

Name – coalition name;
{A1,…, Am} – a collection of agents, forming a coalition;
G_C – coalition goal;
KB_C – coalition knowledge base;
M_In – a collection of incoming messages;
M_Out – a collection of outgoing messages;
SPC – a collection of behaviour scenarious acceptable within coalition;
Control_O – a collection of controlled objects of resource conversion process.

Fig. 5 shows an example of *C1* coalition formation after union of *A2* and *A3* agents. Here *C1* coalition controls agents *A2* and *A3*, but *A1* agent acts independently.

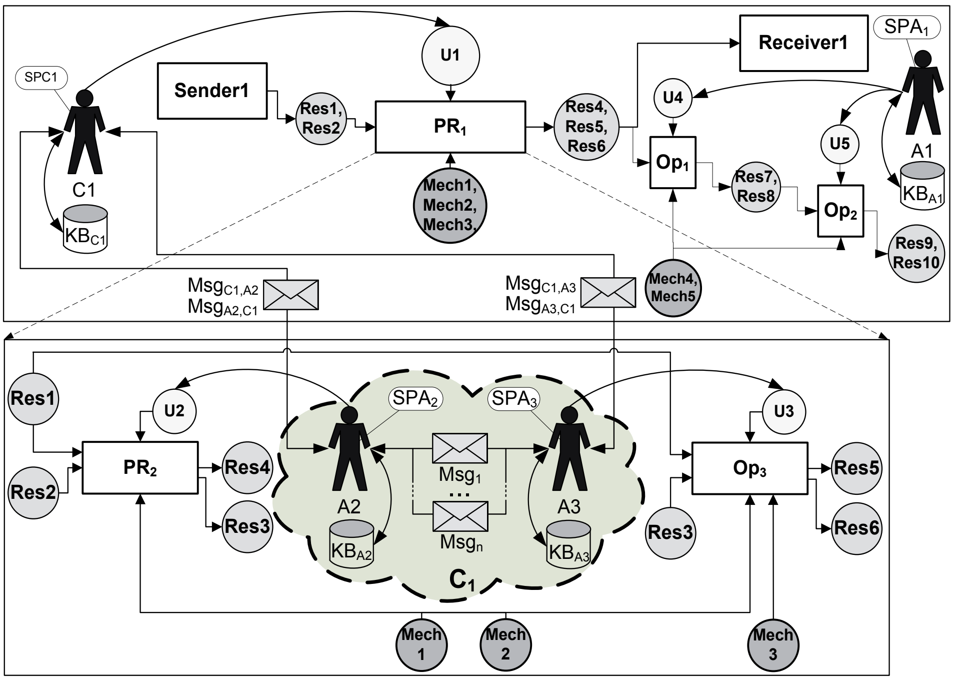

Fig. 5. Coalition formation

Simulation engine algorithm of agent-containing model consists of the following main stages: current point of system time identification $SysTime = \min_{j \in RULE} T_j$; agent and coalition actions processing (state diagnosis, control commands generation); conversion rules queue generation; conversion rules execution and operation memory state (i.e. resources and mechanisms values) modification. Simulator makes use of expert system unit for situations diagnosis and control commands generation (Aksyonov et al., 2008a).

Each agent possesses its knowledge base, set of goals that are needed for behavior configuration setting, and priority that defines agent order in control gaining queue.

Generally in case of any corresponding to agent's activity situation an agent tries to find a decision (action scenario) in the knowledge base or work it out itself; makes a decision; controls goals achievement; delegates the goals to its own or another agent's RCP objects; exchanges messages with others.

Multi-agent resource conversion process agent may have hybrid nature and contain two components (Fig. 6):

- Intelligent (production rules and/or frame-based expert system access).
- Reactive (agent activity is defined on UML activity diagram)

Two main agent architecture classes are distinguished. They are:

1. **Deliberative** agent architecture (Wooldridge, 2005), based on artificial intelligence principles and methods, i.e. knowledge-based systems;
2. **Reactive** architecture, based on system reaction to external environment events.

All currently existing architectures cannot be defined as purely behavioral or purely knowledge-based. Any designed architecture is hybrid, offering features of both types.

Multi-agent resource conversion process architecture is based on InteRRaP (Muller & Pischel, 1993; Aksyonov et al., 2009a) architecture, as the most appropriate for problem domain.

In accordance with InteRRaP architecture common concept, multi-agent RCP agent model is represented in four levels:

1. **External environment** model corresponds to the following MRCP elements: convertors, resources, tools, parameters, goals. External environment performs the following actions: generates tasks, transfers messages between agents, processes agent commands (performs resource conversion), alters current state of external environment (transfers situation S_n into state S_{n+1}).
2. **External environment interface** and reactive behavior components are implemented in form of agent productional rules base and inference machine (simulation algorithm).
3. **Reactive behavior** components performs the following actions: receives tasks from external environment, places tasks in goal stack, collates goal stack in accordance with adopted goal ranging strategy, selects top goal from stack, searches knowledge base. If appropriate rule is located, component transfers control to corresponding resource convertor from external environment. Otherwise, component queries local planning sub-system.
4. **Local planning** level purpose is effective search for solutions in complex situations (e.g. when goal achievement requires several steps or several ways for goal achievement are available). Local planning component is based on frame expert system. Frame-concept and conceptual-graph based approach is utilized for knowledge formalization.

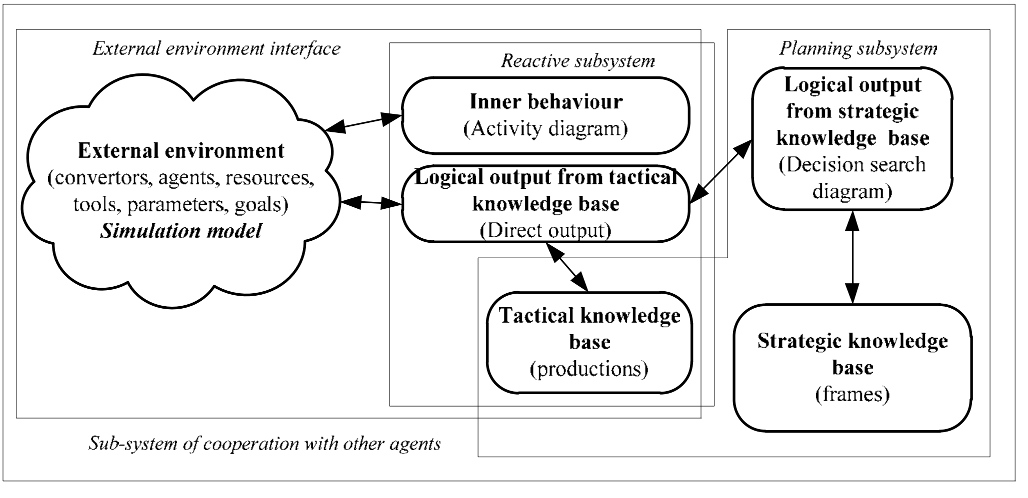

Fig. 6. MRCP agent hybrid architecture

Problem domain conceptual model and agent local planning knowledge base design is based on UML class diagram extension. Semantically this notion may be interpreted as definition of full decision search graph, containing all available goal achievement ways (pre-defined by experts). Current knowledge base inference machine is implemented in decision search diagram (Fig. 7), based on UML sequence diagram. Each decision represents agent activity plan. Each plan consists of a set of rules from reactive component knowledge base. Based on located decision, current agent plan is updated. Examination of all available options, contained in knowledge base, generates agent plans library.

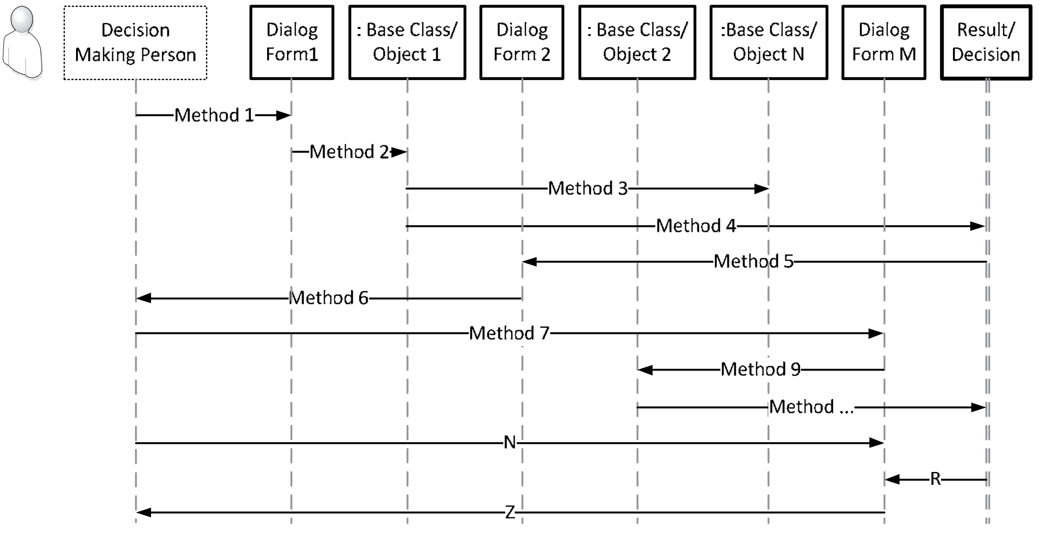

Fig. 7. General decision search diagram in decision support system BPsim.DSS

If an agent, when processing task or message received from external environment, is unable to locate appropriate rule in its knowledge base (e.g., select an option from several ones), the reactive behavior component queries plans library, indicating goal (i.e. task to execute, or external environment state to bring into). Planning sub-system searches plans library, selects appropriate plan and places first rule of selected plan into reactive component goals stack.

Comparison of described models in presented in Table 1. The following comparison criteria has been selected: resource convertor model (discrete business process model); queue system model – tool for analysis of discrete stochastic systems and business process; reactive agent and intelligent agent models (tool for decision making people definition).

Full potential of intelligent agents is implemented in Bugaichenko, Maslovboev and MRCP models. At the same time Buhgaichenko's agent is not equivalent to decision making person, but is a software entity that works independent from an expert (analyst). Masloboev uses a complex of continuous system dynamics models for agent actions forecast and has no support for discrete-event processes. SMIAI model is oriented on agent communication methods research and does not integrate with simulation modeling system. Gaia model has support for information resources convertor and intelligent agent, but has less functional capabilities, than RAO and MRCP.

RAO model is similar to MRCP in areas of decision support and has powerful tools for business processes formalization. A serious disadvantage is missing support of intelligent agents. MRCP model includes a hybrid agent model (intelligent and reactive), model of resource convertor and queue system, allowing the analyst to analyze dynamic features of business processes. Hybrid agent model allows analysis of various decision making people behavior scenarios.

Comparison criteria	Bugaichen-ko's model	Masloboev's model	Rybina's model	Gaia model	RAO model	MRCP model
Resource convertor model						
input/output/start conditions/duration				● / ● / ● / ○	● / ● / ● / ●	● / ● / ● / ●
hierarchical model of convertor	○	○	○	○	○	●
operations timely interrupts				○	○	●
Queue system	○	○	○	○	●	●
Reactive agent model (knowledge representation form)	MASL temporal logic	Producti-ons	Painted Petri nets	○	Producti-ons	Producti-ons
Intelligent agent model						
agent goals	●	●	●	●		●
actions forecast	●	●	○	○		●
action analysis and planning	●	●	●	●		●
agents self-study	●	●	●	○		●
planning, forecast, self-study implementation technology	Resolving diagrams -based expert system	System dynamics simula-tion	Expert system	Expert system	○	Frame-based expert system
message exchange language	TPA / Signals	TPA	TPA	Signals		Signals
agents cooperation model	●	●	●	●		●
Software implementation of the model	Beta	Proto-type	Proto-type	○	Beta	RTM

Table 1. Comparison of dynamic situation modeling models

Thus, MRCP model and BPsim products have the fullest functionality in area of business processes formalization.

3. Current state of dynamic situations modeling systems

Dynamic situations modeling systems area state analysis reveals unavailability of resource conversion processes oriented systems. Nearest functionality analogs (Table 2) include simulation and expert modeling tools, particularly real-time expert system G2 (G), multi-agent simulation system AnyLogic (L), business-processes modeling system ARIS (T), simulation system Arena (A) , simulation model of intelligent agents interaction SMIAI (S), Masloboev's innovations support system (M), Resource-Activity-Operation model (R). The last three are unavailable for purchase, that is the reason for zero in retail price line.

Comparison criteria	T	G	L	A	S	M	R
Problem domain conceptual model design	○	○	○	○	○	○	●
RCP description language	●	●	●	●	●	●	●
Systems goals definition:							
• Graphical	●	●	○	○	○	○	○
• Balanced ScoreCard based	●	○	○	○	○	○	○
Hierarchical process model	●	●	●	●	●	○	○
Commands description language	○	●	○	○	○	○	○
Use of natural language for model definition	○	●	○	○	●	○	○
Multi-agent modeling availability							
• "Agent" element	○	○	●	○	●	●	○
• Agents behavior models	○	○	●	○	●	●	○
• Agent's knowledge base support	○	○	○	○	●	●	○
• Message exchange language	○	○	○	○	●	○	○
Discrete event Simulation modelling	●	●	●	●	●	○	●
Expert modeling	○	●	○	○	●	○	○
Situational modeling	○	●	○	○	●	○	○
Object-oriented approach							
• Use of UML language	●	○	○	○	○	○	○
• Object-oriented programming	○	●	●	○	●	○	●
• Object-oriented simulation	○	●	●	○	●	○	●
• Problem domain conceptual model and object-oriented simulation integration	○	○	○	○	○	○	●
Retail price, ths $	50	70	8	4	0	0	0

Table 2. Modeling tools comparison

As we can see, all current systems lack support of some features that might be useful in effective simulation. For example, problem domain conceptual model design and agent-based approach implementation is limited, except RAO system that makes use of internal programming language. Another disadvantage of two most powerful systems, ARIS ToolSet and G2, is a very high retail price, which might stop a potential customer. Also systems such as AnyLogic, G2, SMIAI and RAO require programming skills from users. So, from a non-programming user's point of view, no system has convenient multi-agent resource

conversion process definition aids. Again, AnyLogic and G2 make use of high-level programming language, which results in these products being highly functional.
Simulation, situational modeling and expert systems are used in modeling, analysis and synthesis of organizational-technical systems and business processes. Multi-agent resource conversion processes theory (Aksyonov & Goncharova, 2006) may be used for organizational-technical systems definition from decision support point of view, a dynamic component of business processes, expert systems, situational modeling and multi-agent systems.
Next section presents development principles and technical decisions of designed object-oriented multi-agent resource conversion processes based decision support system, relying on above-stated multi-agent resource conversion process model and multi-agent architecture.

4. Multi-agent systems simulation and engineering systems integration

Object-oriented decision support system BPsim.DSS ("Business Processes Simulation – Decision Support System") is implemented on basis of dynamic situations modeling system BPsim.MAS ("Multi-Agent Simulation"), software engineering system BPsim.SD ("Software Designer") and technical economical engineering system BPsim.MSN ("Multi-Service Network") integration.
The following program packages are being used during multi-agent resource conversion processes problem domain business process modeling and software design (www.bpsim.ru), offering a comprehensive solution for business modeling and techno-economic engineering problems, which in turn considerably simplifies and speeds analysts' work:

- *BPsim.MAS* – multi-agent dynamic situations modeling system (Aksyonov et al., 2008a). BPsim.MAS offers the following functionality:
  a. Multi-agent resource conversion process model design;
  b. Dynamic simulation;
  c. Experiment results analysis;
  d. Model- and results-based reporting;
  e. Experiment data export to Microsoft Office family products.
- *BPsim.SD* – Software Developer CASE tool
  BPsim.SD offers automation on the following phases of software development:
  a. DFD diagrams design is not automated. As in every CASE tool a DFD diagram needs to be designed manually;
  b. Use-case diagrams design is fully automated, use-case diagrams are achieved by a transition from a DFD diagram. This process lets us keep our business objects;
  c. Classes diagram design is partially automated. The core classes frames are generated automatically, that greatly simplifies work on the final classes diagram. Benefit is estimated in 10-15%;
  d. Sequence diagram design is semi-automatic.
  e. Database structure generation is automated.

BPsim.SD offers an opportunity of forms design. This allows the end-user place the controls on the form as he wants them to be positioned. Some of the controls can be associated with data on the phase of GUI design before passing the project to the developers. After this phase a developer receives GUI forms in an appropriate format, i.e. the forms are saved in a software development file format (Aksyonov et al., 2008b).

- *BPsim.MSN* – techno-economic engineering intellectual system (Aksyonov et al., 2009b) automates the following functions:
  a. Problem domain conceptual model engineering;
  b. Filling the knowledge base data;
  c. Decision search diagrams design, setting up dialog-based expert system;
  d. Decision search.
- *BPsim Wizard Technology* – a framework of intelligent software assistants for step-by-step model definition. A wizard is a dialog-based program assistant targeting information integration and conversion from one system (BPsim.DSS / BPsim.MAS / BPsim.SD) to another. BPsim Wizard Technology performs the following functions:
  a. Transfers information between simulation, decision support and software engineering modules in the framework of a single complex problem;
  b. Simplifies a non-programming user experience when getting started with BPsim products family;
  c. Validates data on various stages of simulation model design, problem domain conceptual model and information system engineering.

Various tools and methods use on all stages of organizational technical systems analysis and synthesis and their support by BPsim products is presented in Table 3.

BPsim.DSS agent model is represented with four levels in compliance with InteRRaP architecture general concept. External interface and reactive behavior components together with external environment model are implemented in BPsim.MAS tool. Local planning component is based on BPsim.MSN expert system module. Expert system shell visual output mechanism builder is based on decision search diagrams (UML sequence diagram extension). Cooperation level is based on both modules.

No	Stage	Tool	Support in BPsim
1.	Processes definition	IDEF0 notation	SD, MSN
		DFD notation	SD, MSN
		UML use-case diagram	SD, MSN
		Multi-agent resource conversion processes notation	MAS
2.	Software engineering	DFD use-case, class, sequence diagrams	SD, MSN
3.	Knowledge formalization	Semantic networks	MSN
		Frames	MSN
		Production rules	MAS
4.	Decision support	Simulation	MAS
		Multi-agent simulation	MAS
		Situational control	MAS, MSN
		Dialog-based expert systems	MSN

Table 3. Methods used in BPsim products

An example, illustrating decision search diagram workflow, is presented on Fig. 8. For simplification the dialog form classes are not shown on the diagram. The example illustrates work of expert system for real estate agency. The figure shows available house/apartment search in the database on the basis of user set criteria. The search is run in form of decision search diagram.

Object-oriented decision support system BPsim.DSS allows the following features implementation:

1. Problem domain conceptual model definition
2. Multi-agent resource conversion process dynamic model design
3. Dynamic simulation
4. Experiment results analysis
5. Reporting on models and experiment results
6. Data export to MS Excel and MS Project

Decision support system visual output mechanism builder, based on decision search diagrams (Fig. 7), as well represents agent knowledge base, based on frame-concepts. So, agent knowledge base may be defined in two ways: productive and frame-concept – based.

Here is an example of wizard implementation. This one focuses on analysis an re-engineering of business processes.

System analysis in area of business process management implies design of various system models (or views) by the analyst, each of which reflects certain aspects of its behavior. Re-engineering of these models targets the search of alternative ways of system processes development by means of consolidation of certain model sub-elements into a single process. There are three ways of achieving this. One is *parametric synthesis*, when initial model is converted into series of new models by modifying separate parameters. Another is *structural synthesis*, this is a way of forming new models by modifying model structure according certain rules. *Mixed synthesis* uses features of both options. An actual task is development of algorithm for model analysis and mixed synthesis.

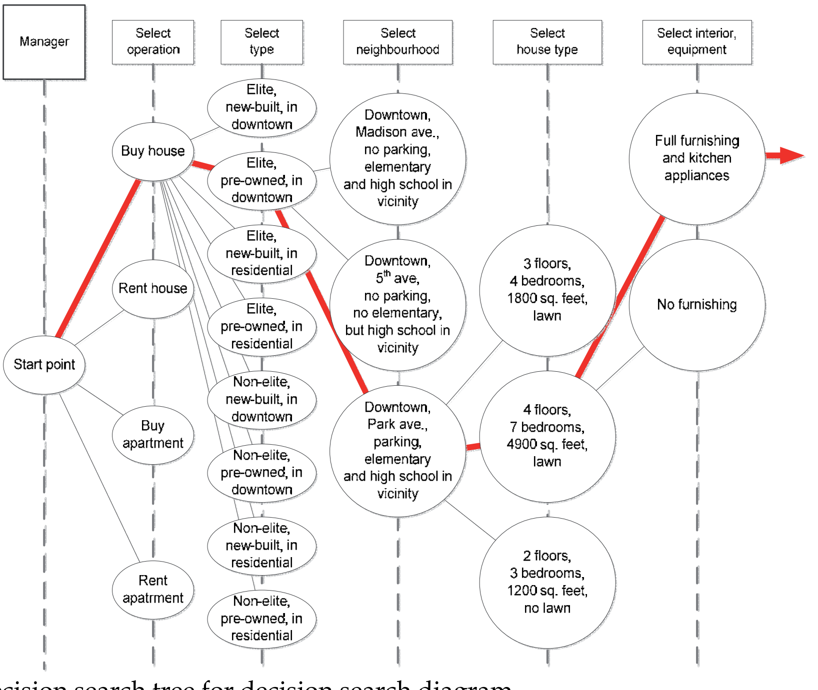

Fig. 8. Decision search tree for decision search diagram

Consider initial model M_0 of multi-agent resource conversion process. Carrying out of experiments gathers statistical data of operation execution, agent activity and tools utilization in operations. Analysis and mixed synthesis algorithm is shown on Fig. 9 in form of decision search graph. Graph nodes stand for: 0 – zero value, L – low value, A – average value, H – high value – of corresponding graph object (queue size, load or idling). Directed graph arcs connect fulfilled conditions of model analysis (nodes) into a general solution of synthesis operator application. For example, solution for application of operator "Delete parallel operation" is the following chain execution: model statistics contains zero values of average transact queue for operation, average operation load, operation idling caused by missing resources or occupied tools. Dashed arcs correspond to solutions with zero-length or short transact queue for operation. Solid arcs correspond to solutions with long transact queue for operation.

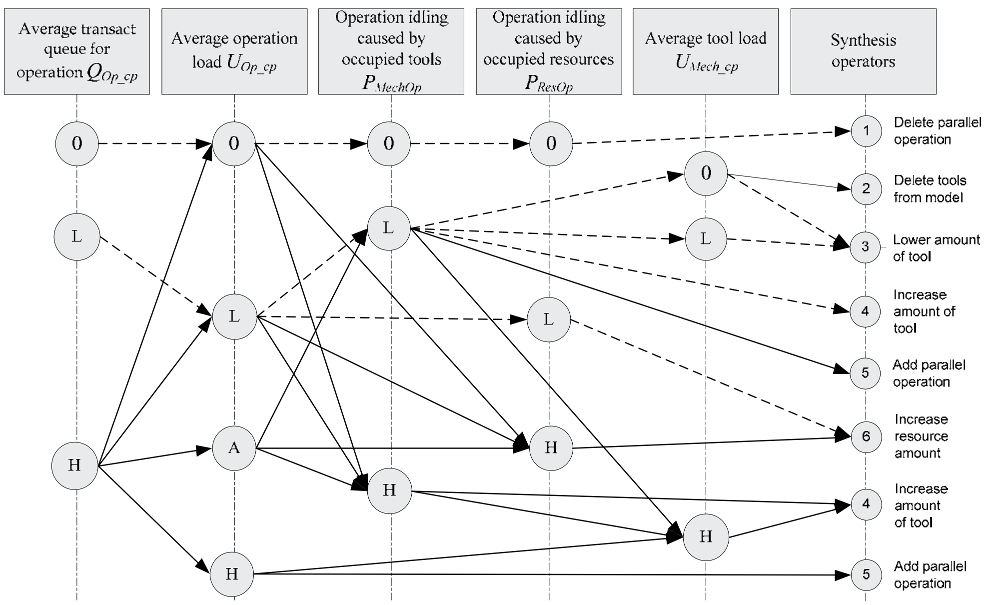

Fig. 9. Decision search graph for synthesis operators application, implemented in intelligent agent

There are several examples demonstrating BPsim.DSS system application. They are presented in the next section.

5. BPsim.DSS system application

5.1 BPsim.DSS application to IT projects management

Decision support system BPsim.DSS was used on various stages of Ural State Technical University Common Information System (CIS) development and deployment, starting with educational process analysis stage, performing re-engineering, and ending with separate CIS units deployment efficiency estimation.

Model of an agent (decision making person), controlling software development process in Ural State Technical University, was developed in decision support system BPsim.DSS. Model consists of simulation model "Educational process software development" and decision support models, including the main model "CIS implementation options selection". Model knowledge base contains information on networking, hardware and software, information systems, IT-projects, teams of IT-specialists.

Expert system module is used for project alternatives and effective alternative search algorithms knowledge base development. Simulation model is used for separate project stages monitoring, detection of errors and conflicts, occurred on initial planning stage, solution of vis major (i.e. search of decision in a force majeure situation that occurs under irresistible force or compulsion and may drastically change system certain parameters), that happens during development project control and CIS deployment. Simulation model is based on Spiral model of software lifecycle and is designed in BPsim.DSS.

BPsim line products were used for business processes analysis and requirements specification development for Common Information System (CIS) of Ural Federal University. University has complex organizational structure (faculties, departments, subsidiaries and representative offices), which means that success of University business processes optimization depends on quality of survey and enterprise model comprehensiveness. Survey revealed non-optimal implementation of certain processes at the University, e.g. movement of personnel (Fig. 10).

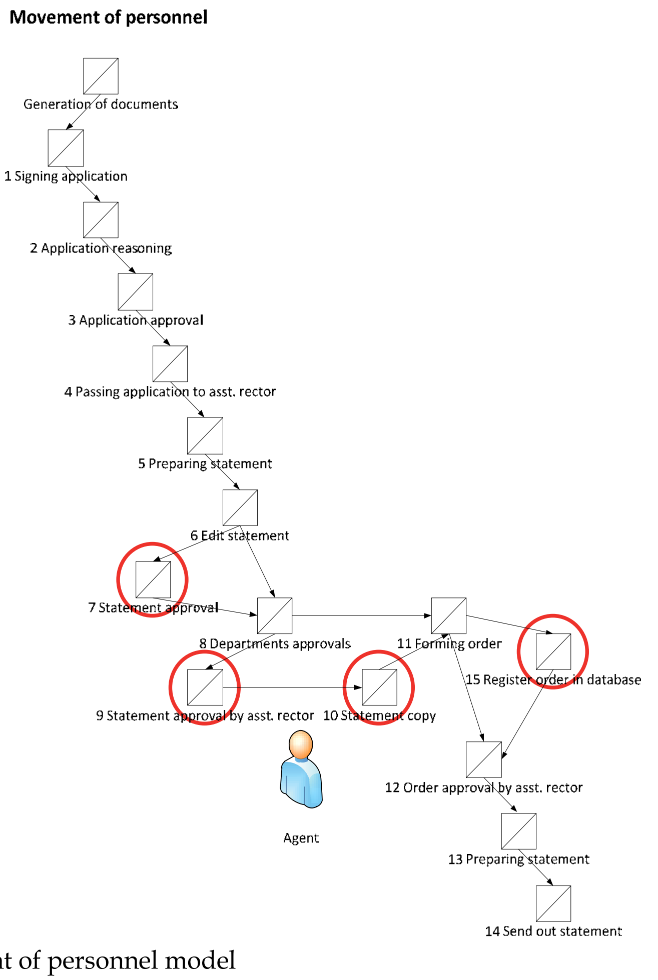

Fig. 10. Movement of personnel model

Simulation model “as-is” of the process was designed in dynamic situations modeling system BPsim.MAS. Model data has been achieved from questioning employees of personnel office, IT department, and four selected dean offices. Model nodes represent document processing stages. Nodes 1-10 correspond to document processing within faculty, nodes 11-14 – processing of faculties weekly documents in personnel office. Use of intelligent agent for business process analysis and re-engineering allowed fixing certain problems.

1. Intelligent agent discovered two identical transacts within the model. Analyst decided that dean office employees prepared two similar documents on different stages – application and first statement. Recommendation – unification of these documents.
2. Intelligent agent discovered a feedback loop, which is a negative indicator for document flow business process. Analysis of highly-loaded personnel affairs-involved employees revealed that dean offices allowed generation of long document queues. Also asst. rector was required to approve 3 similar documents at different stages. Recommendation – process automation, use of electronic documents.
3. Analyst discovered that IT personnel assistance is required for database data modification. Recommendation – process automation, data changes should be carried out by information-specific personnel, IT dept. employees should not perform uncommon functions.

The following process updates were offered after analysis and re-engineering:

1. When employee signs an application, the dean office representative creates its electronic copy in common database;
2. First statement is not necessary, all information needed for the order is stored in common database, so, approvals need to be gathered only once;
3. All process participants work directly with electronic application, without requirement of sending documents to dean office;
4. Availability of storing files electronically;
5. Asst. rector approves only application and order;
6. Availability of tracing document route;
7. Employees of IT department no longer perform uncommon function of updating database;
8. In case of urgent order the corresponding information objects are generated by the dean office employee.

As a result, the “as-to-be” model no longer has nodes 7, 9, 10, 15 (Fig. 10). New business process definition became a basis for CIS module “Movement of personnel” requirements specification, which as well used diagrams, designed in BPsim.SD CASE tool. The deployment effectiveness was estimated after deployment and half-year use of the module based on simulation models “as-is” (old model) and “as-to-be” (new model). Results are presented in Table 4.

Thus, due to “Movement of personnel” process improvement and automation dean’s office employees work efficiency was raised by 27%, student desk employees work efficiency was raised by 229%. Deployment economical effect is estimated by about 25 thousand euro per calendar year. Economical effect is achieved in shortening and automation of unnecessary document processing stages, information double input prevention and employee load decrease.

Indicators	"AS-IS" model	"AS-TO-BE" model
Documents processed, per month	390	1264
Documents lost, per month	12	0
Dean office employees performance, documents per hour	0.4	0.5
Personnel office employees performance, documents per hour	2.4	7.9

Table 4. "Movement of personnel" deployment effect estimation

5.2 BPsim.DSS application to Subaru auto dealer logistical processes simulation

Finally, BPsim.DSS was applied to Subaru auto dealer sale process. Simulation result analysis helped this process be optimized, i.e. certain initial parameters being modified, resulting in effective logistics and warehouse processes. Initial data for simulation included sales statistics for each model, average retail pricing and dealer price markup, together with sales statistics depending on initial car location (at warehouse on location, at official Subary representative's warehouse in Moscow, at Japanese warehouse ready for delivery), including number of contracts and average delivery time from the order date. The main purpose was to estimate the necessary number of cars of each model at the warehouses on location and in Moscow, in order to achieve sales results of 20 to 40 cars per month.

Another model for Subaru auto included simulation of car repair process. The model considered main repair process stages, resulting in effective search of repair strategy.

Model was designed to examine, analyse and improve repair department activity of two dealers in Siberian region of Russia, and was based on the statistical data from the dealers. The model can be used by other enterprises, provided that it is adapted accordingly.

5.3 BPsim.DSS application to multi-service telecommunication networks technical economical engineering

Another application of BPsim.DSS included multi-service telecommunication network models design and telecommunication services area business processes dynamic simulation. Currently leading Russian region cellular carriers engineers polling revealed, that carriers' development departments use their own experimental knowledge base when engineering data-communication networks, while data-communication implementation engineering solutions are foisted by hardware vendors. No operator either makes use of data-communication networks automated design aids, or models various designed/existing network behaviour situations when developing new regions, introducing new services or modifying data-communication network topology.

Development of automated design and modelling methods and aids requires large quantity of primary data for qualitative MSN technical and economical engineering, which includes: telecommunication hardware and technologies types and parameters; engineers, economists, project managers, marketers, and lawyers' level of knowledge.

Decision support systems fit most for MSN technical and economical engineering problem solution. Decision support systems can make use of simulation, expert and situational modelling (Aksyonov & Goncharova, 2006). Decision support systems development and deployment within cellular communication operators is a pressing and needed problem.

The following mathematical methods are used in MSN and business processes modelling, analysis and synthesis tasks: teletraffic theory may be used on all MSN levels except services level; simulation, situational and expert modelling methods are used for business processes analysis and synthesis tasks. Expert and situational modelling methods, neural networks, multi-agent and evolutionary modelling methods can be used in RCP formalization.

Multi-agent resource conversion processes theory is applied for MSN definition from decision support point of view.

Frame-concept and conceptual graphs based approach, offered by A. N. Shvetsov and implemented in form of «Frame systems constructor» expert system shell (FSC), is used as a means of knowledge formalization (Shvetsov, 2004). A frame-based semantic network, representing feasible relations between frame-concepts, is defined in form of extended UML classes diagram, at the stage of system analysis.

UML sequence diagram is used for visual FSC output mechanism builder implementation. This approach allows visual (in form of flowchart) problem solution flow definition, when solution turns into a sequence of procedure (method/daemon) calls from one frame to another. Hereby, this approach allowed visual object-oriented ontology and knowledge-based output mechanism constructor implementation in form of decision search diagrams.

BPsim.DSS was applied for MSN technical economical engineering in Ural region, covering metropolis Ekaterinburg, Russia, and satellites. Designed model is shown on Fig. 11.

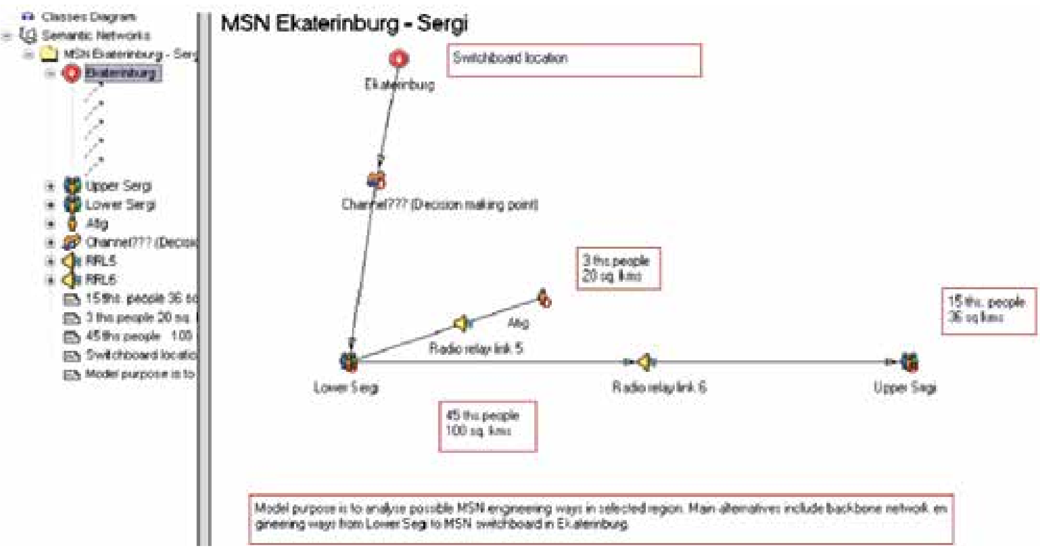

Fig. 11. MSN Ekaterinburg – Sergi model view

This constructor, provided that being filled with MSN subject area knowledge and technical and economical engineering rules, represents an intelligent MSN automated engineering system.

Graphical implementation of the model is presented on Fig. 12. Model allows switching on and off Base Stations (Access network elements) and Transport Networks, as well as changing elements parameters and allowing to select from options of renting or constructing a specific element.

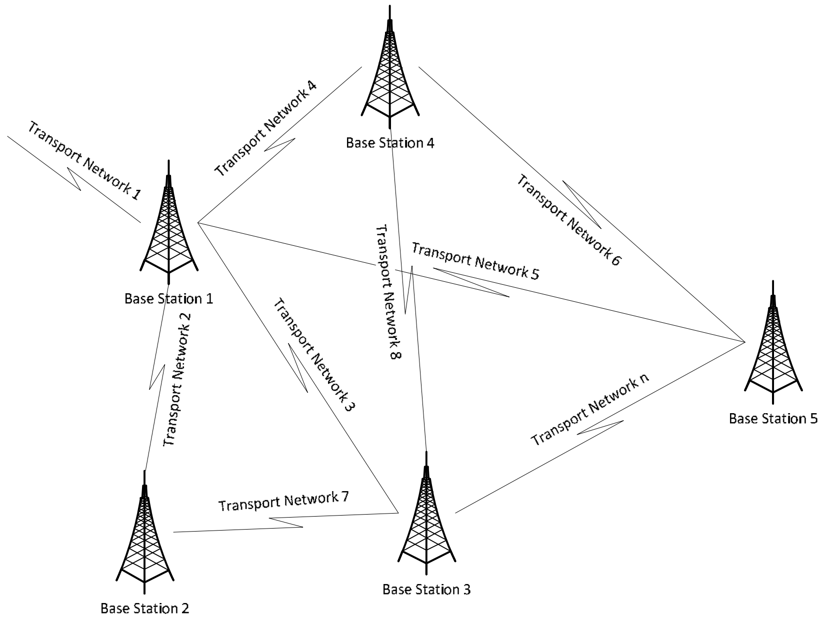

Fig. 12. Modelled MSN graphical model

The model is designed with a main purpose of MSN technical economical engineering with a centre in the metropolis and covering surrounding towns. Main goal is to estimate available MSN deployment options for provision of cellular and data transfer services.

Synthesized model allows estimation of main investment indicators (IRR, EBI, Payback Period), that are required for substantiated decision making in MSN engineering.

Live, one of the experiments that performed best, was implemented and performance indicators were measured after a certain while of performance. The real indicators were close to ones estimated with aid of decision support system BPsim.DSS.

6. Conclusion

In this chapter we have presented the following keynote features.

Some popular dynamic situations modelling systems including AnyLogic, ARIS, G2, Arena, RAO and models/prototypes of other systems were compared. This comparison revealed the necessity of a new system development, for it to be focused on multi-agent resource conversion processes. Among the disadvantages of the named systems we can name an incomplete set of features for dynamic situations modelling system; no support for problem domain conceptual model engineering and multi-agent models, containing intelligent agents, design; incomplete multi-agent resource conversion processes problem orientation; programming user orientation; high retail price.

Multi-agent resource conversion process situational mathematical model requirements were designed. The model must provide the following functions: dynamic resource conversion processes modelling; definition of intelligent agent communities, controlling the resource conversion process; situational approach application.

System development required multi-agent resource conversion process model definition. The following features of the model were designed:

- Multi-agent resource conversion process main objects;
- Graphical notation;
- System graphs apparatus was applied to hierarchical process structure definition;
- Frame-semantic representation, based on frame-concepts and semantic graphs, was selected for knowledge representation model, which allowed problem domain conceptual model definition;
- InteRRaP hybrid architecture was selected as a basis of multi-agent system;
- Multi-agent resource conversion process output mechanism, rule types, intelligent agent activity algorithm and situational simulation modelling algorithm were designed.

Based on the model and multi-agent resource conversion process system analysis, a software family of BPsim products was developed. It offers the full list of functional features, required from a problem-oriented dynamic simulation modelling systems and implements the following specific features:

- Problem domain conceptual model definition;
- Multi-agent models definition, including both reactive and intelligent agents;
- Multi-agent resource conversion processes problem orientation;
- Balanced scorecard methodology integration;
- Significantly lower retail price.

Simulation, expert, situational and multi-agent modeling integration with object-oriented approach allowed implementation of new object-oriented multi-agent resource conversion processes simulation and decision support method, reflected in development of object-oriented decision support system BPsim.DSS, deployed at companies in Ural region of Russia.

The mathematical model is based on discrete resource conversion process model. Within its framework the problem of transition between the knowledge representation, conceptual model and their technical implementation on relational database level, was solved. This approach allows Transact-SQL language to be used for problem domain models design, data and knowledge input, logical output mechanism implementation.

7. Acknowledgment

This work was supported by the State Contract No. 02.740.11.0512.

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6

Intelligence Decision Support Systems in E-commerce

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1. Introduction

The present state of world economy urges managers to look for new methods which can help to start the economic growth. To achieve this goal, managers use standard as well as new procedures and tools. Development of information society and so-called new economy has created a whole new business environment that is more extensive and rapidly changing. Become a standard the use of modern information and communication technologies (ICT), which enable faster and cheaper communication and an increase in the number of business activities. Today in the world's economy, a major role plays electronic business (e-business).
Basic support for the e-business transactions are so-called e-commerce systems. E-commerce systems became standard interface between sellers (or suppliers and manufactures) and customers. E-commerce systems can be considered for systems with large geographical distribution. This follows from their nature, when they are based on the Internet. Statistics show an increasing interest in cross-border online shopping. This is also dependent on the efforts of manufacturers and retailers to establish themselves on foreign markets. E-commerce systems allow them to do it quickly and at relatively low financial cost.
One of basic features of efficient e-commerce is correct definition and description of all internal and external processes. All the management activities and decision making has to be targeted to customers´ needs and requirements. The optimal and most exact way how to obtain and find optimal solution of e-commerce system and its procedural structure is modelling and simulation. Organizations developing e-business and e-commerce solutions consider business modelling as a central part of their projects. The latest theoretical and practical experiences are testaments to how great strategic advantage for organizations doing business is creation and use of new e-business and e-commerce models. The importance and necessity of the creation and use of new models is described as the most recent publications, for example in (Laudon & Traver, 2009) or (Laudon & Traver, 2010) as well as in older, for example (Barnes & Hunt, 2000). Next to the business model, a big attention must be paid to models of e-commerce systems from a technical point of view. (Rajput, 2000)
Expanded scope, creation and use of new models create the need for increased demands on decision-making. Social and business environment is changing very rapidly and this has an impact on managerial approaches. ICT became basic decision-making support. Technological bases of e-commerce systems are ERP and CRM systems, which constitute the core of enterprise informatics. Now almost all of them contain decision-making support

modules and tools, which fall into the decision support system (DSS) or business intelligence (BI) category. In this context it is appropriate to ask, what is the difference between DSS and BI, how can these systems be used in e-commerce, which of these systems is more appropriate for decision support and what are the conditions that these systems could be classified as so-called intelligent decision support systems.
On the basis of these facts main goal of this chapter is to present new approaches to the creation of e-commerce systems models and new approaches to managing e-commerce systems using modern software tools for decision support.

2. E-commerce system

E-commerce systems are fundamental aids of online shopping. According to (Velmurugan & Narayanasamy, 2008) e-commerce is defined as an attempt to increase transactional efficiency and effectiveness in all aspects of the design, production, marketing and sales of products or services for existing and developing marketplaces through the utilization of current and emerging electronic technologies. In the globalization era, understanding the adoption of information communication technology, including e-commerce by developing countries is becoming important to improve its adoption success. This, in turn, enables developed countries to trade with developing countries more efficiently.
Generally and simply, e-commerce system can be defined as a web server linked by company´s information system. Detailed definition of e-commerce system appears from definition of information system whose basic components are information and communication technologies and users. Information systems are developed mainly for management support. Managers are in a way, a special group of users. Information system for them is on the one hand, a tool to support management activities, on the other hand, the source of current information describing the current state of managed objects. It is a principle of feedback, which is one of the fundamental principles of management.
Some authors (in some publications) consider as an e-commerce system only web server that contains all the necessary functionality (for example (Garcia et al., 2002)). Main model of e-commerce system based on process-oriented approach is shown for example in (Rajput, 2000). This model can be extended and then we can define main components of e-commerce systems which are (Fig. 1):

- customers;
- internet;
- web server (web interface);
- CRM (Customer Relationship Management);
- ERP (Enterprise Resource Planning);
- LAN (Local Network Area);
- payment system;
- delivery of goods;
- after-delivery (after-sales) services;
- information systems of cooperating suppliers and customers.

E-commerce systems are developed to support business activities. Customers (buyers) have their own requirements and corporate managers have to find all the ways, methods and resources to meet their needs and requirements. Great emphasis must be placed on all management control systems and systems to support the decision-making processes. The deployment of e-commerce could be seen mainly in the CRM (Customer Relationship Management), SCM (Supply Chain Management), FRM (Financial Resource Management), HRM (Human Resource Management), MRP (Manufacturing Resource Planning) and CPM (Composite Product Mapping).

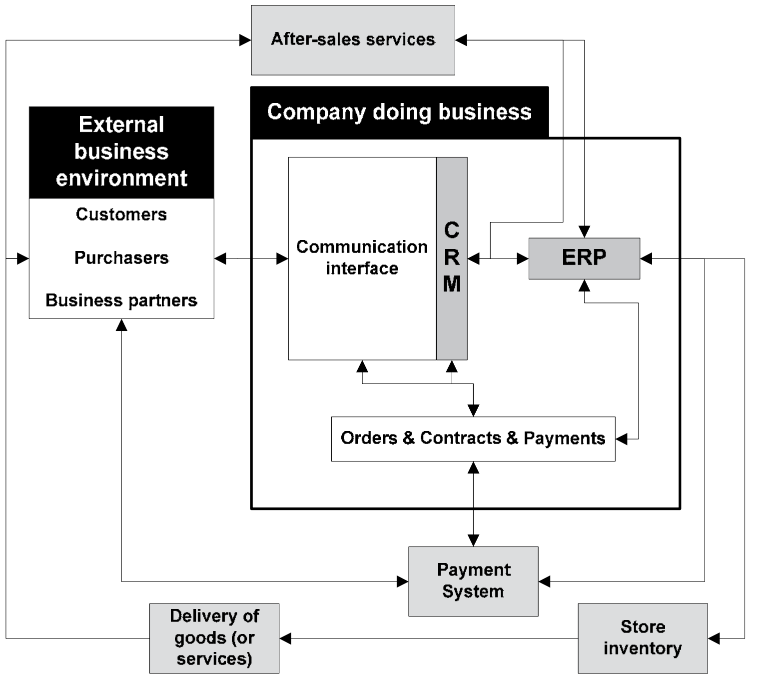

Fig. 1. E-commerce system

When implementing e-commerce system it is important to link new system with company's information system. All changes in e-commerce system will be immediately performed into the information system to ensure the data consistency. Enterprise Resource Planning (ERP) is suitable for global operations as it encompasses all the domestic jargons, currency conversions, diverse accounting standards, and multilingual facilities. ERP software attempts to integrate business processes across departments onto a single enterprise-wide information system. The major benefits of ERP are improved coordination across functional departments and increased efficiencies of doing business. The goal of CRM is to collect information gained by doing business in a central repository, analyze it, and make it available to all departments. In many cases, CRM are integrated into ERP, but it is not the rule. CRM and ERP benefits can be measured and quantified. With usage of ERP, company can gain following benefits:

- improved alignment of strategies and operations;
- improved productivity and insight;
- reduced costs through increased flexibility;
- supported changing industry requirements;
- reduced risk;
- improved financial management and corporate governance;
- optimized IT spending;

- gained higher ROI (Return on Investment) faster;
- retained top performers;
- provided immediate access to enterprise information.

A major benefit of CRM can be the development of better relations with the existing and new customers, which can lead to:

- increased sales through better timing due to anticipating needs based on historic trends;
- identifying needs more effectively by understanding specific customer requirements;
- cross-selling of other products by highlighting and suggesting alternatives or enhancements;
- identifying which of your customers are profitable and which are not.

The condition of an entry to global markets through e-commerce deployment is an adjustment of the information system to global information and business system management standards. Management standards are defined for three basic sectors, which are customer relationship management, supply chain management and operating management. These sectors can be further refined into information system management, business processes management, management of logistics and production logistics, management of human resources, legal rules in relation to international law etc. (Vymětal & Suchánek, 2009)

Payment systems are often one of the problem areas of e-commerce. It can be seen especially in the context of cross-border online shopping. There are numerous different payments systems available for online merchants. These include the traditional credit, debit and charge card but also new technologies such as digital-wallets, e-cash, mobile payment, e-checks, cash on delivery. To support the cross-border online shopping development, it is necessary to provide the customers safe payment environment and to give support to the international bank clearing. It is one of the tasks of e-commerce system to ensure the correctness of financial flows e.g. from the sales when converting and storing the business results to the company's account information system. Dispatch is supported and controlled by SCM. SCM is the oversight of materials, information, and finances as they move in a process from supplier to manufacturer to wholesaler to retailer to consumer. Supply chain management involves coordinating and integrating these flows both within and among companies. Supply-chain management, at least in the largest multi-national corporations, is a global endeavor (Murillo, 2001). More about efficient SCM is discussed in (Šperka, 2010).

Like every area of business in these days, e-commerce is surrounded by a maze of red tape, rules and regulations. In fact, selling online tends to be worse because of the international dimension. On the one hand, legislature can help to online shopping and cross-border online shopping, on the other hand it can scant e-commerce development (Suchánek, 2010a).

Following part of the text is about requirements management. It will be explained why it's so important for companies to meet customers' requirements when developing an e-commerce system.

3. Customer requirements and management needs

When starting to develop an e-commerce system it is important to think about future functions of the system from the customer's point of view. Development process of the most recent projects initiates with requirements analysis. In terms of e-commerce, customer requirements can be separated up two groups. The first group of customer requirements results from exploitation of IS/IT as the main technological support of e-business and e-commerce environment. In 2003, ANEC Policy Statement on Design for All called upon the standard-makers to take the following generic consumer requirements into account when designing, selecting, commissioning, modifying and standardizing ICT systems. Requirements for IS/IT were summarized as accessibility/design for all, adaptability, child safety issues, comprehensible standards, consistent user interface, cost transparency, easily adaptable access and content control, ease of use, environmental issues, error tolerance and system stability, exportability, functionality of solution, health and safety issues, information supply for first-time user set-up procedure, interoperability and compatibility, multi-cultural and multi-lingual aspects, provision of system status information, privacy and security of information, quality of service, system reliability and durability, rating and grading systems, reliability of information, terminology. (ANEC, 2005)

The second group of customer requirements is closely associated with business transactions (Suchánek, 2010a). Customers want to find what they want easily and in short time, to get sufficient number of information, to place an order easily, payment system to be secured and failsafe, to get goods in quality of service and in short time, goods to be guaranteed by sellers (producers) and to get benefits in dependence on a number of purchases. To be reliable in an uncertain and changing environment companies must be able to respond to the changes quickly. To obtain it, management needs actual information. The most important condition of customer satisfaction is feedback. Suppliers and producers have to monitor market environment and all have to be targeted to the customers. All customer requirements have to be monitored for ever and company information system with the all company´ processes have to be formed to ensure quality and rapid processing of the all customer feedback information, needs and requirements. Feedback information can be getting by the communication channels which are usually integrated in CRM (Customer Relationship Management). Feedback is the most important condition of getting information. If managers want to satisfy all customer requirements, they should:

- get precision information;
- get information in time;
- get information in required form;
- get information in visual form;
- know information they want to.

Managers need besides information:

- to develop the ability to apply information technology in complex and sustained situations and to understand the consequences of doing so;
- to learn the foundations on which information technology and applications are built;
- and current or contemporary skills.

4. Decision-making processes in e-commerce system environment

When the company, implementing e-commerce system wants to use full potential of new solution it is necessary to decide according to the relevant information. E-commerce systems produce amount of raw data. Why not to use these data to improve the decision-making? Decision Support System (DSS) is an umbrella term used to describe any computer application that enhances the user's ability to make decisions. More specifically, the term is usually used to describe a computer based system designed to help decision makers use data, knowledge and communications technology to identify problems and make decisions to solve those problems. DSS systems can be separated into seven broad categories namely

Communications Driven DSS, Data Driven DSS, Document Driven DSS, Knowledge Driven DSS, Model Driven DSS, Spreadsheet based DSS and Web-based DSS. Communications Driven DSS is a type of DSS that enhances decision-making by enabling communication and sharing of information between groups of people. Data Driven DSS are a form of support system that focuses on the provision of internal (and sometimes external) data to aid decision making. Document Driven DSS are support systems designed to convert documents into valuable business data. Knowledge Driven DSS are systems designed to recommend actions to users. Model Driven DSS support systems incorporate the ability to manipulate data to generate statistical and financial reports, as well as simulation models, to aid decision-makers. Spreadsheet based DSS offer decision-makers easy to understand representations of large amounts of data. Web-based DSS system is operated through the interface of a web browser, even if the data used for decision support remains confined to a legacy system such as a data warehouse. (Velmurugan & Narayanasamy, 2008)
Decision making processes need combination of skills, creativity, recognition of the problems, and lucidity of judgment, determination, and effective implementation in operational plan. Generally, decision making process has five stages: (Harrison, 1998)

- problem determination (definition of objectives);
- collection of information (identification of alternatives);
- choosing of optimal decision;
- implementation of a decision;
- evaluation of decision.

To adopt a right decision, managers have to get correct information in right time. In connection with e-commerce source system of data set is extended. With a view to minimization of failure during the domestic and especially cross-border online selling, it is necessary to allow for many factors. Besides typically economic indicators, source information of management systems have to be for example legislature, culture, conventions etc. (Fig. 2)
Decision making processes are also proceed on the side of customers. The customers´ decision-making process is the process they go through when they decide to purchase something. (Olsen, 2003) Research suggests that customers go through a five-stage decision-making process in any purchase:

- need recognition and problem awareness;
- information search;
- evaluation of alternatives;
- purchase decision;
- post-purchase evaluation.

Managers´ decisions should lead to make the customers´ decision-making process easier. All decision making processes have to be targeted to the customers and their needs and requirements. Customers´ needs and requirements are usually different in a number of countries. This fact is always a cause of unsuccessfully cross-border online selling transactions. Only the way leading to reduce the number of unsuccessfully cross-border online selling transactions is an optimal management system making use of all necessary source information. To obtain an efficient decision-making, there are used mathematical models of allocation processes (Bucki, 2008). More about mathematical model of e-commerce simulation example is written at the end of this chapter. Supranational character of e-commerce systems evokes the need to process an extensive set of information and urges the managers to look for the new methods leading to maintenance and improvement of position in domestic and especially foreign markets. This is possible only with the aid of modern information technologies. Current trend is oriented to the development and usage of systems with business intelligence tools. (Suchánek et al., 2010b)

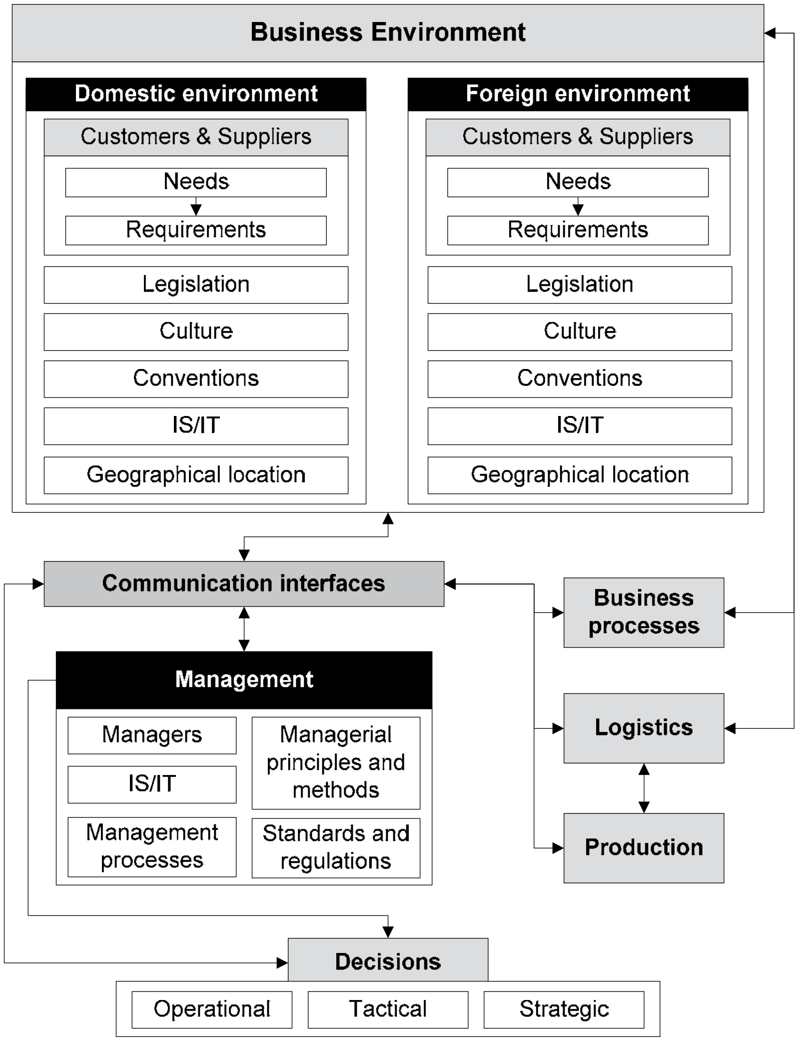

Fig. 2. Management system and its source information areas

5. E-commerce systems modelling to assess the added value

Modelling and system design techniques are currently widely required. This is caused by information technologies support needed to achieve and sustain necessary business flexibility imposed by market fluctuations. There are two substantial ways to use the model. During the system design, the model serves as a conceptual description of the future system. After the new system is put into operation, the management can use it also for decision support. Typical management control loop incorporates the measurement of the controlled system outputs (“what has happened” - facts) which are evaluated and compared with the company objectives (targets). The controller – manager then takes corrective action (“what should or must be done”) in order to reach the specified targets. In case of decision support by simulation the outputs of the controlled subsystem and the data concerning company environment have to be included in the model structure. The results of simulation are presented to decision maker – manager for evaluating possible decision alternatives. While conceptual modelling forms the base of new system design, the simulation modelling can be seen as operations support. This is why both ways of modelling are important for achieving flexibility of data processing in particular, the company management effectiveness in general.

E-commerce systems to work properly should support and cover all company’s core processes. Correct processes identifying, mapping and implementing into e-commerce system is the main condition of successful business. E-commerce dramatically and strategically changes traditional business models. Companies are now pursuing more intensive and interactive relationships with their business partners: suppliers and customers. Competitive conditions and pressures on global market are forcing companies to search for strategies of streamlining the entire value chain. To compete effectively, companies must structurally transform its internal and external processes. These goals could be reached by simultaneous renovation of business processes and implementation of electronic business solutions. Business Process Reengineering (BPR) is an organizational method demanding radical redesign of business processes in order to achieve more efficiency, better quality and more competitive production. BPR has become one of the most popular topics in organisational management creating new ways of doing business. Many leading organisations have conducted BPR in order to improve productivity and gain competitive advantage. However, regardless of the number of companies involved in re-engineering, the rate of re-engineering projects success is less than 50%. Some of the frequently mentioned problems related to BPR include the inability to accurately predict the outcome of a radical change, difficulty in capturing existing processes in a structured way, shortage of creativity in process redesign, the level of costs incurred by implementing the new process, or inability to recognize the dynamic nature of the processes. An e-commerce model generally means the adoption of company’s current business model to the Internet economy. Main purpose of developing and analysing business models is to find revenue and value generators inside reversible value chain or business model's value network. BPR in 90-s has been focused on internal benefits such as a cost reduction, downsizing of company and operational efficiency which is rather tactical then strategic focus. Nowadays, e-business renovation strategies put their focus on the processes between business partners and the applications supporting these processes. These strategies are designed to address different types of processes with the emphasis on different aspects: customer relationship management (CRM), supply chain management (SCM), selling-chain management and enterprise resource planning (ERP).

It is well known that e-commerce might bring several advantages to the company. However, existing practical business applications have not always been able to deliver the benefits they promise in the theory. Prior to adopting e-business, companies need to assess the costs needed for setting up and maintaining the necessary infrastructure and applications and compare it with the expected benefits. Although the evaluation of alternative solutions might be difficult, it is essential in order to reduce some of the risks associated with BPR projects.

Before implementing the e-commerce model we should know if the designed model works properly. For this verification process is often used the simulation. Simulation has an important role in modelling and analysing the activities in introducing BPR since it enables quantitative estimations of influence of the redesigned process on system performances. Simulation of business processes represents one of the most widely used applications of operational research as it allows understanding the essence of business systems, identifying opportunities for change, and evaluating the impact of proposed changes on key performance indicators. The design of business simulation models that will incorporate the costs and effects of e-commerce implementation and will allow for experimentation and analysis of alternative investments is proposed as a suitable tool for BPR projects. Some of the benefits can be directly evaluated and predicted, but the others are difficult to measure (intangible benefits).

5.1 Process oriented approach

Often used approaches to model the e-commerce systems are process and business oriented systems. Process oriented model will be used to describe the basic structure and data flow. Process modelling is one of the most cost-effective and rewarding ideas to come along in years. Many different techniques can be used for modelling business processes in order to give an understanding of possible scenarios for improvement. Flowcharting, IDEF0, IDEF3, Petri Nets, System Dynamics, Knowledge-based Techniques, Activity Based Costing and Discrete-Event Simulation are only some examples of business process modelling techniques widely used. There are also many software tools on the market using these modelling techniques. In terms of methods, we can use three ways of modelling. E-commerce systems can be modeled using process-oriented, value-oriented and/or multi-agents-oriented approaches.

The goal for process-oriented modelling is a specification of activities and their structure. Each activity can be looked upon as a process and decomposed into further ones until the set of single activities is reached. The activities do not come into being or exist independently from the environment. They are instigated by defined external or internal impulses or reasons. The basic elements of a process model include usually (Řepa, 2006):

- process;
- activity;
- initiative or instigation;
- relations among processes and activities.

Process oriented approach can be used for many purposes. As an example we can specify the model describing the activities taking place during the execution of transactions in the on-line shopping. A diagram of existing process could be seen on Fig. 3.

In many cases customers find and select a product in web-stores and then buy it later in traditional (physical) stores. The technique should be capable of representing one of more of the following modelling perspectives: functional (represents what activities are being performed), behavioural (represents when and how activities are performed), organizational (represents where and by whom activities are performed) and informational (represents the informational entities – data). (Bosilj-Vukšic et al., 2010)

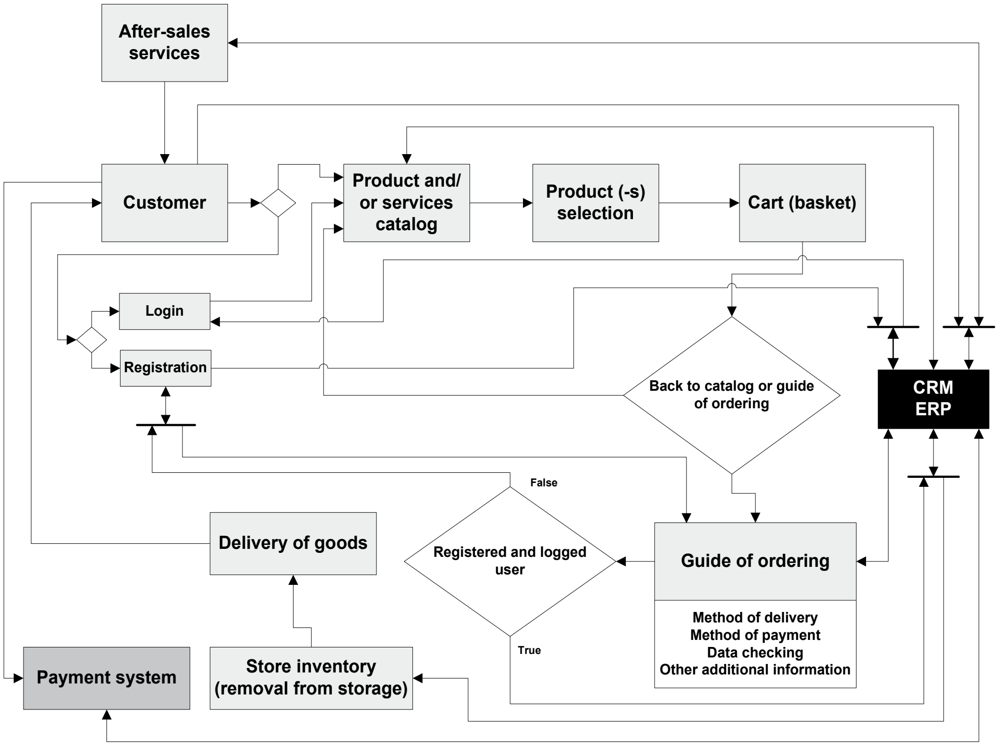

Fig. 3. Process model of e-commerce system

5.2 Value-chain oriented approach

Business oriented model works with value chains of business processes. It is used to define the methods and possibilities of e-commerce system. A Value Chain perspective, developed and introduced by Michael Porter (Porter, 1980) can be arranged as a series of input-output business processes with resource flows between them. (Dunn et. al., 2005), (Hruby, 2006). Value chain models deal with the participants of the value flow (customer, enterprise etc.); define the objects of value flow (like goods, services, cash) and types of economic events accomplishing the actual value flow itself. The basic difference to traditional business process models explains how processes happen by means of general process description concepts such as the activity, entity, process state, is that value chain models explain why processes happen in terms of the added value to the participants' entrepreneurial goals.

5.3 Multi-agents oriented approach

Another attitude to this activity brings the advantages of the model based on multi-agents oriented approach to model the e-commerce system and to validate it with simulation. (Vymětal, 2009) gives perfect example for using multi-agents simulation in business processes of a corporation. (Šperka, 2010) explains the advantages of multi-agents simulation methods for the increasing of the competitiveness of the enterprises. A multi-agent system is a system composed of multiple interacting intelligent agents. Multi-agent systems can be used to solve problems which are difficult or impossible for an individual agent or monolithic system to solve. Examples of problems which are appropriate to multi-agent systems research include online trading, (Rogers, 2007) disaster response, (Schurr, 2005) and modelling social structures. (Ron & Naveh, 2004) The agents in a multi-agent system have several important characteristics: (Wooldridge, 2004)

- **autonomy** - the agents are at least partially autonomous;
- **local views** - no agent has a full global view of the system, or the system is too complex for an agent to make practical use of such knowledge;
- **decentralization** - there is no designated controlling agent (or the system is effectively reduced to a monolithic system). (Panait & Luke, 2005)

Typically multi-agent systems research refers to software agents. However, the agents in a multi-agent system could equally well be robots, (Kaminka, 2004) humans or human teams. A multi-agent system may contain combined human-agent teams. Multi-agent systems can manifest self-organization and complex behaviors even when the individual strategies of all their agents are simple. Model based on multi-agents-oriented approach can be used to define the methods and possibilities of e-commerce systems simulation.

As above, in the area of e-commerce, multi-agent system (MAS) consists of various number of software components, called agents. An agent is an entity that is designed to undertake autonomous action on behalf of a user in pursuit of his desired goal. This implies that agents are intelligent and autonomous objects that are capable of behaving like a human being. Therefore agent technology is a suitable means for expanding business activities and saving cost. Agents possess some form of basic intelligence to allow decision-making or have a structured response to a given set of circumstances. These behaviour patterns are acquired from or given to the agent by the user, this enables the agent to be capable of flexible actions. Allowing it to exhibit good oriented and opportunistic behaviour to meet it's objective. Agents exist in an environment and can also respond to changes therein. Complex tasks can be broken down into smaller components that can each be the responsibility of an agent. They concentrate on their individual components, find optimal solution and combine their efforts by inter-agent communication. (Folorunso et al., 2006)

6. Parameters for describing models

Models can be described by a number of parameters which are often called key indicators. There are a number of indicators that can be measured and calculated and by which we can make a description of current e-commerce system performance. If we consider the sales system in the form of an internet shop (e-shop), fundamental question is what are the most important indicators and key numbers that can be used to measure the success or failure of internet-based sales, rather e-commerce system, and how can they be measured? Measurement is a very important thing, because in general, what can´t be measured, can´t be improved. In this context, objective will be the systemization of measurable key indicators, which are input values of DSS and BI.

Within e-commerce systems, measurements can be divided into the following types:

- performance measurement - measurement of technical parameters (for example web page load time, speed of processing user commands, speed reporting, etc.);
- usability testing – usability testing is done in laboratory conditions (for experienced users are set various tasks);

- measurement of the success – measurement of the success should answer the question how e-commerce system helps to meet company objectives. Outcomes of this measurement are used primarily to optimize and control.

Source data can be divided into next groups:

- operational characteristics – on the web interface there are, for example, number of displayed web pages, number of website visitors, in connection with the information system there can be, for example, number of successfully completed transactions, number of failed transactions (may be associated with system disturbances), etc.;
- customer data – data relate primarily to demographic characteristics of visitors and their preferences (city listed in the order, city listed in the query or demand, gender of customer, etc.);
- transactional data – data directly related to the sale of goods or services. These data are the basis for financial analysis. (average order value);
- data from other sources - other data relating to consumer behaviour in the website.

6.1 Key indicators of websites success and performance

One of the technologies used for the web indicators measurement is so called clickstream. (Sweiger et al., 2002) The result of clickstream analysis may be two groups of characteristics. Outputs belonging to the first group are data representing the operating characteristics (for example number of pages viewed, number of unique IP addresses, etc.), the second group consists of characteristics of a commercial nature (cross-selling analyses, abandonment of the shopping cart, number of the orders, etc.). Other outputs, which are the numbers of orders, inquiries, etc. are processed and analyzed in the context of CRM and ERP. In these systems some specific business cases and business activities are already processed. Generally, on the website, measurements can be realized with help of traffic volume measurement from panels, TCP/IP packet sniffing, direct server measurement, browser based measurement, server-based measurement or internet traffic measurement.

The first group of parameters includes the key indicators for the measurement of the e-commerce system success. In this case, the input data are the number of days (time period), site visits (unique visits), number of demands received from the web, number of orders received from the web, number of users who have made an order, and data from CRM and ERP (amount of orders – revenue, margin orders).

Based on these input data, there can be made the calculations, from which we can obtain sales (total orders), margin (after deduction of all costs), conversion ratio of demands, conversion ratio of orders, average value per order, average returns per customer, average number of order per customer, average margin of one order, average margin per customer, average returns per visit, average margin per demand, and average margin per visit. These indicators are used for the basic analysis and are very important for the management activities related to the sale, planning and finance.

Web interface is usually a part of a CRM system that is connected with the ERP. CRM and ERP are the information systems that are at the core of the enterprise informatics. The indicators from this group belongs to the area of IS/IT. The basic indicators for the proper operation of the information system are: system availability, average response time, breakdown intensity, breakdown rate, average download time, failure rate.

The integral part of the enterprise information system is created by its users at all levels of the corporate activities, and in particular, of the management. Each user carries out various activities, while each of them constitutes interference in the system. In this context, there are indicators that can be included in the administrative field, partly in the area of security and personnel. In this group of indicators, there can be included: number of correct user intervention, number of incorrect user intervention (for example, it may be related to poor secure system, inappropriate user interface, incompetence users), number of system administrator intervention (corrections system) and number of users involved in processing by one commercial transaction.

Another important area is the logistics. The logistics is a channel of the supply chain which adds the value of time and place utility. The basic indicators tracked in this area are: product availability, number of successfully delivered products, number of unsuccessfully delivered products (for example customer entered incorrect address or error occurred at the side of vendor or carrier), average length of warranty service, storage costs, cost to deliver goods, average delivery time of goods, number of cooperating suppliers offering the same goods.

The Internet has allowed the development of the new methods of marketing that provide very important information useful for the management support and the planning. In this area, the important key indicators are: number of unique customers, average visit frequency, number of repeat customers, margin per customer, number of first buyer, average sales per repeat customers, average order value per repeat customer, market share, percentage share of new vs. returning visitors, average conversion rate, average time spent on the website, average number of pages displayed per visit, percentage share of returns (one page visits), average number of clicks on adverts. One of the key methods of e-marketing is a campaign. For example, in the campaigns we can trace percentage share of visits according to the type of campaign and percentage share of conversion rate according to the type of campaign. These values are the basis for the determination of index of campaign quality.

The e-commerce systems are implemented with a goal to expanse the sales channels, and thus to increase the profits. In this context, the important general indicator is the return on investments (ROI). To calculate ROI in the web projects, we can use, inter alia, an online calculator on the website. In this case, the source data can include: number of days (time period), regular fixed cost (the cost of webhosting, salary, etc.), cost per customer acquisition, the current daily visit site, the current conversion ratio of orders, the percentage increase of conversion ratio due to investments, percentage increase of average order value due to investments, estimated average order value increase after, the current average margins, the percentage increase of average margins due to investment, and estimated average margin value increase after.

Using these data, we can calculate: number of visitors, number of orders, yields, margins, fixed costs, direct cost of acquiring visitors, profit, profit per days, and return on initial investments.

6.2 Data in e-commerce systems

E-commerce system produces a huge amount of data collection. Data has potentially great value. Data must be accepted, processed and appropriately presented. This is the main prerequisite for successful management. To adopt a right decision, managers have to get correct information in right time. In connection with e-commerce and especially online selling, source system of data set is extended. With a view to minimization of failure during the domestic and cross-border online selling, it is necessary to allow for many factors. Besides typically economic indicators, source information of management systems have to be for example legislation, culture, conventions etc. (see Fig. 2)

Data can be processed by the using of ICT and then may be obtained from them valuable information for decision-making. We can find new customer segments, analyze trends or uncover new business opportunities. Business intelligence solutions are used for the purposes of advanced data analysis and search for hidden dependencies. Business intelligence aims to support better business decision-making and also can be helpful in process of retaining existing customers and acquiring new customers. In next part of this chapter will be mentioned more about BI.

7. Business intelligence

It's common knowledge that Decision Support Systems are a specific class of computerized information system that supports business and organizational decision-making activities. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from raw data, documents, personal knowledge, and/or business models to identify and solve problems and make decisions. But what about so-called intelligence decision support system? What should this type of systems meet the requirements? From our perspective, an intelligent decision support system is a system containing BI tools. Business Intelligence is a term that refers to the sum total, or effect, of gathering and processing data, building rich and relevant information, and feeding it back into daily operations so that managers can make timely, effective decisions and better plans for the future. Generally business intelligence brings to managers a quite number of advantages. The advantages enjoyed by market leaders and made possible by business intelligence include the high responsiveness of the company to the needs of its customers, recognition of customer needs, ability to act on market changes, optimization of operations, cost-effectiveness, quality analysis as the basis for future projections, the best possible utilization of resources etc.

Business intelligence is oriented to the management needs and decision making support. Optimal setting of control processes is a prerequisite of the planned and expected aims. Business processes are the collections of activities designed to produce a specific output for a particular customer or market. It implies a strong emphasis on how the work is done within an organization, in contrast to a product's focus on what. To do right decisions, managers need information. Data that is relevant to a business decision may come from anywhere. The most important sources of data include: (Suchánek, 2010a)

- Master data - this is data collected (usually once and once only) to define the entities in an e-business system (customer file, product file, account codes, pricing codes, etc...). Scores of the time we can meet with term of Master Data Management (MDM). MDM comprises a set of processes and tools that consistently define and manage the non-transactional data entities of an organization (which may include reference data).
- Configuration data - as the term implies this is data defining the nature of the system itself. The system is configured to reflect the nature and needs of the business.
- Operations data (OLTP - Online Transaction Processing) - also known as activity. This data is generated by daily business activities such as sales orders, purchase orders, invoices, accounting entries, and so on. OLTP refers to a class of system that facilitates and manages transaction-oriented applications, typically for data entry and retrieval transaction processing.

Information systems (OLAP - Online Analytical Processing) - these are sophisticated applications collecting information from various internal and external sources to analyze data and distill meaningful information. OLAP software is used for the real-time analysis of data stored in a database. The OLAP server is normally a separate component that contains specialized algorithms and indexing tools to efficiently process data mining tasks with minimal impact on database performance.

Almost all requisite data for the decision making support in e-commerce comes from CRM and ERP systems. Business intelligence is closely related to data warehousing. Data has to be processed (data selection, data analysis, data clearing etc.) and sent in right time and in required form to the competent person usually acting in management system. (Fig. 4) Obtained data are basis for decision making support at all levels and kinds of management.

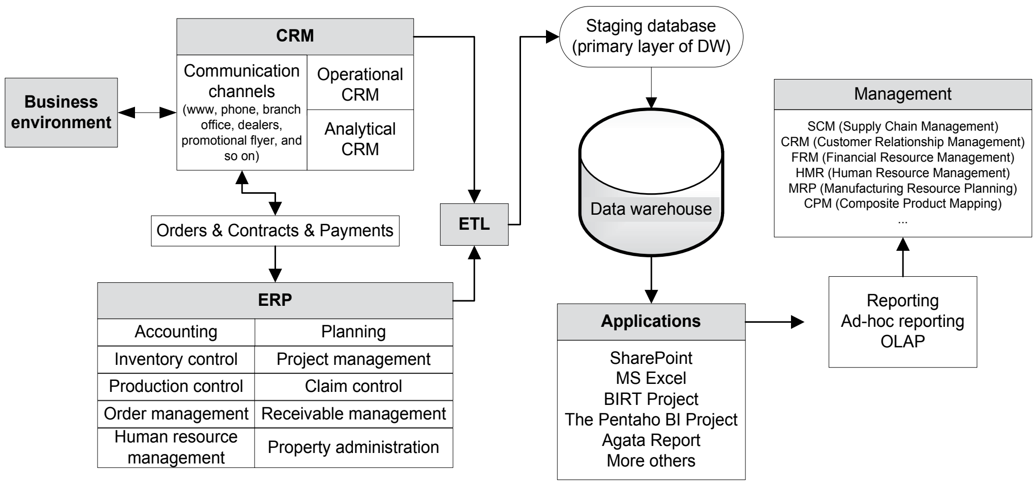

Fig. 4. Business intelligence system. Source: Suchánek, 2010a.

Data processing is supported by ETL (Extraction, Transformation and Loading). The ETL process is also very often referred to as Data Integration process and ETL tool as a Data Integration platform. The terms closely related to and managed by ETL processes are: data migration, data management, data cleansing, data synchronization and data consolidation. (ETL-Tools.Info, 2009)

The purpose of the Data Warehouse in the overall Data Warehousing Architecture is to integrate corporate data. Data warehousing evolved through 1990s to environments that typically featured batch-oriented “stocking” and “restocking” of the data warehouse, primarily for purposes of after-the-fact reporting and analysis. (Simon & Shaffer, 2001) The amount of data in the data warehouse is massive. Data is stored at a very granular level of detail. For example, every sale that has ever occurred in the organization is recorded and related to dimensions of interest. This allows data to be sliced and diced, summed and grouped in unimaginable ways. Recent technological advancements in data warehousing have been contributing to the emergence of business intelligence useful for managerial decision making. (Taniar, 2009)

BI applications are for example SharePoint, MS Excel, BIRT Project, The Pentaho BI Project, Agata Report and many others (some of applications can be interconnected). These applications are fundamental interface between system and managers. With the aid of shown application users can choose and manipulate a wide variety of visual representations, including map-based data displays to review business intelligence reporting results geographically, multidimensional scatter plots to view data statistically, and bar charts, pie charts, line graphs, profile charts and more. At present, when the world economic conditions are not affable, companies look for all information which would help them to start economic growth. In this respect e-commerce companies have recently started to capture data on the social interaction between consumers in their websites, with the potential objective of understanding and leveraging social influence in customers' purchase decision making to improve customer relationship management and increase sales. (Young & Srivastava, 2007)

Business intelligence systems are able to provide the managers quite a number of statistics dealing with customers and their environment. As important customer statistics can be considered, for example, matching sales revenues with site visitor activity, by week and month, in total and by product line, matching weekly and monthly sales with site visitor activity over time (trend analysis), in total and by product line, matching sales revenues with site visitor activity, by day and hour, in total and by product line (to measure the effectiveness of advertising campaigns), matching sales revenues with site visitor activity from main referrers, by week and month, in total and by product line. Where the referrer is a search engine, also matching the search query with sales revenues. These statistics respond the managers to questions:

- Who did buy?
- How much did they buy?
- When did they buy?
- What did they buy?
- From where customers arrived at the site?
- In which region customer are located?
- How they arrived at the site (e.g. by what search engine query)?
- From which page customer entered the site?
- What is their path through the site?
- From which page customer left the site?
- On a weekly and monthly basis and the trends, over time.

Advantages and benefits of business intelligence in the sphere of e-commerce can be summarized as:

- Business intelligence gives any firm the specific view of corporate data that is required for progress (quickly access sales, product and organizational data in any database).
- In sales and marketing, business intelligence offers new tools for understanding customers' needs and responding to market opportunities
- By providing financial planners with immediate access to real-time data, Business Intelligence builds new value into all financial operations including budgeting & forecasting.
- Business intelligence supports decision-making with automatic alerts and automatically refreshed data.
- Business intelligence provides performance monitoring for accelerated action and decision making.
- Business intelligence makes companies possible to receive and process data from cross-border business activities (above all from cross-border online shopping).
- Business intelligence can bring to companies competitive advantage.

Besides data from business intelligence systems, companies can use services of the consultation companies. There are many consultation companies providing information and doing analyses. Correct source information are necessary, but usually have to be paid for. There are many sources providing statistical data on the Internet, but these are usually not adequate. Managers can acquire correct information from the many sources. (Molnár, 2009) Following sources supply the attested information usable for manager´s decision making in the global markets. Foreign stock market information can be found on (for example):

- http://www.bloomberg.com;
- http://www.dowjones.com;
- http://www.nyse.com;
- http://www.nasdaq.com;
- http://www.reuters.com;
- http://money.cnn.com;
- http://www.imrworld.org/;
- http://finance.yahoo.com/;
- http://www.marketwatch.com/;
- http://www.indiainfoline.com/.

Marketing information can be found on (for example):

- http://www.formacompany.ie;
- http://reports.mintel.com/;
- http://www.eiu.com;
- http://www.frost.com;
- http://www.adlittle.com;
- http://www.datamonitor.com;
- http://www.euromonitor.com/.

Law and legislative information can be found on (for example):

- http://www.iblc.com/home/;
- http://www.iblc.com/;
- http://www.ibls.com/;
- http://www.enterweb.org/law.htm;
- http://euro.ecom.cmu.edu/resources/elibrary/ecllinks.shtml.

Properly implemented BI tools into the DSS in conjunction with multi-agents-oriented approach enable the implementation of simulation methods. Simulation can be described as a technologically and logically the highest level of decision-making support. DSS allows simulation can fit neatly into the category of intelligent DSS.

The reasons for the introduction of simulation modelling into process modelling can be summarized as follows (Bosilj-Vukšic et al., 2010):

- simulation enables modelling of process dynamics;
- influence of random variables on process development can be investigated;
- anticipation of reengineering effects can be specified in a quantitative way;
- process visualization and animation are provided;
- simulation models facilitate communication between clients and an analyst.

In this context, in the following section, we will present an example of simulations that can be carried out within the e-commerce system.

8. Simulation of e-commerce systems

Simulation is generally defined as a method to analyze the behavior of complex systems by monitoring the behavior of the model (currently in particular computer model). Simulation system can be described as intelligent decision support systems. Simulation system must take into account all the areas described in the preceding sections. Simulation system should allow to enter input parameters which are analyzed by the system. The resulting output parameters describe the state of the system under the conditions of entry.

8.1 Control loop as the default model of simulation system

A suitable way can be a system simulation based on the control loop (Fig. 5).

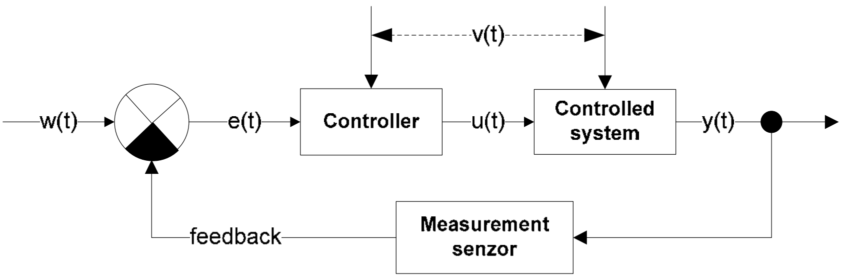

Fig. 5. Control loop

Key to figure: w(t) – desired value; e(t) – controller error (w(t) – value of feedback); u(t) – manipulated variable; y(t) – process variable (output value); v(t) - disturbances
Diagram in Figure 5 can be used as a starting model for a generic model of e-commerce system (Fig. 6). A similar, much simpler model can be found for example in (Wolf, 2006).
Model in Figure 6 can be used to create realistic simulation models based on software support. Input variables (desired value) represent the input data of simulation. This data can be entered by the user manually or automatically generated for example by genetic algorithms when the user only sets the initial conditions (criteria).

8.2 Integration of simulation into the management structure

For a comprehensive description of the architecture and design of simulation system three layers can be used (Fig. 7). There is a layer of management control activities primarily focused on real activity. The default values used in the simulations as a comparative are contained in the plan. Real regulatory interventions are implemented after their verification in the simulation layer. In the layer of simulations we can perform simulations based on all types of models (process oriented, value-chain oriented, multi-agents). Assuming the correct model and mathematical description, this system may help managers to test some of the assumptions on which it can be effective decisions.
As we can see in Figure 7, simulation system should be integrated into the overall management system. Whereas, for the purposes of simulation software tools are used, integration of simulation into the management system is becoming increasingly easier. Economic system simulations are used increasingly. Reason is the advantages of simulation, which can be facts, that simulations are able to provide users with practical feedback when designing real world systems; simulations permit system designers to study a problem at several different levels of abstraction and/or simulators can be used as an effective means for teaching or demonstrating concepts to students.

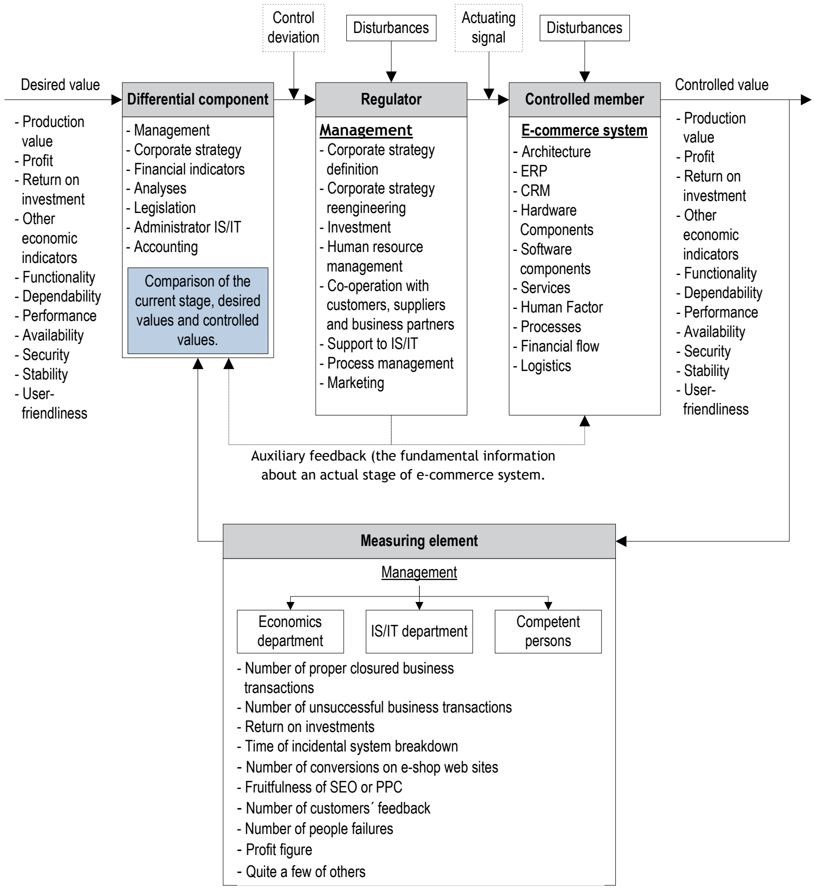

Fig. 6. Generic e-commerce model

9. Conclusion

E-commerce systems are fundamental aids of online shopping. These systems are focused on customer needs and requirements. E-commerce systems are large systems and produce a huge amount of data collection particularly data related to the behavior of customers. Data has potentially great value for management and decision making support. Data must be accepted, processed and appropriately presented using appropriate tools. Only modern software tools can provide data quickly and with the required quality. Modern software tools for processing large data collections are BI and DSS systems. Development of e-commerce systems places increasing emphasis on the need to create models of these systems. The modelling of e-commerce systems can be effectively done by use of a process-oriented approach, value-oriented approach or approach based on multi-agents systems. The main difference between process modelling and value chain modelling is that process modelling specifies "How" a process is realized and implemented, while value chain modelling specifies "Why" the process occurs in terms of added value to the process participants. Multi-agents approach is primarily used to support simulation.

Simulations more often help the managers implement viable plans and adequate management activities. Simulation system can be described as intelligent decision support systems. Important is that the simulation system would be integrated into the management system as an automatic or semiautomatic system.

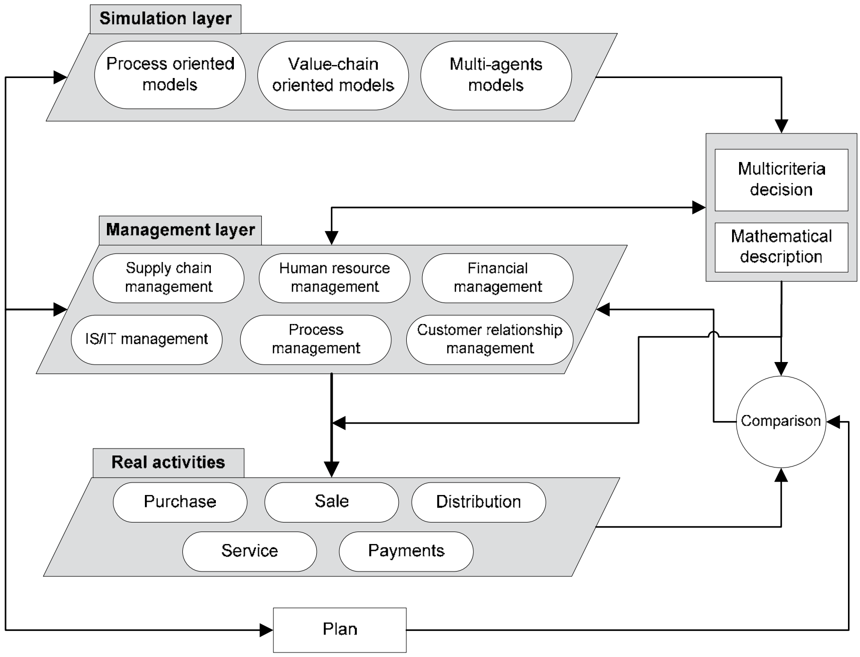

Fig. 7. The model links management layers, real activities and simulations

10. Acknowledgment

Chapter's content is based on the outputs of the project SGS/24/2010 - Use of BI and BPM to support effective management (project is carried out at The Silesian University in Opava, School of Business Administration in Karviná – Czech Republic).

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7

Quick Response in a Continuous-Replenishment-Programme Based Manufacturer-Retailer Supply Chain

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1. Introduction

With the widespread concept of partnership in supply chain management, the traditional replenishment process is fast giving way to the Quick Response (QR) and Continuous Replenishment Programme (CRP). QR is a movement in industries to shorten the replenishment lead time which is critical to reduce inventory level and improve the levels of customer service. Wal-Mart, Seven-Eleven Japan, and many other retailers apply tremendous pressure on their suppliers to reduce the replenishment lead time (Chopra and Mendil 2007). CRP is an efficient replenishment initiative which focuses on removing excess inventory throughout the pipeline and synchronizes demand with production (EAN International 2000). In CRP, the inventory of retailer is planned, monitored, and replenished by the supplier on behalf of the consumers. To enable CRP, sales data and inventory level of the retailer must be provided to the supplier via Electronic Data Interchange (EDI) or other electronic means. Thus, to successfully implement CRP requires the supplier and the retailer to work in a cooperative manner based on mutual trust and joint gains.

The lead time is needed for several operations among trading parties, such as ordering, manufacturing, delivering, and handling. In practice, lead time can be shortened with extra crashing costs. Many researchers have studied the inventory decision incorporating lead time reduction under various assumptions. For example, Liao and Shyu (1991) first developed an inventory model in which lead time was the unique decision variable. Ben-Daya and Raouf (1994) extended the previous model by including both lead time and order quantity as decision variables. Pan and Yang (2002) and Pan and Hsiao (2005) considered lead time crashing cost as a function of both the order quantity and the reduced lead time. Since the reduction of lead time may involve with the vendor and the buyer to improve the related operations, a dyadic vendor-buyer viewpoint for shortening lead time is often suggested. For instance, Iyer and Bergen (1997) compare the profits of a single vendor and a single buyer supply chain before and after QR based on a newsboy inventory model. Ben-Daya and Hariga (2004), Ouyang et al. (2004), Chang et al. (2006), and Ouyang et al. (2007)

investigated the decision of lead time reduction in a context of a single-vendor-single-retailer integrated inventory system, in which the possibility of stockout of the supplier was ignored.

The study of inventory decision of CRP based inventory systems was initiated by Goyal (1976) by presenting a joint economic lot-size model for a supplier and a retailer. Subsequently, many researchers investigated this issue under various assumptions. For example, Banerjee (1986) generalized the model of Goyal (1976) by incorporating a finite replenishment rate for the supplier. Goyal (1988) extended Banerjee's work by relaxing the lot-for-lot policy for the supplier and assumed that the supplier's lot size is an integral multiple of retailer's order quantity. Goyal and Srinivasan (1992) further extended the model by relaxing the assumption that the supplier can supply to the retailer only after completing the entire production lot. At the same time, Banerjee and Banerjee (1992) extended the study of integrated inventory control to a multiple-retailer case by considering that the supplier delivers items to several buyers at a coordinated common cycle time. Banerjee and Banerjee (1994) generalized their previous model by dealing with the normally distributed demand case and assuming a fixed shortage cost attributable to each stockout incident.

To understand the effects of QR on the CRP based supply chains, we build a formal model of lead time reduction and replenishment decisions for a supply chain consisting of a manufacturer and multiple retailers in which the inventory throughout the supply chain is managed in a CRP context. The model extends the work of Banerjee and Banerjee (1994) by including the ordering cost and adopting QR with the expenditure regarded as a function of the reduced lead time. In stead of explicitly estimating the shortage cost, a service level constraint (SLC) approach is applied to the problem for which may skirt the difficult practical issue of explicitly determining the shortage cost (Chen and Krass 2001). According to the definition in Ouyang and Chuang (2000), the service level in this study is measured by the expected fraction of demand met from inventory on hand in an inventory cycle. The objective of the model is to determine the common shipment cycle time and the replenishment lead time for the retailers, the manufacturer's production cycle time, and the target levels of replenishment for the manufacturer and each retailer so that the expected total system cost can be minimized under the service level constraint.

2. Notations and assumptions

To develop the proposed models, we adopt the following notation which is principally the same as that in Banerjee and Banerjee (1994):

n = total number of retailers;

d_i = demand rate of retailer i, which follows a probability density function (p.d.f.) $f_i(d_i)$ with mean D_i and variance σ_i^2 , i =1, 2,…, n;

h_i = carrying cost per unit per year for retailer i (\$/unit/year);

h_v = carrying cost per unit per year for the manufacturer (\$/unit/year);

l = length of lead time for retailers (year), a decision variable;

x_i = demand during the protection period (T+l) on retailer i, which has a p.d.f. $f_{i\,T+L}(x_i)$ with the mean $D_i(T+l)$ and the variance σ_i^2 (T+l);

y = demand during the production cycle time of KT on manufacturer, which has a p.d.f. $g(y)$ with the mean $KT\sum_{i=1}^{n} D_i$ and the variance $KT\sum_{i=1}^{n}\sigma_i^2$;

z_i = safety factor for retailer i with $z_i \geq 0$;

z_v = safety factor for the manufacturer with $z_v \geq 0$;

a_i = the threshold of retailer i's service level, $0 \leq a_i \leq 1$;

a_v = the threshold of manufacturer's service level, $0 \leq a_v \leq 1$;

A = setup cost for the manufacturer ($/per setup);

C = common ordering cost shared by all retailers ($/per order);

C_i = individual ordering cost for retailer i ($/per order);

$C_r(l)$ = lead-time crashing cost per order;

P = production rate of manufacturer, which is a known constant;

D = $\sum_{i=1}^{n} d_i$, total demand from all the retailers on the manufacturer per year, which has mean $\sum_{i=1}^{n} D_i$ and variance $\sum_{i=1}^{n}\sigma_i^2$. Note that, of necessity, $P > \sum_{i=1}^{n} D_i$;

K = integral number of shipments to retailers per manufacturer's production cycle, which is a decision variable with $K \geq 1$;

S_i = replenish-up-to level after placing a new order for retailer i, a decision variable;

S_v = produce-up-to level after placing a new manufacture order for the manufacturer, a decision variable;

T = common shipment cycle time to all retailers (year), a decision variable;

EC_i = the expected annual inventory cost for retailer i;

EC_v = the expected annual inventory cost for the manufacturer;

ETC = the expected annual total cost for the system.

The major assumptions made in this study are the following:

1. In the CRP context, the manufacturer plans, monitors, and replenishes the inventory of retailers based on the information of sales data and inventory level provided by all the retailers to minimize the expected annual total cost of the supply chain.
2. The demand rate of each retailer is independently distributed.
3. Each production lot of the manufacturer will be delivered in an integral number, K, of shipments to all retailers periodically.
4. The target level of replenishment of S_i units for retailer i is equal to the sum of retailer i's expected demand during the protection period, $D_i(T+l)$, and the safety stock, where safety stock = $z_i\sigma_i\sqrt{T+l}$.
5. The target level of production of S_v units for the manufacturer is equal to the sum of manufacturer's expected demand during the production cycle, $KT\sum_{i=1}^{n} D_i$, and safety stock, where safety stock = $z_v\sqrt{KT\sum_{i=1}^{n}\sigma_i^2}$.
6. For each order, a common ordering cost C is incurred to and shared by all retailers and an individual ordering cost C_i is incurred to the retailer i.
7. The manufacturer incurs a setup cost A for each production run.

8. The service level measures, i.e., fraction of demand met per cycle, for the retailer i and for the manufacturer are defined as $1-\frac{E(x_i-S_i)^+}{D_i(T+l)}$ and $1-\frac{E(y-S_v)^+}{KT\sum_{i=1}^{n}D_i}$, respectively.
9. The expenditure for implementing QR is modeled as the lead-time crashing cost per order, $C_r(l)$, and is assumed to be a non-increasing stairstep function of l, such as:

$$C_r(l)=\begin{cases}0 & l=l_0,\\ r_1 & l_1\le l<l_0,\\ \vdots & \vdots\\ r_b & l_b\le l<l_{b-1},\end{cases}$$

where l_0 and l_b represent the existing and the minimal length of lead times, respectively. This cost could be expenditure on equipment improvement, order expediting, or special shipping and handling.

3. Model development and solution

Figure 1 depicting the inventory time plots for a manufacturer and n retailers, illustrates the CRP based inventory control system proposed in this work. For the retailer i, there is a target level of replenishment of S_i units. For the manufacturer, there is a target level of production of S_v units. Given a common shipment cycle time of T years, the manufacturer produces a batch of item every KT years. After the Kth shipment cycle since the beginning of the last production cycle, the manufacturer begins the production of another lot DT/P years prior to the next scheduled shipment time, as shown in Figure 1, which is illustrated the case of K =3. In order to cope with a stochastic demand, all of the trading parties carry safety stocks.

The demand during the protection period for retailer i is assumed to be normally distributed with mean $D_i(T+l)$ and standard deviation $\sigma_i\sqrt{T+l}$. Then, the total demand from all retailers on the manufacturer during a production cycle of KT is normally distributed with the mean $KT\sum_{i=1}^{n}D_i$ and the standard deviation $\sqrt{KT\sum_{i=1}^{n}\sigma_i^2}$. For the retailer i, with a cycle of T, a replenishment lead time of l, and a target level of S_i, the expected net inventory level just before receipt of an order is given by S_i–D_il–D_iT and the expected net inventory level immediately after the successive order is S_i–D_il. Then, the average inventory over the cycle is approximated by $\frac{1}{2}\left[\left(S_i-D_il-D_iT\right)+\left(S_i-D_il\right)\right]$. According to the fourth assumption, the target levels of replenishments, S_i, is set as

$$S_i=D_i\left(T+l\right)+z_i\sigma_i\sqrt{T+l}\,. \tag{1}$$

So that the retailer i's expected annual carrying cost is

$$\frac{h_i}{2}\left[\left(S_i-D_il-D_iT\right)+\left(S_i-D_il\right)\right]=h_i\left(S_i-D_il-\frac{D_iT}{2}\right)=h_i\left(\frac{D_iT}{2}+z_i\sigma_i\sqrt{T+l}\right).$$

The annual individual ordering cost incurred to retailer i is C_i/T. Then, the expected annual inventory cost for all retailers, consisting of common ordering cost, individual ordering cost, and carrying cost, is given by

$$\sum_{i=1}^{n} EC_i = \frac{1}{T}\left(C + \sum_{i=1}^{n} C_i\right) + \sum_{i=1}^{n} h_i\left(\frac{D_i T}{2} + z_i\sigma_i\sqrt{T+l}\right).$$

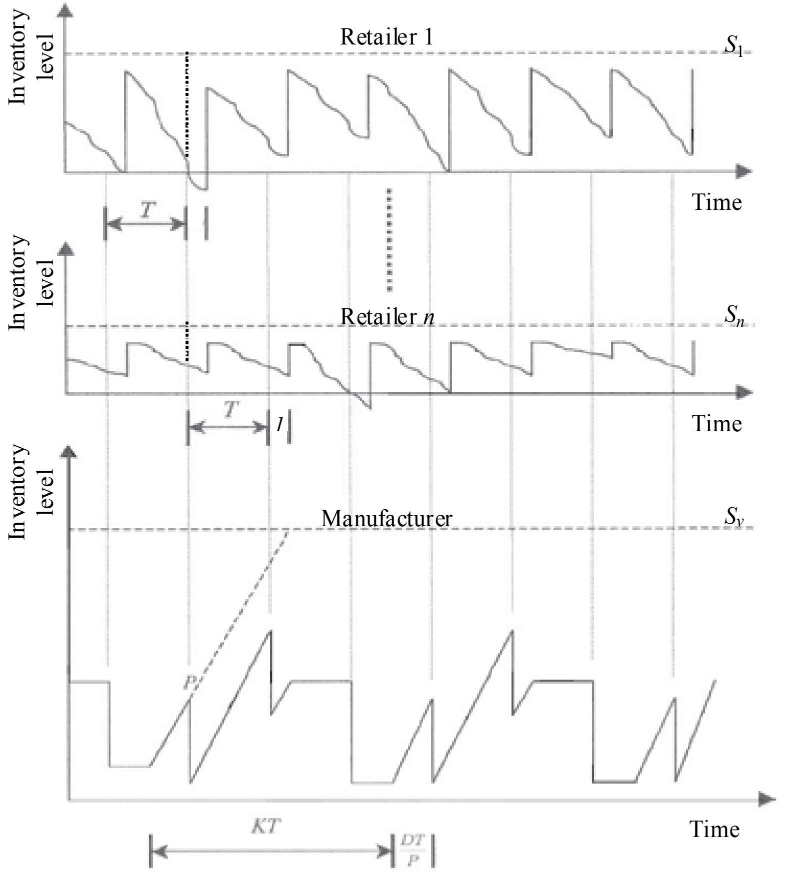

Fig. 1. Inventory levels for a manufacturer and multiple retailers under a coordinated common shipment cycle time

Based on the fifth assumption, the target levels of replenishments, S_v, is set as

$$S_v = KT\sum_{i=1}^{n} D_i + z_v\sqrt{KT\sum_{i=1}^{n}\sigma_i^2}\ . \tag{2}$$

According to Banerjee and Banerjee (1994) with Eq. (2), the manufacturer's average inventory can be derived as

$$\frac{\sum_{i=1}^{n} D_i T}{2}\left[\frac{\sum_{i=1}^{n} D_i}{P}(2-K)+K-1\right]+S_v-KT\sum_{i=1}^{n} D_i=\frac{\sum_{i=1}^{n} D_i T}{2}\left[K\left(1-\frac{\sum_{i=1}^{n} D_i}{P}\right)+\frac{2\sum_{i=1}^{n} D_i}{P}-1\right]+z_v\sqrt{KT\sum_{i=1}^{n}\sigma_i^2}.$$

Then, the manufacturer's expected annual inventory cost is given by

$$EC_v=\frac{A}{KT}+h_v\left\{\frac{\sum_{i=1}^{n} D_i T}{2}\left[K\left(1-\frac{\sum_{i=1}^{n} D_i}{P}\right)+\frac{2\sum_{i=1}^{n} D_i}{P}-1\right]+z_v\sqrt{KT\sum_{i=1}^{n}\sigma_i^2}\right\},$$

where the first term represents the average annual setup cost and the second term is the average carrying cost.

Based on the service level measure defined in Ouyang and Chuang (2000), the following service level constraints are specified:

service level constraint on retailer $i = 1-\frac{\int_{S_i}^{\infty}(x_i-S_i)f_{i\ T+l}(x_i)dx_i}{D_i(T+l)} \ge a_i$, i =1, 2,…, n, (3)

service level constraint on the manufacturer $= 1-\frac{\int_{S_v}^{\infty}(y-S_v)g(y)dy}{KT\sum_{i=1}^{n} D_i} \ge a_v$. (4)

As the demand is normally distributed, (3) and (4) can be rewritten as (see Appendix for proof):

service level constraint on retailer $i = \phi(z_i)-z_i\Phi(z_i)-\frac{(1-\alpha_i)D_i\sqrt{T+l}}{\sigma_i} \le 0$, i =1, 2,…, n, (5)

service level constraint on the manufacturer $= \phi(z_v)-z_v\Phi(z_v)-\frac{(1-\alpha_v)\sqrt{KT}\sum_{i=1}^{n} D_i}{\sqrt{\sum_{i=1}^{n}\sigma_i^2}} \le 0$, (6)

where $\phi(z)$ and $\Phi(z)$ represent the standard normal distribution and the complementary cumulative normal distribution function, respectively. The expected annual total cost for the system, comprising the expected annual inventory costs for all parties and the lead time crashing cost, is given by

$$ETC(K, T, l, \underline{z}, z_v) = \sum_{i=1}^{n} EC_i + EC_v + \frac{C_r(l)}{T}$$

$$= \frac{C + \sum_{i=1}^{n} C_i + \frac{A}{K} + C_r(l)}{T} + T\left\{ \frac{h_v \sum_{i=1}^{n} D_i}{2} \left[K\left(1 - \frac{\sum_{i=1}^{n} D_i}{P}\right) + \frac{2\sum_{i=1}^{n} D_i}{P} - 1 \right] + \sum_{i=1}^{n} \frac{D_i h_i}{2} \right\}$$

$$+ h_v z_v \sqrt{KT \sum_{i=1}^{n} \sigma_i^2} + \sum_{i=1}^{n} h_i z_i \sigma_i \sqrt{T + l}\ , \qquad (7)$$

where the vector $\underline{z} = \{z_1, z_2, \ldots, z_n\}$. Then, the decision is to minimize $ETC(K, T, l, \underline{z}, z_v)$ under the constraints (5) and (6).

In order to solve the nonlinear programming problem, the following propositions are needed.

Proposition 1. For any given K, T, $\underline{z}$, and z_v, the minimal ETC will occur at the end points of the interval $[l_{j+1}, l_j]$ when $C_r(l)$ is a stairstep function.

Proof:

As $C_r(l)$ is a stairstep function, $\frac{\partial^2 C_r(l)}{\partial l^2} = 0$ for any l in a continuous interval $[l_{j+1}, l_j]$. The second derivative of (7) with respect to l is equal to

$$\frac{\partial^2 ETC}{\partial l^2} = \frac{1}{T}\frac{\partial^2 C_r(l)}{\partial l^2} - \frac{\sum_{i=1}^{n} h_i z_i \sigma_i}{4\sqrt{(T+l)^3}} < 0$$

for any l in a continuous interval $[l_{j+1}, l_j]$. Therefore, the proposition holds.

Proposition 2. For any fixed K, l, $\underline{z}$, and z_v, there is a unique optimal T to ETC in (7).

Proof:

For any given K, l, $\underline{z}$, and z_v in a continuous interval $[l_{j+1}, l_j]$, a necessary condition for a solution of T to be optimal for (7) is

$$\frac{\partial ETC}{\partial T} = \frac{C + \sum_{i=1}^{n} C_i + \frac{A}{K} + C_r(l)}{-T^2} + \frac{h_v \sum_{i=1}^{n} D_i}{2}\left[K\left(1 - \frac{\sum_{i=1}^{n} D_i}{P}\right) + \frac{2\sum_{i=1}^{n} D_i}{P} - 1 \right]$$

$$+ \frac{\sum_{i=1}^{n} D_i h_i}{2} + \frac{h_v z_v \sqrt{K \sum_{i=1}^{n} \sigma_i^2}}{2\sqrt{T}} + \frac{\sum_{i=1}^{n} h_i z_i \sigma_i}{2\sqrt{T+l}} = 0.$$

The above equation can be rearranged as

$$\frac{C+\sum_{i=1}^{n}C_i+\frac{A}{K}+C_r(l)}{T^2}=\frac{h_v\sum_{i=1}^{n}D_i}{2}\left[K\left(1-\frac{\sum_{i=1}^{n}D_i}{P}\right)+\frac{2\sum_{i=1}^{n}D_i}{P}-1\right]+\sum_{i=1}^{n}\frac{D_ih_i}{2}+\frac{h_vz_v\sqrt{K\sum_{i=1}^{n}\sigma_i^2}}{2\sqrt{T}}+\frac{\sum_{i=1}^{n}h_iz_i\sigma_i}{2\sqrt{T+l}}. \tag{8}$$

Let T_f be the solution to (8). Then, the second derivative of (7) at T_f satisfies

$$\frac{\partial^2 ETC}{\partial T^2(T_f)}=\frac{2\left(C+\sum_{i=1}^{n}C_i+\frac{A}{K}+C_r(l)\right)}{T_f^3}-\frac{h_vz_v\sqrt{K\sum_{i=1}^{n}\sigma_i^2}}{4T_f^{3/2}}-\frac{\sum_{i=1}^{n}h_iz_i\sigma_i}{4\left(T_f+l\right)^{3/2}}$$

$$=\frac{2}{T_f}\left\{\frac{h_v\sum_{i=1}^{n}D_i}{2}\left[K\left(1-\frac{\sum_{i=1}^{n}D_i}{P}\right)+\frac{2\sum_{i=1}^{n}D_i}{P}-1\right]+\sum_{i=1}^{n}\frac{D_ih_i}{2}+\frac{h_vz_v\sqrt{K\sum_{i=1}^{n}\sigma_i^2}}{2\sqrt{T_f}}+\frac{\sum_{i=1}^{n}h_iz_i\sigma_i}{2\sqrt{T_f+l}}\right\}-\frac{h_vz_v\sqrt{K\sum_{i=1}^{n}\sigma_i^2}}{4T_f^{3/2}}-\frac{\sum_{i=1}^{n}h_iz_i\sigma_i}{4\left(T_f+l\right)^{3/2}}$$

$$=\frac{h_v\sum_{i=1}^{n}D_i}{T_f}\left[K\left(1-\frac{\sum_{i=1}^{n}D_i}{P}\right)+\frac{2\sum_{i=1}^{n}D_i}{P}-1\right]+\sum_{i=1}^{n}\frac{D_ih_i}{T_f}+\frac{3h_vz_v\sqrt{K\sum_{i=1}^{n}\sigma_i^2}}{4T_f\sqrt{T_f}}+\frac{\left(3T_f+4l\right)\sum_{i=1}^{n}h_iz_i\sigma_i}{T_f\left(T_f+l\right)^{3/2}}>0.$$

That is, the second derivative of ETC at each T_f is positive. The result implies that, for given K, l, $\underline{z}$, and z_v, an only solution for T, corresponding to the minimum of ETC, can be derived from (8). This completes the proof.

Proposition 3. For any given K, T, and l in a continuous interval $[l_{j+1}, l_j]$, the boundary solution for $\underline{z}$ and z_v derived from (5) and (6) is the optimal solution to this nonlinear programming problem.

Proof:
By using the method of Lagrange multipliers, the problem can be transformed into

$$ETC(K, T, l, \underline{z}, z_v, \underline{\lambda}, \underline{s}) = \frac{C + \sum_{i=1}^{n} C_i + \frac{A}{K} + C_r(l)}{T} + T\left\{ \frac{h_v \sum_{i=1}^{n} D_i}{2} \left[K\left(1 - \frac{\sum_{i=1}^{n} D_i}{P}\right) + \frac{2\sum_{i=1}^{n} D_i}{P} - 1 \right] + \sum_{i=1}^{n} \frac{D_i h_i}{2} \right\}$$

$$+ h_v z_v \sqrt{KT \sum_{i=1}^{n} \sigma_i^2} + \sum_{i=1}^{n} h_i z_i \sigma_i \sqrt{T+l} + \sum_{i=1}^{n} \lambda_i \left[\phi(z_i) - z_i \Phi(z_i) - \frac{(1-\alpha_i) D_i \sqrt{T+l}}{\sigma_i} + s_i^2 \right]$$

$$+ \lambda_v \left[\phi(z_v) - z_v \Phi(z_v) - \frac{(1-\alpha_v)\sqrt{KT} \sum_{i=1}^{n} D_i}{\sqrt{\sum_{i=1}^{n} \sigma_i^2}} + s_v^2 \right], \quad (9)$$

where $\underline{\lambda}$ is a vector of Lagrange multipliers with $\underline{\lambda}=\{\lambda_1, \lambda_2,\ldots, \lambda_n, \lambda_v\}\geq 0$, and $\underline{s}$ is a vector of slack variables with $\underline{s} = \{s_1^2, s_2^2,\ldots, s_n^2, s_v^2\}$. According to Kuhn-Tucker theorem (Taha, 2002), for any given l in a continuous interval $[l_{j+1}, l_j]$, it can be shown that $\underline{s} = \{0,0,\ldots,0\}$ is a necessary condition for a solution in (9) to be optimal. Then, for any given l in a continuous interval $[l_{j+1}, l_j]$, the necessary conditions for (9) to be minimized are

$$\frac{\partial ETC}{\partial z_i} = h_i \sigma_i \sqrt{T+l} - \lambda_i \Phi(z_i) = 0, \; i = 1, 2,.., n, \quad (10)$$

$$\frac{\partial ETC}{\partial z_v} = h_v \sqrt{KT \sum_{i=1}^{n} \sigma_i^2} - \lambda_v \Phi(z_v) = 0, \quad (11)$$

$$\frac{\partial ETC}{\partial \lambda_i} = \phi(z_i) - z_i \Phi(z_i) - (1-\alpha_i) D_i \frac{\sqrt{T+l}}{\sigma_i} = 0, \quad (12)$$

$$\frac{\partial ETC}{\lambda_v} = \phi(z_v) - z_v \Phi(z_v) - \frac{(1-\alpha_v)\sqrt{KT} \sum_{i=1}^{n} D_i}{\sqrt{\sum_{i=1}^{n} \sigma_i^2}} = 0, \quad (13)$$

From (10) and (11), we have

$$\lambda_i^*(z_i) = \frac{h_i \sigma_i \sqrt{T+l}}{\Phi(z_i)} > 0, \; i = 1, 2,\ldots, n, \text{ and } \lambda_v^*(z_v) = \frac{h_v \sqrt{KT \sum_{i=1}^{n} \sigma_i^2}}{\Phi(z_v)} > 0.$$

Therefore, constraints (5) and (6) are binding. In addition, $\frac{\partial^2 ETC}{\partial z_i^2} = \lambda_i \phi(z_i) > 0$ (i=1, 2,…, n, m), then the $\underline{z}$ and z_v derived from (12) and (13) (i.e., the boundary solutions to (5) and (6)) are optimal to (9) with given K, T, and l.

Based on the above propositions, the optimal solution for K, T, l, $\underline{S}$, and S_v to this nonlinear programming problem can be obtained by the following algorithm:

Algorithm

10. Set K=1.
11. Find $ETC^*(K, l_j \mid j = 0,1,...,b)$
    2.1 Let j =0
    2.2 Set $l = l_j$. z_i (i =1, 2,…, n) = 0, and z_v = 0.
    2.3 Compute T^* by substituting K, l_j, $\underline{z}$ and z_v into (8). Set $T_{kj} = T^*$.
    2.4 Compute $\underline{z}^*$ by substituting l_j and T_{kj} into (12) and compute z_v^* by substituting K and T_{kj} into (13).
    2.5 Compute T^* by substituting K, l_j, $\underline{z}^*$, and z_v^* into (8).
    2.6 If $T^* = T_{kj}$, go to step 2.7; otherwise, set $T_{kj} = T^*$ and go to step 2.4.
    2.7 Set $T^*(K,l_j)=T_{kj}$, $\underline{z}^*(K,l_j)=\underline{z}^*$, and $z_v^*(K,l_j) = z_v^*$. Compute $ETC^*(K,l_j)$ by substituting K, l_j, $T^*(K,l_j)$, $\underline{z}^*(K,l_j)$, and $z_v^*(K,l_j)$ into (7).
    2.8 Let $j = j$+1 and go back to step 2.2 until $j = b$.
12. Set $ETC(K,l)$ =Min[$ETC(K,l_j) \mid j$ = 0,1,…,b].
13. If K = 1, set $ETC_s = ETC(K,l)$, $K = K$+1, z_i (i =1, 2,…, n) = 0, z_v = 0 and go back to step 2; otherwise go to step 5.
14. If $ETC(K,l) < ETC_s$, let $ETC_s = ETC(K,l)$, $K = K$+1, z_i (i =1, 2,…, n) = 0, z_v = 0, and go back to step 2; otherwise let $ETC^* = ETC_s$ along with the corresponding values of K and l being the value of K^* and l^*, respectively.
15. Find T^* from (8) with the obtained K^* and l^*. Find $\underline{z}^*$ from (12) and z_v^* from (13) with the obtained K^*, l^*, and T^*. Find $\underline{S}^*$ from (1) and S_v^* from (2) with the obtained K^*, l^*, T^*, $\underline{z}^*$, and z_v^*. Output the values of K^*, l^*, T^*, $\underline{S}^*$, S_v^*, ETC^* and Stop.

4. Computer implementation

The algorithm proposed in Section 3 has been implemented as a decision support system on a personal computer in which Intel Pentium D 2.8 GHz CPU with 1024 MB RAM inside it. Visual Basic 2005 is utilized as the software platform to develop the decision support system. Figure 2 shows the window to input the numbers of retailers, e.g., n =3 in this case, and steps of the lead-time crashing cost function, e.g., three steps in this case, involved in the replenishment and lead time reduction decisions. Once the decision maker inputs the numbers, a window to specify the relevant parameters will be displayed as shown in Figure 2. If all of the relevant parameters are input for the system, the decision maker then clicks the label "Find Solution" to select the lead time policy and to set the options of output. Figure 3 illustrates the result that the system derives the solution in which K^* = 2, l^* = 0.005 years, T^* = 0.0709 years, S_1^* =708, S_2^* = 760, S_3^* = 1276, S_v^* = 3574, and ETC^* = $19455.5 for the case of implementing QR (representing by the controllable lead time option) after the

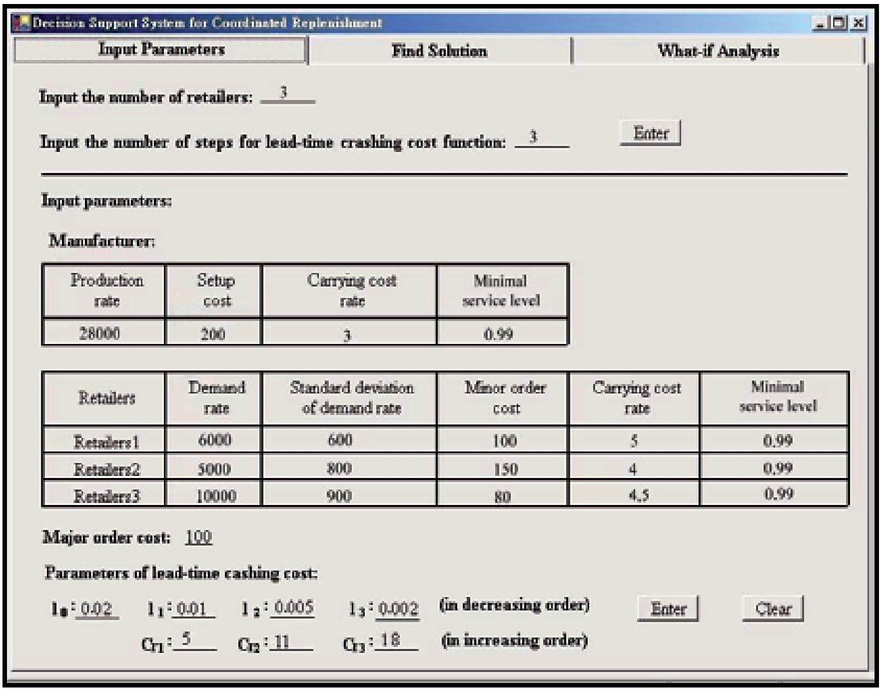

Fig. 2. The system window to input parameters

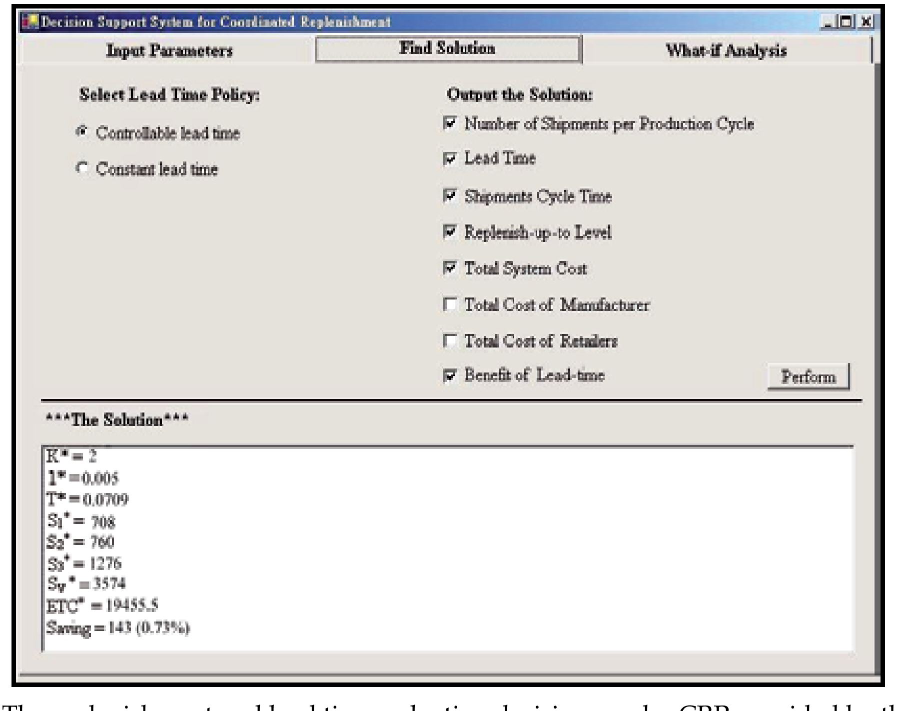

Fig. 3. The replenishment and lead time reduction decisions under CRP provided by the decision support system

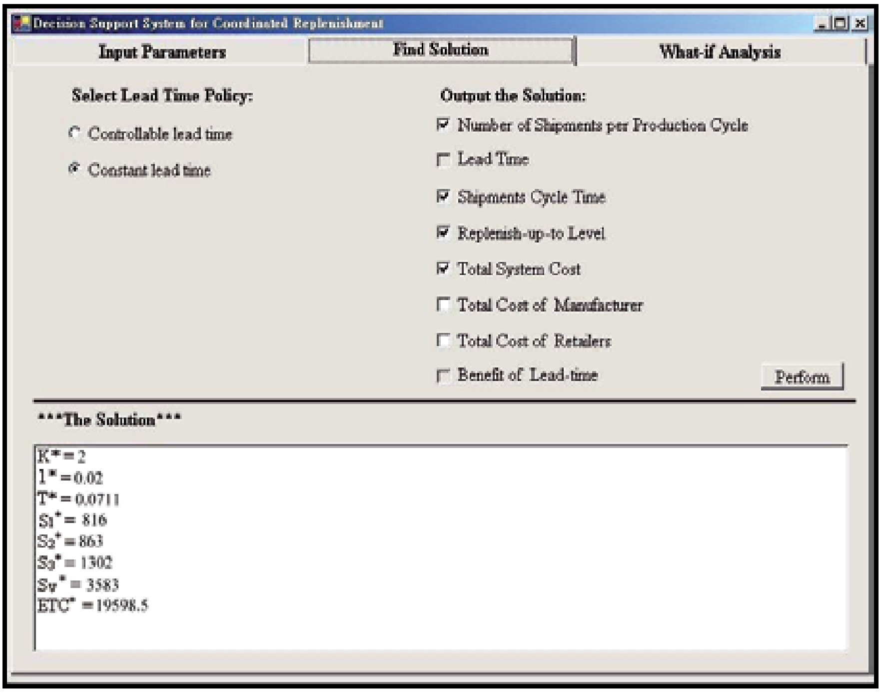

Fig. 4. The coordinated replenishment decision under CRP provided by the decision support system

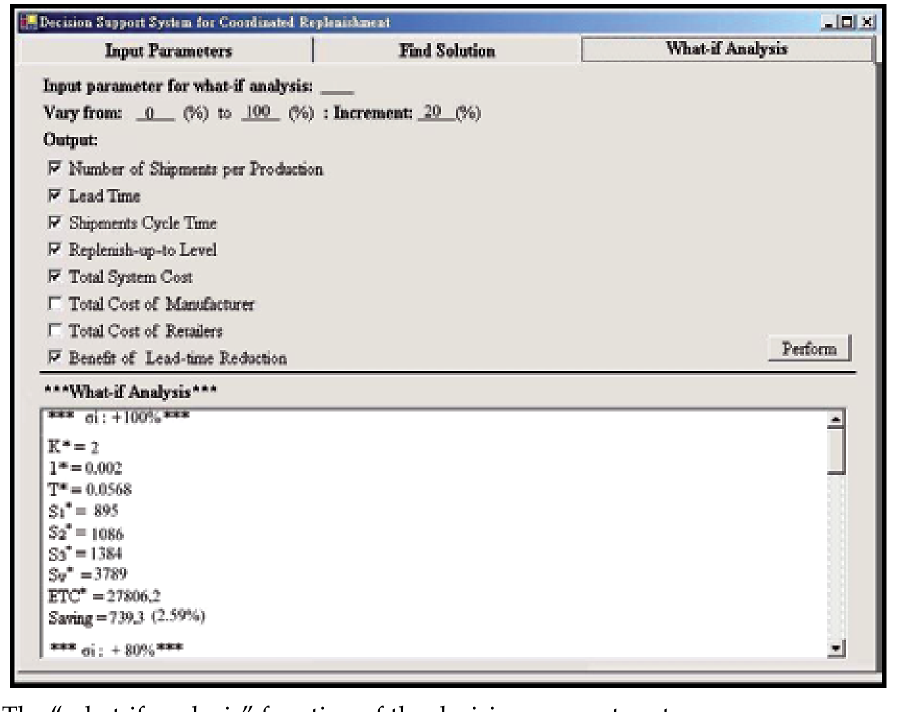

Fig. 5. The “what-if analysis” function of the decision support system

decision maker clicks "Perform". From the value of "Saving", the benefit derived from implementing QR can be learned. As shown in Figure 4, the system also provides the inventory decision before QR (represented by the constant lead time option). One advantage of the system is that the decision maker can learn the sensitivity of replenishment and lead time decisions and the expected annual total cost of the chain by specifying the parameter with the variation range in the Window of "What-if Analysis". Figure 5 illustrates the output of the what-if analysis of K^*, l^*, T^*, $\underline{S}^*$, S_v^*, ETC^*, and the cost saving after QR against the variation of standard deviation of demand.

		K^*	T^*	l^*	S_1^*	S_2^*	S_3^*	S_v^*	ETC^*	K_0[a]	T_0[a]	$\Delta ETC(\%)$[b]
Base example		2	0.0709	0.005	708	760	1276	3574	19455.3	2	0.0711	0.73
σ_i (i=1,2,3)	+100%	2	0.0568	0.002	895	1086	1384	3789	27806.2	2	0.0577	2.59
P	+100%	1	0.0877	0.005	827	874	1320	2357	18822.3	1	0.0880	0.71
C	+100%	2	0.0779	0.005	758	808	1208	3885	20799.7	2	0.0781	0.67
C_i (i=1,2,3)	+100%	1	0.1024	0.005	930	970	1488	2691	23410.0	1	0.1027	0.54
A	+100%	3	0.0705	0.005	705	757	1291	5108	20696.8	2	0.0781	1.16
h_i (i=1,2,3)	+100%	3	0.0507	0.005	560	616	886	3803	26567.3	3	0.0513	1.88
h_v	+100%	1	0.0704	0.005	704	756	1120	1958	23078.6	1	0.0705	0.62
1-a_i (i=1,2,3)	+100%	2	0.0733	0.01	705	741	1128	3681	18548.2	2	0.0735	0.32
1-a_v	+100%	2	0.0727	0.005	721	772	1147	3467	18897.2	2	0.0728	0.75

a: K_0 and T_0 represent the optimal K and T, respectively, before QR is implemented.
b: $\Delta ETC(\%)=(1-ETC^*/ETC_0)\times 100\%$, where ETC_0 represents the optimal ETC before QR is implemented.

Table 1. Sensitivity analysis for parameters

The sensitivity of the optimal solution has been further examined by conducting several numerical experiments. The results are illustrated by a base case and are shown in Table 1. Some findings are summarized as follows:

1. The amount of $\Delta ETC(\%)$ measures the improvement rate of expected annual total system cost after implementing QR. The behavior of $\Delta ETC(\%)$ reveals that the supply chain may benefit from shortening the replenishment lead time.
2. The value of $\Delta ETC(\%)$ is especially sensitive to the variation of σ_i or h_i. As σ_i or h_i increases, the value of $\Delta ETC(\%)$ increases. The results mean that the return of investment in QR is especially significant for a system with high uncertainty in demand or with high carrying costs incurred to the retailers.
3. The common shipment cycle time is more sensitive to the variance of demand, the variation of manufacturer's production rate, the individual ordering cost, and the retailer's carrying cost.
4. The shipment cycle time, T^*, will be reduced after implementing QR in which the replenishment lead time for retailers has been shortened. Moreover, the target levels of

replenishments for the manufacturer and the retailers may become lower after bringing QR into practice.

5. The number of shipments per production cycle, K^*, after implementing QR is always no less than that before implementing QR. When the values of K for the two situations are equal, the optimal shipment cycle time, T^* as well as the protection period, T^*+l^*, after QR is always no large than those before QR. The result implies that under a fixed number of shipments during a production cycle, the protection period for the retailer will be reduced after implementing QR.
6. The increase of production rate will result in a longer shipment cycle time and higher target levels of replenishments for the retailers. In contrast, as the value of P increases, the number of shipment per production cycle and the target level of production for the manufacturer will become smaller.
7. When the ordering cost increases, the shipment cycle time and the target levels of replenishments for each party will increase.
8. The value of a_i specifies the minimal fraction of demand met per cycle for the retailer and directly relates with the length of protection period ($T+l$). It can be found that the amount of ΔETC(%) decreases as the retailer's maximal fraction of demand unfilled per cycle increases. The result implies that the benefit from implementing QR is significantly related to the retailer's service level threshold and the benefit is substantial for a supply chain requesting a high customer service level.
9. The numerical example shows that as $1-a_v$ increases from 1% to 2%, the length of common shipment cycle time increases by 2.54% (from 0.0709 to 0.0727) but the lead time is unaffected. The result implies that the effect of manufacturer's service level threshold is more significant on the common shipment cycle time than on the reduction of lead time.

5. Conclusions

Speed, service, and supply chain management have been core capabilities for business competition. The reduction of overall system response time with a satisfied service level has received a great deal of attention from researchers and practitioners. In this study, we investigated the effect of investing in QR on a CRP based supply chain where a manufacturer produces and delivers items to multiple retailers at a coordinated common cycle time with the minimized expected total system cost and satisfied service levels. Extending the work of Banerjee and Banerjee (1994) by involving ordering costs and the reducible replenishment lead time, a model and an algorithm are proposed to simultaneously determine the optimal shipment cycle time, target levels of replenishments, lead time, and number of shipments pre production cycle under service level constraints for the supply chain.

A numerical experiment along with sensitivity analysis was performed and the results explain the effect of QR on the replenishment decisions and the total system cost. The results provide the following findings about our model:

1. The system can reduce the stocks throughout the pipeline and remain service levels of retailers via investing in QR initiative.
2. The benefit from implementing QR is especially significant for a supply chain with high uncertainty in demand or the retailers requesting high service levels or incurring high carrying costs.

3. The shipment cycle time will decrease after QR implemented. Additionally, the shipment cycle time is especially sensitive to the variation of manufacturer's production rate, the individual ordering cost, the variance of demand, and the retailer's carrying cost.
4. The decision of adopting QR is mainly influenced by the variance of demand and the retailer's service level threshold. The higher the demand uncertainty or the higher the retailer's service level threshold, the more beneficial to implement QR in supply chains.

Appendix

Let $G=\int_{S_i}^{\infty}(x-S_i)f(x_i)dx_i$ and $z_i=\dfrac{x_i-\mu_i}{\theta_i}$, where $f(x_i)$ represents a normal distribution with the mean μ_i and the standard deviation θ_i. By replacing x_i with $\mu_i+z_i\theta_i$, we have

$$G=\int_{\frac{S_i-\mu_i}{\theta_i}}^{\infty}(\mu_i+z_i\theta_i-S_i)\,\phi(z_i)dz_i=\sigma_i\int_{\frac{S_i-\mu_i}{\theta_i}}^{\infty}z_i\phi(z_i)dz_i-(S_i-\mu_i)\int_{\frac{S_i-\mu_i}{\theta_i}}^{\infty}\phi(z_i)dz_i\,, \tag{A.1}$$

where $\phi(z_i)$ is the standard normal distribution and $\Phi(z_i)$ is the complementary cumulative normal distribution function defined as

$$\Phi(z_i)=\int_{z_i}^{\infty}\phi(w)dw=\frac{1}{\sqrt{2\pi}}\int_{z_i}^{\infty}e^{-\frac{w^2}{2}}dw\,.$$

Let $v=\dfrac{z_i^2}{2}$, then there is $dv=z_i dz_i$ and

$$\int_{\frac{S_i-\mu_i}{\theta_i}}^{\infty}z_i\phi(z_i)dz=\frac{1}{\sqrt{2\pi}}\int_{\frac{1}{2}\left[\frac{(S_i-\mu_i)}{\theta_i}\right]^2}^{\infty}e^{-v}dv=\frac{-1}{\sqrt{2\pi}}e^{-v}\Bigg|_{\frac{1}{2}\left[\frac{(S_i-\mu_i)}{\theta_i}\right]^2}^{\infty}=\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{S_i-\mu_i}{\theta_i}\right)^2}=\phi(z_i) \tag{A.2}$$

Next,

$$(S_i-\mu_i)\int_{\frac{S_i-\mu_i}{\theta_i}}^{\infty}\phi(z_i)dz_i=(S_i-\mu_i)\Phi(z_i)\,. \tag{A.3}$$

By substituting (A.2) and (A.3) into (A.1), we have

$$G=\int_{S_i}^{\infty}(x-S_i)f(x_i)dx_i=\theta_i\phi(z_i)-(S_i-\mu_i)\Phi(z_i)\,. \tag{A.4}$$

Let $\mu_i = D_i(T+l)$ and $\theta_i = \sigma_i\sqrt{T+l}$ and apply (A.4) to (3), (3) can be rewritten as

$$1-\frac{\sigma_i\sqrt{T+l}\phi(z_i)-\left[S_i-D_i(T+l)\right]\Phi(z_i)}{D_i(T+l)}\geq a_i,\ i=1, 2, 3. \tag{A.5}$$

By substituting (1) in to (A.5) and rearranging the inequality, we have

$$\phi(z_i)-z_i\Phi(z_i)-(1-\alpha_i)D_i\frac{\sqrt{T+l}}{\sigma_i}\leq 0,\ i=1, 2, 3.$$

This completes the proof for (5). Accordingly, (6) can be proved.

6. Acknowledgment

This research was partially supported by the National Science Council, Taiwan ROC (Plan No. NSC 98-2410-H-415 -007).

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8

Collaboration in Decision Making: A Semi-Automated Support for Managing the Evolution of Virtual Enterprises

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1. Introduction

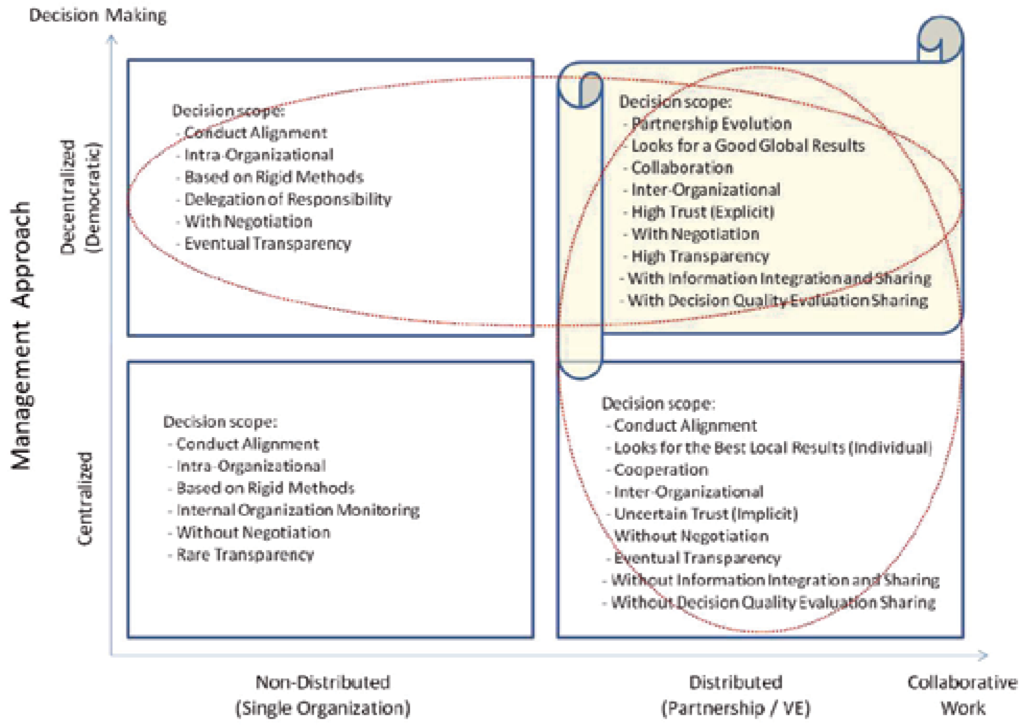
Collaborative Networked Organizations (CNO) has become one of the most prominent strategic paradigms that companies have sought as a mean to face the challenges imposed by globalization (Camarinha-Matos *et al.*, 2005). There are several types of CNOs, like as supply chain, virtual labs, virtual organizations breeding environment (VBE), extended enterprises, virtual organizations and virtual enterprises. The common rationale behind such alliances is that they rely on collaboration with other companies to be more competitive. This work focuses on virtual enterprise.

A Virtual Enterprise (VE) can be generally defined as a temporary alliance of autonomous and heterogeneous enterprises that dynamically joint together to cope with a given business opportunity, acting as one single enterprise. A VE dismiss itself after accomplishing its goal (Rabelo *et al.*, 2004).

Managing the VE life cycle very efficiently is crucial for the business realization. This involves the creation, the operation, the evolution and the dissolution of a VE. This work focuses on the VE evolution phase. In general, the VE evolution phase comprises activities related to managing changes and adaptations in the VE's plan (i.e. the VE operation phase) in order to guarantee the achievement of its goals and duties. This can comprehend actions like simple modifications in some technical specification, passing by changes in and/or negotiations on the VE's schedule, or more drastically the replacement of some of its members.

VEs have, however, some intrinsic and particular characteristics which impose respecting a number of requirements in decision making. The most important one is that decision should be performed in a collaborative, decentralized, distributed and transparent way, considering that VE members are autonomous, independent and geographically dispersed. Besides that, the fact that each VE is per definition completely different from one to another (in terms of number of partners, their skills, culture, local regulations, specificities determined by the given client, etc.) makes the solution of some problems not necessarily deterministic and the use of previous decisions for equivalent problems not necessarily useful. As such, managing the VE evolution requires additional approaches in order to be properly handled (Drissen-Silva & Rabelo, 2009b).

Figure 1 presents a general vision of the aspects related to the management approach and the decision making process in a centralized and decentralized ways, trying to expose the necessary requirements for offering a new decentralized and collaborative decision making model for the Virtual Enterprise evolution, as offered by this work.



Source: Extended from Ollus *et al.*, 2009 and Loss, 2007.

Fig. 1. Requirements for a decentralized decision with collaborative work.

Considering that a VE is usually a grasp-driven alliance for a short-term business opportunity, the major challenge for a decision making that respects those requirements is to be agile. This means that, once identified, a problem should be solved as fast as possible, with high quality and feasibility, and relying on trustful information. It has to be also taken into account that enterprises are often involved in several VEs simultaneously and that some of them are inter-related. Therefore, managing the evolution of a VE requires an ample spectrum of issues that make decision-making extremely complex, making phone calls or chatting among VE members by far insufficient to solve a problem.

This work proposes a novel decision-making approach and framework as a contribution to face those requirements. It is represented by an integrated collaborative decision making framework that assist VE managers along the entire decision making process, including the possibility of evaluating decision feasibility and its impact over each VE that members are involved in.

This chapter is organized as follows: Section 1 presented a general analysis of the requirements for VE management and the evolution phase. Section 2 discusses the problem related to a collaborative decision making and its requirements for the offered framework. Section 3 introduces the proposed framework for managing the virtual enterprise evolution with a collaborative discussion. Section 4 presents the results of the framework considering a prototype development. Section 5 provides a general evaluation with contributions, limitations and future research. Finally, section 6 discuss around the conclusions reached on termination this work.

2. Collaborative decision making

Distributed decision-making is not a new research topic and many works have been developed along the last decade concerning this matter, especially in the form of distributed decision support systems (Bostrom *et al*., 2003). Actually, the work presented in this chapter follows the same line but it adds diverse elements and requirements from the VE area. The approach addressed in this paper is anchored in the following scenario:
"Partners, although being distributed and autonomous, belong to a long-term alliance of type VBE (Virtual Organization Breeding Environment), so sharing common operating principles. One of the main principles is that they trust on each other and they should collaborate towards reaching a globally feasible solution for a problem that takes place during the VE operation. Partners should solve the problem related to the VE they are involved in and hence they should discuss about it through a computing network (e.g. Internet). The discussion should be structured in order to get focused and to have potentially better quality, making use of a shared distributed decision-making environment guided by a decision protocol. This structure should be connected to business processes management. Besides that, it should be flexible and adaptive regarding the problem and the VE characteristics. However, there is not one very pre-defined protocol for every single problem. Each VE tends to be so unique and problems so particular for a given business context and VE composition. Partners should have some freedom to exchange ideas while they evaluate possibilities against their availabilities. This evaluation should be made via an easy access to the most common managerial supporting software tools in order to facilitate Small and Medium Enterprises (SME) managers' activities. After this, they should have means to evaluate the impact of their decisions before acting. All this should be supported by adequate ICT infrastructures, which can also provide the necessary security in the communications and access rights."
In order to cope with this scenario and with those requirements previously mentioned, six aspects have to be supported by a comprehensive decision-making environment for the VE evolution: 1) *Partners' discussion*; 2) *Methodological guidance*; 3) *Modular and flexible execution of decision protocols, aligning business and processes*; 4) *Performance measurement*; 5) *Performance evaluation*; and 6) *ICT Infrastructure*. Next sections provide a resumed revision of the most important techniques used to support these six aspects. The methodological approach followed in this work is to use existing theoretical and software results related to those aspects and to combine and adapt them respecting the envisaged environment.

2.1 Partners' discussion

This issue is related to endowing partners with a collaborative environment where they can exchange information towards the problem resolution. In this sense, Groupware or CSCW tools (Wulf *et al*., 2008) have been largely used to support multiple users working on related tasks in local and remote networks. However, they cope with a partial – and perhaps less complex – part of the problem. The issue here is not only to make partners interact with each other, but also to globally coordinate their discussions about each identified problem, and as fast as possible. Besides that, it is necessary to integrate information for further auditing, giving transparency to the whole process, as well as to regulate partners' involvement and information access as long as decisions are taken. After a review in the literature, three works have been found out that offer elements for this desired environment.

HERMES (Karacapilidis & Papadias, 2001) is a support system used for collaborative decision-making via argumentation. It helps in the solution of non-structured problems, coordinating a joint discussion among decision makers. It offers an online discussion about one or more specific subjects, where each participant can suggest alternatives to the problem or simply point out their pros and cons in relation to current alternatives. There is an association of weights that considers the positioning in favor of or against the suggestions, hence providing a global vision of the opinions.

DELPHI is a classical method (Dalkey & Helmer, 1963) created with the purpose of finding a consensus about a given topic of discussion but without confrontation. Essentially, a summary of the opinions is elaborated along diverse rounds and it is sent back to the participants keeping the names anonymous. The process continues until the consensus / final decision or opinion is reached.

Woelfel *et al*. (described in Rabelo *et al*., 2008) developed an integrated suite of web-based groupware services that has considered CNOs requirements. This suite includes the services of instant messaging, mailing, discussion forum, calendar, wiki, content management system, and news & announcement. One interesting feature of the instant messaging service is the possibility of having private discussions rooms, allowing having several parallel discussions involving all partners and some rooms only available for authorized partners.

2.2 Methodological guidance

The methodology's goal is to prevent partners from dealing with the problem without any guidance, losing time and resources, which can hazard the VE's business. An approach for that is to see a VE as a project, making use of project management reference models. This means making partners to be guided along the problem resolution through a set of steps grounded on project management foundations.

One of the most relevant foundations to support VE as a project is the *Project Management Body of Knowledge*, or just *PMBOK* (PMBOK, 2004). PMBOK states that "a project is a temporary effort to create a unique product or service". Respecting the VE evolution phase and the VE definition (see section 1), it is argued that a VE can be seen as a project as both are temporary and unique in view of the creation of a product or service or to cope with a specific collaboration need. Jansson and Eschenbaecher (2005) advocate that managing a VE is more than managing a project as the creation of VEs requires a long and previous preparation. However, this also embraces the VE creation phase, whereas the focus here is the VE evolution phase, i.e. when the VE is already in execution.

In spite of being is a very comprehensive model, PMBOK is too general for handling changes in projects subjected to constant changes - which is the case of VE - and for which other models have been proposed.

The model called as *Capability Maturity Model Integration* (CMMI, 2006) has been fundamentally used in the area of software development. It presents a decision and resolution analysis with more details (compared to PMBOK), and gives a strong foundation to assist organizations in the improvement of their processes and in their capacity to manage the development, acquisition and maintenance of products and services. Some CMMI steps can be useful in the development of an agile method for the VE concept, but it is too focused on software development business processes.

The *Agile Project Management (APM)* model sees the changing need as an adaptation in the exploration of alternatives that can fit to new scenes. APM was essentially created for projects which demand more agility and dynamism (Leite, 2004), presenting a deeper set of actions for handling changes. There are other management models that handle changes in a project, namely *ECM - Engineering Change Management* (Tavčar & Duhovnik, 2005), *CC - Configuration Control* (Military Handbook, 2001) and *CM – Change Management* (Weerd, 2007). In general, they organize the phases of change management in four macro phases: i) *need of change identification*, where the causes of the problem and the affected members are identified in order to prepare a change solicitation; ii) *change proposal*, where the members that are going to participate in the change analysis are defined; iii) *change planning*, where the different possible scenarios to solve the problem are evaluated via general evaluations, and; iv) *Implementation*, where the most suitable alternative for the problem is settled and the new project's parameters are reconfigured.

All these reference models are very general and they can be instantiated to any type of VE topology. As such, any managerial style and model, different support techniques, management tools and performance evaluation methods can be applied in each case (Karvonen *et al*., 2005). Considering their generality the models are not ready used in VE evolution scenarios. Therefore, in spite of the extremely importance of their foundations, they should be adapted for that.

2.3 Decision protocols

Decision protocols are seen in this work as an instrument to: i) systemize a set of actions where there is a strong human intervention, ii) to standardize and iii) to enhance their execution efficiency. In the context of VE, three works were found out in the literature those offer some computer assistance for handling decision protocols.

ILMSS system (Rabelo *et al*., 1998) was developed to systemize logistic actions in Extended Enterprises following a pre-defined and general decision-protocol. DBPMS system (Rabelo *et al*., 2000) was an evolution of ILMSS, and it was developed to coordinate conflicts among partners in a Supply Chain applying a modular but fixed approach to generate decision protocols. SC^2 (Rabelo & Pereira-Klen 2002) was a multi-agent system developed as an evolution of DBPMS. One of its agents was responsible for managing conflicts that took place along the execution of tasks in dynamic Supply Chains. The decision "blocks" were chosen by an agent but the blocks had a high granularity. Another relevant particularity – and limitation – of these three works is that they assumed that the main coordinator was the only one who could trigger the process of looking for solutions close to members when problems arose, as well as the only one who could make suggestions, who could have access to the others' information, and who took the decision. Besides that, these works only dealt with rescheduling and basic actions towards partners' replacement. As it was stressed in the previous section, managing VE evolution requires several other features and types of actions.

The VOM Toolkit (Pěchouček & Hodík 2007) is an integrated environment that has been developed to help the VE coordinator in doing several activities, such as VE performance monitoring, alerting about changes in the expected performance, and rescheduling and reconfiguration simulation to optimize the VE performance. However, likewise in those other three systems, it leaves totally to the VE coordinator to implement the corrections to solve the conflict. No guidelines or supporting methodology are offered to help in these activities.

Another perspective is that all these works - and some other more recent ones (e.g. Hodík & Stach, 2008; Negretto *et al*., 2008; Muller *et al*., 2008) – are however disconnected from the global operation ambient of the companies. This means that the decision-making process is carried out separated of the other processes. In practice, this obliges managers to switch from one environment to another and to cope with different sources of information (this is a problem as SMEs usually have several basic problems of systems integration). A sound alternative for that is the BPM (*Business Process Management*) approach (Grefen *et al*., 2009) and the SOA (*Service Oriented Architecture*) paradigm (Ordanini & Pasini, 2008). BPM provides foundations for a loose-coupled, modular, composite and integrated definition of business processes. From the process execution point of view, BPM tools generate BPEL (*Business Process Execution Language*) files as output, allowing a direct integration among business level (BPM) and execution level (SOA / web services). There are both commercial and academic supporting tools for that (e.g. Oracle BPEL Designer, IBM WebSphere). This combination can provide the notion of flexible and modular decision protocols.

2.4 Performance monitoring and measurement

Performance monitoring and measurement look to the current situation of the production system, treating the problem in the (VE) operation phase. The goal of this aspect from the VE evolution management point of view is to offer conditions for the VE partners to measure their own performance and to check their capacity in order to get more confidence when deciding about how to do respecting the given problem. This involves, therefore, monitoring (i.e. gathering of internal information) and further analysis (performance measurement). There are a number of performance measurement models. Two of the most relevant ones are the Balanced Scorecard (BSC) and SCOR (Supply Chain Operation Reference).

BSC is a method that "translates the mission and the view of companies in a wide group of performance measures which is a foundation to a measurement system and strategic management" (Kaplan & Norton, 1997). It allows managers to identify which of the activities could be considered as critical for the well functioning of the organization that are directly responsible for the generation of value to the shareholders, clients, partners, providers and to the community.

SCOR is as the cross-industry *de facto* standard diagnostic tool for supply chain management grounded on three fundamental perspectives: processes, performance indicators and best practices (Supply Chain Council, 2005). SCOR is based on five distinct management processes: Plan, Source, Make, Deliver, and Return, which have many standard performance indicators associated to. The goal is to optimize and integrate processes and logistics while attending client needs.

In terms of performance indicators, Baldo *et al*. (2008) has developed a framework to identify the most relevant performance indicators that should be applied to a VE regarding the characteristics of the business opportunity and involved partners.

In terms of techniques, OLAP (*On-line Analytical Processing*) is an approach to quickly provide answers to analytical queries that are multi-dimensional in nature (sales, marketing, budgeting, forecasting, capacity, etc.). Via the so-called OLAP cube, it allows for complex analytical and ad-hoc queries with a rapid execution time based on historical data facilitating decision-making (adapted from Lechtenborger & Vossenm, 2003; Moon *et al*., 2007).

2.5 Performance evaluation

Performance evaluation aims at providing decision elements based on performance measurement results. The goal of this aspect in the context of VE evolution management is to provide partners with techniques that help them to evaluate the impact of their decisions at their companies along the discussion process. At the same time, it allows the VE coordinator to evaluate the global solution before validating the final decision.

According to Raj Jain (1991), the three techniques of performance evaluation are: (i) analytical modeling, (ii) simulation, and (iii) direct measurement. Each one has pros and cons, and there are several considerations to decide which technique is better to use, like modeling time, data acquisition, model complexity, execution time, required skills, among others. Actually, simulation has been attracting a large number of users due to its intrinsic capability for creating and evaluating *what-if* scenarios, capturing the dynamic behavior of the system (Johnsson & Johanson, 2003). On the other hand, analytical models are more adequate when near-optimum solutions are needed. Capacity planning is a sensible part as most of the problems that use to happen in the VE operation requires changes in the companies' production capacity.

2.6 Information and Communication Technology Infrastructure

Information and Communication Technology (ICT) Infrastructures are a mean to support all (or almost all) the transactions among partners in a CNO. Actually, this is one of the conditions to work as such. In the context of VE evolution and decision-making, ICT infrastructures are responsible for providing the necessary functionalities to allow partners in making all the previously mentioned tasks: partners' discussion, methodological guidance, decision protocols, performance measurement and monitoring and performance evaluation.

Security is a crucial issue to provide the required trust building in CNOs. Sowa and Sniezynsky (2007) developed a security framework that controls information access dynamically according to partners' roles in a VE. This guarantees that all the sensible information can be accessed only by authorized partners. Yet, that the information comes from recognized and authenticated partners and sources.

Rabelo *et al*. (2008) developed an integrated, web-based and on-demand ICT infrastructure devoted to cope with CNO requirements. Although it currently does not have implemented all those necessary functionalities to support the VE evolution phase (at least in the way the problem is approached in this work), it is opened to receive new functions.

The combination and some adaptations in all these mentioned works are seen as a feasible starting point to support the envisaged distributed and collaborative decision support scenario.

3. Collaborative decision support for the virtual enterprise evolution

Previous section has presented the scenario for the management of VE evolution associated to the collaborative decision making as well as the aspects to support it. In order to cope with all of them, a framework has been conceived. This framework gathers such aspects and groups them into four categories, or pillars: *Human, Organizational, Knowledge* and *Technological*. The essential rationale of these four pillars is to enable *humans* to discuss and to decide about a problem related to a given *organizational* process, applying a set of *organizational* procedures and methods, using information and *knowledge* available in the

VBE's repositories, all this supported by a sort of ICT (*technological*) tools and infrastructures (Drissen-Silva & Rabelo, 2009a). That discussion is framed by a decision protocol (conceived using project management foundations) and is carried out within a distributed and collaborative decision support environment. The decision protocol is the mechanism which "links" the four pillars according to the particular problem to be solved within the VE evolution phase. Figure 2 shows the framework.

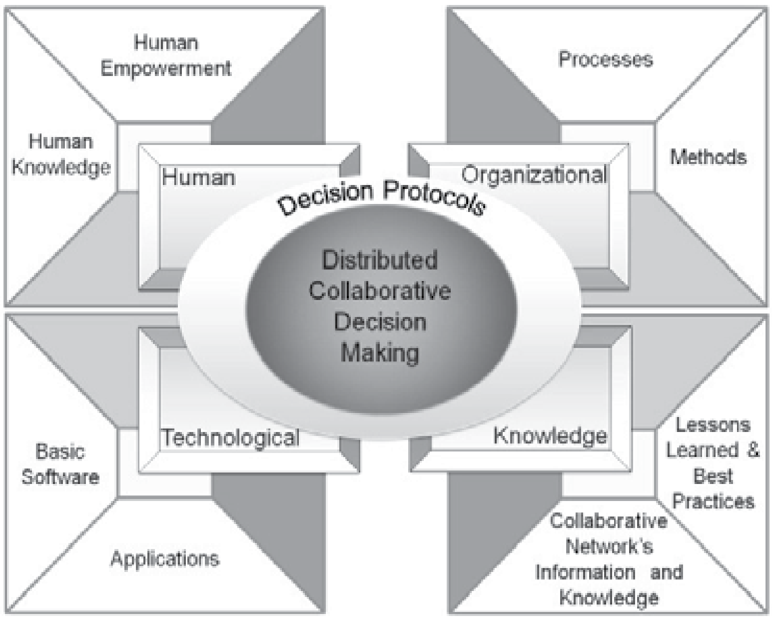


Fig. 2. Framework for VE Evolution Management.

The *Human* pillar represents people, i.e. the VE companies' managers who use their tacit knowledge and collaborative attitude to help solving the problem came from the VE operation phase. It embraces the empowered managers and the experts that can (re)configure the decision protocols. The *Organizational* pillar comprises intra and inter-enterprises processes, ontologies as well as working methods, techniques and procedures that should be involved in a distributed and collaborative decision-making process. It embraces companies' business processes themselves, project management, performance measurement and performance evaluation methods and techniques, and decision procedures and rules to be followed. The *Knowledge* pillar comprises explicit information and knowledge that are available in the VBE's repositories and that managers can have access to for helping in the decision-making process. This embraces lessons learned, best practices as well as information about partners, regulations, historical data, etc. The *Technological* pillar refers to all kind of ICT tools, platforms and security artifacts that should be available to support managers in managing the processes accessing suitable methods. It embraces OLAP, BPM, simulators and groupware tools, besides databases, ontology management systems and the general computing infrastructure for systems deployment, security, communication, interoperation and services management.

It is important to point out an issue about the human pillar. SMEs have many difficulties in terms of management skills, whereas working in collaborative networks requires several levels of additional preparedness (Afsarmanesh & Camarinha-Matos, 2005). In fact, it seems unrealistic to assume that VE partners are already prepared and know the most relevant managerial and performance evaluation techniques and methods that can help them during the discussions and decision-making. If on one hand their experience and knowledge are of extremely importance for that, on the other hand they are insufficient for dealing with all the intrinsic complexity that managing the VE evolution represents. Therefore, in order to effectively support the use of the proposed framework, it is essential that VE partners are also empowered with adequate training. Klen *et al*. (2008) has proposed a methodology for training VBE members relying on governance and individual competences on VE management.

The proposed approach relies on and combines two basic areas: Project Management (PM) and Decision Support Systems (DSS). One of the most important framework's elements is a decision protocol. It corresponds to a mechanism that coordinates the problem solving and that is based on an adaptation of the ECM (Engineering Change Management) model (Rozenfeld *et al.*, 2006) for agile and change management. This protocol has the aim of guiding decision-makers towards more effective solutions in a methodological way. In essence, this all aims at offering a Collaborative and Distributed DSS for VE's partners to get together to discuss about necessary changes but guided by a decision protocol that consider the most relevant VE characteristics. A set of performance evaluation and knowledge mechanisms completes the framework, providing a previous analysis before decisions are implemented. A database model saves all the discussed information for further auditing.

The management of collaborative projects deals within distributed environments. Activities and process are distributed through partners and organizations on different locations and countries, with different cultures but the management could be done in centralized or distributed way (Ollus *et al.*, 2009). Collaborative work has been imposing the conception of a new kind of tools for supporting its management offering lessons learned and knowledge for future decisions (Loss, 2007). Differently from extended enterprises where there is a dominant enterprise (O'Neill, 1995), managing the VE evolution implies to consider that all partners are autonomous and have to participate in the decision making process transforming the evolution management a complex process.

3.1 Framework architecture

The four framework's pillars are operated through three concrete elements: the decision protocol, the distributed and collaborative decision support computing environment, and the ICT Toolbox. They all form the Distributed Collaborative Decision Support System for the Management of VE Evolution (DDSS-VE). Figure 3 presents the framework architecture, also illustrating the relation of the elements with the pillars. Yet, it shows the three different types of actors that are involved in the discussions about the problem detected in the VE operation. To be highlighted the fact that all transactions – involving both humans and systems – are carried out over computing networks making use an adequate ICT supporting infrastructure.

3.1.1 Decision protocol

The decision protocol is a sequence of steps that defines the activities that have be executed in given situations within a given context to solve a problem. Conceptually, it should indicate what has to be done, why, by whom, where, when, how, and with which resources.

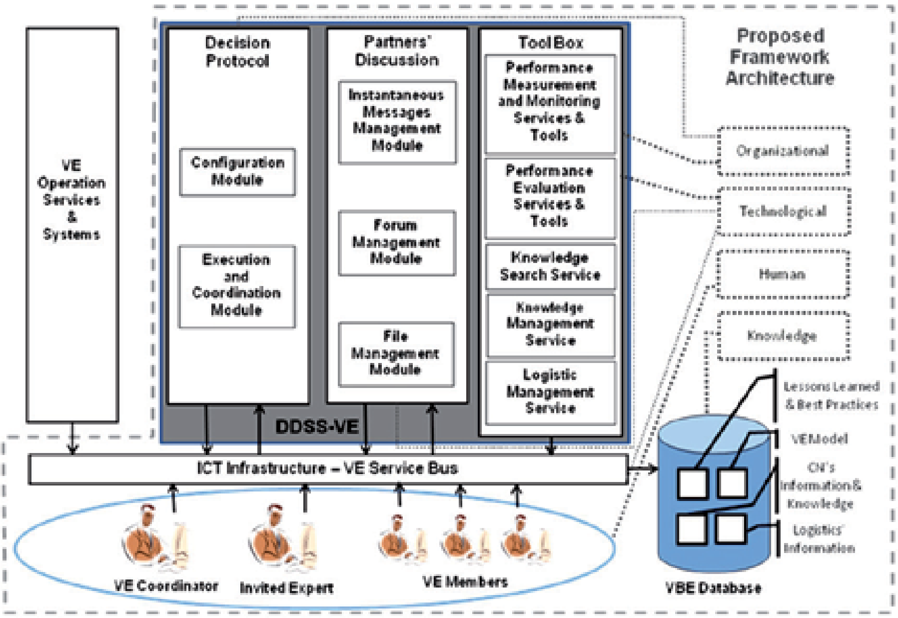


Fig. 3. Framework Architecture.

The conception of the proposed protocol has considered three aspects: its generality, its underlying foundation, and its execution automation. As far as the generality is concerned, the protocol is not seen as a reference protocol that would be generic enough to comprise all possibilities of how every single different problem should be solved by/at certain companies related to a certain VE. Instead, it is seen as a basis on which *particular* protocols can be derived, grounded on project management reference models, considering the VBE policies and operation rules. Figure 4 shows the proposed decision protocol.

This particularization means that new steps can be added, some modified / adapted and some disabled (Figure 5). The whole approach can be seen under three layers: basis protocol, specific protocol, and computer aided. As said before, the *basis protocol layer* for the VE *evolution* phase is the one showed in the figure 4, where the box outside the main square contains activities within the VE *operation* phase. The *specific protocol layer* represents the one that would have been customized for a given VBE and that would be effectively applied in the VEs created from it. The *computer aided layer* contains digital information repositories and very concrete ICT tools and infrastructure that are used to support the diverse actions in a decision-making process. This is made available via an ICT toolbox (see section 3.1.3).

A modification in the basis protocol is however not hard coded made. Thanks to a BPM tool, the protocol is flexibly modeled and directed connected to software services that execute the protocol's steps themselves. Therefore, if a modification is required, the user modifies the processes at BPM level (or even at the SOA level), but not at programming code level. However, a protocol particularization has some restrictions. This refers to the second aspect of its design, which is the underlying foundation. Actually, the steps of the basis protocol comprehend the most typical ones presented in the changes management reference models, and ECM in particular (see section 2.2). Thus, users are not allowed to change its essential logical structure (the macro steps *Need of Change Identification, Change Proposal, Change*

Planning, and *Implementation*, as well as some of their sub-steps). Besides using ECM and adapting it to the VE evolution context, this work has also used some ideas proposed in O'Neill (1995) when determining the most significant events to handle in more strategic decisions. In resume, this proposed decision protocol represents the mentioned framework's methodology and it is modeled via BPM and SOA-based tools.

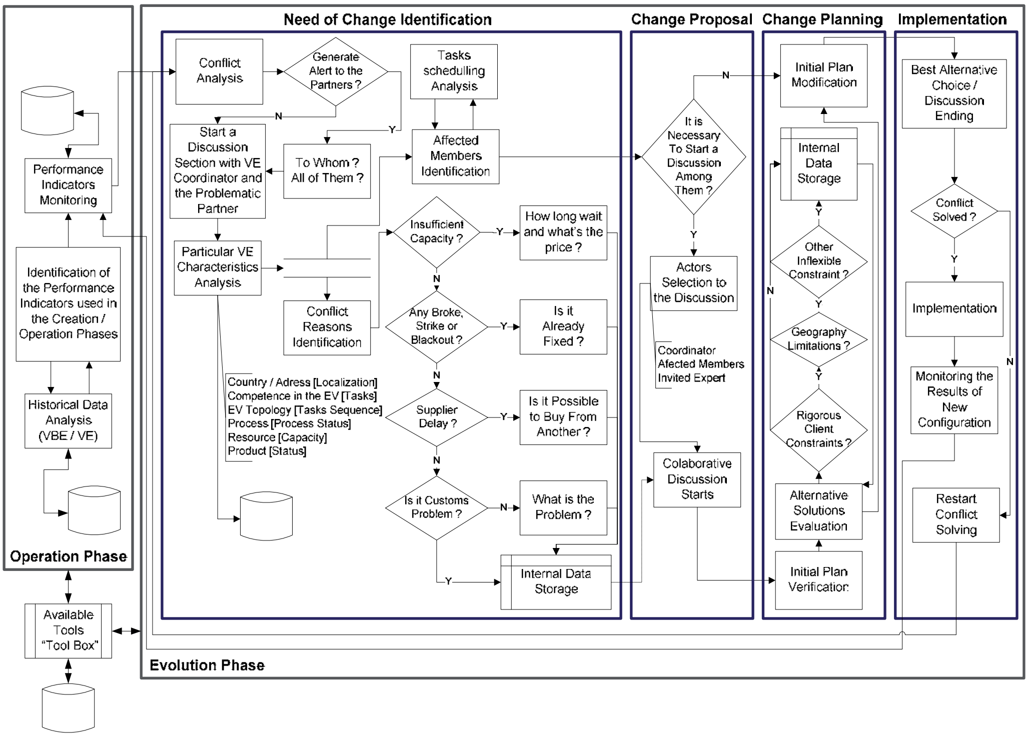


Fig. 4. Basis Protocol for the VE Evolution Management.

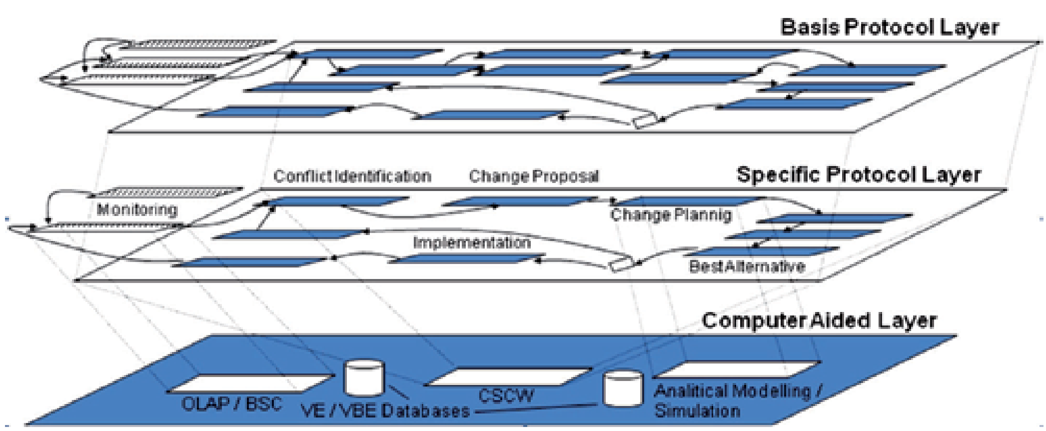


Fig. 5. Multi-layered conceptual scenario of the proposed framework.

3.1.2 Partners' discussion environment

This second element of the framework corresponds to the Distributed Collaborative Decision environment and it is the main element to support partners' discussion over the network.

It is important to point out that VE partners are fundamentally composed of SMEs. Therefore, it is important to offer an easy and low cost way to support the access to management methods, techniques and tools to help the involved people in the discussions, performance measurement and evaluation.

This underlying vision of this environment relies on the assumption that there is no sense to develop a wizard-like, expert systems or agent-based decision support systems solution that are used for modeling closed world problems (e.g. Baffo *et al.*, 2008). Instead, partners should have room – with a methodological support and integrated within the companies' business process environment – for exchanging ideas, exercising their creativity, and reasoning about particular cases based on the very current status of the involved companies.

In this environment, the actors involved in a discussion are (figure 3) the *VE partners*: 1) the *VE coordinator*, who owns the business and who is, at last, responsible for it; 2) the *VE members*, who are the companies' representatives in the given VE and; 3) an *invited expert* (e.g. the broker, a specialized technician, a VBE's representative), an *ad-hoc* member who may participate in the discussions and whose role is defined for each case.

This environment is controlled by the DDSS-VE. Based on different classifications for decision support systems (Turban & Aronson, 1998; Phillips-Wren & Forgionne, 2001) this model for distributed decisions support system with argumentation and moderation for the VE evolution (DDSS-VE) is of type:

- Negotiation: decision about a problem is reached via a negotiation process, where the reaching of the solution involves relaxations of constraints and changes in the plan;
- Decentralized: the VE coordinator coordinates the discussion but the decision itself emerge from the discussions;
- Partially hierarchical: the VE coordinator has the power to validate the final decision achieved after a (non-hierarchical) discussion;
- Multi-stage: a decision can be reached after several rounds of discussion;
- With semi-structured tasks: the problem and related information is partially made available by the DDSS-VE system and VBE's information repositories, and the discussion is generally assisted. The other part of the information and knowledge come from the tacit knowledge of the own participants;
- Multi-participant: several members can participate simultaneously in the discussion;
- Team-based: although autonomous and independent, VE members act collaboratively as they share the same goal.

In order to give an overview on how the framework works, figure 6 illustrates an abstract discussion scenario to be supported by the DDSS-VE where partners would exchange their opinions about a given problem. Actually, DDSS-VE will manage the interaction among three entities. One entity is the companies' representatives, each one having a DDSS-VE's graphical interface to interact with. Another entity is the set of ICT and network infrastructure, tools (the ones common to all VBE members, and the local ones, accessible only by each company) and VBE's information repositories (see next section). The third entity is the decision protocol, which will help guiding the discussions.

After the problem has been detected, DDSS-VE starts the protocol steps (Figure 4), within the Need of Change Identification phase. In this phase the goal is to identify the problem reasons and to check if it can be solved by the own partner, without impacting the other VE members. This reveals the strategy to involve the other partners only if the problem cannot be solved at a "local" level. For this, the VE coordinator and the partner that has generated the conflict (illustrated as Partner 1) discuss together (e.g. via chat and file transfer), initially. After discussions and evaluations, if the problem is considered solved without needing the other partners, the protocol's flow goes through another phases, the Change Proposal, Planning and Implementation phases. In the case the problem could not be solved, it is necessary to evaluate which partners were affected and that should then be involved in the collaborative discussion and decision-making. In the Change Proposal phase, the discussion is supported by the services that combine the ideas of HERMES and Delphi methods (see section 2.1). The part inspired in HERMES aims to organize partners' arguments in a concise structure, using an appropriate semantic, communicating their suggestions but in a compiled way, including an association of weights to the most important arguments. This aims at finding the better (and faster) consensus about the problem. The part inspired in the Delphi method aims at avoiding direct confrontations among participants, which could generate counterproductive discussions. In this sense, all the arguments are gathered by the VE Coordinator who, in a first moment, acts as the moderator selecting, deleting, changing or suggesting changes in the arguments received before they can be published to all participants. Actually, it is not the aim to restrain partners conversation and information exchange, but rather to guarantee a faster discussion and, mainly, that some sensible information (e.g. the precise level of capacity of a given partner) can be disclosed to everybody. In this way, the VE coordinator have the option to just say to the others that the given partner has "enough" capacity. This discussion round, with the compiled opinions, is illustrated as gray frames in figure 6, at each member's side. The white frames illustrate the argumentation console where partners expresses their opinions as well as where the VE coordinator receives them. He moderates the discussion via this console. After the arguments have been sent out to the other participants, they can reevaluate their considerations and make other suggestions. This process continues until a consensus is reached (within the Change Planning phase).

The protocol is not fixed in its inner actions. Regarding VE uniqueness and topology, and the natural partners' heterogeneity, the protocol can be different for each situation. There are many possible scenarios that could influence the decision to be taken in order to solve the current problem. In this way, the protocol acts as a reminder of some more important questions so that partners can recall they should check them. For example, if an item is delayed and the final customer is very important or the fine is too high, partners can agree on subcontracting part of the production in order to keep the delivery date. If the client has a very rigorous quality control and he manages the suppliers' certification level quite tightly, perhaps is not possible to hire any company, but one equivalent, and so forth. In the case of any other particular issue, partners should handle this, managed by the VE coordinator. Once the problem is solved, the new VE's parameters are set up (Implementation phase) and the control flow goes back to the VE *operation* phase.

This hypothetical argumentation scenario would be based on the results achieved helped by a pool of tools for performance evaluation modeling, monitoring and tasks rescheduling, which can also involve the invited expert's opinion (Change Planning). Some participants could use their own tools or the common toolbox (including the access to the VBE database) available to all participants to help in the discussions.

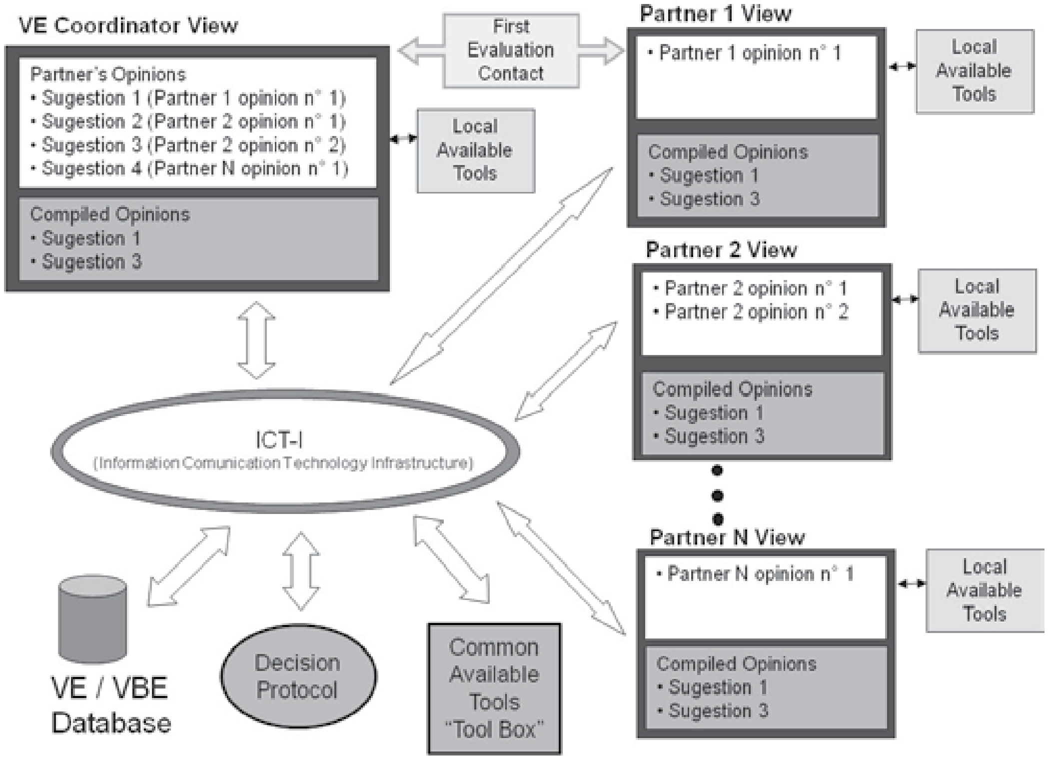


Fig. 6. Illustration of the collaborative decision support environment.

3.1.3 The tool box

Traditionally, SMEs have many difficulties to access, use and maintain software, mainly due to its costs and to the required expertise to do that. The *toolbox* concept was introduced in (Bernhard, 1992) with the goal of providing a pool of industrial software to help users from all departments of a single company to implement the CIM philosophy (Computer Integrated Manufacturing).
This concept was largely extended in Rabelo *et al*. (2008) through the development of a web based distributed ICT infrastructure (ICT-I) devoted to CNOs. The access to ICT-I is totally made in the form of services, which are invoked either by the user or by other software services. Besides integrating many CNO supporting tools, it provides the access to the VBE's information repositories. These tools cover the VE creation (Afsarmanesh *et al*., 2008) and operation phases (Negretto *et al*., 2008). However, there are no specialized services for the VE evolution and dissolution phases yet.
Taking the ICT-I scalability facilities into account, the framework for the VE evolution and associated protocol was added to and seen as another class of services of ICT-I. This also involves some non directed CNO-related services, such as simulators, spread sheets, CSCW, assisted methods and other supporting tools that help VE members along the protocol execution. This all corresponds to the computer aided layer illustrated in figure 5.
In this work, these supporting tools are group into a logically centralized repository of ICT tools called *ICT Toolbox*. ICT Toolbox is therefore a pool of common tools that are accessed via ICT-I – hence via the network – facilitating members' acceptance and use of

management methods. This however does not cover the existing local tools used by each member at their companies. The Toolbox's tools themselves can congregate both the set of tools previously agreed (or existing) in the VBE and tools that can be accessed on demand from other providers.

4. Prototype implementation

This section presents the results of the implementation of the DDSS-VE framework, which is concentrated in three different functionalities: the Decision Protocol, the Partners' Discussion Environment and a Tool for previous evaluation scenarios. The decision protocol once started will help manager to do actions in the right moment in the decision making process. It was used an adapted VBE database in order to access the competences of all partner in the usage scenario. Partner's Discussion Environment is implemented considering ideas from HERMES System and Delphi method, applying a collaborative discussion with voting and comparing suggestions all on supervision by the moderator. The Toolbox is populated with a tool for capacity planning using the performance evaluation method applied in advanced dashboards. Within a controlled testing environment, the problems detected in the VE operation phase are manually introduced and the discussions are simulated in a distributed scenario using a number of PCs.

As already said, the Collaborative Discussion Environment has the goal to combine HERMES system and Delphi method, and to adapt them to the desired decision philosophy. In other words, it aimed at facing the partners' autonomy and transparency requirements as well as the need for a more structured way of deciding. The main adaptations include:

- The creation of a moderator (role), who is responsible to evaluate and to make available the arguments sent by members. Depending on the case, the moderator can be the own VE coordinator;
- The comparison of two different arguments using different *connectors* (better than; worse than; equal to; as bad as; as good as). Each comparison assigns negative and/or positive points to each argument, depending on the connector;
- Voting: Partners can vote pro or against to each argument;
- During the discussion, partner are guided by the Decision Protocol;
- Is possible to use a previous evaluation decision tool, in order to evaluated the impact of a new scenario into the VE operation.

4.1 Usage scenario

In order to evaluate the collaborative discussion using the DDSS-VE, a VE scenario has been created. This VE would be responsible to develop a new helmet style for racing, involving four partners from different countries (Drissen-Silva & Rabelo, 2009b).

Considering the decision protocol showed in figure 4, it is assumed that the phase "Need of Change Identification" has been passed. Figure 7 illustrates in a general way how the discussion would try to solve the conflict resolution from the protocol's phase "Change Proposal" on. All this have been implemented in a web portal, on top of *Liferay* web application server (www.liferay.com). In this example, the VE Coordinator (*Mr. Ricardo*) has concluded that it is necessary to start a discussion with two members (*Mr. Marcus* and *Mr. Rui*) due to a problem detected in the specification of the first lot. After starting the collaborative discussion, the protocol gets in the "Changing Planning" phase where different scenarios are evaluated using tools form the tool box. "Changing Planning" phase ends when the best alternative has been chosen in the "Implementation" phase, where the new scenario is put on practice. The sequence described below quickly explains figure 7.

1. *Starting the discussion (to be conducted via the DDSS-VE):*
   - *The protocol ask some questions to delineate the better attitude for each case (e. g. if it is a rigorous client constraint that avoids from choosing another supplier);*
   - *Each participant can use some tools to preview which different scenarios could be acceptable to reschedule the activities that have to be done, choosing the best one, and publishing it as a suggestion for the problem resolution:*
     a. *Mr. Rui posts the first suggestion: 'Buy from another supplier' (Figure 7a);*
     b. *Each partner can vote pro or against it (bottom Figure 7a);*
     c. *Each suggestion can be compared with other suggestions using 'COMPARE' button (Figure 7a). Figure 7b presents the list of suggestions and the possible logical connectors. For example, a comparison using 'is better than' as the connector assigns +1 point to the best suggestion and -1 to the worst;*
     d. *Figure 7c shows a tree (associated to the detected problem: helmet strip allotment) with the three posted suggestions (plus authors) and four comparisons among them. One of them is not yet evaluated as it is 'awaiting approval';*
   - *The moderator (Mr. Ricardo) evaluates the different suggestions and the comparisons, mainly to see if there is some confrontation among the participants:*
     a. *Figure 7d shows the Moderator's view. He can modify and/or simply approve Mr. Rui's opinion ("RE: buy from another supplier is as good as …") and send them to the group;*
     b. *Figure 7e represents the vision seen by the other two members before Mr. Rui's opinion approval. Thus, they only see 'message awaiting approval';*
   - *In what the final voting result is concerned:*
     a. *It is possible to see the number of votes of each suggestion, which is +3 in relation to the Mr. Rui's one (Figure 7a), also meaning that the three consulted members (including the VE coordinator) have agreed on it;*
     b. *Figure 7c shows a signaled number beside each suggestion expressing the final sum of voting with the weights of comparisons. In this case, 'Buy from another supplier' has more positions in favor (+3 from direct voting) that is added to more 2 points from two positive comparisons, resulting 5 points in favor;*
2. *Once agreed, the most suitable solution is settled on the VE plan and partners (re)start to work based on it. This means that VE evolution is ended and the VE management goes back to the operation phase.*

4.2 Previous evaluation tool for decision making

Performance evaluation needs the selection of the most important factors for the best system's performance. For each factor is necessary to set some levels (in terms of numbers) they could assume. In a manufacture environment the factors could be machines or employees, for example, and levels could be the quantity each one could be available. The performance evaluation could indicate which is the most important factor in the system's performance effect.

In order to offer a tool for previous evaluation of the decision's impact using performance evaluation it was developed a module adequate to the conceptual model previous described. This tool uses different spreadsheets compounding a dashboard that offers the possibility to see each partner's competence, production scheduling, available resources, number of resources looking for the integrations of the scheduling in order to calculate another scenario for solving the problem in the discussion on DDSS-VE. Figure 8 shows the developed *dashboard*.

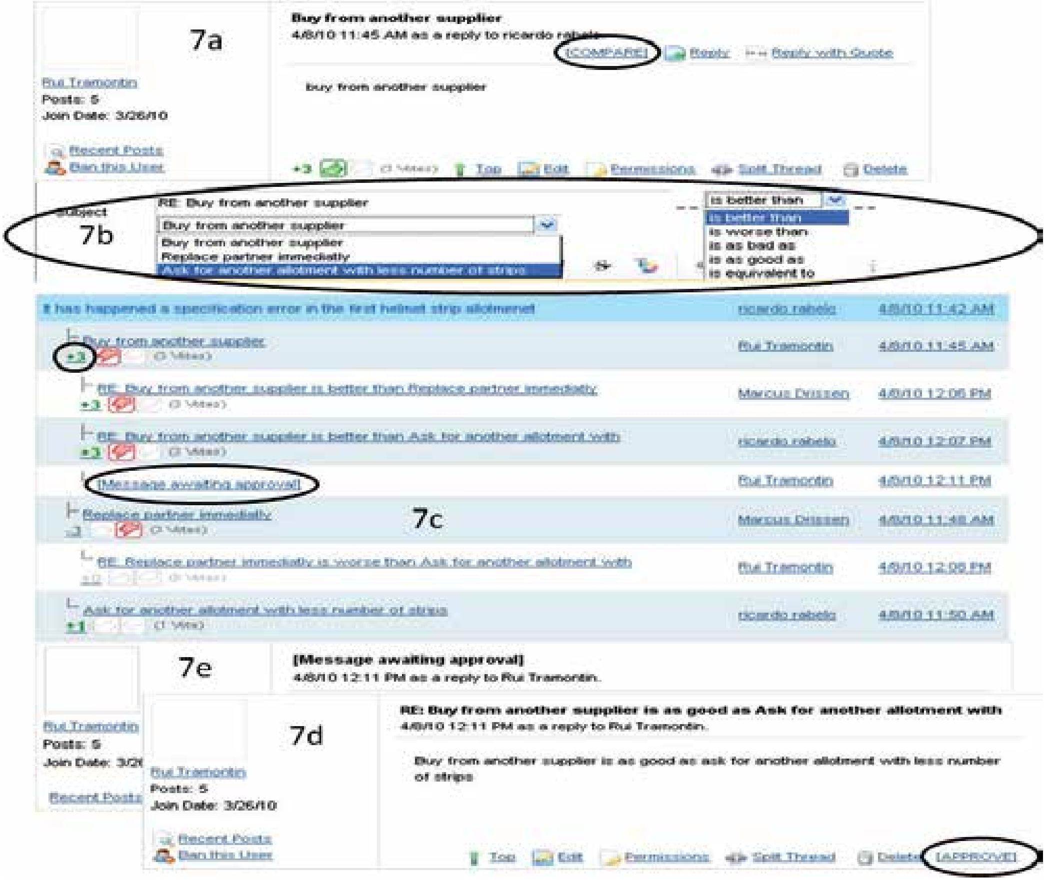


Fig. 7. Some snapshots of the Partner's Discussion Environment.

5. General evaluation

The developed prototype passed through a sequence of exhaustive tests for the verification and validation of the conceptual model for the collaborative discussion around a problem emerged in the Virtual Enterprise operation phase forcing it to go on the evolution phase. The conceptual model and the prototype were evaluated by experts on the main areas studied in the model development process. In the evaluating average all experts agreed in the contribution, relevance and attending the needs of the scientific problem to be solved: 'to find a more transparent and collaborative environment that puts autonomous partners in a discussion around the partnership conflict using a set of computable tools and a decision protocol to support the decision'. The methodology used to evaluate this work followed three main steps: i) prototype evaluation in a sequence of stressed tests; ii) explanation the conceptual model by a scientific article to the experts with a number of questions answered with their evaluation; iii) explanation the prototype functionalities in an example execution with another number of questions answered with their opinions.

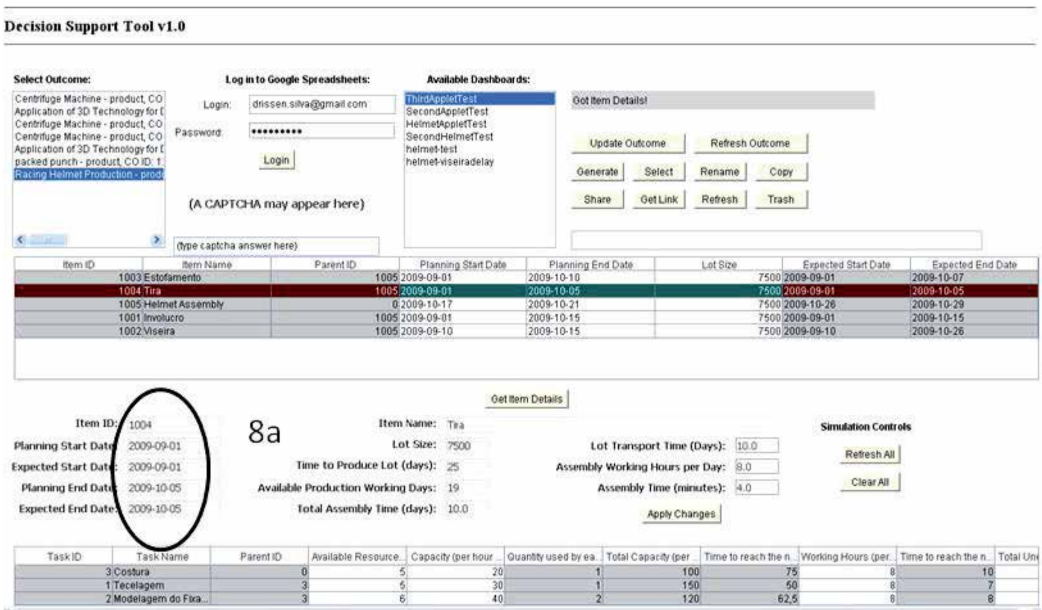


Fig. 8. Previous Evaluation Scenarios Tool using Dashboards for Tasks Rescheduling.

5.1 Contributions

Main scientific contribution of this work is centered in using different techniques, tools and methods already acceptable in an adequate semi-automated system that help managers in the decision making process around a problem in the VE operation phase. The integration of those different methods can offer a distributed and collaborative discussion with transparency, controlled by moderation using previous analysis of the decision's impact.

Central element is the human, who has the ability to feel and to decide what is the best scenario respecting his knowledge. The framework can only support his decision offering flexibility, calculus tools and communication availability through partners.

Compared with the state-of-the-art in the area, this work covers different aspects, which are showed in the Table 1.

Considering the flexibility offered by the decision protocol, this framework could be adapted to other strategic alliances models and also to the management of virtual organization operation phase, only making the necessary modification on the some phases and processes in the base protocol in order to attend different cases needs.

5.2 Limitations

The main limitation of this work is related to CNO concept that assumes each partner are autonomous and has to participate in a collaborative way trying to help other partners in difficulties. Some aspects related to VE concept is difficult to reach in the reality because trust among partners has to be strong, and also it is necessary a well developed ICT infrastructure to put this environment on work. But on the other hand, there are a number of VBE in execution in the world that feed expectative of a strong dissemination of the VE concepts to these kinds of enterprises collaborative environment.

	Traditional Management Model	CNOs / VEs (current approaches)	CNOs / VEs (proposed approach)
Decision	Centralized	Centralized	**Decentralized**
Information sharing between partners	No or eventual	Yes	Yes
Transparency in the decision	No or partial	Partial	**Yes**
Decision quality evaluation	No	Low and Eventual	**Yes**
Decision scope	Intra-organizational	Inter-organizational	Inter-organizational
Decision process Rigidity	Inflexible / "Data flow"	Inflexible / "Data flow"	**Flexible / Systemized / Adaptable**
Information integration between partners	Low / Medium	Medium / High	High / **Very high**
Trust between partners	Implicit	Explicit	Explicit / **Reinforced**
Decision objective	Best global results	Good global results	Good global results **with previous analysis**
Mutual help between partners	Cooperation	Punctual Collaboration	Full-fledged Collaboration **along decision making**
Methodological aid / Assisted decision	No or partial	Low efficiency and without assistance	**Yes**

Source: Adapted from Drissen-Silva & Rabelo, 2008.

Table 1. Comparison between traditional management model, current and proposed CNOs/VEs approaches.

Considering the prototype it was developed only with one tool for supporting previous impact analysis of the decision, but the conceptual model can consider a big number of available tools those could be put in a collaborative access environment for all partners.

5.3 Future research

Considering the high complexity of the problem presented in this work, there were another themes to be researched to better develop the ideas described in the Distributed and Collaborative Decision Making Environment for the Virtual Enterprise Evolution (DDSS-VE), for example:

- Development of a model that consider aspects of hierarchy, power and governance between VBE and VE partners. A model that also consider the moderator's competence and his position during the decision process;

- Adequate the collaborative discussion environment, that uses ideas from HERMES system and Delphi method to the Moodle system;
- Creation of an ontology that describes formally the relations, hierarchies and concepts associated to the explored domain on decision making in the Collaborative Networked Organizations (CNO).

6. Conclusion

This chapter has presented a framework to support a collaborative discussion among VE members for solving problems during the VE evolution phase. It is essentially composed of a decision protocol, a distributed and collaborative decision support system, and of ICT supporting tools and communication infrastructure. It was designed to cope with the VE requirements, mainly in what members' autonomy and decision transparency is concerned.

Developed based on project management methodologies, discussions are guided and assisted by the system but preserving and counting on the members' experience and knowledge in order to reach a suitable/feasible solution for the given problem.

The proposed framework groups such requirements and organizes them into four pillars: Human, Organizational, Knowledge and Technological. The essential rationale of these four pillars is to enable humans to discuss and to decide about a problem related to a given organizational process, applying a set of organizational procedures and methods, using information and knowledge available in the VBE's repositories, supported by a sort of ICT tools. A crucial aspect in the proposed approach is the human intervention, i.e. the problem is so complex that is unfeasible to try to automate the decisions. Instead, the approach is to put the managers in the centre of the process, surrounding them with adequate tools and methods.

All the framework's elements operates in a methodological way by the human element, on a democratic, transparent, decentralized, systematized and moderated basis, considering their geographical distribution.

In order to offer more quality in the suggestions made by each partner during a discussion around a problem resolution, different tools, techniques and methods for performance evaluation are offered to provide a vision for a future capacity planning in order to evaluate different scenarios for solving the problem in discussion. In this way, the participants have conditions to previously evaluate the impact of the decision to be taken. This evaluation can be made isolated by each participant during the conflict resolution process.

A software prototype has been implemented to evaluate the framework, and it was tested in an open but controlled environment. The implementation copes with the required flexibility and adaptability of the decision protocol to different VEs, applying BPM (Business Process Management) e SOA (Service Oriented Architecture) technologies as a support for. The developed framework fundamentally assumes that VE partners are all members of a kind of cluster of companies. This presupposes the presence of a reasonable degree of trust among members, of an adequate computing infrastructure, of common organization vision (in terms of collaboration and enterprise networking) and operational procedures to be followed when problems take place, and that VE managers are trained for that.

The implementation results have showed that the proposed mechanisms for supporting partners' autonomy, Internet-based decentralized decision-making, voting and transparency have worked out in a controlled environment. During the discussions, selected partners can have access to the problem, can freely exchange opinions about how to solve it, and can express their preferences via voting. This guarantees that the solution emerges from the collaboration and trust among partners. The decision protocol helps participants to take the right action on the right moment. The scenarios evaluation tools is capable to offer a pre-evaluation of the decision impact.

This work's evaluation was composed of a set of procedures that offers conditions to affirm the final general research conclusion: "*A semi-automated decision protocol, flexible and adaptable, integrated with scenarios analysis tools and a collaborative discussion environment makes better the quality and trust in the decision around a problem in a VE*".

7. Acknowledgment

This work is partially supported by CNPq – The Brazilian Council for Research and Scientific Development (www.cnpq.br). The authors would like to thanks Ms. Cindy Dalfovo, Mr. Leonardo G. Bilck and Mr. André C. Brunelli for the software implementation.

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9

A Lean Balanced Scorecard Using the Delphi Process: Enhancements for Decision Making

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1. Introduction

Kaplan & Norton's Balanced Scorecard (BSC) first appeared in the *Harvard Business Review* in 1992 (Kaplan and Norton, 1992). It described in general terms a method by which management may improve the organization's competitive advantage by broadening the scope of evaluation from the usual *Financial* dimension to include: the organization's *Customer* base, the constitution and functioning of the firm's *Internal Business* processes, and the necessity of *Innovation and Learning* as a condition for growth. Over the years, these four constituent elements of the BSC have remained largely unchanged, with the exception of a modification in 1996 when Innovation and Learning was changed to *Learning and Growth* (Kaplan and Norton, 1996).

As the BSC is now in its second decade of use, there have been a number of articles suggesting that the BSC is in need of refocusing. Lusk, Halperin & Zhang (2006) and Van der Woerd, F. & Van den Brink (2004). This refocusing suggests two changes in the *Financial Dimension* of the BSC. First, the *Financial Dimension* of the BSC needs to be broadened from measures that only address internal financial performance to those that are more market-oriented. For example, according to the Hackett Group (2004: 67), the majority of Balanced Scorecards are "out of balance because they are overweight with internal financial measures". Second, there seems to be a tendency to add evaluation variables with little regard for their relationship to existing variables. This "piecemeal approach" results in a lack of coherence and often causes Information Overload. This tendency is underscored by Robert Paladino (2005), former vice president and global leader of the Telecommunications and Utility Practice for Norton's company, the Balanced Scorecard Collaborative, http://www.bscol.com/, who suggests that a major failure of the BSC is that many organizations adopt a piecemeal approach that generates an information set consisting of too many highly associated variables without independent associational linkages to the firm's evaluation system. The observation is consistent with one of the classic issues first addressed by Shannon (1948) often labelled as the Shannon-Weaver Communication Theory which in turn lead to the concept of *Information Overload*.

Information Overload is particularly germane, because from the beginning of the Internet Era, management has succumbed to the irresistible temptation to collect too many financial performance variables due to the plethora of data sources offering simple downloads of hundreds of financial performance variables. For example, Standard & Poors™ and Bloomberg™, to mention a few, have data on thousands of organisations for hundreds of variables.

In this study, we answer the call for refocusing the Financial Dimension of the BSC. The purpose of this study is twofold. First, as suggested by Lusk, Halperin & Zhang (2006) we add two market-oriented variables - the standard CAPM Market *Beta* and *Tobin's q* to broaden the financial dimension of the BSC. And second, we suggest, in detail, a simple modelling procedure to avoid the "Information Overload and Variable Redundancy" so often found in the Financial Dimension of the BSC. Although this study is focused only on the Financial Dimension of the BSC, the modelling process that we suggest in this study may be also applied to the other dimensions of the BSC.

This study is organized as follows:

1. First, we suggest a simple procedure for generating a "lean" i.e.,—parsimonious, variable characterisation of the firm's financial profile and then use that lean or consolidated variable set as an input to a standard Delphi process.
2. Second, we present an empirical study to illustrate the lean BSC modelling system.
3. Lastly, we offer some concluding remarks as to use of our refined information set.

2. Our simple procedures leading to parsimony in the BSC

As an overview, as discussed above the BSC has been criticized as being "too endowed" with financial performance variables due to the convenience of downloading financial variables using the standard databases. Simply put, many of these financial variables are merely expressing the same firm process characterization but in a different variable voice. To deal with this "redundancy" issue, we are following the suggestion of Jones (2006) who recommends factor analysis, essentially based upon the standard Harmon (1960) Factor model [SHFM], as the best technique to develop non-overlapping categorizations of impact variables for risk assessment. His model forms the basis of the Information Risk Management module of the Certified Information Security Manager manual (2009, Ch 2).

The essential idea is that factor analysis reduces the "over-endowed" variable space to its factor equivalent; this will achieve parsimony in the variable space and thus enable firm decision-makers to better understand their processes as characterisations of independent factors. This factor reduction thus addresses the issues of Variable Redundancy and Information Overload discussed above. Consider now how factor analysis and benchmarking can be used to develop the Lean BSC.

2.1 Three variable contexts of factor analysis and the Delphi Process: our lean modelling system

In the process of using factor analysis to develop lean variable set characterizations, we suggest performing factor analyses in three variable contexts: (1) the *Industry*, (2) a *Benchmarked Comparison Organisation* and (3) the *Particular Firm*. These three variable contexts[1] taken together help management refocus on variables that may be productively

[1]The above lean modelling framework and benchmarking procedure was used by one of the authors as a member of the Busch Center of the Wharton School of the University of Pennsylvania, the consulting arm of the Department of Social Systems Science, as a way to focus decision-makers' attention on differences between their organisation and (1) the related industry as well as (2) a selected firm in the

used in planning and executing the navigation of the firm. Specifically, the feedback from these three variable contexts will be organized as a Delphi Process as the information processing logic of the BSC. Consider now the details of the Information Processing logic for the BSC as organized through the Delphi process.

2.2 The two-stage Delphi Process in our lean modelling system

Because the principal information link in the Delphi Process is generated by factor analysis, the decision makers [DM] must have a practical understanding of the output of the factor model—i.e., a working familiarity with the output of the factor model is essential to the successful creation of a Lean BSC. Accordingly, we suggest the Delphi Process to be achieved in the following two stages.

2.2.1 Stage 1: unfreezing stage –familiarize the decision makers with "factors"

The goal of the *Unfreezing* stage is to have the DM feel comfortable with the logic of factor analysis as a statistical technique that groups BSC Variables into Factors. To effect the Unfreezing stage we recommend using an intuitive example dealing with the simple question: ***What is a Computer?*** It is based upon an example, the data of which is presented following in Table 1, used by Paul Green and Donald Tull (1975) in their classic text on marketing research; they used it to illustrate the logic of Factor Analysis.

Computers n=15	Basic Processing	Advanced Processing	Minimum Storage	Maximum Non-swap Storage	Add-Ons Non-buffer	Cycle Time
1	-0.28	-0.36	-0.49	-0.52	-0.48	-0.27
2	3.51	3.61	-0.55	-0.6	-0.87	3.74
3	-0.39	-0.34	-0.55	-0.53	-0.59	-0.27
4	-0.06	-0.28	-0.55	-1.07	-0.83	-0.26
5	0.38	-0.27	-0.46	-0.50	-0.88	-0.27
6	-0.43	-0.38	-0.55	-0.52	-0.48	-0.27
7	-0.26	0.37	-0.55	-0.52	-0.59	-0.27
8	0.70	0.68	-0.60	-0.61	-0.92	-0.27
9	-0.47	-0.39	-0.37	-0.52	-0.48	-0.27
10	-0.28	-0.23	-0.02	-0.14	-0.77	-0.27
11	-0.49	-0.39	-0.13	0.16	1.71	-0.27
12	-0.50	-0.39	1.32	2.47	1.08	-0.27
13	-0.51	-0.39	0.36	0.16	1.70	-0.27
14	-0.51	-0.39	3.26	2.47	1.08	-0.27
15	-0.52	-0.12	-0.13	-0.23	1.33	-0.27

Table 1. The Green and Tull Computer Factor Dataset

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industry used as a positive benchmark—that is, a best practices case that the study firm would like to emulate. Sometimes, a negative benchmark was also used—in this case an organisation from which the study firm wished to distance itself.

To start the Unfreezing process, we suggest presenting to the DM the following information processing task:
Assume that you do not know anything about Computers, and you wish to better understand the essential functioning of Computers. Unfortunately, as you are not gifted "technically, it is not possible for you to reverse-engineer a computer and tinker with it so as to understand its essential features. So, you are left with an "empirical" or analytic option. Therefore, with the aid of your tech-friends you collect six performance Variables on 15 different models of computers: (1) ***Basic Processing Speed****, (2)* ***Advanced Processing Speed****, (3)* ***Minimum Storage****, (4)* ***Maximum Non-Swap Storage****, (5)* ***Add-Ons Non-buffer Capacity****, and (6)* ***Cycle Time****. So now you have a dataset with 15 computers measured on six performance variables – i.e., a matrix of size 15 rows and 6 columns as presented in* ***Table 1****.*
As we continue with the Unfreezing stage, we distribute to all the DM a copy of the dataset in Table 1 for anchoring their processing of the variable reduction from this dataset. We, the group conducting the Unfreezing, enter the dataset into the Standard Harmon Factor Model [SHFM] statistical program; the results produced are presented in Table 2. We recommend that Table 2 be displayed either: (1) on the computers of the DM, (2) on a projection screen for all to see or (3) distributed to the DM as printed copies. They need to be able to see and discuss the information in Table 1 and the factor results as presented in Table 2.

Variables	Factor A	Factor B
Basic Processing	**0.96**	-0.22
Advanced Processing	**0.98**	-0.16
Minimum Storage	-0.07	**0.94**
Maximum Non-Swap Storage	-0.07	**0.96**
Add-on Non Buffer	-0.25	**0.75**
Cycle Time	**0.98**	-0.06

Table 2. Two Factor Rotation of the Six Variables of the Computer Dataset

Using the above information and the usual Factor Definition Rule that: *any variable score greater than 0.71 is an important variable descriptor of that factor* – here bolded in Table 2, we discuss with the DM that the six variables really describe just two Factors[2]. Factor A is described predominately by the variables: *Basic Processing*, *Advanced Processing* and *Cycle Time* all of which have variable scores greater than 0.71. These are all measures of **Speed**. Factor B, on the other hand, is described predominately by *Minimum Storage*, *Maximum Non-Swap Storage* and *Add-on Non Buffer* which are all measures of **Storage**. The results in Table 2 provide simple and intuitive information which speaks in a straightforward way to the question which started the Unfreezing analysis "What is a Computer?" The DM now recognizes and, of course, probably knew at the outset that *Computers are devices that have* ***Speed of Processing*** *and* ***Storage Capacity*** *as their essential profiling characteristics*. Also, they

[2] We do not discuss with the DM the $\sqrt{0.5}$ loading rule because this concept requires a relatively sophisticated understanding of the mathematical statistics of factor models. Rather we use the simple loading rule that if a *Variable* had a weight of 0.71 or greater then that variable is a meaningful descriptor of that *Factor*. In our experience, this level of detail is sufficient for the DM to use the results of the Factor Model. This does assume, of course, that there will be someone in the firm with sufficient training in statistical modeling to actually use the factor software that is to be used in the Delphi process. This is usually the case.

understand, via the comparison of the data in Table 1 and the results in Table 2, that there were not really six variables but rather two variables: Speed and Storage with each of them measured in three different ways.

In summary, to wind-down the Unfreezing stage, we emphasize that the initial set of six variables was by definition "over-weight" or redundant and so the six variables were consolidation by the SHFM to form only two dimensions: Speed and Storage in the lean-version characterization of the dataset.

This simple computer example is critical to the understanding of the use of factor analysis to reduce variable redundancy and so deals with "over-weight" variable characterizations. We find that this simple and intuitive example unfreezes the DM in the sense that they knew that computers were fast storage computation devices and this is exactly what the factor analysis shows; this reinforcing their belief that the Factor Analysis can be "trusted" to replicate the reality of the associated variable space with fewer variables.

2.2.2 Stage 2: Factor analysis in three contexts and brainstorming

Following the first or Unfreezing Stage, the next stage is where we engage the Delphi process. We recommend that the Delphi process be used in its EDI-mode (See Jung-Erceg, Pandza, Armbruster & Dreher (2007)) where the DM discuss, in a Chat-Loop-Context, the various information sets until they are satisfied with their insights and then they propose the Action Plan for the firm derived from the Lean-BSC.

Specifically we recommend that the firm, given its understanding of the Mission, Goals and Objectives, engages the Delphi Process to generate the Lean-BSC using the following steps:

1. The firm will identify the set of DM who intend to navigate their firm using the BSC.
2. This group of DM will select the longitudinal panel consisting of (i) a sample of firms from their industry, *possibly all*, and (ii) a particular firm that could be a positive or negative benchmark—meaning that the DM judge the benchmark to be a firm that they wish to emulated or a firm from which they wish to distance themselves.
3. Then the DM will select a Comprehensive Variable Set [CVS] that they believe are the firm performance variables that can be used to best profile their firm. In our experience the best profiling variables may include those financial performance variables that (i) are simple to measure, (ii) have operational measures that are sensitive indicators of change, and (iii) are themselves considered as direct measures of effects relative to the Mission, Goals and Objectives of the firm. This will be important in constructing the necessary reward linkages which is one of the principal reasons to use the BSC. The CVS, itself, is very likely to be a variable set that the firm has been using in the past and so may be characterized as the "over-weight" variable set. This is not a problem as the intention at this stage is to incorporate all the variables that the DM feel to be important. We expect that the CVS will be formidably large.
4. The "Overweight" CVS will be inputted to the SHFM so as to consolidate the variable set to the factors—i.e., the lean variable set. This process will be repeated for the Industry and the Firm-benchmark respectively (i.e., the other two contexts of factor analysis).
5. And finally, these three lean-variable sets, one for: *the Firm*, *the Industry* and *the Firm-benchmark*, will be sent to the Chat-Loop-Context-Delphi-Space and the DM will begin the convergent process of deciding the Financial Action Plan that will be integrated into the full BSC evaluation process. This process will lead to the final action plan of the firm considering all four of the BSC dimensions.

To enrich understanding of how these five steps will be used for a particular firm, we will now present a detailed and comprehensive example of all the steps that are needed to create the Lean BSC.

Study Firm: A.D.A.M. Inc. (ADAM). [http://www.adam.com] The principal activity of A.D.A.M.,Inc is to provide health information services and technology solutions to healthcare organizations, group insurance brokers, employers, consumers, and educational institutions. The products of the Group are used for learning about health, wellness, disease, treatments, alternative medicine, anatomy, nutrition and general medical reference in both the healthcare and education markets. The products contain physician-reviewed text, in-house developed medical graphics and multimedia to create health information that offers visual learning experience. The Group provides information on annual licensing agreements to healthcare organizations, Internet websites and educational institutions. **Benchmark: Amdocs** (DOX). [http://www.amdocs.com/Site/AmdocsCom.htm] Amdocs,Inc is a leading provider of customer care, billing and order management systems for communications and Internet services. Amdocs has an unparalleled success record in project delivery of its mission-critical products. With human resources of over 5,900 information systems professionals, Amdocs has an installed base of successful projects with more than 75 service providers throughout the world. In April 2000, Amdocs completed the acquisition of Solect Technology Group Inc., a leading provider of customer care and billing systems for IP providers.

Table 3. Brief Profiles of the Study Firm and its Benchmark

3. Illustrative example – pre-packaged software: SIC 7372

We next present an illustrative example of the BSC Delphi Factor Procedure [Delphi BSC] using an actual **firm: A.D.A.M. Inc. in the** SIC 7372. It is not our intention to suggest that this selected dataset speaks to actual recommendations drawn from the BSC analysis as this is clearly the domain of the DM of the firm using the Delphi BSC. We offer this example as a detailed illustration of the guidance through the process. To this end we, the authors, have assumed the role of the DM **for A.D.A.M. Inc.** and will (1) discuss our reaction to the information that we have generated using the Delphi BSC and (2) how this may be used to develop the BSC navigation information for the sample firm. Our assuming the roles of decision makers is only to illustrate the possible functioning of the Delphi BSC—i.e., our Lean-BSC navigation recommendations for the actual firm that we have selected are not normative in nature.

3.1 Selection of three lean variable contexts

We assume the role of DM for A.D.A.M. Inc. (Ticker: ADAM; NASDAQ) which is in the software and related devices industry in the SIC: 7372. The principal activity of our company, A.D.A.M. Inc., is to provide health information services and technology solutions to healthcare organizations, group insurance brokers, employers, consumers, and educational institutions. Our positive benchmark is Amdocs (Ticker: DOX; NYSE), a leading provider of customer care, billing and order management systems for communications and

Internet services (See Table 3 above for a brief description of these firms and their URL-links). Our Industry Benchmark includes all 7372 SIC Firms that had data reported in COMPUSTAT from 2003 to and including 2006. We selected this time period as it was after Sarbanes-Oxley: 2002, and before the lead-up to the sub-prime debacle in 2008, which we view as event partitions of reported firm data. This accrual yielded 411 firms and netted a variable-panel of 1,161 observations.

3.2 Selection of a comprehensive variable set [CVS]

We, the DM for A.D.A.M. Inc., began the Delphi BSC process by selecting from the extensive COMPUSTAT™ menu 15 variables which we believe are useful in portraying the financial profile of market traded organizations. Further, we have used these variables in characterizing our operating profile in that, over time, these variables have been instrumental change variables for us, and have been used in the evaluation of our firm. These DM-selected variables are presented in Table 4. The seven (7) variables that were not downloaded from COMPUSTAT™, but rather calculated from COMPUSTAT™ variables are noted in **boldface**. The computation of these variables is detailed in the Table 5. The other definitions are available from COMPUSTAT™. Finally, we downloaded Beta from CRSP™. Therefore, in total, we have 23 variables as our financial profile, two of which are Tobin's q and the CAPM β as suggested by Lusk, Halperin & Zhang (2006).

Cash & Short-Term Investments	Net Sales	Diluted EPS before extraordinary items	**Current Ratio**
Receivables Total	Market Value: Fiscal Year End	Net Income (Loss)	**Quick Ratio**
Cash	Number of Common Shares outstanding	Cash from Operations	**Accounts Receivable Turnover**
Current Assets	Net PPE	Depreciation & Amortization	**Tobin's Q**
Current Liabilities	Beta	**Gross Margin**	**EPS Growth**
Total Assets	Cost of Goods Sold	**ROA**	

Table 4. The 23 Judgmental Variables Selected by the Decision-makers of A.D.A.M. Inc.

Effectively we are saying that these 23 variables would be important in profiling our organization as we play the role of DM for A.D.A.M. Inc.; other DM as well as other firms may, and probably will, select other variables. This is a positive feature of the Delphi BSC in that it provides the needed idiosyncratic flexibility in selecting the variables that will be inputted into the Factor Analysis, and so constitutes the judgmental factor set critical in the analysis.

3.3 The results of the factor study

All of the results of the factor study reported in Tables 6, 7 and 8 were created using the SHFM; the standard Varimax rotation on the Pearson correlation matrix, as programmed in JMP of the SAS Institute, version 6.0 (see Sall, Lehman & Creighton, 2005). The number of factors selected was the number of factors in the un-rotated factor space—i.e., the correlation matrix—for which the eigenvalue was greater than 1.0. Finally, variable loadings greater than √0.5 were used in the description of the factors. For ease of reading, the variable loadings are presented only to the second decimal, and those loading greater than √0.5 are **bolded**. For the industry factor analysis, we excluded *A.D.A.M. Inc.* and *Amdocs* as they are the study firm and the benchmark firm respectively.

Tobin's q	=(A25xA199+A130+A9)/A6
Current Ratio	=A4/A5
Quick Ratio	=(A1+A2)/A5
ROA	=(A172-A19)/A6
EPS Growth	=((A57t-A57t-1)/ | A57t-1 |
Gross Margin	=A12-A41
Accounts Receivable Turnover	=A12/((A2t+A2t-1)/2)
Where:	
A1-	Cash and short term investments
A2-	Receivables
A4-	Current Assets
A5-	Current liabilities
A6-	Total assets
A9-	Total long-term liabilities
A12-	Net sales
A19-	Preferred Dividends
A25-	Common shares outstanding
A41-	Cost of goods sold
A57-	Diluted earnings per share excluding extraordinary items
A130-	Preferred stock-carrying value
A172-	Net income (loss)
A199-	Common Stock Price: Fiscal year end

Table 5. Computation of Ratios Based on COMPUSTAT Data

3.3.1 The Delphi Process judgmental interpretation of the representative variables for the various factors

We, in the role of DM for A.D.A.M. Inc. were guided by the factor loading results and also by those variables that did not load across the final factors. These latter variables are interesting in that they are independent, in the strong scene, as they did not achieve association in the rotated space greater than √0.5. We will note these non-associative variables in the Tables 6, 7 and 8 using ***Bold-Italics***. Therefore, we will have two groups of variables that exhaust the Factor/Variable Space: Those variables that have loaded on a factor such that the rotate loading is greater than √0.5 and those that did not exhibit such an association. Both groups have guided our interpretation of the Delphi BSC.

3.3.2 The industry factor profile and its relation to the BSC

The *industry* Factor analysis is presented in Table 6. We remark that both Beta and Tobin's q do not align in association with any of the COMPUSTAT™ financial performance profile variables. This suggests that relative market volatility and stockholder preference are independent measures for the Pre-Packaged Software industry—*in and of itself an interesting* *result*. One strong implication of Table 6 for us as DM for A.D.A.M. is that insofar as the BSC analysis is concerned the *industry* is a mixed portfolio with both disparate hedge and market sub-groupings. See two recent articles that treat these topical relationships in the hedge fund context: Vincent (2008) and Grene (2008). Confirmatory information is also

Beta	0.02	0	0.01	0	-0.1	0	0.03	**0.98**	0
Tobin's Q	0.02	0.11	0.1	0.03	0	0.04	**0.99**	0.03	0.03
Current Ratio	0	**0.99**	0.01	0	0.03	0.07	0.06	0	0.01
Quick Ratio	0	**0.99**	0	0	0.04	0.06	0.06	0	0
ROA	0.11	0.08	0.23	0.2	**0.92**	0.04	0	-0.1	0.15
Gross Margin	**0.99**	0	0.08	0	0.04	0.02	0.03	0	0.04
A/R Turnover	0.02	0.12	0.05	-0.1	0.03	**0.99**	0.04	0	0
EPS Growth	0.01	0	0.07	**0.97**	0.17	-0.1	0.03	0	0.12
Cash	**0.94**	0	0.05	0	0.04	0	0.01	0.02	0.03
Cash & Short-term Investment	**0.89**	0.05	0.17	0.03	0.02	0.07	0	0.04	0.03
Cash from operations	**0.98**	0	0.05	0	0.04	0.02	0.05	0	0.06
Receivables Total	**0.96**	0	0	0.01	0.04	-0.1	0	0.01	0.04
Current Assets	**0.96**	0.02	0.14	0.02	0.03	0.04	0	0.02	0.03
Current Liabilities	**0.98**	-0.1	0	0	0.03	0	0	0.01	0.02
Total Assets	**0.98**	0	0.06	0.01	0.03	0	0	0.03	0
PPE Net	**0.94**	0	0.1	0.01	0.03	0	0	0.01	-0.1
Net Sales	**0.98**	0	0.09	0	0.04	0.04	0.01	0	0.04
Depreciation & Amortization	**0.90**	-0.1	0.2	0.07	0.03	0.02	-0.1	0.02	-0.2
Common Shares Outstanding	**0.94**	0	-0.2	0	0.02	0	0.04	0.01	0.06
COGS	**0.82**	0	0.09	0	0.03	0.08	0	0.01	0.05
Net Income(Loss)	**0.92**	0	0.01	0.01	0.05	0.03	0.08	0	0.18
Diluted EPS	0.10	0	0.48	0.29	0.34	0	0.06	0	**0.73**
Market Value- Fiscal Year end	0.22	0.01	**0.92**	0.06	0.2	0.06	0.11	0.02	0.16

Table 6. Industry Factor Analysis: Mid-Range Year Randomly Selected 2004

provided by the fact that EPS Growth and Market Value are independent variables with respect to the other factor defined variables. For this reason, we note: *It will be important to understand that A.D.A.M. Inc., our firm, does not have to compete on a market relative basis – i.e., against the industry as a portfolio.* One possible reaction to this, that the decision-makers may decide, is that it would be useful in a strategic planning context to partition the industry into various profile groupings and then re-start the Delphi BSC using these industry sub-groupings as additional benchmarks. We have opted for the other approach that is to use the Amdocs benchmark and continue with the Delphi BSC.

3.3.3 The study firm—A.D.A.M., Inc. and the selected benchmark: Amdocs

We will now concentrate on the relative analysis of the study firm and *Amdocs*, our positive benchmark. One of the underlying assumptions of this comparative analysis is the stability of the factors in the panel. As we have an auto-correlated panel for these two firms, there is no statistical test for stability for the particular factor arrangement that was produced. If one seeks to have a demonstration of this stability then a simple boot-strapping test will give the required information. See Tamhane and Dunlop (2000, p. 600). For our data test, we conducted a relational test for this data set and found it to be stable over the two following partitions: years 2005 and 2006 compared to 2003 to 2006 and this argues for factor stability.

Beta	**-0.81**	0.55	0.20
Tobin's Q	-0.59	**0.75**	0.30
Current Ratio	**-0.82**	0.52	-0.24
Quick Ratio	**-0.84**	0.49	-0.23
ROA	-0.42	**0.91**	-0.03
Gross Margin	**0.98**	0.22	0.00
A/R Turnover	**0.88**	-0.19	-0.43
EPS Growth	**-0.88**	0.47	0.00
Cash	**0.88**	-0.40	-0.26
Cash & Short-term Investment	0.42	**0.91**	-0.02
Cash from Operations	0.11	**0.86**	0.50
Receivables Total	**0.92**	0.11	0.38
Current Assets	0.65	**0.75**	0.06
Current Liabilities	**0.98**	0.16	0.12
Total Assets	**0.98**	0.20	-0.01
PPE Net	**0.99**	0.10	-0.05
Net Sales	**0.98**	0.22	-0.01
Depreciation & Amortization	-0.54	**-0.84**	-0.10
Common Shares Outstanding	**0.92**	0.40	0.02
COGS	**0.97**	0.22	-0.03
Net Income(Loss)	-0.08	**0.99**	-0.09
Diluted EPS	-0.13	**0.99**	-0.07
Market Value-Fiscal Year End	0.28	**0.96**	0.09

Table 7. Factor Analysis: A.D.A.M., Inc. [ADAM]

As part of the Delhi process as it relates to the interchange of information among the DM so as to create the BCS navigation we, the authors, using the information in Tables 6, 7 and 8 exchanged our ideas as to the interpretation of the information generated by the factor analyses as presented in Tables 6, 7 and 8 by email and also in face-to-face meetings. This was done over a two week period; after that time we felt that we had closure and developed the following two Observations: One using the information in Table 7 above for A.D.A.M and One using the information in Table 8 following for Amdocs. Finally from these two observations we developed the Navigation information for A.D.A.M. Inc. Consider these Observations and the related Navigation Imperatives next.

Observation I: Consider these relative to A.D.A.M. Inc.

For our organization, A.D.A.M. Inc., in the first column of Table 7 (i.e., Factor 1) we note that Beta is inversely associated with the direct—i.e., not computed—balance sheet variables representing the resource configuration of the firm such as: Total Assets, Net PPE, and Total

Receivables. This suggests that more resources are associated with lower market volatility. Further, we observe a positive association between Gross Margin (i.e., Net Sales less COGS) and certain balance sheet variables such as Total Assets and Liabilities, but we do not observe any relationship between Reported Net Income [RNI] and these balance sheet variables, implying that although our resource configuration effort is influencing the gross margin it is not aligned with our bottom line RNI improvement. It is also interesting to note that Factor 1 and Beta are not associated with Factor 2 which seems to be best characterized as the growth dimension of A.D.A.M. Inc. For the second factor, our RNI movement is consistent with our cash management (Cash & Short-term Investments) and assets management (ROA) as well as our potential to grow as measured by Tobin's q.

Beta	**-0.94**	-0.22	0.25
Tobin's Q	**0.99**	-0.07	0.16
Current Ratio	-0.05	**-0.99**	-0.09
Quick Ratio	-0.20	**-0.98**	-0.10
ROA	**0.84**	-0.50	-0.24
Gross Margin	**0.98**	0.05	0.17
A/R Turnover	0.30	**-0.95**	0.09
EPS Growth	**-0.73**	0.67	-0.09
Cash	-0.48	0.69	-0.54
Cash & Short-term Investment	**-0.96**	-0.02	-0.28
Cash from Operations	**0.71**	0.70	0.07
Receivables Total	**0.97**	0.08	0.24
Current Assets	0.34	**0.88**	-0.32
Current Liabilities	0.03	**0.99**	0.09
Total Assets	**0.91**	0.34	0.23
PPE Net	0.37	**0.81**	0.45
Net Sales	**0.99**	0.01	0.16
Depreciation & Amortization	0.62	0.30	**0.73**
Common Shares Outstanding	-0.48	**0.86**	0.17
COGS	**0.99**	-0.01	0.16
Net Income(Loss)	**0.98**	-0.20	-0.01
Diluted EPS	**0.97**	-0.23	-0.01
Market Value-Fiscal Year End	**0.96**	0.19	0.21

Table 8. Factor Analysis: Amdocs,Inc. [DOX]

Observation II : Relative to Amdocs,Inc.

In comparison, Table 8 presents a very different profile of Amdocs, Inc., our positive benchmark. The first factor of Table 8 has many of the same resource configuration aspects except that both Beta and Tobin's q are featured in Factor 1 as well as is RNI! This strongly indicates that the resource configuration is aligned linearly with the income producing potential. In this way, Amdocs, our positive benchmark, seems to have worked out the asset employment relation to RNI that is not found for our firm, A.D.A.M. Inc. Further, Beta is inversely associated with the "income machine" as reflected by Tobin's q, RNI and Net Sales for Amdocs meaning that the more assets the more they are converted linearly to Reported

Net Income and this has a dampening effect on Market volatility. This certainly is a positive/desirable profile and is probably why Tobin's q is positively associated with this profile; we do not see this for A.D.A.M. Inc. as Tobin's q is only associated with growth and is invariant to Beta and the resources employed as discussed above.

3.3.4 BSC implications: input to the navigation plan

Navigation Imperative I

The benchmarking with Amdocs, Inc. suggests that if we, A.D.A.M. Inc., value the performance configuration as profiled in Table 8 of Amdocs Inc., then we should endeavour to align our resource employment with Reported Net Income (RNI) generation. Based on the benchmarking results, we seem to be successful in utilizing resources to improve Gross Margin but fail to make our resource configuration deliver with respect to the bottom line: Reported Net Income [RNI] as we observed for Amdocs Inc. our positive benchmark.

To align our resource employment with Net Income, we need to examine our policies as they relate to project acceptance and management to make sure that we effectively manage our resources to achieve a higher net income, leading to a higher return on assets (ROA). Accordingly, the principal Financial Profiling action we need to take is to: **Attend to ROA**. This objective can be accomplished in a variety of ways—either by generating relatively abnormally high RNI but doing so by moderately increasing the Asset generating base or by achieving average or below average RNI but doing so with a highly efficient Asset configuration—i.e., a reduction in the asset base.

For example, consider an example taken from the A.D.A.M. Inc. website http://www.adam.com/ we learn that we have developed:

"*The A.D.A.M. Symptom Navigator for the iPhone that is an innovative web application designed and developed specifically for the iPhone, and runs using Apple's Safari browser. This unique tool allows consumers to quickly and easily find important information about health symptoms, all with just a few taps on their iPhone. With a home screen icon branded specifically to your organization, the application also allows your facility to be seen as a leading provider of health information and services among today's growing market of mobile users.*"

Let us assume that there were two projects which have equal expectation on profitability—i.e., RNI. However, the iPhone Symptom Navigator has double the ROA compared to, let us assume, a PDA-Telemetry Download System—i.e., Project B. In this case, given the Delphi BSC navigation information generated, the DM would prefer the iPhone project on the basis of ROA.

Navigation Imperative II

Our Tobin's q, which acts as a proxy of growth potential perceived by the market participants, is aligned with the ROA and RNI but cannot line up with our resource configuration variables such as total assets, receivables and net sales. In other words, if we cannot use our resources in a way to boost our RNI and ROA, we will fail to improve our growth profile as well in the eyes of the market participants. Accordingly, this missing connection between our resource configuration variables (e.g., our assets) and our Tobin's q (i.e., our growth potential) indicates that the principal Market Profiling action we need to take is to: **Manage our Growth Profile While Attending to ROA**. This action requires us to (1) consider new investment projects that will not only improve short-term financial performance such as ROA but also offer strategic profiling information for informing the market, and (2) pay attention to the impact of the new investment projects as they impact our recorded book value as we consider the return from the new investment projects.

To continue with the simple two project example, if two projects are the same in terms of profitability (e.g., ROA), we should consider the project that will offer richer strategic opportunities. Also, if these two projects permit various asset contracting possibilities such as Operating Leases, Capital Leasing, or Purchasing and there are relatively wide ranges for: Useful Economic Life, Resale Market Valuation as well as the methods of depreciating the asset, then we should consider the project that will have the more favorable impact on our recorded book value given the same performance in profitability.

4. Conclusion

To "close-the-loop" we wish to note that the *Financial* Dimension information developed from the Delphi BSC or Lean Modeling approach will be included in the BSC along with information on the other three dimensions of the BSC: *Customers*, *Internal Processes*, and *Learning and Growth*. These BSC dimensional encodings are the input to the firm DSS needed to develop priority information for the various projects that the firm may be considering—i.e., project prioritization is the fundamental reason that firms use the BSC or budgeting models. This is to say that the BSC information is "intermediate" information in that this BSC information will be used to characterize the projects that are the planned future of the firm. The final task in the Delphi BSC process then is selecting from the BSC-encoded projects the actual projects to be funded by the firm.

In this regard, to conclude our research report, we wish to note a simple way that one may "prioritize" the navigation information from all four dimensions of the BSC as they are encoded in the projects. For example, in our simple illustrative example where we have focused on the *Financial* Dimension, we have proposed that there were two projects and the iPhone Project dominated on both of the criteria variables: **ROA** and **Growth Profile Management**. It is more likely the case that there will be multiple criteria that result from the Delphi BSC and that the preference weights considering all four of the BSC dimensions will be distributed over the various projects so that there would be no clear dominance. To determine the actual project-action plan from the output of the Lean-version of the Delphi BSC is indeed a daunting task even with a relatively small number of performance criteria. In this regard, it is necessary for the firm to select a method to determine the final set of projects in which the firm will invest so as to satisfy the Overall BSC navigational imperatives for the firm.

There are many such preference or priority processing methods. Based upon our consulting work, we prefer the *Expert Choice Model*™ [http://www.expertchoice.com/] developed by Saaty (1980 and 1990). We find this Alternative/Project Ranking methodology to be the simplest, easiest to communicate to the DM, and most researched Ranking Model according the average number of annual citations in the literature. As a disclose note: we have no financial interest in *Expert Choice Inc.* the firm which has developed the application software for the *Expert Choice Model*™.

5. Acknowledgements

We wish to thank the following individuals for their detailed and constructive comments on previous versions of the paper: The participants in Technical Session 9 of the 2010 Global Accounting and Organizational Change conference at Babson College, Babson Park, MA USA, in particular Professor Ruzita Jusoh, University of Malaya, Malaysia; the participants at the 2009 National Meeting of the Decision Science Institute, New Orleans LA, USA in particular Professor Sorensen, University of Denver, and additionally Professor Neuhauser of the Department of Finance, Lamar University, Beaumont Texas, USA and Professor Razvan Pascalau of the Department of Finance and Economics, SUNY; Plattsburgh, Plattsburgh, NY, USA.

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Part 2

Applications in Water Resource Management

10

Linking a Developed Decision Support System with Advanced Methodologies for Optimized Agricultural Water Delivery

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1. Introduction

Water is the lifeblood of the American West and the foundation of its economy, but it remains its scarcest resource. The explosive population growth in the Western United States, the emerging additional need for water for environmental uses, and the national importance of the domestic food production are driving major conflicts between these competing water uses. Irrigated agriculture in particular is by far the largest water user of diverted water – 80% country wide and 90% in the Western U.S – and since it is perceived to be a comparatively inefficient user, it is frequently asked to decrease its water consumption. The case of the Middle Rio Grande illustrates the problem very well. The Rio Grande is the ecological backbone of the Chihuahuan Desert region in the western United States, and supports its dynamic and diverse ecology, including the fish and wildlife habitat. The Rio Grande Silvery Minnow is a federally listed as endangered species, and irrigated agriculture in the Middle Rio Grande has come under increasing pressure to reduce its water consumption, while maintaining the desired level of service to its water users.
Irrigated agriculture in the Western United States has traditionally been the backbone of the rural economy. The climate in the American West with low annual rainfall of 10 to 14 inches is not conducive to dry land farming. Topography in the West is characterized by the Rocky Mountains which accumulate significant snowfall, and the peaks of the snowmelt hydrograph are stored in reservoirs allowing for irrigation throughout the summer crop growing season. Of the total available surface water irrigated agriculture uses roughly 80 to 90% (Oad and Kullman, 2006). The combined demands of agriculture, urban, and industrial sectors in the past have left little water for fish and wildlife. Since irrigated agriculture uses roughly 80 to 90% of surface water in the West, it is often targeted to decrease diversions. Due to wildlife concerns and demands from an ever growing urban population, the pressure for flow reductions on irrigated agriculture increases every year. In order to sustain itself and deal with external pressure for reduced river diversions irrigated agriculture has to become more efficient in its water consumption. This chapter focuses on research regarding improving water delivery operations in the Middle Rio Grande Conservancy District system through the use of a decision support system linked with advanced infrastructure, methodologies, and technology.

The Middle Rio Grande (MRG) Valley runs north to south through central New Mexico from Cochiti Reservoir to the headwaters of Elephant Butte Reservoir, a distance of approximately 175 miles. The MRG Valley is displayed in Figure 1.

Fig. 1. Middle Rio Grande Valley (Barta, 2003)

The valley is narrow, with the majority of water use occurring within five miles on either side of the river. The bosque, or riverside forest of cottonwood and salt cedar, is supported by waters of the Rio Grande; the bosque being surrounded by widespread irrigated farming. The Cities of Albuquerque, Rio Rancho, Belen and several smaller communities are located in and adjacent to the MRG Valley. Although the valley receives less than 10 inches of rainfall annually, it supports a rich and diverse ecosystem of fish and wildlife and is a common outdoor resource for communities in the region. Water supply available for use in the MRG Valley includes: native flow of the Rio Grande and its tributaries, allocated according to the Rio Grande Compact of 1938; San Juan-Chama (SJC) project water, obtained via a trans-mountain diversion from the Colorado River system; and groundwater. Water is fully appropriated in the MRG Valley and its utilization is limited by the Rio Grande Compact, which sets forth a schedule of deliveries of native Rio Grande water from Colorado to New Mexico and from New Mexico to Texas (Rio Grande Compact Commission, 1997). Water demand in the MRG Valley includes irrigated agriculture in the Middle Rio Grande Conservancy District (MRGCD) Indian Lands, and municipal and industrial consumption. In addition to these demands, there are significant consumptive uses associated with riparian vegetation, reservoir evaporation, and river flow targets associated with two federally-listed endangered species, the Rio Grande silvery minnow

(*Hybognathus amarus*), and the southwestern willow fly catcher (*Empidonax traillii extimus) (USFWS, 2003). Figure 2 displays the Rio Grande silvery minnow and the southwestern willow fly catcher.*

Fig. 2. Federally-listed endangered species, the silvery minnow (*Hybognathus amarus*), and the southwestern willow fly catcher (*Empidonax traillii extimus)*.

This chapter will focus on research for improving water delivery operations in irrigation systems through the innovative use of water delivery decision support systems (DSS) linked with SCADA technology and infrastructure modernization. The chapter will present decision support modeling of irrigation systems in a broad sense and present the model development and structure of a decision support system developed specifically for the Middle Rio Grande Conservancy District to provide for more efficient and effective management of water supplies, and more timely delivery of irrigation water to agricultural users. The developed DSS will be presented in detail and all three modules that function together to create water delivery schedules will be explained and examined. The chapter will address the development of the DSS and will also present the utility of linking the developed DSS to the SCADA (Supervisory Control And Data Acquisition) system and automated structure network that the Middle Rio Grande Conservancy District utilizes to manage water delivery. Linking the DSS and SCADA allows water managers to implement DSS water delivery schedules at the touch of a button by remotely controlling water delivery structures. Linking the DSS water distribution recommendations with the MRGCD SCADA provides a simple and effective medium for managers to implement DSS recommended water delivery schedules. Additionally, the combination of both programs allowed for real-time management that converged river diversions and the water required by the DSS. As the demand for water increases globally throughout the next decades, water managers will be faced with significant challenges. The use of decision support systems linked with SCADA and automated structures presents an advanced, efficient, and innovative approach for meeting water management challenges in the future.

2. Middle Rio Grande Conservancy District

The Middle Rio Grande Conservancy District (MRGCD) may be one of the oldest operating irrigation systems in North America (Gensler et al. 2009). Prior to Spanish settlement in the 1600s the area was being flood irrigated by the native Pueblo Indians. At the time of Albuquerque's founding in 1706 the ditches that now constitute the MRGCD were in already existence and were operating as independent acequia (tertiary canal) associations (Gensler et al. 2009). Acequias consisted of farmer groups that maintained individual irrigation canals. The acequia system was introduced to the MRG Valley by Spanish settlers. In acequia communities, each farmer was responsible for maintaining a certain length of canal and would in return receive irrigation water. The use of irrigation water was managed by an elected mayordomo (Gensler et al. 2009).

Irrigated agriculture in the MRG Valley reached its greatest extent in the 1880s, but thereafter underwent a significant decline partially caused by an overabundance of water. By the early 1920s inadequate drainage and periodic flooding resulted in water logging throughout the MRG Valley. Swamps, seeps, and salinization of agricultural lands were the result. In 1925, the State of New Mexico passed the Conservancy Act, which allowed for the creation of the MRGCD, by combining 79 independent acequia associations into a single entity (Gensler et al. 2009; Shah, 2001). Over the next twenty years the MRGCD provided benefits of irrigation, drainage, and flood control; however, by the late 1940's, the MRGCD was financially unstable and further rehabilitation of structures was required. In 1950, the MRGCD established a 50-year contract termed the Middle Rio Grande Project with the USBR to provide financial assistance, system rehabilitation, and system improvement. System improvements and oversight from the USBR continued until 1975 when the MRGCD resumed operation and maintenance of the system. The loan from the USBR to the MRGCD for improvements and operational expenses was repaid in 1999 (Shah, 2001). Currently the MRGCD operates and maintains nearly 1,200 miles of canals and drains throughout the valley in addition to nearly 200 miles of levees for flood protection.

Water use in the MRG Valley has not been adjudicated but the MRGCD holds various water rights and permits for irrigation (Oad and Kullman, 2006). Some users in the MRGCD hold vested water rights that are surface rights claimed by land owners who irrigated prior to 1907 (SSPA, 2002). Most water users in the MRGCD receive water through state permits held by the MRGCD. In 1930, the MRGCD filed two permits (#0620 and #1690) with the Office of the State Engineer that allow for storage of water in El Vado reservoir (180,000 acre feet capacity), release of the water to meet irrigation demand, and diversion rights from the Rio Grande to irrigate lands served by the MRGCD. The permits allow the MRGCD to irrigate 123,000 acres although only about 70,000 acres are currently served (MRGCD, 2007). This acreage includes roughly 10,000 acres irrigated by pueblo farmers. The MRGCD charges water users an annual service charge per acre to operate and maintain the irrigation system. In 2000 the MRGCD charged $28 per acre per year for the right to irrigate land within the district (Barta, 2003). The MRGCD services irrigators from Cochiti Reservoir to the Bosque del Apache National Wildlife Refuge. An overview map of the MRGCD is displayed in Figure 3.

Irrigation structures managed by the MRGCD divert water from the Rio Grande to service agricultural lands that include both small urban landscapes and large scale production of alfalfa, corn, vegetable crops such as chile, orchards, and grass pasture. The majority of the planted acreage, approximately 85%, consists of alfalfa, grass hay, and corn. In the period from 1991 to 1998, USBR crop production and water utilization data indicate that the average irrigated acreage in the MRGCD, excluding pueblo lands, was 53,400 acres (21,600 ha) (SSPA, 2002). Analysis from 2003 through 2009 indicates that roughly 50,000 acres (20,200 ha) are irrigated as non-pueblo or privately owned lands and 10,000 acres (4,000 ha) are irrigated within the six Indian Pueblos (Cochiti, San Felipe, Santo Domingo, Santa Ana, Sandia, and Isleta). Agriculture in the MRGCD is a $142 million a year industry (MRGCD, 2007). Water users in the MRGCD include large farmers, community ditch associations, six Native American pueblos, independent acequia communities and urban landscape irrigators. The MRGCD supplies water to its four divisions -- Cochiti, Albuquerque, Belen and Socorro -- through Cochiti Dam and Angostura, Isleta and San Acacia diversion weirs, respectively (Oad et al. 2009; Oad et al. 2006; Oad and Kinzli, 2006). In addition to diversions, all divisions except Cochiti receive return flow from upstream divisions.

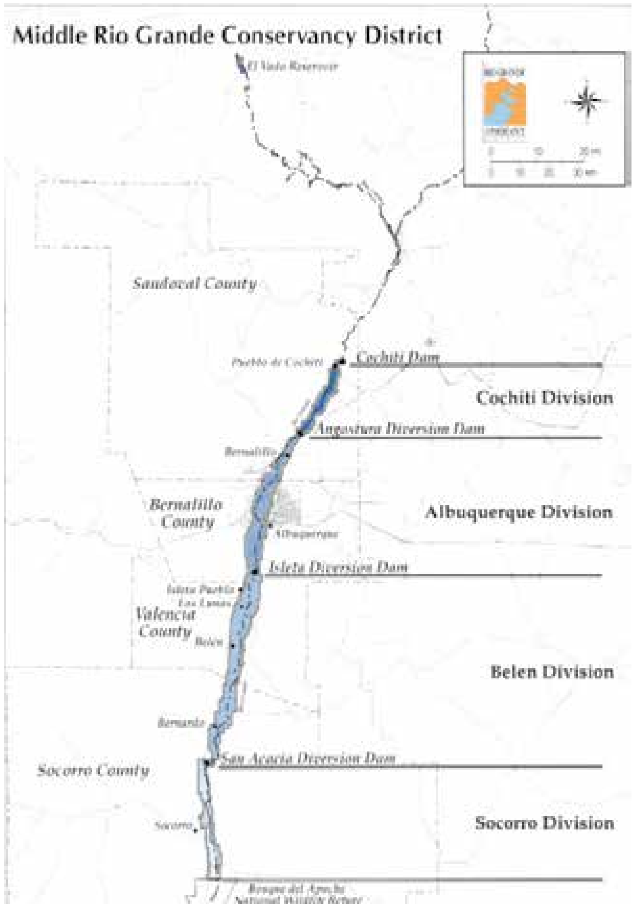


Fig. 3. Overview Map of MRGCD (MRGCD, 2009)

Return flows are conveyed through interior and riverside drains. From the drains, excess water is diverted into main canals in the downstream divisions for reuse or eventual return to the Rio Grande. Drains were originally designed to collect excess irrigation water and drain agricultural lands, but are currently used as interceptors of return flow and as water conveyance canals that allow for interdivisional supply.

During the later part of the irrigation season, the MRGCD operates using released storage water from the high mountain reservoirs of El Vado, Heron, and Abiquiu. Water stored in these reservoirs consists of snowmelt runoff captured during the early summer months and water from the San Juan-Chama trans-mountain diversion. These reservoirs are located 98 river miles upstream and water delivery is associated with a significant time lag, which can approach seven days to reach the southern portion of the district.

The Cochiti Division consists primarily of Native American pueblo land. The pueblo and non-pueblo lands in the Cochiti Division are managed by four MRGCD ditch-riders and represent 4800 acres. The Albuquerque Division services many small urban irrigators, but also provides irrigation water to pueblo irrigators at the northern and southern boundaries of the division. The Albuquerque Division is managed by one water master and 12 ditch-riders to oversee the complex irrigation scheme. The Albuquerque Division acreage is 10,300 acres. The Belen Division is the largest in terms of overall service area with a total irrigated acreage of 31,400 acres. Irrigation in the Belen Division is comprised of large farms, pueblo irrigators, and urban water users. In Belen the MRGCD employs one water master and 11 ditch-riders. The Socorro Division consists of mostly large parcel irrigators with a total irrigated acreage of 13,600 acres. Water distribution in Socorro is straightforward when compared to the Albuquerque and Belen Division, and is managed by one water master and four ditch-riders. Water availability in Socorro can become problematic since the division depends on return flows from upstream users.

Water in the MRGCD is delivered in hierarchical fashion; first, it is diverted from the river into a main canal, then to a secondary canal or lateral, and eventually to an acequia or small ditch. Figure 4 displays the organization of water delivery in the MRGCD. Conveyance canals in the MRGCD are primarily earthen canals but concrete lined canals exist in areas where bank stability and seepage are of special concern. After water is conveyed through laterals or acequias it is delivered to the farm turnouts, with the aid of check structures when necessary. Once water passes the farm turnout it is the responsibility of individual farmers to apply water and it is applied to fields generally using basin or furrow irrigation techniques.

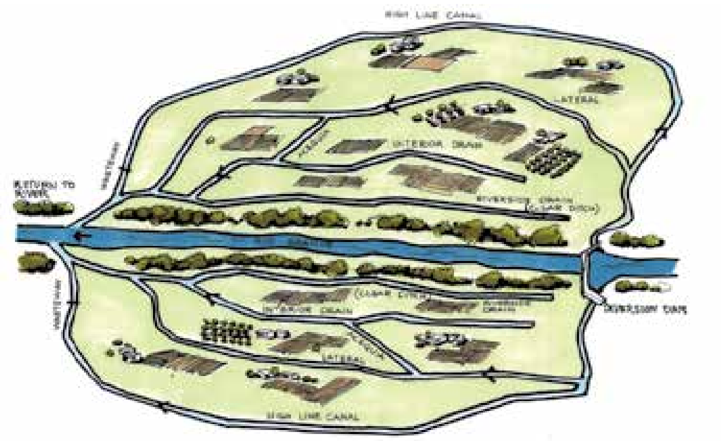


Fig. 4. Representation of MRGCD Irrigation System

Water in the MRGCD is delivered to users through management and administration provided at a central office and four divisional offices. The central office in Albuquerque provides oversight of the four divisional offices and assesses service charges for water use. Each division office includes administrative, field and equipment maintenance, and water operations personnel. Water operations in each division are managed by a division manger, a water master, and ditch-riders in each division. The division managers oversee all aspects of the division, and water masters coordinate ditch-rider operations. Ditch-riders are responsible for managing water delivery in a particular service area. Ditch-riders have anywhere from 250 to 900 irrigators they are responsible for in their service area. Check structures and head gates are controlled by ditch-riders to deliver irrigation water in their service area to meet user demand. Water delivery and water use conditions are monitored by ditch-riders through the physical riding of ditches and through communication with water users. Ditch-riders generally cover all of the ditches in their service area twice a day and are in constant contact with water users via cellular phones. Ditch-riders are on call 24 hours a day to deal with emergencies and water disputes, in addition to daily operations.

Water delivery in the MRGCD is not metered at individual farm turnouts. To determine water delivery the ditch-riders estimate the time required for irrigation. The historic practice in the MRGCD was to operate main canals and laterals as full as possible throughout the entire irrigation season. This practice provided for flexible and reliable water delivery with minimal managerial and financial ramifications; also known as on-demand water delivery. On-demand or continuous water delivery, however resulted in large diversions from the Rio Grande. During the past decade, the MRGCD has voluntarily reduced river diversions by switching to scheduled water delivery. The drawback to this approach is the increased managerial involvement and the overall cost of water delivery. To aid with the operational and managerial challenges posed by scheduled water delivery, the MRGCD has developed and implemented a Decision Support System (DSS) to aid in facilitating scheduled water delivery. Additionally, the MRGCD has begun to replace aging water delivery infrastructure with automated control gates that allow for precise control of canal flow rates, a requirement for scheduled water delivery.

3. Decision support system for the Middle Rio Grande Conservancy District

The New Mexico Interstate Stream Commission and the MRGCD, in cooperation with Colorado State Univeristy have sponsored a research project from 2003 to 2010 to develop a decision support system (DSS), to model and assist implementation of scheduled water delivery for efficiency improvements in the MRGCD's service area. A DSS is a logical arrangement of information including engineering models, field data, GIS and graphical user interfaces, and is used by managers to make informed decisions. In irrigation systems, a DSS can organize information about water demand in the service area and then schedule available water supplies to efficiently fulfill the demand.

The conceptual problem addressed by a DSS for an irrigation system, then, is: how best to route water supply in a main canal to its laterals so that the required river water diversion is minimized. The desirable solution to this problem should be "demand-driven", in the sense that it should be based on a realistic estimation of water demand. The water demand in a lateral canal service area, or for an irrigated parcel, can be predicted throughout the season through analysis of information on the irrigated area, crop type and soil characteristics. The important demand concepts are: When is water supply needed to meet crop demand (Irrigation Timing), How long is the water supply needed during an irrigation event (Irrigation Duration), and How often must irrigation events occur for given service area (Frequency of Irrigation). Decision support systems have found implementation throughout the American West and are mostly used to regulate river flow. Decision support systems on the river level are linked to gauging stations and are used to administer water rights at diversions points. Although decision support systems have proved their worth in river management, few have been implemented for modeling irrigation canals and laterals and improving water delivery (NMISC, 2006). The following section will focus on developing a decision support system capable of modeling flow on a canal and lateral level, with the overall goal of efficient irrigation water delivery.

The DSS has been formulated to model and manage water delivery in the MRGCD. The DSS was designed to optimize water scheduling and delivery to meet crop water demand, and, specifically, to aid in the implementation of scheduled water delivery (Oad et al. 2009; NMISC, 2006). The DSS consists of three elements, or modules:

- A water demand module that calculates crop consumptive use and soil moisture storage, aggregated by lateral service area;
- A water supply network module that represents the layout of the conveyance system, main canal inflow, conveyance system physical properties, and the relative location of diversions for lateral service area; and,
- A scheduling module that routes water through the supply network to meet irrigation demand using a mass-balance approach and based on a ranking system that depends on the existing water deficit in the root-zone.

A Graphical User Interface (GUI) was designed to link the three modules of the DSS together allowing users to access data and output for the system. A schematic of the three modules and the way that they relate within the DSS framework is shown in Figure 5. Figure 6 displays a simplified view of the DSS. GIS information and data obtained from the MRGCD were used to develop input for both the water demand and the supply network modules. Some of the input is directly linked through the GUI and some is handled externally (NMISC, 2006).

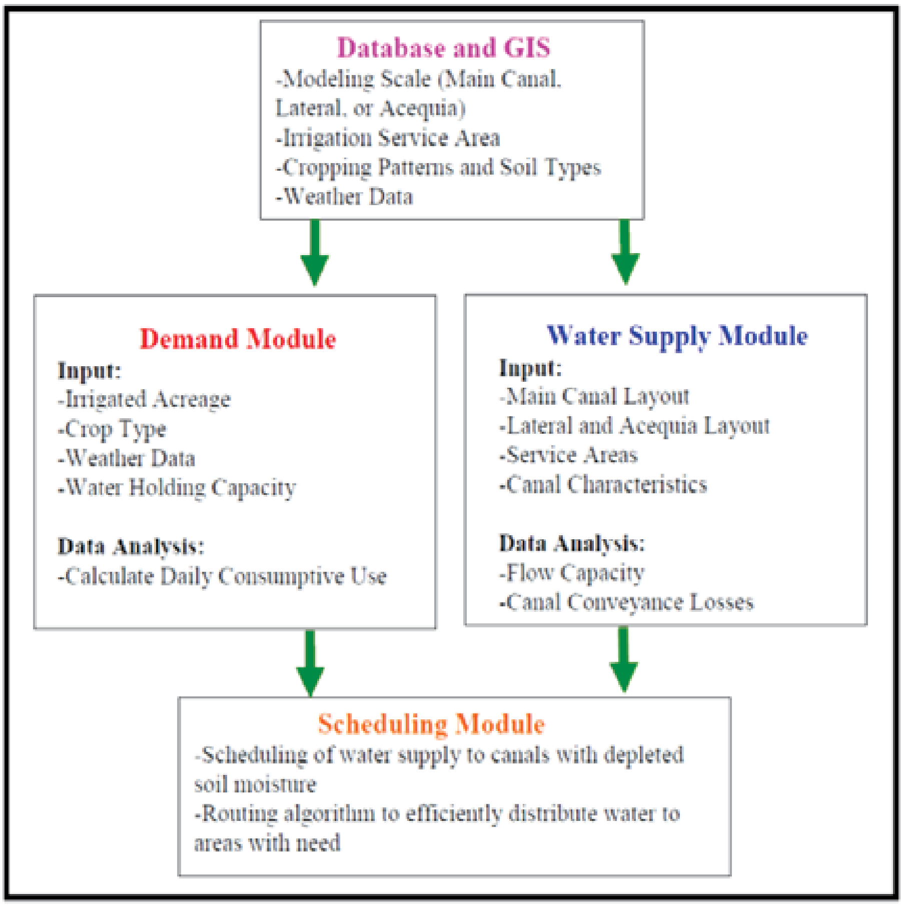


Fig. 5. DSS Model Structure Showing Modules

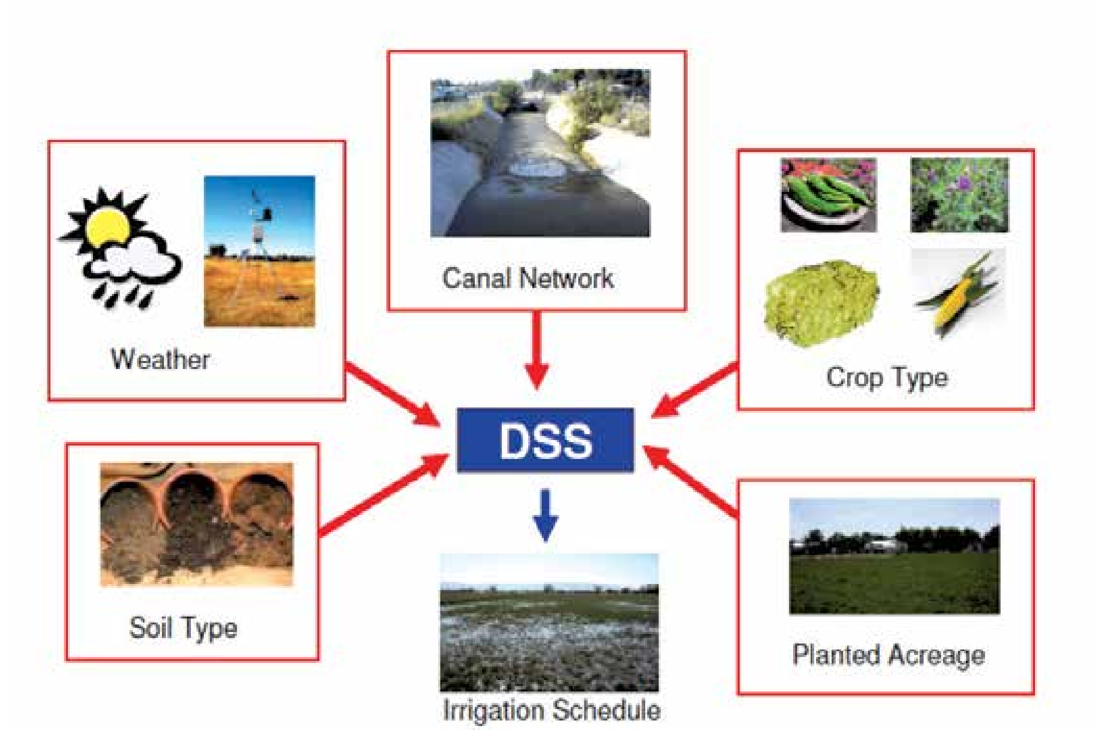


Fig. 6. Simplified View of the DSS

The DSS has two modes of operation: planning mode and operation mode. In planning mode, the user inputs an anticipated cropping pattern for the season and other related data, and the model calculates the required main canal diversions as a function of time based on the calculated demand. In operation mode, the user inputs the available main canal flows, and the model recommends a water delivery schedule for the lateral canal service areas within the main canal that optimizes the use of available water (Oad et al. 2009; NMISC, 2006).

3.1 Model structure

The MRGCD DSS was developed using three modules. The three modules that comprise the MRGCD DSS are the water demand module, the supply network module, and the irrigation scheduling module. The following subsections describe the three modules in detail.

3.1.1 Water demand module

The water demand module of the MRGCD DSS is implemented through the Integrated Decision Support Consumptive Use (IDSCU) model code or the ET Toolbox. The IDSCU model was developed over a period of years by Colorado State University. The IDSCU code consists of a GUI written in Visual C++ and program calculations implemented with FORTRAN (Oad et al. 2009; NMISC, 2006). The ET Toolbox was developed specifically for the Middle Rio Grande and calculates the crop consumptive use using a system of weather stations throughout the valley. Using either the IDSCU or the ET Toolbox, the following variables are determined in the water demand module:

- Crop consumptive use (CU);
- Crop irrigation requirement (CIR); and,
- Readily available (soil) moisture (RAM), as a capacity.

CIR and RAM as a capacity, are used in the supply network module. Required data for the water demand module, the source of these data, and the spatial unit for which the information is aggregated, are shown in Table 1.

Data for Water Demand Module		
Required data	**Source of data**	**Mgmt. level in irrigation system**
Service area and irrigated area	MRGCD GIS database: legal parcel delineation, lateral service area boundaries	Sample lateral canals
Cropping patterns	MRGCD database, field observation	Cumulative for lateral service areas
Soil: Available water holding capacity (*AWC*)	NRCS SSURGO Database	Lateral service areas
Weather data, rainfall, crop coefficients, planting / harvest dates	USBR ET Toolbox, Penman-Montieth Equation	Averages for lateral service areas
Other variables: root zone depth and management allowable depletion	ASCE Manual 70 (FAO. 1998)	Averages for lateral service areas

Table 1. Required Data for Water Demand Module (NMISC, 2006)

The Penman-Monteith method suggested by FAO is used to determine the crop consumptive use for the system when using the IDSCU. The Penman-Monteith equation is discussed in detail in Chapter 3. When using the IDSCU, weather data required for the calculation are obtained from the USBR ET Toolbox (USBR, 2003). The USBR ET Toolbox obtains weather data from 16 weather stations throughout the MRG Valley. In the water demand module, crop coefficients using growing degree days are combined with the Penman-Monteith based ET to obtain a consumptive use for each crop type throughout the growing season. Crop coefficients using growing degree days were obtained from the New Mexico Climate Center and are based on work done by (King et al. 2000). The water demand module performs calculations to obtain a spatially-averaged CU at the lateral service area level using the distribution of crop types within each service area. When the ET Toolbox is used in the demand module, the consumptive use is already calculated within the ET Toolbox using grid cells throughout the valley.

The Penman-Monteith-based CU is adjusted to account for effective precipitation, and is used to obtain a CIR for each lateral service area. Effective precipitation is calculated according to the Soil Conservation Service Method and is subtracted from the Penman-Monteith-based CU. The CIR is calculated on a daily basis, corresponding to the water needed to directly satisfy crop needs for all acres in a lateral service area. The CIR for each lateral is subsequently passed to the supply network module, where it is divided by an efficiency factor to obtain a lateral delivery requirement or LDR (Lateral Delivery Requirement)(NMISC, 2006).

RAM is determined by first calculating the total available water (TAW) per unit area, which is the available water-holding capacity (AWC) for a given soil type, multiplied by the root-zone depth. The calculation of TAW is displayed in Equation 1 (Oad et al. 2009; NMISC, 2006).

$$TAW = AWC * \text{root zone depth} \quad (1)$$

Once the TAW is calculated, a management allowed depletion factor (MAD) for each crop type is applied to determine the RAM. The values employed for MAD in the Water Demand Module are crop specific and range from 30% to 60% (NMISC, 2006; FAO, 1998). RAM is calculated using Equation 2.

$$RAM = MAD * TAW \quad (2)$$

Based on acreage, crop type, and soil type within each lateral service area, a value for RAM is calculated. The RAM calculated in this context represents a storage capacity to be filled and depleted over several irrigation cycles during the course of the irrigation season (NMISC, 2006). During each irrigation event, it is expected that an amount of water equal to the RAM will be stored in soils. Then, as crops utilize water, the RAM will become depleted (Oad et al. 2009; NMISC, 2006).

3.1.2 Supply network module

The supply network module consists of data relating to water supply, water demand, and physical information relating to the conveyance network. It represents the layout of the conveyance system, its physical properties, and the relative location of diversions from the network to individual lateral service areas (Oad et al. 2009; NMISC, 2006). The layout of the conveyance system is specified through a user-designed link-node network. Through the DSS GUI, a user can drag and drop in different types of nodes such as inflows, demands, and return flow nodes into the program (NMISC, 2006). Developing the link-node network is straightforward and can be completed by ditch-riders and water master after some short training. The link-node network represents the connections between canals or laterals and water demands for each service area. The GUI also contains information on ditch-rider service area, and includes photographs and locations of all major water control structures. Figure 7 provides a view of the link-node network.

The supply network module obtains the CIR and the RAM from the water demand module, and then associates these parameters with a demand node on the link-node network (Oad et al. 2009; NMISC, 2006). An efficiency factor is applied to the CIR to account for on-farm application efficiency and to account for conveyance losses within the service area. This results in a lateral delivery requirement (LDR) that applies to all acreage served by a given lateral. The efficiency factor can be specified by the user for each lateral service area (NMISC, 2006).

The link-node network representing the layout of the conveyance system within the supply network module consists of inflow nodes, stream nodes, and return-flow nodes, connected by links that represent canals and laterals (NMISC, 2006). Inflow nodes contain information about inflow volume. The user may either type the inflow values into the inflow node GUI, or import them from an inflow table. Stream nodes require the user to provide information about individual lateral service areas, including turnout capacity, the number of days needed to completely irrigate the service area, the lateral service area efficiency factor, which days of the week the service area can be irrigated, the minimum flow required in the canal on a daily basis, and to which "sub-system" a given stream segment belongs (NMISC, 2006). Sub-systems are used to preferentially rank laterals that should be irrigated together.

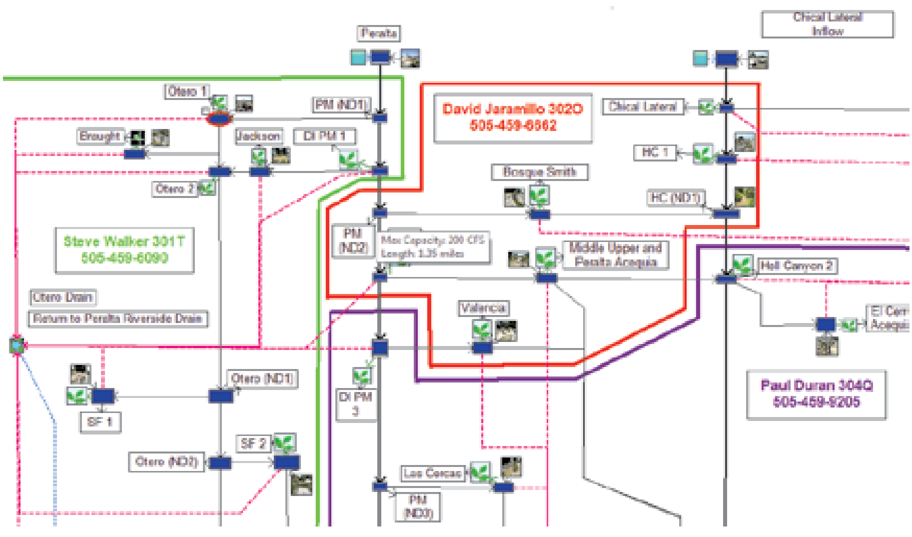


Fig. 7. DSS Link-Node Network

Return flow nodes are used to capture and route drain flow. The percentage of water applied to farms that can be captured by drains is set by the user for the entire project. Each drain has a daily schedule that indicates how much of that return flow is available as inflow in the successive days (NMISC, 2006). Using the information specified, the supply network module calculates a demand-based flow rate associated with each diversion to a lateral service area. The flow rate is calculated as the LDR divided by the irrigation duration. However, if the calculated flow rate exceeds the lateral capacity specified by the user, then the flow rate is set at the user-input lateral capacity. In either case, when irrigation occurs, as determined by the scheduling module, the amount of water removed from the stream link and delivered to the lateral service area for the daily time step is set equal to the volume of water that would be delivered at this flow rate over a one-day period (NMISC, 2006). This volume of water, or time-adjusted portion of LDR, is then reduced by the efficiency factor and added to the daily RAM for the service area. If the LDR is not fully delivered in the one-day irrigation, the irrigation may continue into subsequent days depending on the remaining need within the given lateral, the need of other laterals, and the assigned ranking system in the scheduler (NMISC, 2006).

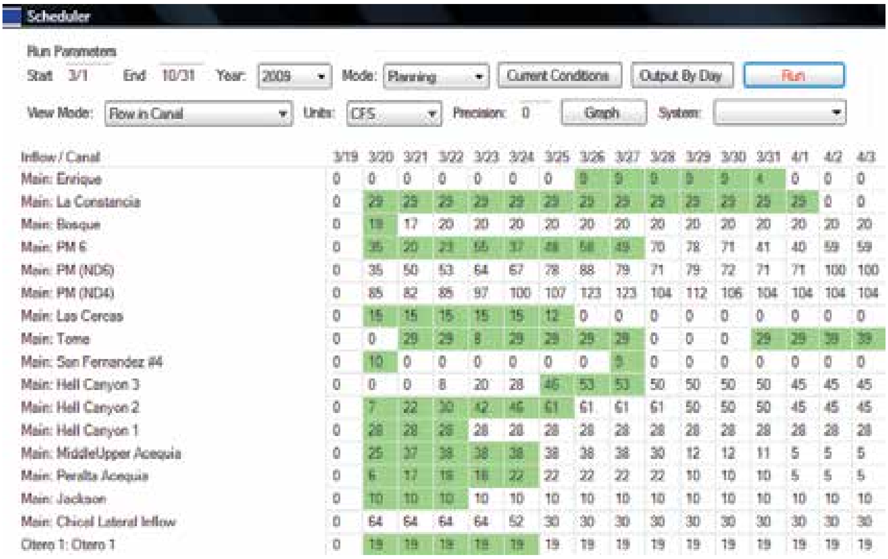
3.1.3 Irrigation scheduling module

The irrigation scheduling module uses the information provided by the water demand and supply network modules to schedule water deliveries to meet crop demand at the lateral level. The irrigation scheduling module calculates and displays a schedule for the laterals on a given main canal. This schedule indicates how many laterals can be run at a time, how long each lateral should run, and how often (NMISC, 2006). Figure 8 displays an irrigation schedule created using the DSS. The module can also create monthly water delivery calendars for individual laterals.

The module is set to run on a daily time step. The irrigation scheduling module calculates the daily irrigation schedule using mass balance equations and a linear programming solver. The module writes out an input file for the solver, executes the solver, and reads the solver output. In the present model version, the module displays results in tabular form. Mass balance calculations used to schedule irrigation timing and duration for lateral canal service areas are based on the consideration that the farm soil root-zone is a reservoir for water storage, for which irrigation applications are inflows and CIR is an outflow (NMISC, 2006). The mass balance approach is displayed in Equation 3:

$$RAM_{t+1} = I_{t+1} - O_{t+1} + RAM_t \quad (3)$$

Where I is inflow, O is outflow (which includes return flow), and t is time.



Inflow / Canal	3/19	3/20	3/21	3/22	3/23	3/24	3/25	3/26	3/27	3/28	3/29	3/30	3/31	4/1	4/2	4/3
Main: Enrique	0	0	0	0	0	0	0	9	9	9	9	9	4	0	0	0
Main: La Constancia	0	29	29	29	29	29	29	29	29	29	29	29	29	29	0	0
Main: Bosque	0	19	17	20	20	20	20	20	20	20	20	20	20	20	20	20
Main: PM 6	0	35	20	23	55	37	48	58	49	70	78	71	41	40	59	59
Main: PM (ND6)	0	35	50	53	64	67	78	88	79	71	79	72	71	71	100	100
Main: PM (ND4)	0	85	82	85	97	100	107	123	123	104	112	106	104	104	104	104
Main: Las Cercas	0	15	15	15	15	15	12	0	0	0	0	0	0	0	0	0
Main: Tome	0	0	29	29	8	29	29	29	29	0	0	0	29	29	39	39
Main: San Fernandez #4	0	10	0	0	0	0	0	0	9	0	0	0	0	0	0	0
Main: Hell Canyon 3	0	0	0	8	20	28	46	53	53	50	50	50	50	45	45	45
Main: Hell Canyon 2	0	7	22	30	42	46	61	61	61	61	50	50	50	45	45	45
Main: Hell Canyon 1	0	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Main: MiddleUpper Acequia	0	25	37	38	38	38	38	38	38	30	12	12	11	5	5	5
Main: Peralta Acequia	0	6	17	18	18	22	22	22	22	22	10	10	10	5	5	5
Main: Jackson	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Main: Chical Lateral Inflow	0	64	64	64	64	52	30	30	30	30	30	30	30	30	30	30
Otero 1: Otero 1	0	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19

Fig. 8. Irrigation Schedule Created Using the DSS

A linear programming approach is used to calculate flows to the service areas by posing the problem as a minimum cost flow optimization. The model uses the projected number of days until the soil moisture storage is depleted using a reverse-ranking system to prioritize the need for irrigation among service areas (NMISC, 2006). Based on observations of the water delivery operations, it appears that water delivery can be changed from one set of laterals to another set within one day.

3.2 Model programming

Model programming for scheduling water supplies to lateral service areas is described in the following section. To obtain the optimum irrigation schedule a linear programming approach is utilized. Linear programming is a method for optimizing a quantity that is defined with a mathematical expression or objective function. Constraints on variables within the objective function are also specified and must be satisfied in determining the optimum solution. This process favors water delivery to laterals with more immediate water needs, and minimizes delivery to laterals that have sufficient water (Oad et al. 2009; NMISC, 2006).

For illustration purposes, the scheduling problem is described using a hypothetical network. Figure 9 shows a simple irrigation network with a main supply canal and a number of laterals that represent crop water demand. The problem is similar to a transportation problem, where the service areas are demand nodes and the inflows are supply nodes (NMISC, 2006). Links are created between nodes where water can be routed. In a transportation problem, the supply needs to equal the demand; in this case, however, both under-supply (excess demand) and excess supply are possible. Therefore, to ensure that the system balances, a "dummy" source node is added that computes the water shortage in the event the system is water-short. Note that in a water-rich scenario, the dummy node is not used because it calculates only water shortage (NMISC, 2006)

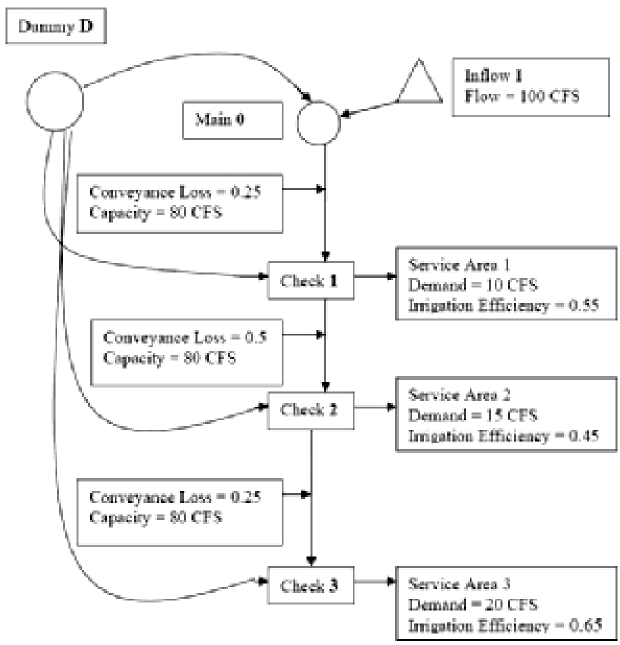


Fig. 9. Hypothetical Irrigation Network (NMISC, 2006)

The scheduling problem is cast as a minimization problem, for which the goal is to provide water to the nodes with the greatest need for water (NMISC, 2006). This is achieved through the use of a ranking system based on water need, the use of water delivery from the dummy supply, and a set of constraints that capture mass balance conditions through the stream network. The objective function is displayed by Equation 4.

$$\text{Minimize } Z = MP_{D\text{-}0}\, X_{D\text{-}0} + MP_{D\text{-}1}\, X_{D\text{-}1} + MP_{D\text{-}2}\, X_{D\text{-}2} + MP_{D\text{-}3}\, X_{D\text{-}3} \tag{4}$$

In this equation Z is the sum of a modified priority (MP) multiplied by the amount of supply (X) from the dummy supply to each demand node. The subscripts refer to the nodal points between which flow occurs, i.e., $X_{D\text{-}1}$ refers to flow from the Dummy supply to Check 1, and $MP_{D\text{-}1}$ refers to the modified priority of demand to be satisfied at Check 1 from the Dummy supply node. The MP value reflects the need-based ranking system where demand nodes with lower available soil moisture are favored for irrigation (NMISC, 2006). The objective function is solved in conjunction with a system of mass balance equations representing the actual water (and dummy water) delivered to demand nodes, along with other physically-based constraints.

The variables in the objective function represent the links in the network between the dummy supply and the demand nodes. The coefficient of each variable represents the flow "cost" of that link. In other words, delivery of water to a node without a need for water results in a higher "cost". As further discussed below, the ranking system has been assigned such that minimization of this objective function will result in minimization of water delivery to demand nodes that already have sufficient RAM (NMISC, 2006).
Constraints on the objective function solution reflect the mass balance relationships throughout the link-node network and the capacity limits on flow (NMISC, 2006). A mass-balance constraint is created for each node (including the dummy) that establishes the inflow and outflow to that node. The coefficients of the variables for each constraint (each row) are represented as a matrix, with a column for every variable in the objective function and a row for every node (NMISC, 2006). Inflows are represented as negative values and outflows as positive values. Outflow coefficients are always one, and inflow coefficients equal the conveyance loss of the connection.
The objective function is subject to the following constraints:

$$
\begin{array}{llllllllll}
X_{I-0} & & & & & & & & \leq & I \\
-X_{I-0} & + X_{0-1} & & & - X_{D-0} & & & & = & R_0 \\
 & - L_1X_{0-1} & + X_{1-2} & & & - X_{D-1} & & & = & R_1 \\
 & & - L_2X_{1-2} & + X_{2-3} & & & - X_{D-2} & & = & R_2 \\
 & & & - L_3X_{2-3} & & & - X_{D-3} & = R_3 & & \\
 & & & & & X_{D-1} & + X_{D-2} & + X_{D-3} & < & \infty
\end{array}
$$

Where

$$X_{0-1} \leq C_{0-1} \quad X_{1-2} \leq C_{1-2} \quad X_{2-3} \leq C_{2-3} \quad \text{All } X_{i-j} \geq 0$$

The variables used are:

- I is the total available inflow
- X_{i-j} is the flow in a canal reach between points i and j
- C_{i-j} is the maximum capacity of the canal reach between points i and j
- D refers to a dummy supply node that is used to force the demands and supplies to balance. The subscript 0 refers to the inflow node, and subscripts 1, 2, 3, … refer to nodal points, typically located at check structures
- L_i is the conveyance loss between in the canal reach
- R_i is the demand (water requirement) at the nodal point indicated by the subscript (can be zero if not associated with a lateral diversion point)

For example, the third row refers to activity at check **1**. There is an inflow from the headgate (**$-L_1X_{0-1}$**), and it is given a negative sign since by convention all inflows are negative. The conveyance loss is represented by the coefficient **L_1.** There is an outflow to check **2** (**$+ X_{1-2}$**) (positive sign, since by convention all outflows are positive). To ensure that the system balances, there is also an inflow from the dummy source (**$- X_{D-1}$**). Because this node represents a demand, the solution for this row is constrained to be exactly the demand (**R_1**). If a node represented a source, then the solution for the row would be constrained to fall between zero and the inflow. That allows the use of less than the total amount of water available if the demands are less than the supplies, or if at some point in the network the capacity is insufficient to route the inflow (NMISC, 2006). The first row in the constraint equations represents this type of node.

The conveyance loss factor specified in the supply network module is a fractional value of flow per mile. The conveyance loss (L) to be applied in the mass balance equation is calculated by subtracting the fractional value from one and raising it to the power of the number of miles of the canal segment between nodes. For example, a 3-mile reach with a 0.015 conveyance loss factor would have a loss of $[1 - (1-0.015)^3]$, or a loss of 0.0443 of the in-stream flow to this reach.

The ranking system used to derive the modified priority (MP) values for the objective function is a two-step process, involving assignment of a priority (P) based on the irrigation need at demand nodes, and then a modified priority that effectively reverses the ranking so that nodes with the least need are the preferred recipients for dummy water (NMISC, 2006). This results in the actual available water being delivered to the demand nodes with highest irrigation need. First, a priority (P) is assigned to each of the demand nodes, with smaller values indicating higher needs for irrigation. The priority is based on the number of days until the service area runs out of RAM (NMISC, 2006). If the service area is not being irrigated, 100 is added to the priority, which forces the system to favor areas being irrigated until the RAM is full again. Subsystems were added to give priority to remaining canals within a group on the assumption that if one canal service area in a subsystem is being irrigated then it is desirable that the remaining canal services areas in the same group be irrigated as well. If a service area is not being irrigated, but is in a subsystem that is being irrigated, 50, rather than 100, is added to the priority. This makes it a higher priority than service areas that are not being irrigated but are not in the subsystem. Normally a service area is irrigated only once during a schedule. However, when excess water is available, service areas in need of water are added back into the scheduling algorithm with a higher priority. The ranking system is implemented by modifying the priorities with respect to the dummy connections, effectively reversing the priorities (NMISC, 2006). Currently the modified priority (MP) for the "dummy -> node x" connection is $100{,}000/P_x$. For example, if the node has a priority of 105, then the priority assigned to the connection is 100,000/105 or 952.38. This will force dummy water to be delivered first to the lower priority nodes, leaving real water for the higher priority nodes. The modified priority (MP) values are represented by the MP variables in the objective function. The linear programming software utilized in the DSS is a package called GLPK (GNU Linear Programming Kit).

4. Supervisory Control and Data Acquisition (SCADA) technology and infrastructure modernization

One of the most critical components to realizing schedule water delivery and utilizing real time recommendations from the DSS to deliver water was the MRGCD SCADA network and infrastructure modernization. The MRGCD SCADA system can be broken into the following components:

- Flow Measurement Structures
- Automated Control Structures
- Instrumentation
- Telemetry
- Software

4.1 Flow measurement structures

Water measurement is the single most important component of the MRGCD's SCADA system, since all operational decisions require sound knowledge of available water supplies and the demand throughout the system. In 1996, crisis struck the MRGCD in the form of drought, endangered species flow requirements, and development of municipal water supplies. At the time, the MRGCD was operating only 15 gauges on 1200 miles of canals. The following year, MRGCD officially embarked upon its modernization program. The construction of new flow gauges was the first step in this program. New gauges were constructed at key points in the canal system, notably at diversion structures and at return flow points. Along with the increase in numbers of gauging stations, efforts were made to improve the quality of measurement. Open channel gauging sites with no control structures gave way to site specific measuring structures. A variety of flow measurement structures were built in the MRGCD and include sharp crested weirs, broad crested weirs, adjustable weirs and Parshall flumes. Currently, the MRGCD is operating over 100 gauges. Figure 10 displays a broad crested with telemetry utilized for flow measurement

Fig. 10. Broad Crested Weir Gauging Station with Radio Telemetry

4.2 Automated control structures

With the advent of better data collection, it became apparent that automated control was necessary. Data from gauges revealed that many operational problems occurred because canal operators could not be physically present at all times. Automation followed shortly thereafter with an experimental effort at a wasteway that had been fitted with an automated Langemann gate for water measurement, and was therefore a practical starting point. The MRGCD built the electronic controller and created the control software for this first automated gate, borrowing heavily from Bureau of Reclamation experience in Utah. Success with the first automated structure led to installation of over 60 additional automated structures. Most of MRGCD's recent automation efforts have involved the installation of Langemann overshot gates (Aqua Systems, 2006). The majority of these can be easily retrofitted to existing structures, though some involve the construction of new check or heading structures. The Langemann Gate has the capability to maintain a constant upstream water level as a check structure or it can provide a constant flow rate to downstream users (Figure 11). The Langemann gate is equipped with solar panels to power both gate operation and telemetry units. The gates employ integrated electronic controllers built around IC Tech radio terminal units (RTU's) and Aqua Systems 2000 software. Langemann gates in the MRGCD are used as checks, turnouts, spillways, and diversion structures.

Fig. 11. Langemann Gate

4.3 Instrumentation

Flow measurement and automated control must include some level of instrumentation. In the 1930's, a float in a stilling well driving a pen across a revolving strip of paper was adequate. In fact, at the beginning of modernization efforts, the MRGCD was still using 15 Stevens A-71 stage recorders. Diversions into the canal system were only known after the strip charts were collected and reduced at the end of the irrigation season. Modernization meant a device was needed to generate an electrical or electronic output that could be digitally stored or transmitted. Initially, shaft encoders were used for this purpose, providing input for electronic data loggers. Experimentation with submersible pressure sensors soon followed, and these have been adopted, although a number of shaft encoders are still in use. Sonar sensors have been used satisfactorily at a number of sites and recently compressed air bubblers have been utilized. Different situations call for specific sensor types and sensors are selected for applications where they are most appropriate.

4.4 Telemetry

Data from electronic data-loggers was initially downloaded manually and proved to be only a minimal improvement over strip chart recording, though processing was much faster. To address data downloading concerns telemetry was adopted to bring the recorded data back to MRGCD headquarters at regular intervals (Figure 12). MRGCD's initial exposure to telemetry was through the addition of GOES satellite transmitters to existing electronic data loggers. This method worked, but presented limitations. Data could only be transmitted periodically, and at regularly scheduled intervals. Of greater consequence was that the GOES system, at least as used by MRGCD, was a one-way link. Data could be received from gauging stations, but not sent back to them. As experiments with automation progressed, it was clear that reliable 2-way communication would be a necessity. To address the rising cost of phone service, experiments with FM radio telemetry were conducted. These began as a way to bring multiple stream gage sites to a central data logger, which would then be relayed via GOES to MRGCD. First attempts with FM radio were not encouraging; however a successful system was eventually developed. As this use of FM radio telemetry (licensed 450 mHz) expanded, and knowledge of radio telemetry grew, it was soon realized that data could be directly transmitted to MRGCD headquarters without using the GOES system. Full conversion to FM radio based telemetry also resulted in very low recurring costs.

The shift to FM radio produced what is one of the more unique features of the MRGCD SCADA system. The data link proved so reliable, that there was no longer a need to store data on site, and the use of data loggers was mostly discontinued, the exception being weather stations. In effect, a single desktop computer at the MRGCD headquarters has become the data-logger for the entire stream gauge and gate system, being connected to sensors in the field through the FM radio link. Three repeater sites are used to relay data up and down the length of the valley, with transmission being up to 75 miles. Also, this has the benefit of being a 2-way link, so various setup and control parameters can be transmitted to devices along the canals. This 2-way link allowed for the system to be linked to the DSS in order to improve water delivery operations. The MRGCD telemetry network consists exclusively of Control Design RTU's. Several different types of these units are used, depending on the application. The simplest units contain only a modem and radio, and transmit collected and processed weather station data from Campbell Scientific CR10X dataloggers.

The majority of the RTU's contain a modem, radio, and an input/output (I/O) board packaged into a single unit. Sensors can be connected directly to these and read remotely over the radio link. A variety of analog (4-20ma, 0-20ma, 0-5v) and digital (SDI-12, RS-485) output devices can be accommodated this way. Another type includes a programmable (RP-52 BASIC) controller in the modem/radio/(I/O) unit. This style is used for all automatic control sites and places where unusual processing of sensor outputs such as averaging values, combining values, or timed functions, are required. At the present time, the MRGCD telemetry network gathers data from over 100 stream flow gages and 18 ag-met stations, and controls 60 automated gates (Figure 12).

4.5 Software

Measurement, automation, and telemetry components were developed simultaneously, but largely independent of one another. While each component functioned as expected, components did not exist as a harmonious whole, or what could truly be called a SCADA system. The missing component was software to tie all the processes together. There are a variety of commercially available software packages for such use and MRGCD experimented with several. Ultimately, the MRGCD chose to purchase the commercial software package Vsystem and to employ the vendor Vista Controls to develop new features specific to the control of a canal network. Installation and setup was done by the MRGCD.

This system, known as the Supervisory Hydro-data Acquisition and Handling System (SHAHS), gathers data from RTU's on a regular basis. With the capability to define both timed and event driven poll routines, and specify a virtually unlimited number of RTU's and MODBUS registers to collect, virtually any piece of information can be collected at any desired time. The Vsystem software can process data through a myriad of mathematical functions, and combine outputs from multiple stations. Vsystem also incorporates the ability to permanently store data in its own internal database, MS Sequel databases, or export data in other formats. Data can be displayed in a user-created graphical user interface (GUI) which MRGCD water operations personnel use to monitor water movement. The screens can also execute scripts to generate data, control parameters, control gate set points, and monitor alarm conditions for automated control structures. Finally, the GUI's can be used to control automated structures by transmitting new parameters and setpoints.

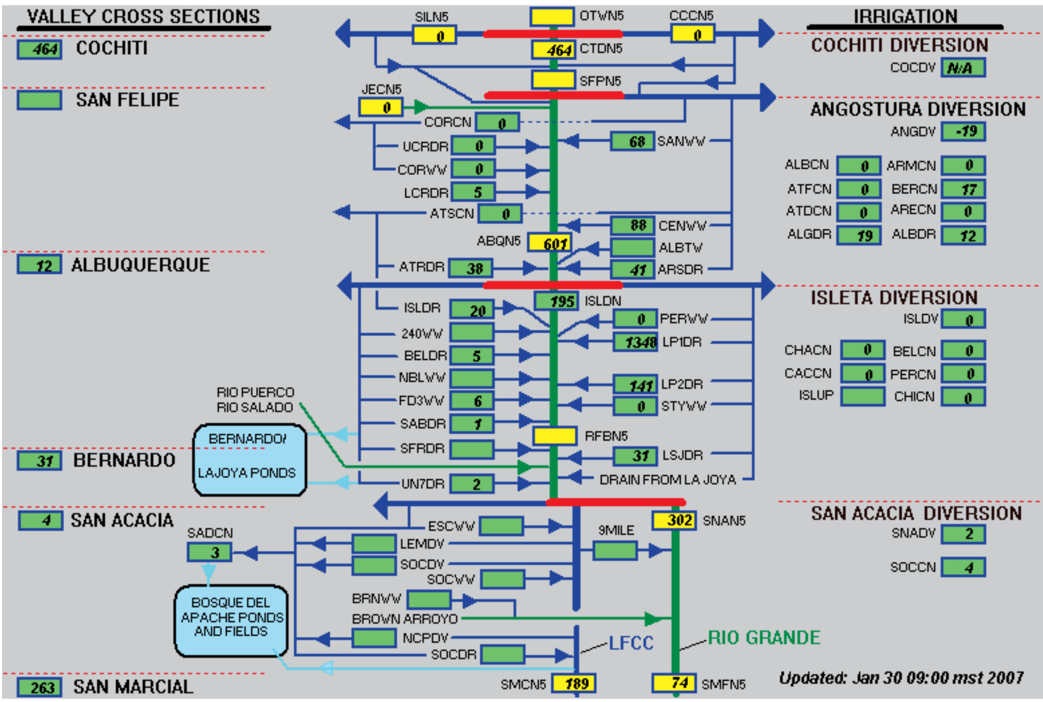


Fig. 12. MRGCD Telemetry Network

5. Linking the decision support system to SCADA network

One of the key components to improving water delivery efficiency was linking the DSS water delivery recommendations to the MRGCD SCADA network. This was done in 2009 so that water operations personnel could closely monitor the actual canal diversions and compare those diversions to the DSS recommendations on a real-time basis. The overall goal was to match the diversions from the Rio Grande to the real-time crop water requirement calculated using the DSS.

Incorporating the DSS with the MRGCD SCADA system involved three distinct steps. First, the DSS was installed on the MRGCD main water operations computer. Second, the DSS output was converted to a format that the Vista software could recognize. The Vista software uses the SHEF.A. file format for data coming into the SCADA system, and the entire MRGCD canal network is set to function on this format. The data for each individual gate or measuring site are characterized by a distinct data stream in the Vista Software, the data and are linked to the appropriate node in the SCADA GUI. The data stream for each node in the GUI is user specified; and therefore, nodes were created that display DSS recommended flow rates. In order to link the DSS to this SCADA software it was necessary to create DSS output files in SHEF.A. format. This was accomplished through cooperative work between Colorado State University, the MRGCD, and Vista Systems. A subroutine in the MRGCD SCADA Vsystem software converts the output from the DSS into the SHEF.A. format. This subroutine allows for the creation of separate data streams from the DSS schedule for each lateral canal service area. These data streams are the same data streams that are used throughout the MRGCD SCADA network.

The third step in linking the DSS was to create a node for the DSS recommended flowrate for each lateral service area in the SCADA GUI that also contains actual flowrate data. This consisted of creating nodes in the SCADA GUI that display the actual flow passing into a lateral on the left side of the node and the recommended flowrate from the DSS in parentheses. The DSS recommended flow was linked to the correct data stream from the DSS output in SHEF.A format. For the 2009 irrigation season actual flow and the DSS recommended flow were displayed side by side for each lateral on the Peralta Main Canal in the SCADA GUI. Figure 13 displays the revised SCADA GUI with the DSS recommendations.

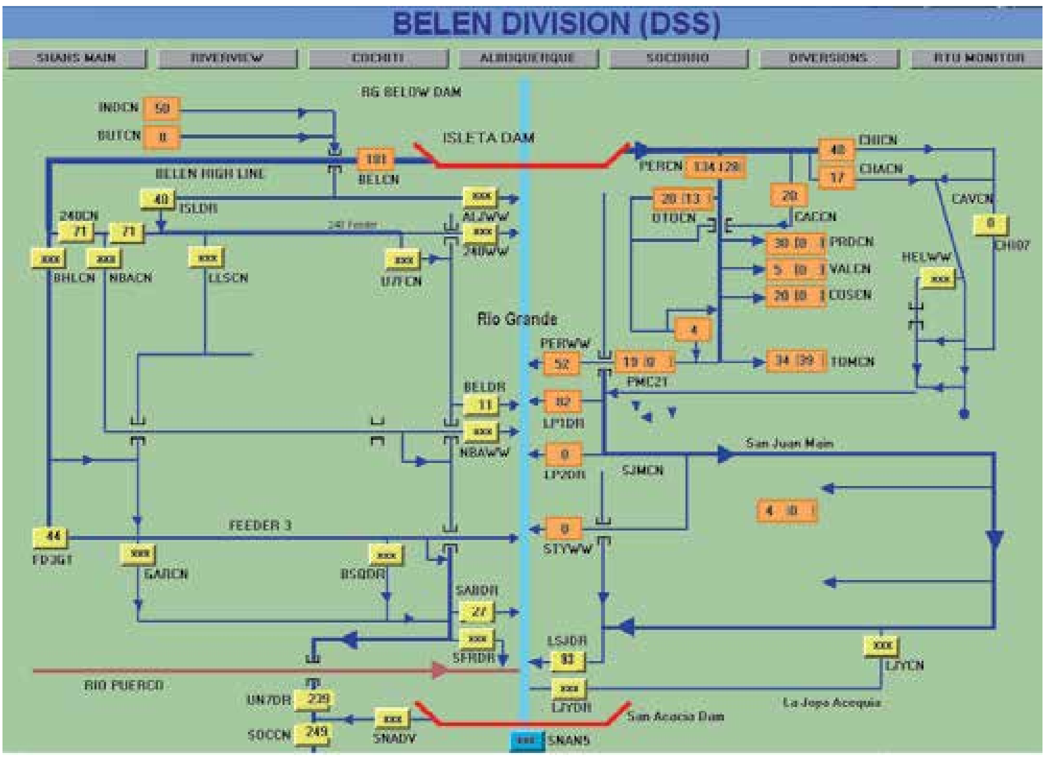


Fig. 13. MRGCD SCADA Screen with Actual Deliveries and DSS Recommendations

Whenever the recommendations for DSS flowrates are updated the DSS is run and the scheduler output saves as a CSV file in Excel. This file is then converted using the Vsystems subroutine and available as a SHEF.A. data stream for each individual lateral. Linking the DSS water distribution recommendations with the MRGCD SCADA provides a simple and effective medium for managers to implement and monitor DSS water delivery schedules. Additionally, the combination of both programs allows for real-time management and the convergence of river diversions and the water required based on crop demand.

6. Results

The DSS linked with SCADA has multiple benefits for the MRGCD. These benefits include providing a method for predicting anticipated water use, sustaining efficient agriculture in the valley, minimizing the difficulty of meeting flow requirements for environmental concerns, and improved reservoir operations. The DSS in concert with SCADA also provides the MRGCD with a powerful tool to manage water during periods of drought.

One of the main benefits that the DSS has for the MRGCD is that the DSS provides a tool to determine anticipated water use. The need for this arises out of the fact that water delivery to farms in the MRGCD is not metered and scheduling is inconsistent. This makes it difficult, if not impossible, to place the appropriate amount of water in a canal at the proper time. The MRGCD dealt with this in the past by typically operating all canals at maximum capacity throughout the irrigation season. This provided a high level of convenience for water users, and made the lack of scheduling unimportant. But this practice has had significant negative consequences. Not least of these consequences was the public perception of irrigated agriculture. The MRGCD practice of operating canals at maximum capacity resulted in diversion rates from the Rio Grande that were large. Through the creation of a thorough and systematic database in the DSS of cropping patterns, irrigated acreage, automated processing of climate data into ET values, and incorporation of a flow-routing component incorporating the physical characteristics of the MRGCD canals, it became possible to predict how much water users will need. The DSS, with the myriad of calculations it performs, provides the MRGCD water operations manager a method to determine water requirements in advance and manage water using SCADA. Problems of timing and crop stress are addressed and the MRGCD can operate at reduced diversion levels, while serving its water users.

Use of the DSS linked with SCADA also has the benefit that it can aid the MRGCD in sustaining irrigated agriculture in the Middle Rio Grande Valley. The agricultural tradition in the Middle Rio Grande Valley dates back over 500 years and one of the main goals of MRGCD is to sustain the agricultural culture, lifestyle and heritage of irrigation. The problem facing the MRGCD is how to sustain irrigated agriculture amidst drought and increased demands for water from the urban and environmental sectors. These demands for water from other sectors will increase as the population in the Middle Rio Grande Valley grows and expands. Additionally, the MRGCD will be faced with dealing with periodic drought and climate change with the possibility of reduced snow melt runoff in the future. The concept of scheduled water delivery, implemented through the use of the DSS linked with SCADA provides the MRGCD with the ability to sustain irrigated agriculture with reduced river diversions. Scheduled water delivery that is based on crop demand calculated using the DSS and delivered through a highly efficient modernized system will allow the MRGCD to continue supplying farmers with adequate water for irrigation, even though the available water supply may be reduced due to natural or societal constraints.

Scheduled water delivery implemented through the use of the DSS and SCADA will also benefit the MRGCD by easing competition with environmental water needs. Due to the Endangered Species Act, water operations and river maintenance procedures have been developed in the Middle Rio Grande Valley to ensure the survival and recovery of the Rio Grande silvery minnow. These procedures include timing of flow requirements to initiate spawning and continuous flow throughout the year to provide suitable habitat. Additionally, the entire Rio Grande in the MRGCD has been designated as critical habitat for the RGSM. The use of the DSS, linked with SCADA provides the MRGCD with the ability to reduce river diversions at certain times during the irrigation season. Reduced river diversions from the MRGCD main canals may at times leave more water in the Rio Grande for the benefit of the RGSM with credit toward the MRGCD for providing the flow requirements for the recovery of the species. The DSS may also be useful in providing deliveries of water specifically for the RGSM. Since the listing of the RGSM, the MRGCD canal system has been used to deliver a specific volume of water to points along the Rio Grande to meet flow requirements for the species. At certain times of the year, this is the only efficient way to maintain RGSM flow targets. While not presently incorporated in the DSS, it would be straightforward to specify delivery volumes at specific points in the MRGCD system. These delivery volumes for the RGSM would be scheduled and routed in a similar fashion to agricultural deliveries. Depending on the outcome of the current process of developing RGSM management strategies, this could someday become a very important component and benefit of the DSS.

One of the significant benefits of using the DSS with SCADA in the MRGCD is improved reservoir operations. The storage reservoirs in the MRGCD are located in the high mountains and it takes up to seven days for released water to reach irrigators. Prior to scheduled water delivery utilizing the DSS, the MRGCD water manager had to guess at what the demand for a main canal would be in advance and then release stored water to meet the assumed demand. Through the use of the DSS and SCADA the water operations manager can utilize historical climate data to predict what the agricultural demand will be in the future. This allows for an accurate calculation of the required release from reservoir storage and minimizes superfluous releases. These reduced reservoir releases have significant benefits for the MRGCD. Since less water is released from storage reservoirs during the irrigation season it allows for increased storage throughout the season. This allows the MRGCD to stretch the limited storage further and minimize the impacts of drought. Decreases in reservoir releases also have the added benefit of providing more carryover storage for the following irrigation season, providing greater certainty for water users in subsequent years. Larger carryover storage also translates to less empty space to fill during spring runoff. This leads to three benefits for the MRGCD. The first is that reservoirs can still be filled, even in a year when runoff is below average. The second benefit is that in above average runoff years the reservoirs will fill quickly and much of the runoff will go downstream, mimicking the hydrograph before the construction of upstream storage reservoirs. This is a subtle but significant environmental benefit to the Middle Rio Grande and RGSM as peaks in the hydrograph induce spawning, provide river channel equilibrium and affect various other ecosystem processes. The third benefit is that increased downstream movement of water during the spring will aid the state of New Mexico in meeting Rio Grande compact obligations to Texas. Overall, scheduled water delivery in the MRGCD provides significant benefits to reservoir operations and will allow the MRGCD to reduce reservoir releases, provide more reliable deliveries, increase certainty of full deliveries, and sustain irrigated agriculture.

In times of surplus water the MRGCD may not utilize the DSS for scheduled water delivery because of the associated increase in management intensity and higher operational costs. In drought years the available water supply will be lower and result in tighter and more stringent management requirements to equitably distribute water to users. It is during times of drought and shortage that the DSS linked with SCADA will provide the necessary management to distribute water based on crop demand. In the future the DSS will be a powerful tool that the MRGCD can utilize to equitably distribute water and sustain irrigated agriculture through times of low water supply resulting from drought.

7. Conclusions

Water delivery through the use of a DSS linked with SCADA has applications and benefits that can be realized throughout the arid regions of the world. The main benefit of scheduled water delivery utilizing a DSS and SCADA is that diversions can more closely match crop water requirements eliminating spills and drainage problems. In the American West urban growth and environmental concerns have forced irrigated agriculture to reduce diversions. In many irrigated systems in the United States that traditionally used surface application, agriculture has opted to improve water use efficiency by changing water application methods to sprinkler and drip irrigation systems. Irrigated agriculture throughout most of the world still relies on surface application and cannot afford to upgrade to systems such as sprinkler or drip irrigation. Therefore, water delivery utilizing a DSS with SCADA has the potential to reduce diversions and sustain agriculture.

The DSS, SCADA, and scheduled water delivery also have the potential of meeting future agricultural demands in developing regions throughout the world. As the world population continues to grow there will be an increased demand for food production and in many cases water resources available for agriculture are already fully utilized. Utilizing a DSS linked to SCADA would allow water users in developing countries with surface application systems to conserve water from their current practices and apply the saved water to increased food production.

The DSS could also be used to refine water delivery scheduling. Many arid regions have been dealing with water shortages for decades and have already implemented scheduled water delivery. In most cases, water delivery schedules are based on a set interval of time and do not coincide with crop demand. In areas where this type of scheduling is practiced the DSS could be used to refine scheduling protocols to include crop demand. Scheduling water deliveries based on crop demands would provide additional saving in areas where scheduled water delivery is already implemented. The developed DSS could be utilized in any irrigation system worldwide that practices surface irrigation techniques. Through scheduling based on crop demand, overall diversions could be significantly reduced. Reduced diversions could help irrigators deal with drought, and climate change by allowing for increased utilization of stored water. Additionally, reduced diversions could be utilized to grow supplementary crops to supply the needs of a growing population in the future.

8. Acknowledgements

The authors would like to thank Subhas Shah, the MRGCD Board of Directors and staff, the New Mexico Interstate Stream Commission, the New Mexico Office of the State Engineer, the Middle Rio Grande Endangered Species Act Collaborative Program, the United States Army Corp of Engineers, and the United States Bureau of Reclamation for the assistance and the financial support to undertake this project. Also, the exceptional support of Jim Conley at Control Design, Gerald Robinson and Lee Allen at Aqua Systems 2000, and Cathy

Laughlin and Peter Clout of Vista Control Systems is graciously recognized. The authors would also like to acknowledge the support of the National Science Foundation

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11

Estimating the Impact on Water Quality under Alternate Land Use Scenarios: A Watershed Level BASINS-SWAT Modeling in West Georgia, United States

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1. Introduction

Non-point source pollution (NPP) is caused by the movement of water over and through the ground, generally after each rainfall. The runoff picks up and carries away natural and man-made pollutants, eventually depositing them in water bodies like lakes, rivers and coastal waters. Thus the pollutants left on the surface from various sources accumulate in receiving water bodies. For example, crop cultivation requires more use of chemicals and nutrients than natural vegetative cover like forest and grasslands. Tillage operations affect the soil structure and the level of chemicals in the soil. Such activities make the nutrient rich topsoil fragile and cause it to lose more chemicals and soil particles during rainfall. Lands in residential and development uses, such as lawns and gardens are managed more intensively, which encourages the generation of even more pollutants. On the other hand, urban areas have higher percentages of impervious to porous surfaces that result in low percolation and higher runoff. During precipitation, the runoff carries more nutrients and sediments from agricultural and residential lands resulting in higher chemical level and turbidity in the water. Thus increasing urbanization coupled with increasing use of nutrients and chemicals in agricultural lands create significant challenges to maintain water quality.

Recent water quality studies have focused on developing and successfully applying various biophysical simulation methods to model levels of NPP and to identify critical locations from which these pollutants originate (Bhuyan et al., 2001; Mankin et al. 1999; Marzen et al., 2000). These models collect and use various geospatial data, facilitating the spatial analysis of sources and effects of point and non-point pollutants with reference to their origin and geographical locations. The findings of such models help the environmental policy planners to understand both the short-term and long-term effects of changes from alternative land management scenarios and simulate how the pollution can be reduced effectively through the institutionalization of best management practices. This study uses the BASINS-SWAT modeling framework, one of the latest biophysical modeling tools to estimate the effects of land use change in the quality of water. Simulations are done to estimate the level of nitrogen, phosphorus and sediment loads using two time period land use maps. This study demonstrates the use of geospatial technologies to gather and organize reliable and current data for inputs into the BASINS-SWAT model runs.

2. The modeling approach

Better Assessment Science Integrating Point and Non-point Sources (BASINS) is a multipurpose environmental analysis system developed by U.S. Environmental Protection Agency's Office of Water. It is used in performing watershed-and water-quality-based studies and can support analysis at a variety of scales using different tools. BASINS can support implementation of TMDLs by state agencies using watershed-based point and nonpoint source analysis for a variety of pollutants including the alternative land management practices. It comprises a suite of interrelated components for performing the various aspects of environmental analysis including data extraction, assessment, watershed delineation, classifying digital elevation models (DEM), land use, soils and water quality observations, and watershed characterization reports (United States Environmental Projection Agency [USEPA], 2001).

Soil and Water Assessment Tool (SWAT) is a river basin or watershed scale model developed by the USDA Agricultural Research Service's Grassland, Soil and Water Research Laboratory which has become an integral component of BASINS. It was designed to assist resource managers in the long-term assessment of sediment and chemical yields in large watersheds and river basins. The model can predict the average impact of land use and management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land uses, and management conditions over long periods of time (DiLuzio et al., 2002; Neitsch et al., 2002). In comparative studies using hydrologic and non-point source pollution models, SWAT has been shown to be among the most promising for simulating long-run NPP in agricultural watersheds (Borah and Bera, 2003).

BASINS-SWAT uses an ArcGIS Geographic Information System interface to derive the model input parameters and simulation. Hydrological modeling relies on elevation data in which watershed and subwatersheds are delineated based on the terrain and flow direction of raindrops. The watershed drains at the lowest point of the catchment area and contains several sequential subwatersheds with directional flow (raindrop flow) to the main channel based on the topography of land and user supplied intermediate outlet points. Subwatersheds are grouped based on climate, hydrologic response units (HRUs), ponds, ground water, and main channels (Borah & Bera, 2003). Each subwatershed is virtually divided into several hydrological response units (HRUs) which are uniquely lumped areas within the subwatershed based on weighted land cover, soil type, and management combinations at a certain threshold level, generally 10% in practice (Saleh et al., 2000). SWAT model simulation requires weather parameter inputs (precipitation, wind, temperature) and management parameter inputs (irrigation, tillage, chemical and fertilizer application). These input variables are converted to standard SWAT input files within the model. The model then simulates the runoff levels of nutrients, chemicals and sediment loadings, as well as crop yields, under a particular combination of land management scenarios. SWAT output can be traced across the watersheds both for short and long period of times.

3. Study area

This study is based on the Mulberry Creek Watershed a 10-digit coded Hydrological Unit (HUC #0313000212) in Harris County, Georgia, nested within the Middle Chattahoochee watershed (HUC# 03130002). The area is situated to the north of Columbus, GA and covers approximately 50% of the county surface area. The map of study area is given in Figure 1.

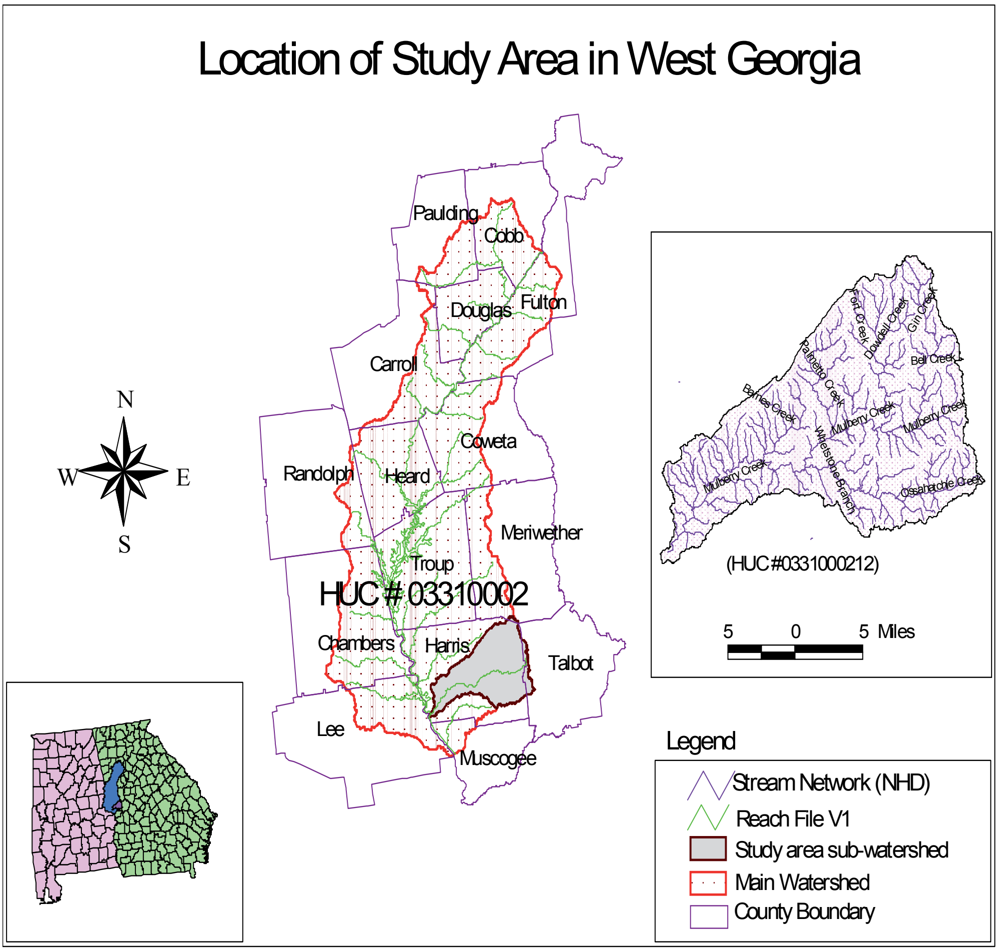
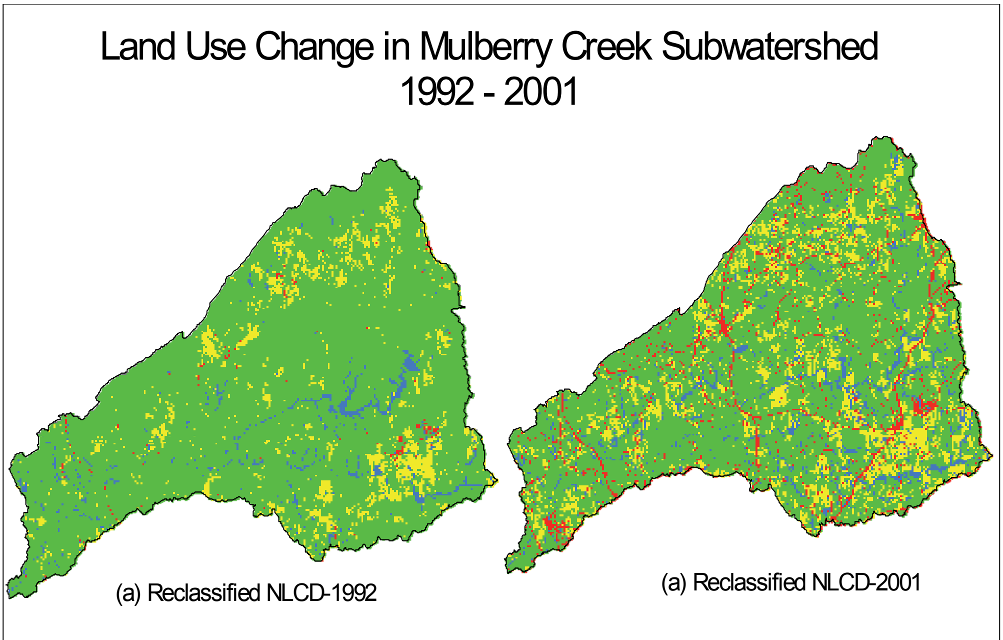


Fig. 1. Map of Study Area

Harris County has experienced a tremendous market influence due to the expansion of the Columbus Metropolitan Area in the last two decades. Limited by the Chattahoochee River on the west and by a military base on the south, the suburban area is expanding mostly to the north and northeast. Harris County experienced a 33.2% increase in total population between 1990 and 2000 census years (United States Census Bureau, 1990, 2000). In the same time, the population in Troup and Muscogee counties increased only by 5.8% and 3.9% along the north and south boarder of the county respectively. On the other hand, Talbot County, which is mostly rural and lies to the east of Harris County did not see any increase in its population. As the demographic structure and other socioeconomic conditions in the area changed between 1990 and 2000 census years, land use distribution has also changed. This provided a very good experiment site to estimate the water quality impact of land use change. Figure 2 compares the land use scenarios within the Mulberry Creek watershed using the National Land Cover Datasets 1992 and 2001 (NLCD-1992 and NLCD-2001).



Land Use Distribution, 1992-2001

Category	1992	2001	Change*
Developed	0.6%	6.1%	900%
Agricultural	8.7%	17.2%	98%
Forest	87.0%	71.2%	-15%
Other	2.9%	5.5%	90%

* Area Weighted Change

Fig. 2. Land use distribution in Mulberry Creek sub-watershed

Delineated watershed covered 58,323 hectares in size, roughly half of the total area in Harris County, GA. There has been significant change in the distribution of land use in the Mulberry Creek sub-watershed between 1992 and 2001. For comparison, land use grids were broadly reclassified into developed, agricultural, forest and other lands for both years. In NLCD-2001, forest land covered 71.2% of total area, down from 87.8% in NLCD-1992. Share of agricultural land increased to 17.2% in NLCD-2001, about two times bigger than in NLCD-1992.Developed land share increased by nine-fold in NLCD-2001. Broadly reclassified land use distribution is given in Figure 2.

The change in the land use pattern in the area is expected to bring changes in water quality through different levels of point and non-point source pollution. According to the EPA's list of impaired water, 13 total maximum daily loads (TMDLs) had been approved in the Middle Chattahoochee Watershed between 1996 and 2004 (EPA, Surf Your Watershed).

4. Methodology

4.1 Data collection and processing

The study uses secondary data obtained from various sources. The sources and processing of the individual data components is described below.

Core BASINS data: Once the BASINS project was opened, basic datasets were extracted from various sources using the data download extension within the BASINS program. These files included various boundary shape files at watershed, county and state levels, soil and land use grids, locations of water quality stations, bacteria stations, USGS gage stations, permit compliance systems and National Hydrography Data (NHD). The BASINS view was projected to Albers Equal-Area Conic projection system. All subsequent data were projected in the same system using grid projector tool in BASINS.

NEM data: The 1:24,000 scale 30x30m resolution national elevation model (NEM) data for the entire area was downloaded from Seamless Data Distribution System of USGS Web Server. The dataset was converted to grid files using ArcView Spatial Analysis tool.

Land use data: Two sets of spatial land use data were obtained from Seamless Data Distribution System of USGS Web Server. The first land use map was the National Land Cover Database 1992 (NLCD-1992), which was prepared based on satellite images taken circa 1990. The second land use map was the National Land Cover Database 2001 (NLCD-2001). This map was prepared from satellite images taken circa 2000. Both of the land cover maps had 30x30m resolution at the scale of 1:24,000 (USGS MRLC metadata information). Land use grids were re-projected to match with the NEM grids projection.

Climate Data: SWAT model uses climate information including precipitation, temperature, wind speed, solar radiation and relative humidity data. However, when no such data are available, the model has capability to simulate data based on historical weather observations from the nearest of more than 800 climate stations (SWAT Users' Manual). Observed daily precipitation and minimum/maximum temperature data were obtained from the National Climate Data Center (NCDC) database for ten nearby climate stations between January 1945 and December 2004. Raw precipitation and temperature data were converted into SWAT readable individual database files for each station.

4.2 Watershed modeling process

Once all data were collected and the geospatial data layers were re-projected and matched to a single view, the BASINS process started with preprocessing of DEM to remove any sinks and holes in the DEM coverage. A masking grid covering the anticipated area of watershed was used as focus area and a Reach File used as a burn-in option to enhance the watershed delineation process. After the preprocessing of DEM, digital stream networks were created with a 100-hectare headwater threshold area, which defines the minimum area required to begin a stream flowing out of the area in any part of the watershed (Figure 3). As a standard, the typical value is 5000 cells (450 hectares) when using National Elevation Dataset. Although any values can be used, threshold under 1000 cells or 90 hectares becomes questionable in the areas of flat terrain (Maidment, 2002).

The lowest outlet point at the stream network was selected as the drainage outlet to define the watershed boundary. Spurious nodes were removed and very long river segments were divided into outlet nodes during the calculation of sub-basin parameters to ensure a uniform size distribution of sub-basins. Sub-basin parameters were calculated within the model that makes the use of DEM and stream network (Figure 4-5).

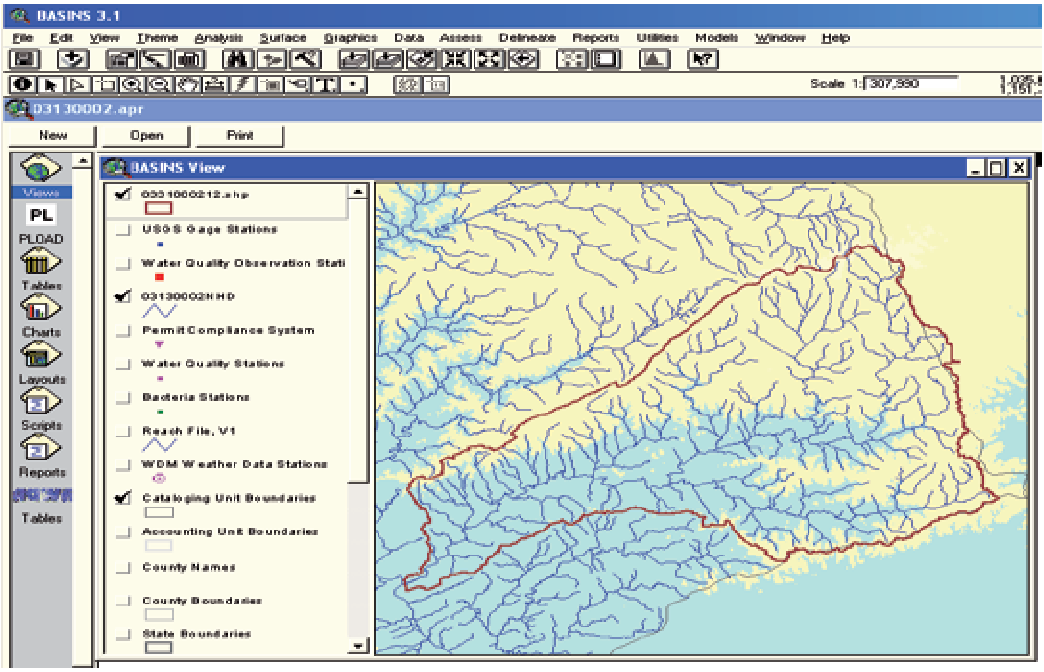


Fig. 3. Overlaying elevation grids, watershed boundary and NHD networks

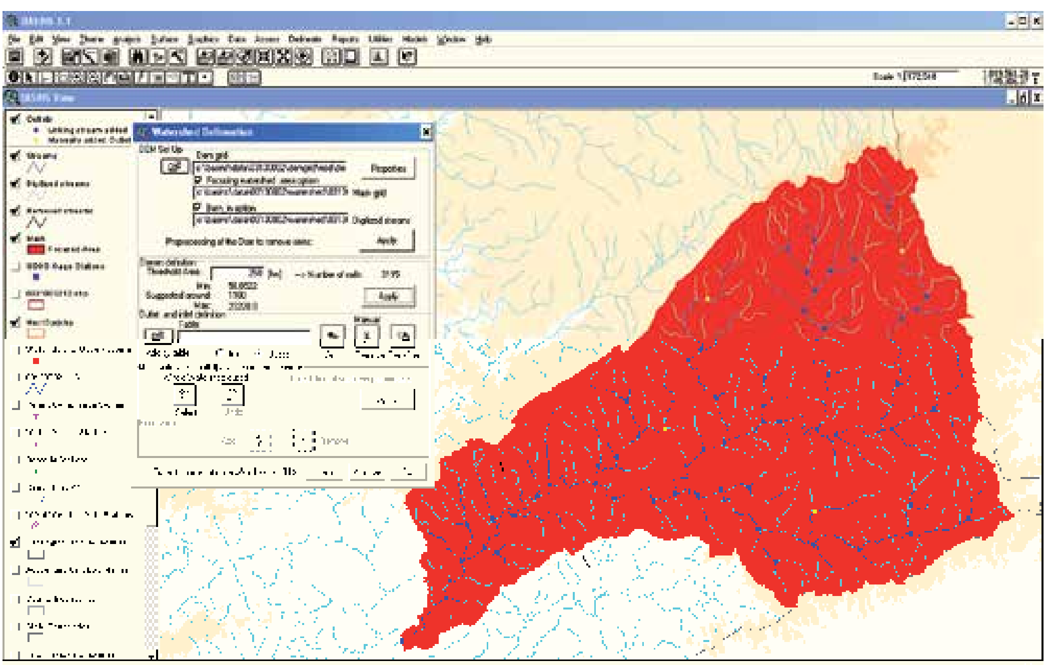


Fig. 4. Digitization of stream networks and nodes

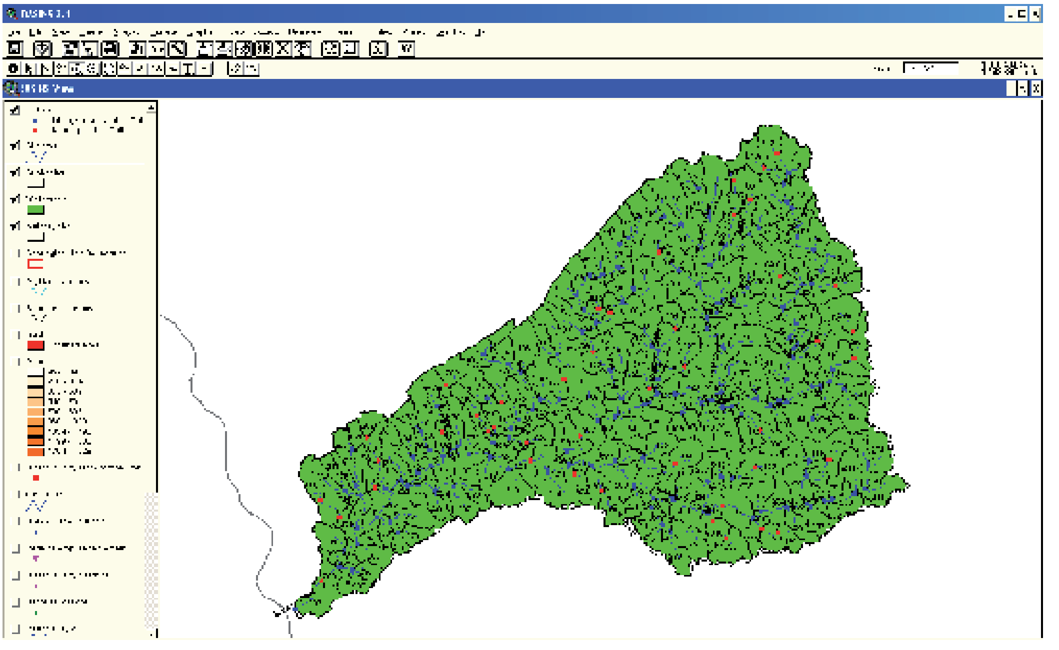


Fig. 5. Creation of sub-basins

Land use grids were loaded in the program and reclassified to standard SWAT codes using the user defined land use look up code created outside of the program. A land use look up code table was prepared to match the land use class to the standard SWAT classification (Table 1). The state soil layer was also loaded and reclassified using the standard STATSGO soils look up codes. Once the reclassification was complete, soils and land use layers were spatially overlaid to facilitate the creation of hydrological response units (HRUs, Figure 6). An HRU is a result of interaction of land use and soils thus creating a unique land area within each sub-basin. Later, several components of the SWAT results, for example, crop yields, biomass would be based at the HRU level. Multiple HRUs were created by setting 5% threshold on land use and 10% threshold on soils.

Upon the successful creation of HRUs the SWAT module was loaded by the system. It started by adding the SWAT database into the model that included the weather and management information. The weather station databases, which included daily precipitation record and daily minimum-maximum temperature records, were created for 10 nearby weather stations outside of the program extracted from the NCDC climate database. During the model simulation, the program assigns the recorded values from the nearest weather station. When data is unavailable for any period of time, the program uses the simulated values based on the information stored for more than 1041 weather stations nationwide (De Luzio et. al., 2000). The other inputs fed into the program were solar radiation, wind speed and relative humidity data. Since none of the weather stations contained these information, it was left to the program to simulate those values from within the internal database. Once the weather station databases were loaded into the system, all necessary SWAT inputs were written using the elevation, land use, soil and weather station databases. This process built the database files containing the information needed to generate default inputs for SWAT. Land management practices, including average nutrients and chemical uses for each

NLCD 1992			NLCD 2001		
GRID	Code	NLCD Description	GRID	Code	NLCD Description
11	WATR	Open Water	11	WATR	Open Water
12	WATR	Perennial Snow/Ice	12	WATR	Perennial Snow/Ice
21	URML	Low Intensity Residential	21	URML	Developed, Open Space
22	URHD	High Intensity Residential	22	URML	Developed, Low Intensity
23	UIDU	Commercial/Transportation	23	URMD	Developed, Medium Intensity
31	UIDU	Rocks/Sand/Clay	24	URHD	Developed, High Intensity
32	UIDU	Quarries/Strip mines/Pits	31	UIDU	Barren Land (Rock/Sand/Clay)
33	FRST	Clear Cut/Sparse Vegetation	32	UIDU	Quarries/Strip Mines/Pits
41	FRSD	Deciduous Forest	41	FRSD	Deciduous Forest
42	FRSE	Evergreen Forest	42	FRSE	Evergreen Forest
43	FRST	Mixed Forest	43	FRST	Mixed Forest
51	RNGB	Shrublands/Brushes	52	RNGB	Shrub/Scrub
81	HAY	Pasture And Hay	71	RNGE	Grasslands/Herbaceous
82	AGRR	Row Crops	81	HAY	Pasture And Hay
83	AGRC	Small Grains	82	AGRR	Cultivated Crops
84	AGRL	Fallow	90	WETF	Forested Wetlands
85	URML	Recreational Grasses	95	WETN	Herbaceous Wetlands
91	WETF	Woody Wetlands			
92	WETN	Herbaceous Wetlands			

Table 1. Reclassification of land use grids to standard SWAT codes

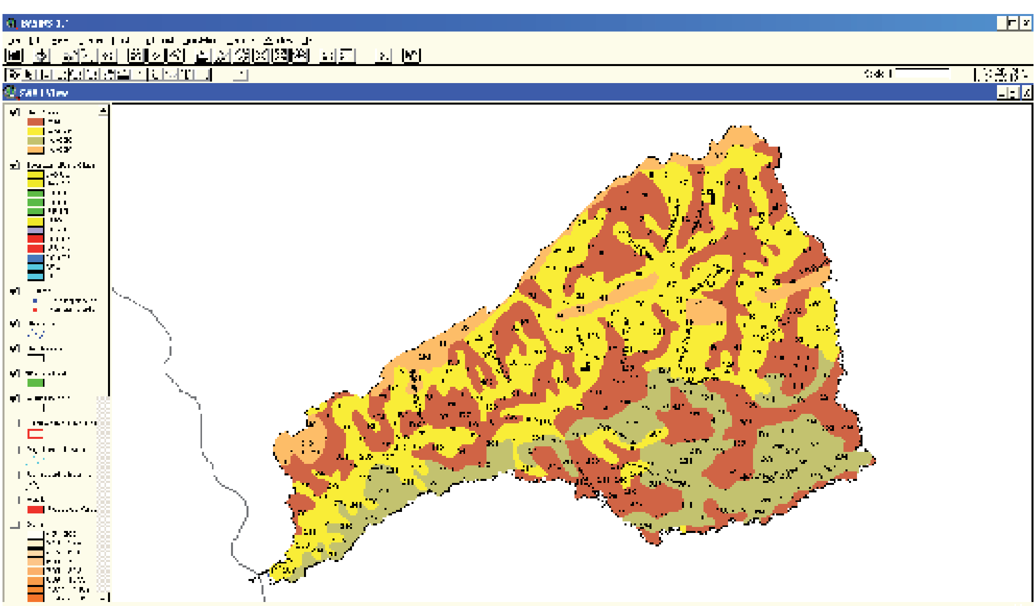


Fig. 6. Land use and soil reclassification and spatial overlay

type of land use were set to common practices reported in various published extension service papers. Sedimentation and nutrient deposition were evaluated for different land use scenarios using NLCD-1992 and NLCD-2001. Since the data on wind, solar radiation and humidity were not available, built-in data from the SWAT model were used. Curve number and Preistley-Taylor methods were used for modeling the rainfall and evapotranspiration respectively.

5. Results

The watershed was divided into 331 sub-basins. The mean elevation of all sub-basins was 216 meters above sea level ranging from 128 to 368 meters. The mean and median sizes of sub-basins were 176.2 hectares and 174.4 hectares respectively. This sub-basins area ranged from 14.3 hectares to 438.9 hectares.

HRUs are determined by the combination of land use and topographic parameters. Therefore, the number of HRUs was different when two land use maps were used. A total of 2089 HRUs were identified by overlaying soils and land use map for land use condition in 1992. On average each sub-basin contained 6.3 HRUs with mean area of each HRU as 27.9 hectares. When NLCD-2001 land use map was overlaid on the same sub-basins with same threshold level, a total of 2158 HRUs were identified. On average each sub-basin contained 6.52 HRUs with the mean area of 27.0 hectares.

Table 2 contains the results from the SWAT run with two sets of land cover data NLCD-1992 and NLCD-2001. Simulations were run for 30 years from 1975 to 2004. SWAT results for the initial years are generally taken as warm up results. Results from the first 10 years were used for calibration and the later twenty years of results (1985-2004) were used for comparative analysis.

Variable	NLCD-1992		NLCD-2001		Change	p-value^
	Mean	Std. Dev.	Mean	Std. Dev.		
Precipitation (mm)	1204.29	194.46	1204.29	194.46	n/a	n/a
Water Yield (mm)*	218.58	75.57	224.82	75.12	2.85%	0.001
Sediment Yield (t/ha)	13.56	7.89	15.60	8.46	15.04%	0.000
Organic Nitrogen (kg/ha)	1.89	1.03	1.98	1.00	4.76%	0.021
Organic Phosphorus (kg/ha)	0.22	0.12	0.23	0.12	4.55%	0.027

^ p-value are for Pair-wise t-test for the comparison of means
* Water Yield = Surface Flow + Lateral Flow + Ground Water Flow–Transportation Loss

Table 2. Average Annual Basin Values (1985–2004)

The modeled area received 1204.29 mm of precipitation per year. When the land use distribution changed from that of 1992 to 2001, there was 2.85% increase on water yield ($p=0.001$) that washed away 15.04% more sediment ($p<0.001$). The sediment level increased from 13.56 t/ha to 15.60 t/ha, equivalent of additional 119,096 tons of sedimentation per year from the entire watershed area. Similarly organic nitrogen runoff increased by 4.76% ($p=0.021$) and organic phosphorus increased by 4.55% ($p=0.027$). The p-values are based on pairwise t-test for the comparison of means and are significant at 5% level of significance. Graphical comparison of sediment loadings and organic nitrogen and phosphorus runoff under two land use scenarios are given in figures 7 – 9.

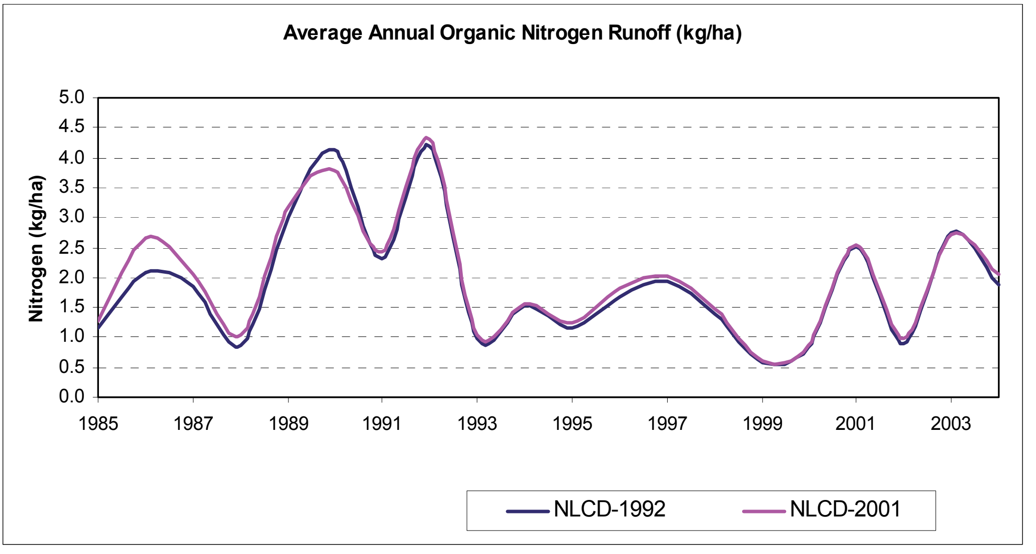


Fig. 7. Simulated average organic nitrogen runoff (1985-2004)

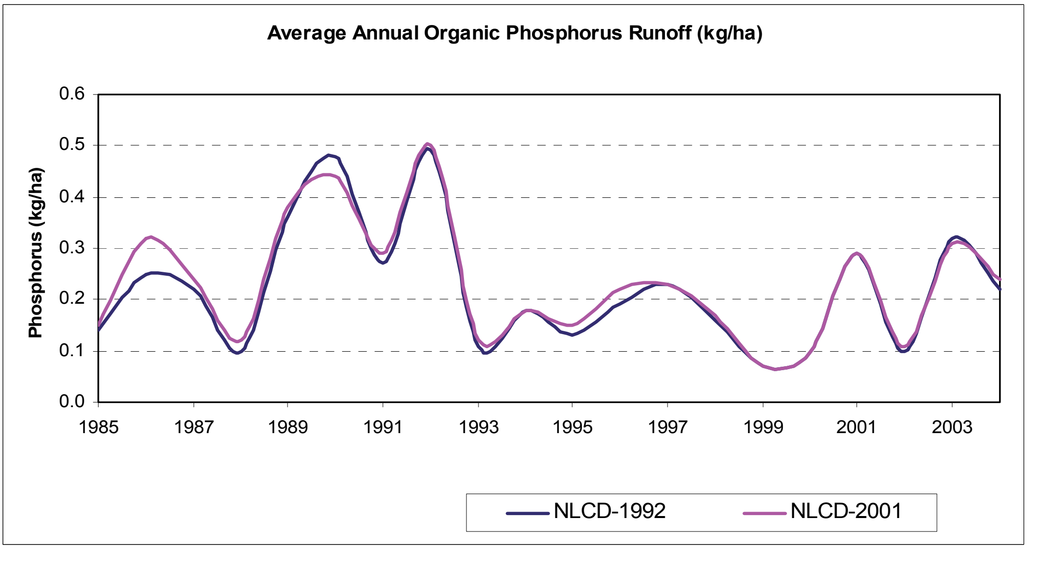


Fig. 8. Simulated average organic phosphorus runoff (1985-2004)

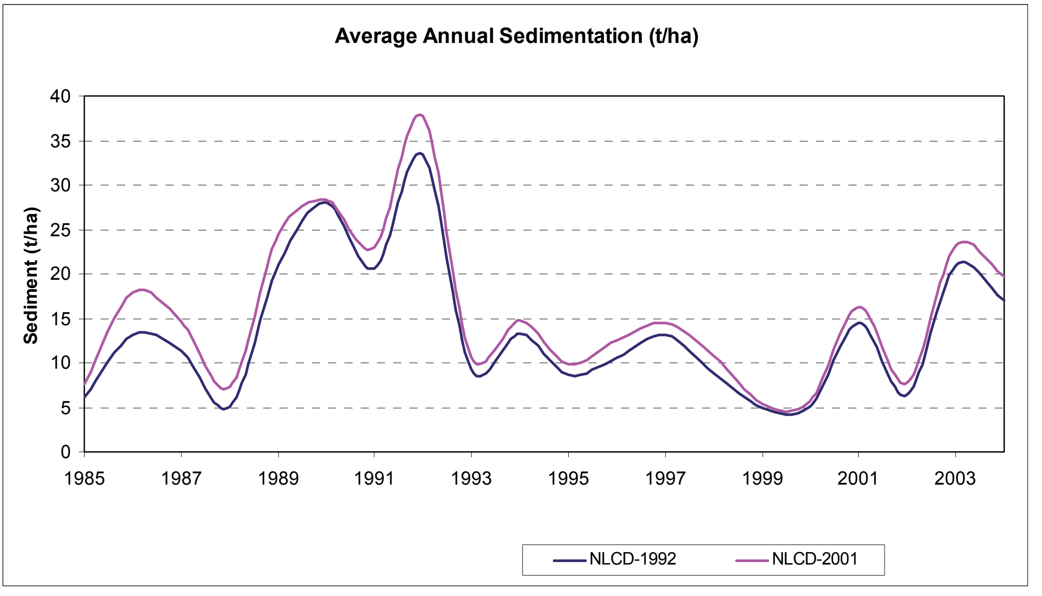


Fig. 9. Simulated average sediment runoff (1985-2004)

6. Discussion

This study demonstrates how changes in land cover scenarios can affect the water quality in the catchment area with quantitative findings. These results are basic to the understanding of water quality impacts of land use change which ultimately helps regional planners and watershed management policy makers by providing the estimates of changes in water quality when land use changes in an area over long run. King and Balogh (2001) applied the methodology to simulate water quality impacts associated with converting farmland and forests to turfgrass. They found SWAT to be a useful tool in evaluating risk assessments associated with land use conversions.

The application of the model can be extended to include much detailed land use and soil distribution facilitating the short-run assessment of point and non-point source pollution. Using recent satellite images to create maps with details of cropping patterns will help to understand the impact of alternative best management practices such as minimum or no-tillage practices and reduced use of fertilizers and pesticides (e.g. Santhi et al., 2001). The fact that the watershed level results can be disaggregated to the individual hydrological response units helps to achieve precise estimate of water quality impact at much smaller level. While these biophysical models are extremely valuable in assessing the physical impacts of BMPs on quantity and quality of water bodies, the results can be combined into a more complex bioeconomic modeling to estimate the impacts of land use changes with respect to economic profitability and the water quality. Bhattarai et al. (2008) demonstrated that a reduction in cropland improved the water quality with an overall loss in agricultural returns. Results from these biophysical results combined with economic analysis helps in setting up a policy that maintains the balance between the water quality and economic incentives among the stakeholders.

7. Limitations of the study

The land in the study area is predominantly forested. The shares of other land uses such as developed land, agricultural land, and wetland, are relatively small. During the HRU distribution process, the model picks up the dominant land use as determined by the threshold level. Thus unique land uses with very small areas may be ignored, leaving out the effects of specific land use in a localized area. The selected sub-watershed does not have enough water quality observation sites and USGS gage stations to calibrate and validate simulated results with the real-time observed daily streamflow data and water quality data. The objective of the study was to compare the levels of nitrogen, phosphorus and sediment achieved under alternative land use scenarios at the aggregated level, ceteris paribus, the results are still valid for comparative analysis.

8. Conclusion

Change in land use distribution had a significant impact on the levels of organic nitrogen and phosphorus runoff and sediment loadings coming out of the watershed. The forest land decreased by 16.6% and mostly the developmental use and agricultural cultivation took that share resulting in overall average annual nutrient runoff increase by 4.76% for nitrogen and 4.55% for phosphorus. Average annual sediment loadings at the basin level increased by more than 15.04%. With the same amount of rainfall and climate conditions, water flowing to the main channel from the catchment area was 2.85% higher. This result confirms to hypothesis that with less vegetative cover, more impervious surfaces in urban areas and increasing fragile agricultural land, there would be less percolation and higher runoff. This resulted in higher organic nitrogen and phosphorus concentration in the discharged water. This study also indicates SWAT's relative strength in quantifying the effect of changes in land use distribution and land management scenarios on water quality.

9. Acknowledgement

Partial funding for this research was provided by the Center for Forest Sustainability through the Peaks of Excellence program at Auburn University. Additional funds were also provided by Auburn University's Environmental Institute. The views expressed in this article are of authors and do not necessarily represent the views of the funding institution or the institution the authors represent.

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12

Flood Progression Modelling and Impact Analysis

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1. Introduction

People living in the lower valley of the St. John River, New Brunswick, Canada, frequently experience flooding when the river overflows its banks during spring ice melt and rain.
Media reports reveal devastating effects of the latest floods that hit New Brunswick, Canada during the summer of 2008 (CTV, 2008). The rising water levels forced the closure of the New Brunswick Legislature, and also resulted in the temporary closures of the international bridge that links the Province to the United States of America. It also closed the operation of the Gagetown ferry. Fredericton experienced its worst floods in 1973, when the St John River reached the 8.6 m mark (ENB-MAL, 1979).
The 2008 flood was recorded as one of the major floods experienced in Fredericton after the 1973 flood (see Figures 1 and 2). On April 24th 2008, due to rapid melting of snow set by an unusually severe winter and combined with intense rainfall, the water level of St. John River reached 7.2 m (TC, 2008). The water levels in Fredericton raised by a meter overnight to 8.33 m on May 1st. Raising St. John River levels peaked at 8.36 m on May 2nd, almost reaching the previous record of 8.61 m set in 1973 (CIWD, 1974).
The closure of roads, government buildings followed by the evacuation of people and their possessions during floods is necessary to avoid the loss of life and property. Raising river water levels could affect electrical, water and telecommunication facilities. It could also affect the sewage system. In such a situation, the public buildings washrooms cannot be used. The question that the government officials are facing is: "When can an office be declared risky to occupy?" The decisions to close public utilities require strong reasons. Such decisions have social, economic and political impacts on the community.
City Managers will require reliable support for the decision to close down government infrastructure. To facilitate this process, we propose the use of 3D flood modelling,

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embedded on 3D terrain together with infrastructure (electrical power, water, telecommunications) and buildings to make correct decisions on when buildings and infrastructure are declared unsafe to use.

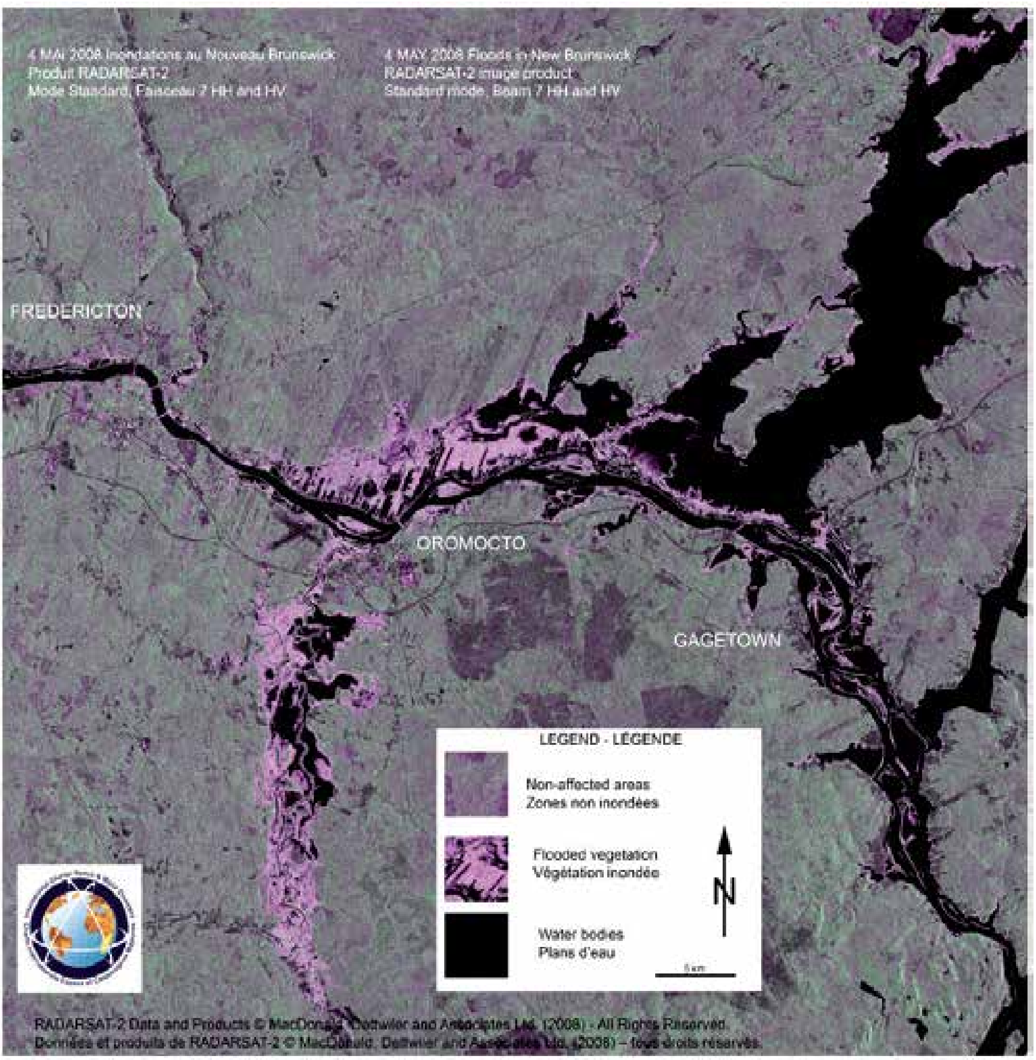

Fig. 1. Flood monitoring using satellite imagery

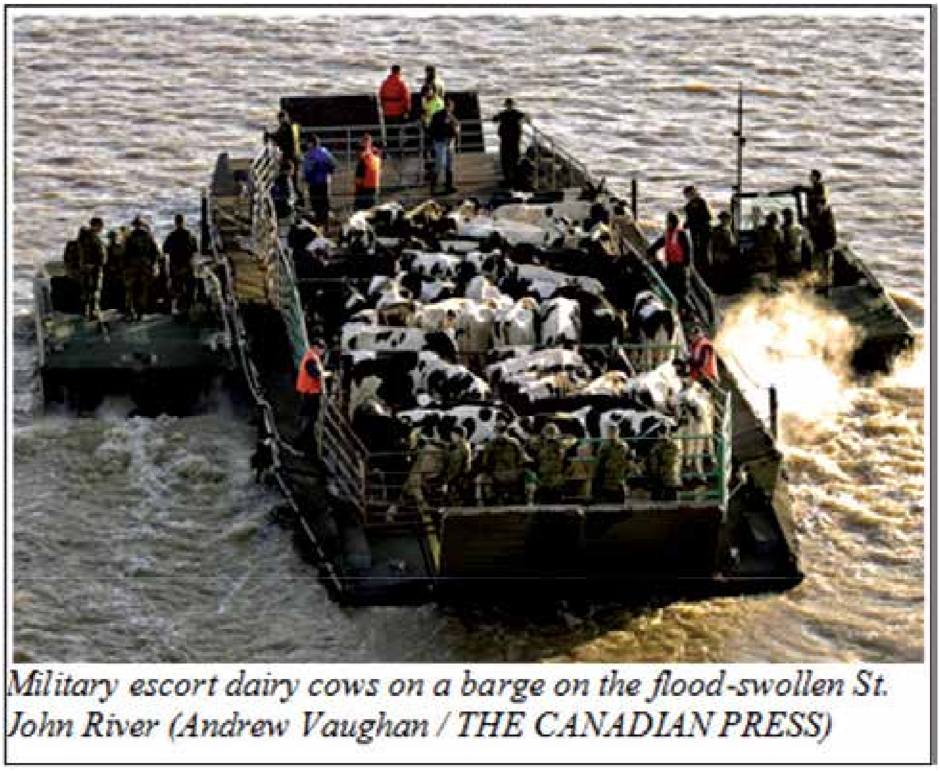

Fig. 2. Evacuation of diary cows during the flood in 2008

2. Previous research

Since ancient times, humans have developed means to monitor flood levels and to some extent, predict the rate of flood rise. People in medieval times marked animals and pushed them down the river to see how deep the river was. According to the director of EMO, Ernest McGillivray, his grandfather had a self-calibrated stick that he used to insert in the river to compare and forecast river flood levels.

Today, more innovative technologies have been developed to study floodings (Jones, 2004; Marks & Bates 2000). These include satellite remote sensing, aerial photogrammetry and LiDAR. Such technologies are combined with computer terrain modelling tools to create scenarios for analysis, as in the case of Geographic Information Systems (GIS).

Previously, the New Brunswick Emergency Measures Organization (EMO) in collaboration with the University of New Brunswick, Canada developed a flood model (available from http://www.gnb.ca/public/Riverwatch/index-e.asp) for the area of lower St. John River, New Brunswick, Canada (EMO, 2008).

The research done so far on early mapping and flood monitoring in the lower St. John produced a web-based system for flood warning (Mioc et al., 2008; Mioc et al., 2010), publicly available to the population living in this area (see Figures 3 and 4). However, the accuracy of existing elevation data was a major problem in this project. The maps we were able to produce were not accurate enough to effectively warn the population and to plan the evacuation. Another problem we faced in the 2008 flood was that even though the buildings were not affected by the flood the electrical and water facilities were not functioning, so the

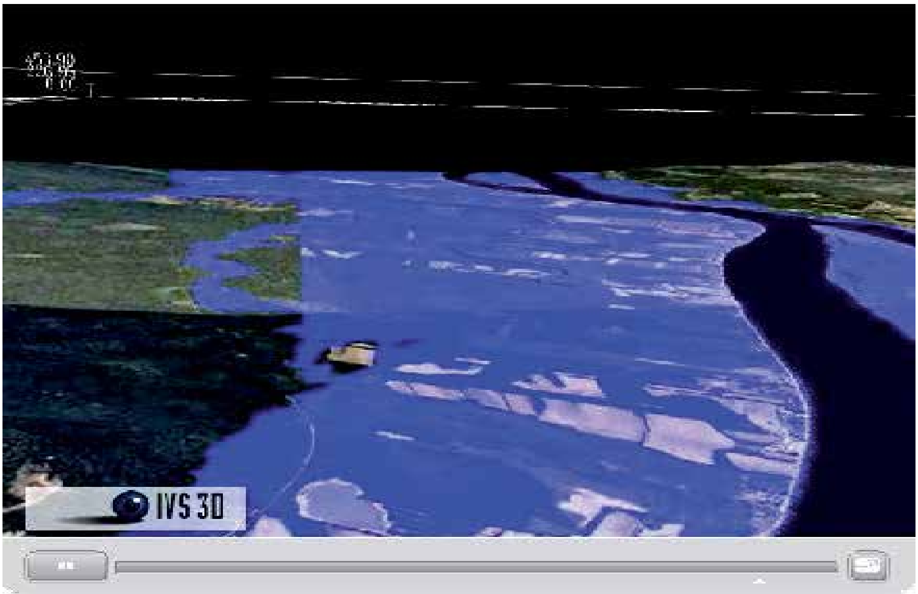

Fig. 3. Fly through simulation of the extreme flood in 1973

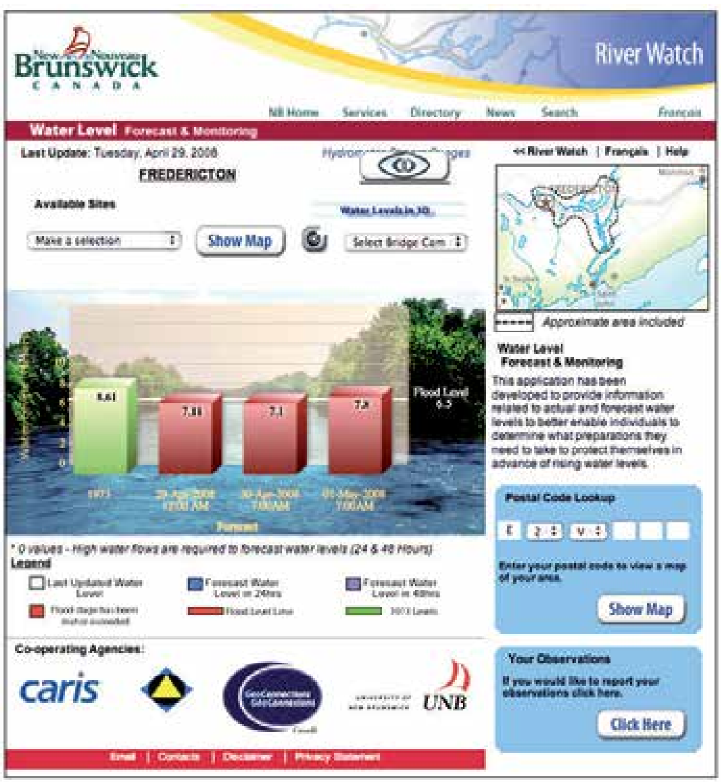

Fig. 4. Riverwatch website for flood warning

buildings and houses were inhabitable. The elevated groundwater levels would affect the power cables causing power outages and the old plumbing installations would cause sewer back-propagation due to the pressure of the rising water from St. John River.
Current visualization methods cannot adequately represent the different perspectives of the affected infrastructure. It can be seen that the building models are represented by polygons only and the detailed 3D views of the buildings and terrain affected by the flooding do not exist. As a result, the public may not have adequate technical or analytical know-how to analyze the polygons. Therefore, they may not find the River watch website very useful (see Figure 4). To overcome these problems we had to develop a new digital terrain model and new techniques for flood modelling. In order to improve the existing digital elevation model we needed to use new technologies for data acquisition (Moore et al., 2005).

3. Data collection and processing

In our research efforts to improve the accuracy of the elevation data, we used new Light Detection and Ranging (LiDAR) data acquisition and LiDAR data processing. Furthermore, the hydrological modelling was integrated with processed LiDAR data within a 3D GIS application.

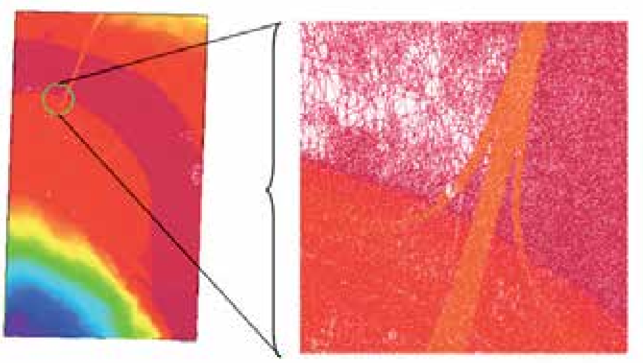

Fig. 5. LiDAR data processing

Light Detection and Ranging (LiDAR) (see Figure 5) has become a useful technology for collecting point cloud data for three-dimensional surface representations. The ability to quantify vegetation height, the roughness of the ground surface, ground elevation, and nearby buildings has greatly improved the parameterization of the two-dimensional hydraulic models, currently at the forefront of flood impact assessment studies (Kraus & Pfeifer, 2001; Hodgson & Bresnahan, 2004).

3.1 Available data

In this research, the newly acquired LiDAR data and Tidal gauge readings from May 1st to May 4th, 2008 were used to delineate the extent of flood during the 2008 flood in Fredericton. Elevation data of Fredericton were obtained using LiDAR techniques and have the vertical accuracy of 15 cm on the hard surface. For this section, only data from Fredericton downtown area are used, as it was the most active area exposed to the flood. The coverage area is shown in Figure 6. Coordinates of river gauges and recorded river levels for four cross-sections over a period of four days (May 1st to May 4th, 2008) are shown in Table 1. Tidal gauge readings were extended to a profile across the river in order to facilitate spatial analysis.

POINT_X	POINT_Y	NAME	1-May	2-May	3-May	4-May
-66.6533	46.02761	13	8.33	8.36	7.78	7.14
-66.6505	45.95549	13	8.33	8.36	7.78	7.14
-66.6322	46.00999	14	8.27	8.3	7.75	7.12
-66.6487	45.95604	14	8.27	8.3	7.75	7.12
-66.6476	45.95384	15	8.12	8.18	7.66	7.07
-66.5804	45.99036	15	8.12	8.18	7.66	7.07
-66.5681	45.95439	16	7.96	8.04	7.57	7.02
-66.6465	45.94944	16	7.96	8.04	7.57	7.02

Table 1. Tidal Gauge Readings

Light Detection and Ranging (LiDAR) is a data collection technique that uses a beam of light to make range-resolved remote measurement of features within the path of a reflected beam of light. The New Brunswick government, through the Department of the Environment and Emergency Measures Organization (EMO), collected LiDAR data sets for great part of the province of New Brunswick after the flood in 2008.

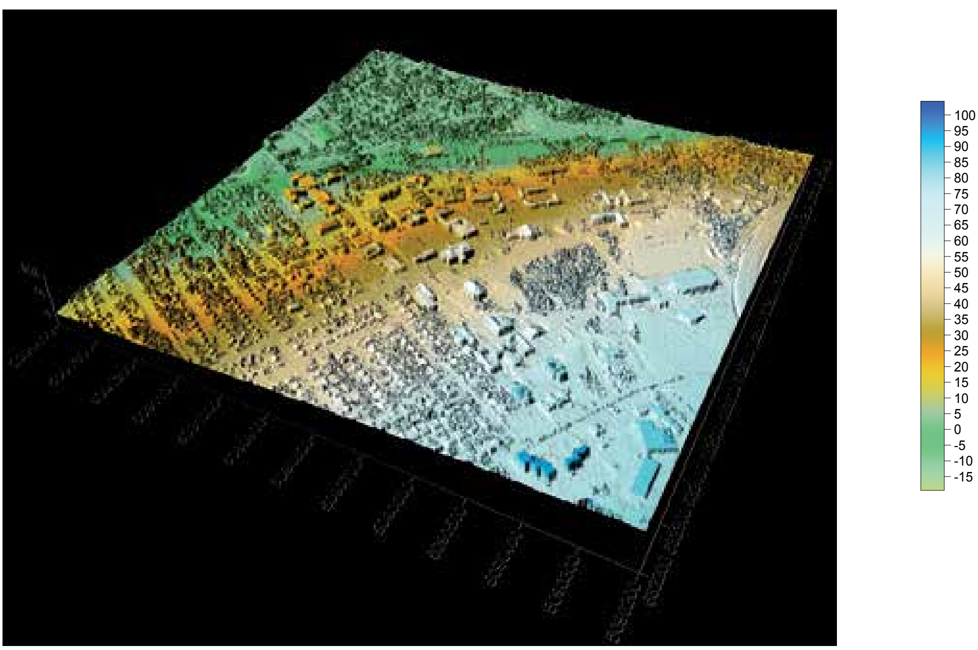

Fig. 6. Downtown Fredericton LiDAR data

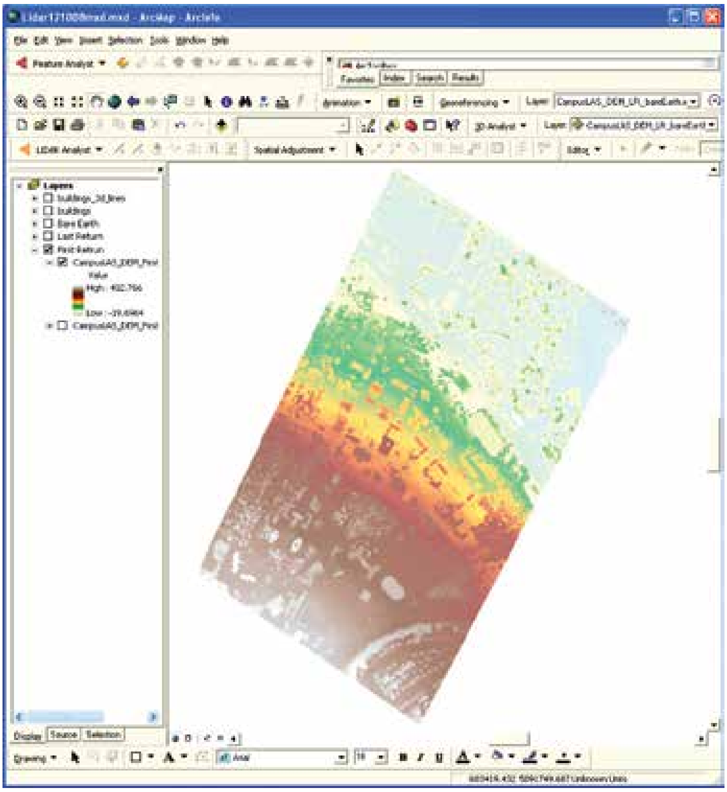

Fig. 7. LiDAR data; First Return, part of Fredericton, NB

3.2 Data processing

For this project, accurate planimetric coordinates and orthometric heights were obtained for the 3D flood modelling. In order to process LiDAR data (Elaksher & Bethel, 2002a, 2002b), we applied the following workflow of tasks:

1. Find LiDAR strip for the project area and extract returns of LiDAR beams (Figures 6 and 7).
2. Extract ground surface, i.e. ground DTM of the area of interest (Figure 8).
3. Extract building footprints from the returns of the LiDAR data (Figure 9).
4. Edit footprints by comparing them with cadastral data. The cadastral map does not contain height values and is not recent. However, based on different predefined parameters, the algorithm used to extract the building footprints produce varying results. The best fit is shown in Figure 10. The results were compared to the digital cadastral map of the study area. Further editing was necessary to correct the planimetric errors from the building footprints obtained from extraction process.
5. Proceed with other modelling tasks (shown in Figure 11) and add attributes and other data necessary for analysis (see Figures 12 and 13). The buildings and utilities, including electrical power, water and telecommunications are all modelled in 3D. Their attributes are also included in the modelling.

LiDAR data is usually collected with reference to ground control points using GPS methods. Subsequently, the output coordinates are ellipsoidal. To obtain accurate flood modelling together with Digital Terrain Model, the data originally available in the geographic coordinates using the ellipsoid defined by the WGS84 geodetic datum are finally transformed to UTM and the CGVD28 vertical datum. To reduce the dataset and improve the processing speed, orthometric heights above 20m were filtered out, since we did not expect flood levels to go above this height. The transformed coordinates are used as the input to the GIS system in order to model a Digital Terrain Model (DTM). Layers containing flood profiles and polygons are created for each day of the extreme flood (1st to 4th of May) in 2008. In addition the extreme flood from 1973 was modelled as well and used for comparison. Existing utilities and buildings in downtown Fredericton we modelled in 3D and geo-referenced to the WGS 84 geodetic datum and the CGVD28 vertical datum. All the developed models and DTMs are then combined under the same coordinate system.

For the efficient decision support system, different flood scenarios were modelled for different flood levels (Sanders et al., 2005; Dal Cin et al., 2009). The technologies for 3D modelling are available in commercial and public domain software. One such tool that was used in this project was Google SketchUp (Chopra, 2007). Although limited in its interaction with other spatial features, Google SketchUp provided the tools needed to model the main features of the buildings (buildings geometry and the texture for the façade and the roof) and surrounding utilities for the test area. As part of future work, advanced tools in the CityGML (Kolbe et al., 2008) could be used for more interactive results.

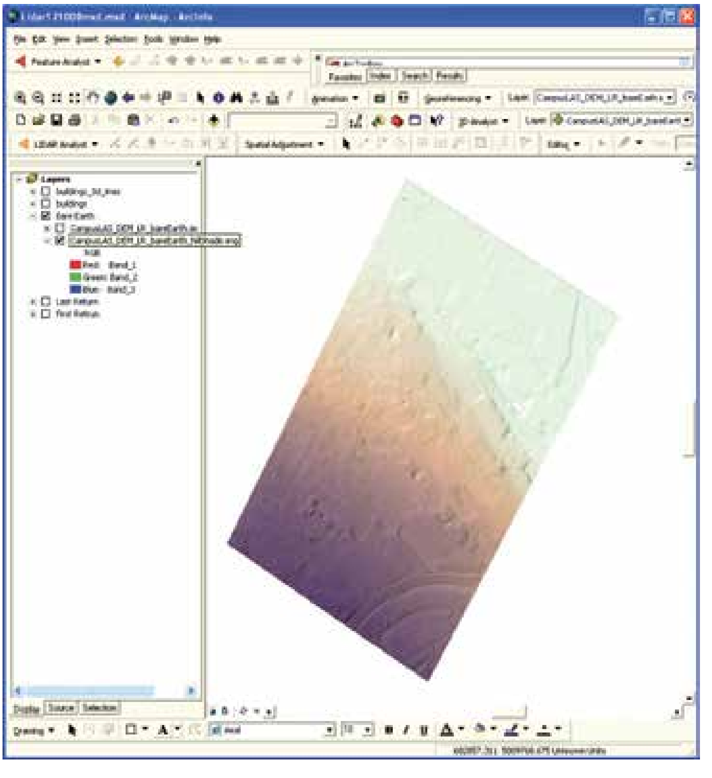

Fig. 8. Extracted ground surface from LiDAR data

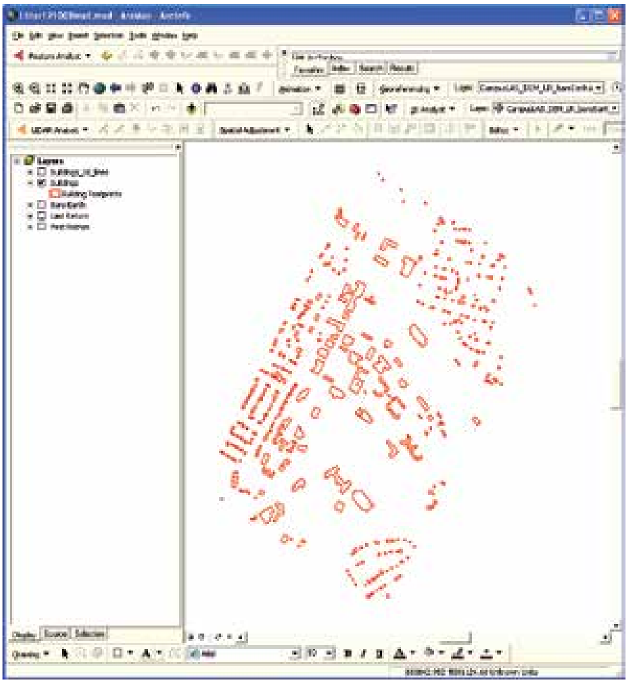

Fig. 9. Extracted Building polygons from LiDAR data

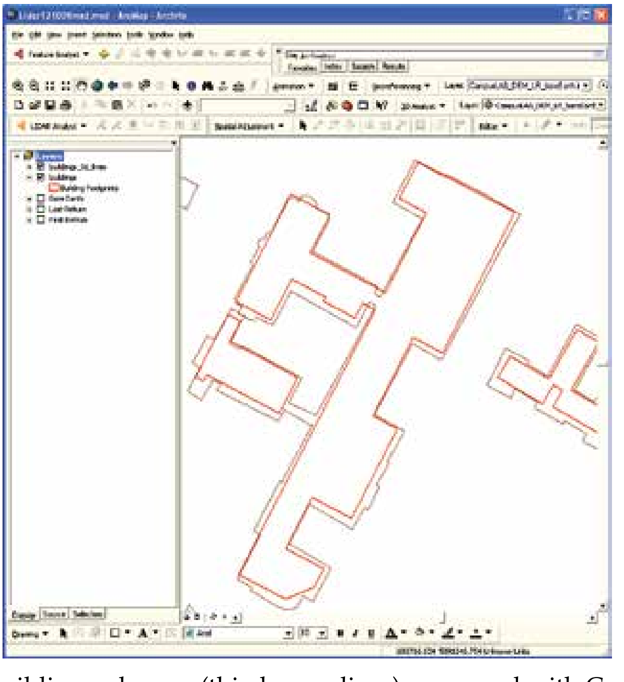

Fig. 10. Extracted building polygons (thin brown lines) compared with Cadastral buildings blueprints (thick red lines)

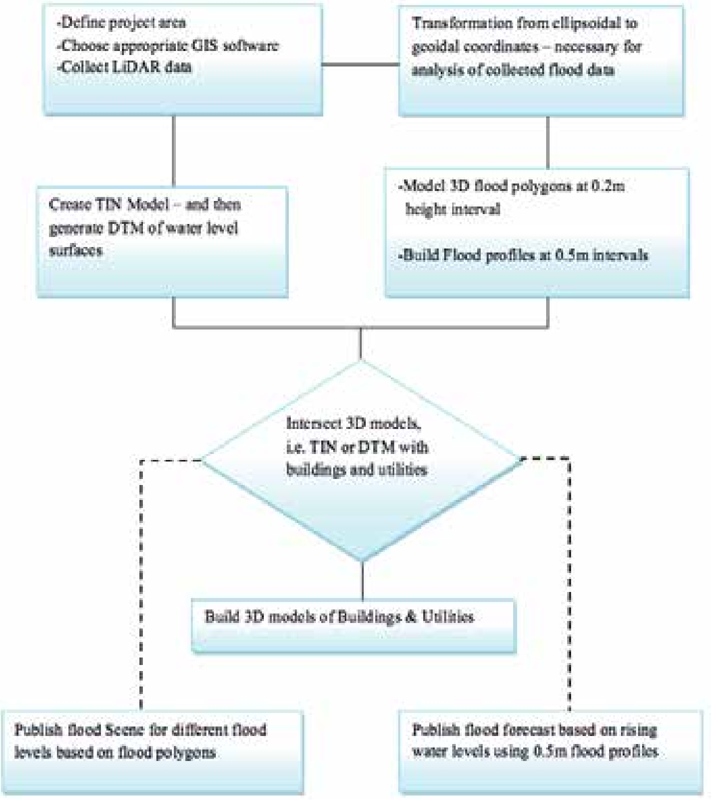

Fig. 11. The workflow of detailed methods and techniques applied for modelling of flooded buildings and infrastructure.

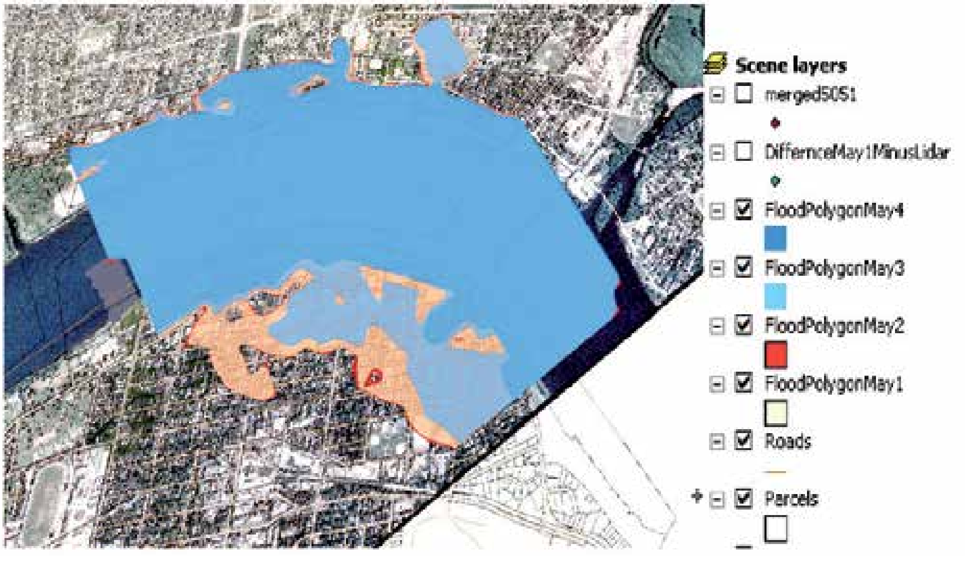

Fig. 12. Flood progression modelling

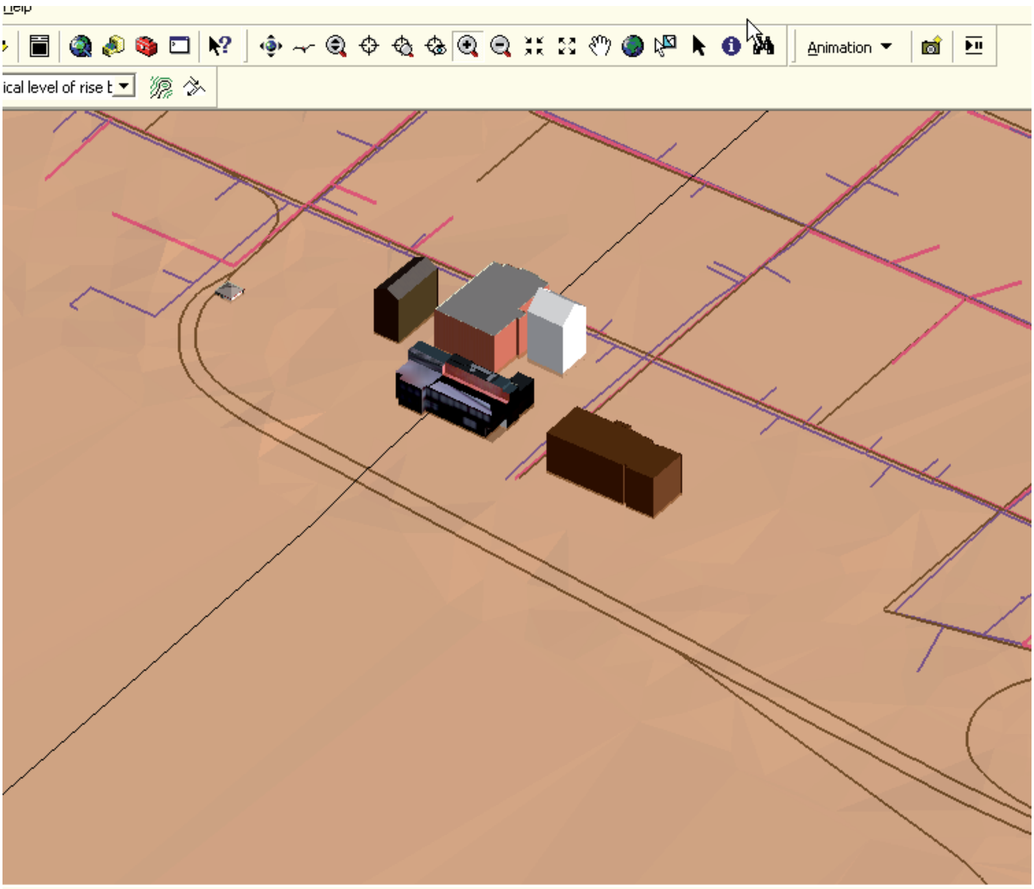

Fig. 13. The 3D model of buildings overlaid over the water and electrical utilities

4. Flood modelling and forecasts

The advanced modelling method we used in this research is based on 3D modelling of flooding, buildings and government infrastructure. The 3D visualizations of the floodplain and its effect on utilities can be discussed in more comprehensive terms, among engineers, government executives and the public. To showcase such a possibility, buildings of downtown Fredericton were extruded in 3D and modelled in detail. Figure 11 shows the processing steps in obtaining 3D models. Embedding the 3D models with the utilities and DTM, through the process of modeling different water rise situations, gives different scenarios of flooding, which can be used for further analysis. Based on this analysis, we show flood levels that could render utilities unavailable and make the government infrastructure risky to occupy.

4.1 Floodplain computations

To accurately compute the floodplain it is important to obtain topography of floodplain areas; the bathymetry of rivers; snow information; storm surges (rainfall forecast); and temperature information to create hydraulic models for effective prediction of inundation areas and risk probabilities. However, water levels obtained by hydraulic modelling do not tell much about the severity and extent of a flood. This motivates the modelling and a visualization of predicted flood areas using GIS. The spatial delineation of flood zones using GIS has become a new research area following the advancement of technologies for data collection (Noman et al, 2001, 2003).

This research uses different spatial analysis tools to create floodplains from LiDAR data in Fredericton area and water gauges for Saint John River. For hydrological modelling we used DWOPER (Fread, 1992, 1993 ; Fread & Lewis, 1998) (as described in Mioc et al., 2010). The results of hydrological modelling were then used within a GIS for 3-dimensional modelling of flood extents (Mioc et al., 2010).

Following our processing workflow (see Figure 11), there were two main objectives in this part of the research:

1. Compare the DTM resulting from LiDAR data with DTMs resulting from water gauges to find the flood extents for Fredericton downtown area.
2. The second objective is to create a single TIN for both LiDAR data and water gauges to calculate the difference of the volume, which represents the floodplain.

The flood progression from May 1st to May 4th, 2008 is analyzed (see Figure 12). Using the results of spatial analysis, a flood prediction model was developed for emergency planning during future floods. In this phase of our research, we were able to obtain the delineation of flood zones using LiDAR and Tidal height information (available from water gauges). In addition, we were able to integrate a number of processes that make flood forecast possible: the acquisition and processing of the elevation data; the use of hydrological software to simulate models of flow across floodplains; the use of spatial analysis software (GIS) that turns the modelling results into maps and overlays them on other layers (thematic maps or aerial photographs); and software that makes these models and predictions available on the Internet in a flexible and user-friendly way.

From the computed floodplain, displayed as superimposed polygon layers, we visualize that the major flood extent occurred from May 1st to May 2nd, with the peak for flood on May 2nd. Furthermore, the flood subsided from May 3rd to May 4th. The system we developed allows the computation of floodplain for predicted flood peak (shown in red on Figure 12) that is critical for emergency managers. Furthermore, the flood modelling results are used to develop a three dimensional model of flooded buildings combined with some city infrastructure, roads, water and electrical utilities (see Figures 14, 15 and 16).

4.2 3D modelling of flooded buildings and infrastructure

The method of simulating and predicting floods and its effects on buildings and utilities provides powerful visual representation for decision making on when the buildings in the flood zone may be safe for people to occupy. Traditional paper maps and digital maps may not give us the possibility to do a 3D visualization in order to study the detailed effect of a flood situation on utilities.

In this research, we used LiDAR data and the application of 3D modelling in order to provide an analysis of the risk of floods on government buildings and utilities. LiDAR data provides a cheaper, faster and denser 3D coverage of features for 3D mapping. LiDAR data was acquired for the city of Fredericton after the flood in 2008 and processed to generate 3D animated views. To further enhance visual perception, 3D buildings, infrastructure and utilities were integrated within a 3D GIS application. The resulting 3D view does not only display a clear-to-nature scenario, but provides also a more realistic outlook of the buildings and infrastructure during floods. Finally, a flood scene was produced for each of the forecasted flood levels for visualization via Web interface.

Using different extrusion heights to represent different flood scenes, it is possible to simulate different flood progression events. The pictorial scene, representation of the building, floods and its effects can be clearly visualized and analyzed. Figure 15 shows a 3D view of the flooding in May 2008. The 3D buildings and utilities can be seen consecutively as a result of applying transparency to the thematic layers. In Figure 16, the utility lines are embedded in the 3D models. Figures 17 and 18 present a 3D visual model of the submerged newly built Public Washroom at the Military Guard Square, in Fredericton, Canada in an extreme flood scenario. At this level of water rise, the electrical boxes would be flooded. It is visible from the model that during flooding, surrounding areas including the Public Library, the Armory and the Military depots will be out of use and certainly inaccessible.

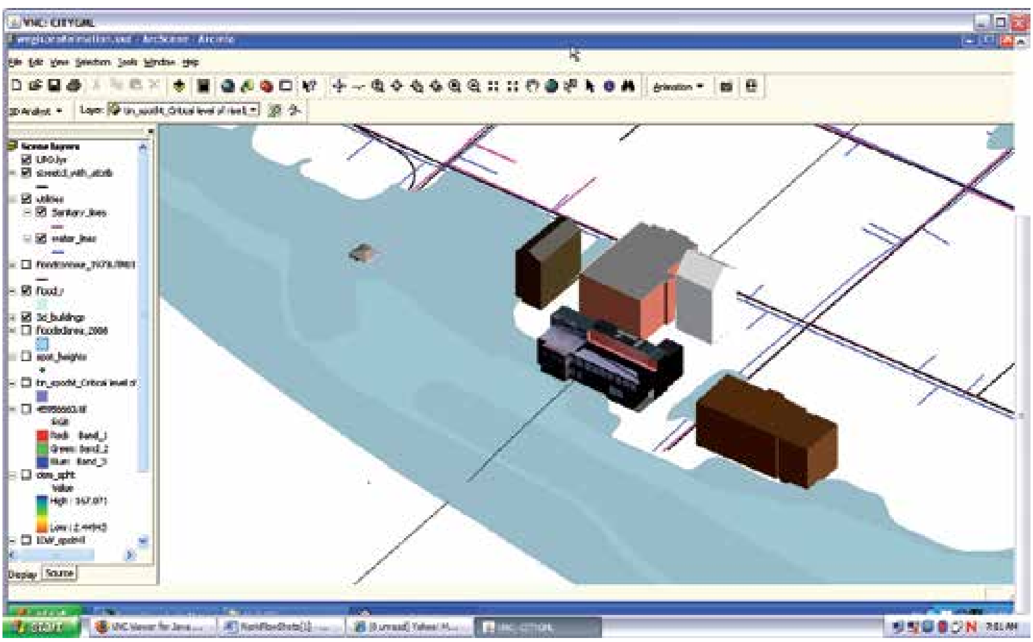

Fig. 14. The 3D model of buildings overlaid over the water and electrical utilities that will be affected by the flood

The DTMs in Figures 15 and 16 show the natural critical point at which water will begin to flow upwards. When ground water rises up to this level, waste matter from the sewage system will flow upward, under pressure from rising water from the river. The washroom facility may not be used under these circumstances. Computing the floodplain for the 20 year statistical flood showed that many parts of Fredericton may have been build on a floodplain. The new analysis of DTMs combined with the groundwater levels shows that, if ground water levels rise across the city, many homes and governmental buildings will be flooded. The electrical utilities and sewage system that are laid in the underground will be affected as well resulting with the sewer back-propagation and the electric power outages. The situation is worse in the downtown area, which has the lowest heights. Priority emergency decisions can be made in this situation to close the downtown offices and infrastructure first, at the start of rising water levels. Based on the results of the overlaying the floodplains with existing utilities and infrastructure, it can be decided when it is risky to occupy or use the buildings or the infrastructure.

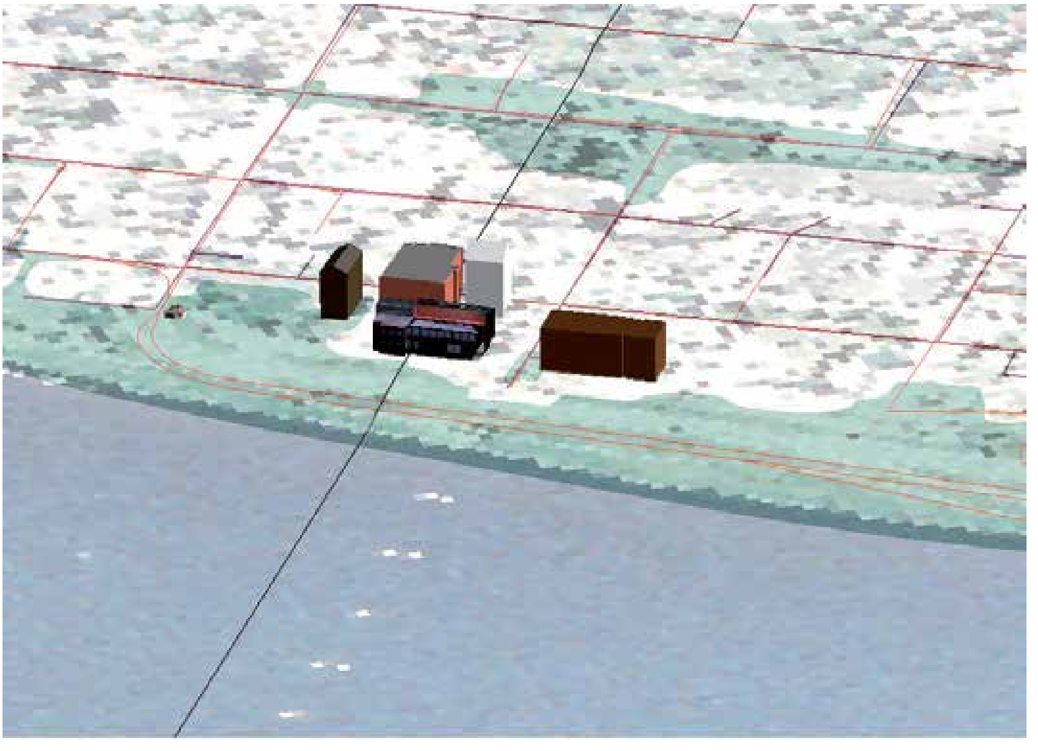

Fig. 15. 3D models of selected buildings in Fredericton integrated with DTM and flood model

Daily automatic generation of flood polygons from the data provided by the existing online River Watch application (see http://www.gnb.ca/public/Riverwatch/index-e.asp) can produce an animated 3D video, which can be uploaded on the Riverwatch website to provide updated 3D models to residents.

It can be seen clearly from the comparison of the model and the picture (shown in the Figure 19) captured during the 2008 flood, that the levels of flooding are the same. The water just touches the back gates of the Fredericton Public library on both of these. The accuracy of the flood model depends on the vertical accuracy of the LiDAR datasets and the accuracy of the hydrological modelling.

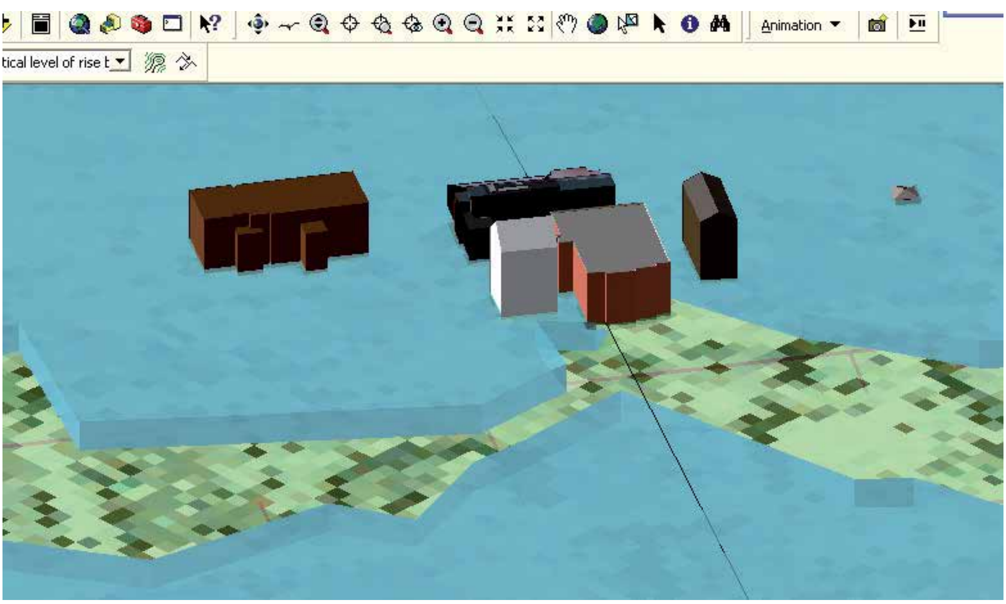

Fig. 16. 3D models of selected buildings in Fredericton affected by the flood

The 3D GIS application provides a better platform for visualizing flood situations than previously done in 2D maps. All exterior parts of a building could be visualized in detail during a flood event. This provides a better tool for analyzing and preparing for emergency measures. It also presents a near to reality situation that can easily be understood. Provincial Ministers and decision makers who may not be familiar with GIS analytical tools and Query Languages can now understand technical discussions on flood analysis through the use of 3D flood models, which are close to reality. It is also possible to simulate floodplain polygons for different river water levels in order to produce different flood scenarios. Simulation can also be used to trace and analyze underground utilities by making thematic layers transparent. Flood scene animations can be published to website for public access.

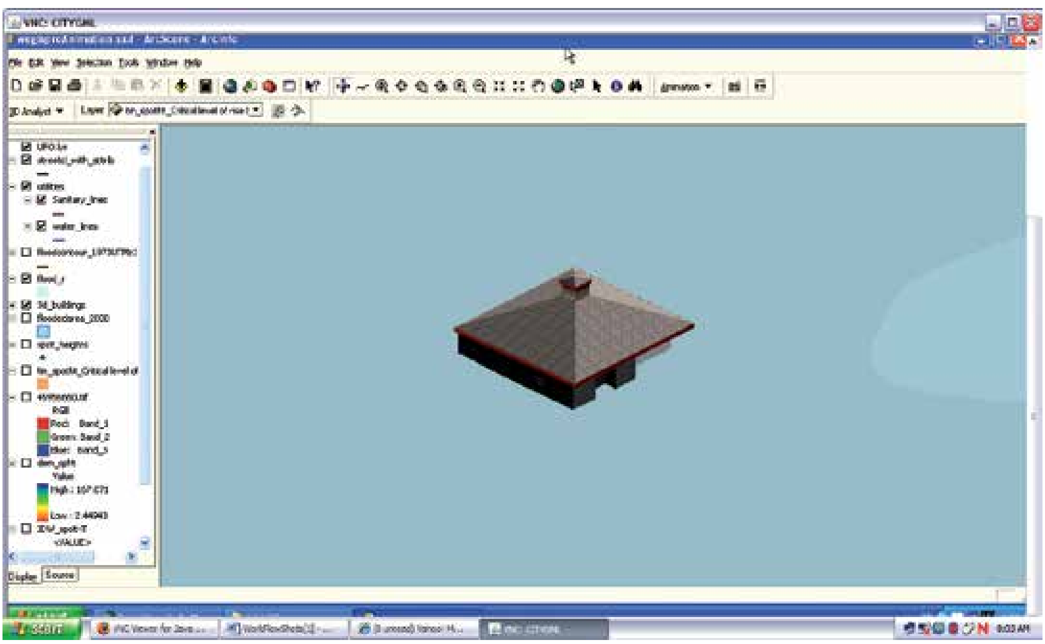

Fig. 17. 3D Washroom, with power box, in the extreme100 year simulated flood

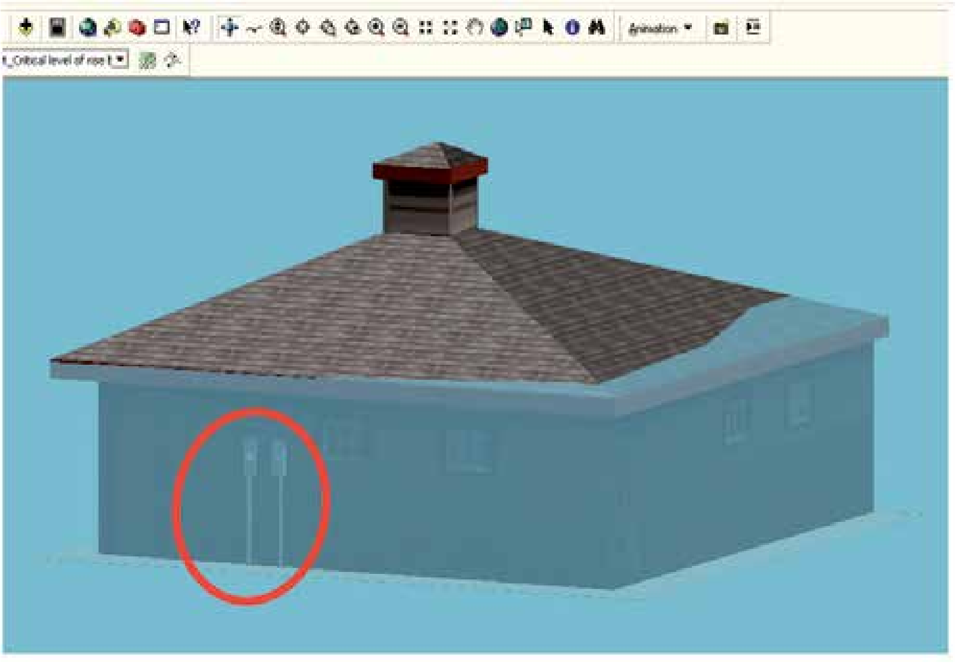

Fig. 18. 3D model of a washroom, with electrical power box, in 1973 simulated flood

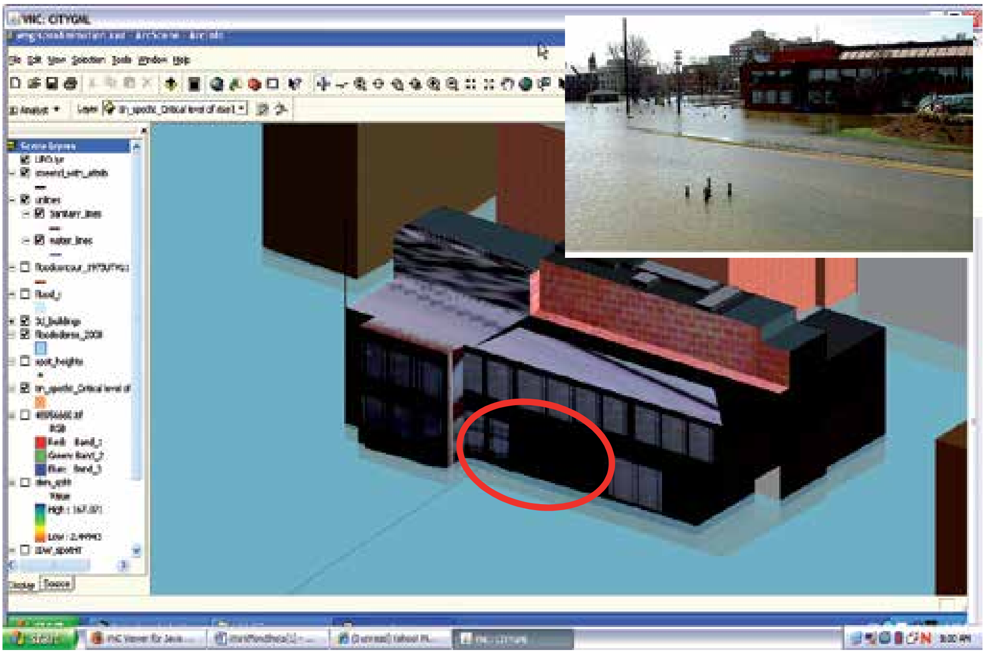

Fig. 19. 3D Model compared with Photograph taken during the flood in 2008

5. Conclusions

The new flood prediction model that computes accurately floodplain polygons directly from the results of hydrological modelling allows emergency managers to access the impact of the flood before it occurs and better prepare for evacuation of the population and flood rescue. The method of simulating and predicting floods and its effects on utilities provides powerful visual representation for decision making on when buildings in the flood zone may be safe for people to occupy. Traditional paper maps and digital maps may not give us the possibility to do a 3D visualization of the detailed effect of a flood on utilities and infrastructure.

This research explores the application of 3D modeling using LiDAR data to provide an analysis of the risk of floods on government buildings and utilities. LiDAR data provides a cheaper, faster and denser coverage of features for 3D mapping. LiDAR data was processed to generate 3D maps. By employing accurate coordinate conversion and transformations with respect to the geoid, a Digital Terrain Model (DTM) was created. Floodplain delineation was computed by intersecting the Digital Terrain Model with the simulated water levels. Furthermore, to enhance visual perception of the upcoming flood, 3D buildings, infrastructure and utilities were modelled for the city downtown area. The DTM and the 3D models of the government buildings, infrastructure and utilities were overlaid and presented as a 3D animation. The resulting 3D view does not only register a clear-to-nature scenario, but also provides a more discerning outlook of the buildings and infrastructure during floods. Finally, in this research we have clearly shown that GIS and LiDAR technologies combined with hydrological modelling can significantly improve the decision making and visualization of flood impact needed for early emergency planning and flood rescue.

6. Acknowledgment

The authors would like to acknowledge the generous contribution of time, materials and resources to this project by the New Brunswick Department of Transportation.

This project was financially supported in part by the N.B. Emergency Measures Organization and the Canadian Department of Natural Resources Geoconnections program as well as the University of New Brunswick and the New Brunswick Innovation Foundation (NBIF). The authors would also like to acknowledge the financial contribution of EMO to the acquisition of new LiDAR datasets (available for this project) after the flood in 2008.

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13

Providing Efficient Decision Support for Green Operations Management: An Integrated Perspective

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1. Introduction

Green operations management (GOM) has emerged to address the environmental and social issues in operations management, so that the Triple Bottom Line (3BL) sustainability can be achieved simultaneously (Rao & Holt, 2005; Zhu, Sarkis & Geng, 2005). The concept of GOM was originally formed in the 1990s. Early research on GOM mainly directed towards segmented areas of operations management, such as quality management. Over the past decades, GOM has attracted significant research interests from academia, many issues remain under-addressed which have hindered the effectiveness of GOM practice (Zhao & Gu, 2009; Yang et al, 2010), although the needs for and benefits of GOM cannot be overemphasised for sustainable development (Svensson, 2007). One of the main reasons for GOM lagging behind quality management advances has been identified as lack of true integration of environmental and social objectives into business operations, i.e. environmental management and social values were viewed as narrow corporate legal functions, primarily concerned with reacting to environmental legislation and social codes of practice. Subsequently research and managerial actions focused on buffering the operations function from external forces in order to improve efficiency, reduce cost, and increase quality (Carter & Rogers, 2008; White & Lee, 2009). Research further reveals that the root cause behind the company's isolated approach to the 3BL sustainability is not because the managers do not appreciate the importance and urgency of addressing them, but lack of efficient support for the management of the complexity of sustainable decisions, especially the provision of powerful analysis approach to support effective decision evaluation (Hill, 2001; Taylor & Taylor, 2009; Zhao & Gu, 2009).

This paper proposes an integrated sustainability analysis approach to provide holistic decision evaluation and support for GOM decision making. There are two key objectives to explore the integrated approach: (a) to understand the GOM decision support requirements from a whole life cycle perspective; (b) to address the GOM decision support issue using multiple decision criteria. Based on a case study in production operations area, the paper concludes that the integrated sustainability analysis can provide more efficient and effective support to decision making in GOM.

This chapter is organised as follows. Next section reviews related work on methods and tools that have been developed to address GOM decision issues, and identifies the gap in literature. Section 3 proposes an integrated approach for systematic analysis of sustainability in GOM. Application of the integrated approach to real operations situation is discussed in Section 4. Then Section 5 reflects on the strengths and limitations of the proposed approach, and draws conclusions.

2. Related work

Sustainability or sustainable development was first defined by the World Commission on Environment and Development as the "development that meets the needs of present generations while not compromising the ability of future generations to meet their needs" (WCED, 1987). It has then been recognised as one of the greatest challenges facing the world (Ulhoi, 1995; Wilkinson et al, 2001; Bateman, 2005; Espinosa et al, 2008). For development to be sustainable, it is essential to integrate environmental, social and economic considerations into the action of greening operations (i.e. the transformation processes which produce usable goods and services) (Kelly, 1998; Gauthier, 2005; Lee & Klassen, 2008), as operations have the greatest environmental and social impacts among all business functions of a manufacturer (Rao, 2004; Nunes & Bennett, 2010). In the context of sustainable development, operations have to be understood from a network's perspective, that is, operations include not only manufacturing, but also design and supply chain management activities across products, processes and systems (Liu and Young, 2004; Geldermann et al, 2007). Without proper consideration of inter-relationships and coherent integration between different operations activities, sustainability objectives cannot be achieved (Sarkis, 2003; Zhu et al, 2005; Matthews et al, 2006). There has been a series of overlapping endeavours and research efforts in literature aiming to address the environmental and social issues in operations management, but earlier efforts have been mostly segmented and uncoordinated. More recently, GOM has been investigated from a more integrative perspective instead of a constraint perspective, where environmental management and corporate social responsibility are viewed as integral components of an enterprise's operations system (Yang et al, 2010). It means that the research foci have shifted to the exploration of the coherent integration of environmental and corporate social responsibility with operations management through business managers' proactive decision making (Ding et al, 2009; Liu et al, 2010). Figure 1 illustrates the key ideas of achieving sustainability objectives through holistic decision making in a sustainable operations system. Compared with traditional open operations model, i.e. the input-transformation-output model (Slack et al, 2010), there are four key features in the sustainable operations system:

1. A sustainable operations system is a closed rather than an open system, i.e. the material (including waste and used products), energy and information produced by the operations system should be treated and fed back as inputs to keep the system self-sustainable;
2. The transformation process not only includes the functions and activities that produce products and service, but also includes that of environmental and social improvements;
3. Wider stakeholders' requirements need to be addressed. Apart from customers, other important stakeholders include environment, community, employee, public etc. Therefore, the requirements such as discharge from operations process, information and social benefits have to be properly addressed;

4. The role of suppliers is changing. Apart from the provision of materials, energy, information and human resources, suppliers are also responsible for recovering used products and materials.

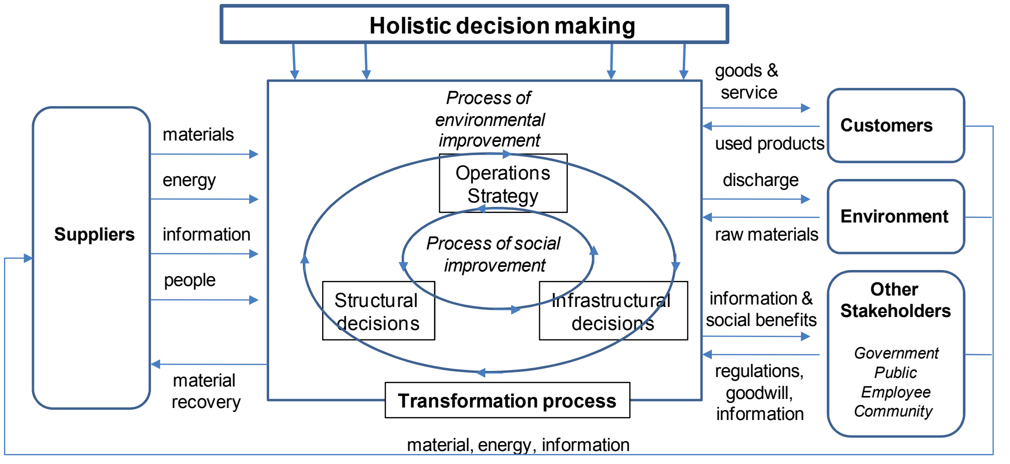


Fig. 1. Holistic decision-making in a sustainable operations system

Many decisions have to be made for green production operations in relation to design, manufacture and supply chain management (Sakis, 2003; Galasso et al, 2009). Slack et al (2010) classified operations strategic decisions into two main categories: structural and infrastructural. Structural decisions are those which primarily influence design activities, such as those relating to new product design and supply network design, while infrastructural decisions are those which influence manufacturing planning and control, and management improvements, such as inventory management and supplier development. Miltenburg (2005) defined six production decision areas: production planning and control, organisation structure and control, human resource, facilities, sourcing, and process technology. This classification scheme was also adopted by Choudhari et al (2010), and 54 decision types were further identified under the six decision areas with 113 decision alternative suggested for the decision types. However, the papers did not provide discussion on how the optimal decision choice could be reached for each decision type. There has been a broad consensus that decision evaluation holds the key to reaching optional decision choice especially under complex decision situations (Mehrabad & Anvari, 2010). Decision evaluation enables decision makers to perform scientific analysis, to weigh, score and rank the alternatives against decision criteria, and to assess the consequences of each decision alternative, so that optimal decision choices become more transparent to decision makers (Karsak & Ahiska, 2008; Chituc et al, 2009). In recent years, sustainability analysis has emerged as an important decision aid to provide efficient and effective decision evaluation in all aspects of business (Hodgman, 2006). Sustainability analysis is important to operations research because decision making in GOM often has high complexity, cost and risk. Getting the decisions right will generate not only considerable economic value, but also great environmental and social impacts which can sharpen a company's competitive edge (Noran, 2010).
Sustainability analysis would be theoretically straightforward if key interacting variables and boundaries of responsibilities were well understood by decision makers (Mihelcic et al,

2003). Unfortunately, such situations are rare, while benefits from sustainability efforts have been elusive. Practitioners continue to grapple with how sustainability analysis should be undertaken, due to the complexities and uncertainties of environmental systems involved and imperfections of human reasoning (Hertwich et al, 2000; Allenby, 2000). According to Hall & Vredenburg (2005), innovating for sustainable development is usually ambiguous, i.e. when it is not possible to identify key parameters or when conflicting pressures are difficult to reconcile, such ambiguities make traditional risk assessment techniques unsuitable for GOM. Researchers further argue that sustainability analysis frequently involves a wide range of stakeholders, many of which are not directly involved with the company's production operations activities. Decision makers are thus likely to have significant difficulties in reaching the right decisions if efficient support is not available. Powerful systematic analysis methodologies have great potential in guiding the decision makers to navigate through the complexities and ambiguities (Matos & Hall, 2007). This section reviews the most influential analysis methodologies that could facilitate efficient and effective GOM decision making: life cycle assessment and multi-criteria decision analysis.

2.1 Life cycle assessment

Life cycle assessment or analysis (LCA) is regarded as a "cradle to grave" technique that can support environmentally friendly product design, manufacture and management (Hunkeler et al, 2003; Verghese & Lewis, 2007; Jose & Jabbour, 2010). It can be used to assess the environmental aspects and potential impacts associated with a product, process or a system (Matos & Hall, 2007; Kim et al, 2010). It also allows decision makers to evaluate the type and quantity of inputs (energy, raw materials, etc.) and outputs (emissions, residues, and other environmental impacts, etc.) of production operations in order to completely understand the context involving product design, production, and final disposal (Fuller & Ottman, 2004; Jose & Jabbour, 2010). Standards for the application of LCA have been set up by ISO (International Standards Organisation). A four stage LCA process has been defined (ISO 14040, 1997), as illustrated in Figure 2.

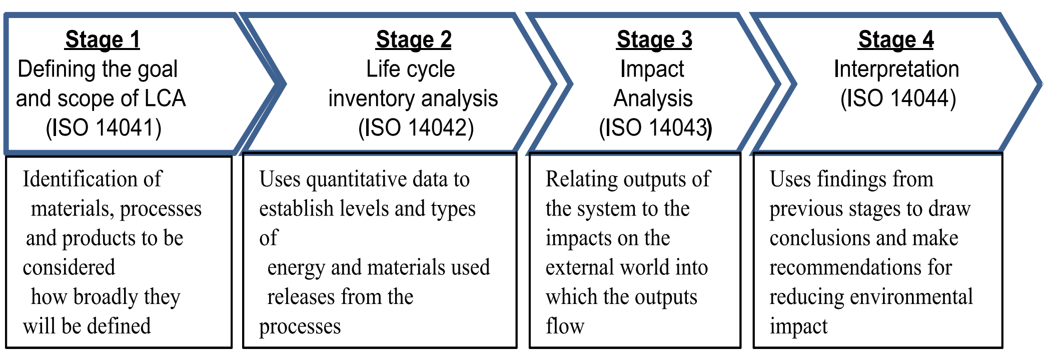


Fig. 2. Four key stages of LCA process (ISO 14040)

LCA can be conducted along two different dimensions: Product Life Cycle (PLC) and Operational Life Cycle (OLC) analysis. A new product progresses through a sequence of stages from development, introduction to growth, maturity, and decline. This sequence is known as the PLC (Sarkis, 2003; Bevilacqua et al, 2007; Gunendran and Young, 2010). On the other hand, OLC includes stages of procurement, production, packaging, distribution, use, end-of-life disposal and reverse logistics (Nunes & Bennett, 2010). The nature of both of these analytical tools can generate important insights into environmentally conscious practices in organisations, and there are close interdependencies between PLC and OLC. For example, in the PLC *introduction* phase, procurement is more influential than production for sustainable practices, whilst in the *maturity* and *decline* stages of the PLC, efficient end-of-life and reverse logistics are more influential than distribution operations. It is also not difficult to understand that distribution decisions such as facility locations and modes of transportation will not only influence the forward but also the reverse logistics networks (Bayazit & Karpak, 2007; Chan et al, 2010). However, it is widely acknowledged that environmental methods (LCA in general, PLC and OLC analysis in specific) should be "connected" with social and economic dimensions to help address the 3BL, and that this is only meaningful if they are applied to support decision making process and are not just a "disintegrated" aggregation of facts (Matos & Hall, 2007). It is advantageous that PLC and OLC analysis are conducted to obtain a more holistic picture of the economic and ecological impacts of production operations (Neto, et al, 2010).

2.2 Multi-criteria decision analysis

There is no doubt that GOM decision making has multiple criteria to meet simultaneously, i.e. environmental, social and economic performance objectives. GOM decisions can envelop quantitative, qualitative, tangible and intangible factors. Multi-Criteria Decision Analysis (MCDA) is a generic approach that can empower decision makers to consider all the decision criteria and decision factors, resolve the conflicts between them, and arrive at justified choice. Over the past three decades, several variants of MCDA have been developed. This section compares four widely used MCDA methods: AHP, ANP, fuzzy set theory and fuzzy AHP/ANP.

Analytical Hierarchy Process (AHP) was introduced by Saaty (2005) for solving unstructured problems. Since its introduction, AHP has become one of the most widely used analysis methods for multi-criteria decision making. AHP requires decision makers to provide judgements about the relative importance of each criterion and specify a preference for each decision alternative using each criterion. The output of AHP is a prioritised ranking of the decision alternatives based on the overall performance expressed by the decision makers (Lee, 2009). The key techniques to successfully implement AHP include developing a goal-criteria-alternatives hierarchy, pairwise comparisons of the importance of each criterion and preference for each decision alterative, and mathematical synthesization to provide an overall ranking of the decision alternatives. The strength of AHP is that it can handle situations in which the unique subjective judgements of the individual decision makers constitute an important part of the decision making process (Anderson et al, 2009). However, its key drawback is that it does not take into account of the relationships between different decision factors.

Analytic Network Process (ANP) is the evolution of AHP (Saaty & Vargas, 2006). Given the limitations of AHP such as sole consideration of one way hierarchical relationships among decision factors, failure to consider interaction between various factors and "rank reversal", ANP has been developed as a more realistic decision method. Many decision problems cannot be built as hierarchical as in AHP because of dependencies (inner/ outer) and influences between and within clusters (goals, criteria and alternatives). ANP provides a more comprehensive framework to deal with decisions without making assumptions about the independence of elements between different levels and within the same level. In fact, ANP uses a network without the need to specify levels as in a hierarchy (Sakis, 2003; Dou &

Sakis, 2010) and allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such interaction and feedback best captures the complex effects of interplay in sustainable production operations decision making (Gencer & Gurpinar, 2007). Both ANP and AHP derive ratio scale priorities for elements and clusters of elements by making paired comparisons of elements on a common property or criterion. ANP disadvantages may arise when the number of decision factors and respective inter-relationships increase, requiring increasing effort by decision makers. Saaty and Vargas (2006) suggested the usage of AHP to solve problems of independence between decision alternatives or criteria, and the usage of ANP to solve problems of dependence among alternatives or criteria.

Both AHP and ANP share the same drawbacks: (a) with numerous pairwise comparisons, perfect consistency is difficult to achieve. In fact, some degree of inconsistency can be expected to exist in almost any set of pairwise comparisons. (b) They can only deal with definite scales in reality, i.e. decision makers are able to give fixed value judgements to the relative importance of the pair wise attributes. In fact, decision makers are usually more confident giving interval judgements rather than fixed value judgements (Kahraman et al, 2010). Furthermore, on some occasions, decision makers may not be able to compare two attributes at all due to the lack of adequate information. In these cases, a typical AHP/ANP method will become unsuitable because of the existence of fuzzy or incomplete comparisons. It is believed that if uncertainty (or fuzziness) of human decision making is not taken into account, the results can be misleading.

To deal quantitatively with such imprecision or uncertainty, fuzzy set theory is appropriate (Huang et al, 2009; Kahraman et al, 2010). Fuzzy set theory was designed specifically to mathematically represent uncertainty and vagueness, and to provide formalised tools for dealing with the imprecision intrinsic to multi-criteria decision problems (Beskese et al, 2004; Mehrabad & Anvari, 2010). The main benefit of extending crisp analysis methods to fuzzy technique is in its strength that it can solve real-world problems, which have imprecision in the variables and parameters measured and processed for the application (Lee, 2009).

To solve decision problems with uncertainty and vague information where decision makers cannot give fixed value judgements, whilst also taking advantage of the systematic weighting system presented by AHP/ANP, many researchers have explored the integration of AHP/ANP and fuzzy set theory to perform more robust decision analysis. The result is the emergence of the advanced analytical method - fuzzy AHP/ANP (Huang et al, 2009). Fuzzy AHP/ANP is considered as an important extension of the conventional AHP/ANP (Kahraman et al, 2010). A key advantage of the fuzzy AHP/ANP is that it allows decision makers to flexibly use a large evaluation pool including linguistic terms, fuzzy numbers, precise numerical values and ranges of numerical values. Hence, it provides the capability of taking care of more comprehensive evaluations to provide more effective decision support (Bozbura et al, 2007). Details of the key features, strengths and weaknesses of different MCDA methods are compared in Table 1.

2.3 Gap between GOM decision requirements and existing research

Separately, both LCA and MCDA are popular analysis technologies for decision making and sustainable development. The reason why LCA stands out from other eco-efficiency technologies such as Environmental Accounting, Value Analysis and Eco-indicators, is in its capability of highlighting environmental issues from a holistic ("cradle to grave") perspective. By breaking down the environmental problems into specific issues at different life cycle stages that can be articulated by operations managers, it helps decision makers to explicitly capture, code and implement corresponding environmental objectives in their decision making process. MCDA's main merit is in its competence in handling complex decision situations by incorporating multiple decision criteria to resolve conflicting interests and preferences.

Analysis methods	Key elements	Strengths	Weaknesses	Selected references
AHP	Multi-criteria and multi-attributes hierarchy; Pair wise comparison; graphical representation.	Can handle situations in which decision maker's subjective judgements constitute a key part of the decision making process	Relationships between decision factors are not considered; inconsistency of the pairwise judgements; cannot deal with uncertainty and vagueness	(Saaty, 2005; Anderson et al, 2009)
ANP	Control network with sub-networks of influence	Allows interaction and feedback between different decision factors	Inconsistency of the pairwise judgements; cannot handle situations where decision makers can only give interval value judgements or cannot give values at all	(Saaty & Vergas, 2006; Dou & Sarkis, 2010)
Fuzzy set theory	Mathematical representation; handle uncertainty, vagueness and imprecision; grouping data with loosely defined boundaries.	Can solve real-world decision problems with imprecision variables	Lack of a systematic weighting system	(Beskese et al, 2004; Mehrabad & Anvari, 2010)
Fuzzy AHP/ ANP	Fuzzy membership functions together with priority weights of attributes	Combined strengths of fuzzy set theory and AHP/ANP	Time consuming; complexity.	(Kahraman et al, 2010)

Table 1. Comparison between different multi-criteria decision analysis methods

GOM decisions need to address the 3BL, which undoubtedly require MCDA methods. In the meantime, it is critical that environmental and social concerns be addressed right from the early stage of product and operational life cycles, so that the adverse impact can be minimised or mitigated. Therefore, GOM decision making requires MCDA and LCA to be explored in an integrated rather than isolated manner. By considering both LCA and MCDA technologies together, it could provide decision makers with the vital analysis tools that enable systematic evaluation for improved decision making capabilities. It therefore could allow operations managers to take concerted decisions (and actions as the implementation of the decisions), not only to limit, but also to reverse any long term environmental damage, and thus ensuring that operations activities are undertaken in a sustainable manner.

Despite the urgent requirements from GOM for powerful analysis support, there is little report in the literature discussing the successful integration of both LCA and MCDA technologies in support of GOM decision making. Next Section of this paper proposes an integrated approach to fill the gap.

3. An integrated sustainability analysis approach

Based on the understanding of the strengths and limitations of different MCDA and LCA methods, this paper proposes an integrated sustainability analysis approach for GOM decision support. The rationality behind the integration approach is that, through integration, LCA will enhance MCDA with the product and operational life cycle stage information so that sustainable operations decision can be made from a more holistic view (through life view), MCDA will enhance LCA with multi-criteria and decision situation information to help pin down stage-specific decision variables and correlations to decision goals and alternatives. The proposed approach comprises two key elements: ANP and OLC analysis. The ANP analysis allows decision makers to address the complexity of decisions situations in sustainable operations. OLC analysis allows decision makers to address the environmental issues across different stages of product's operational life cycle stages. Seamless integration of the ANP and OLC analysis is enabled through immediate sharing of consistent information about the GOM decision context and content.

3.1 Performing OLC analysis to understand decision problems from life cycle perspective

During the OLC process – procurement, production, distribution, use, end-of-life treatment and reverse chain, different green issues need to be addressed at different stages. Therefore environmental objectives may be defined in different forms for GOM decision making. For example, greener material selection at *procurement* stage, cutting down greenhouse gas emission at *production* stage, or reducing energy consumption at the *use* and *distribution* stages, and safe waste management for *end-of-life* treatment, and product recovery through *reverse logistics*. Figure 3 illustrates more comprehensive environmental objectives used at different OLC stages for green operations decision making.

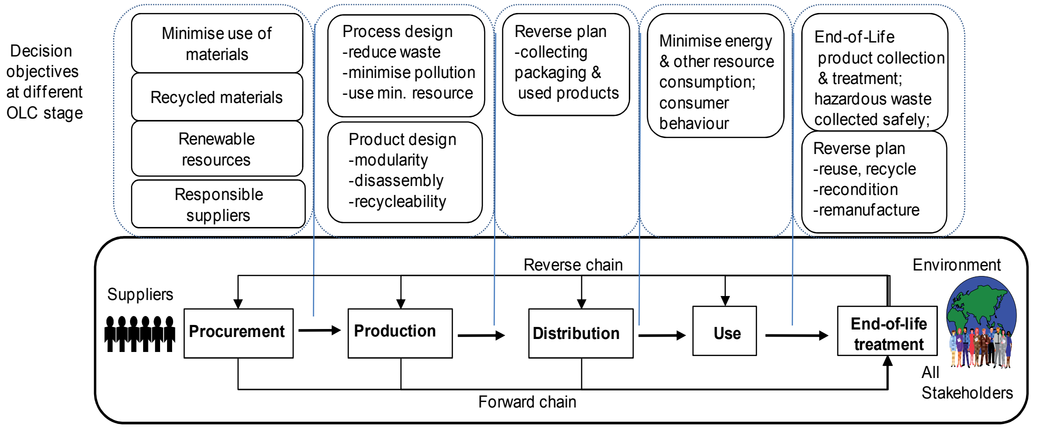


Fig. 3. OLC analysis for GOM

In sustainability analysis, decision objectives can be instantiated by using appropriate indicators (OECD, 1991; Bell & Morse, 1999). An indicator expresses one or more characteristics that can be empirically observed or calculated. An indicator aims at identifying those aspects of phenomenon that are considered to be important as for monitoring and control. Therefore, it is a piece of information that refers to an intrinsic attribute or to a set of attributes of the phenomenon or associated to other phenomena closely related to the former. In GOM, indicators are usually described with reference to the three principal sustainability dimensions. For example, environmental indicators include greenhouse gas emissions, quantity of wastes, etc. Social indicators can be unemployment rate and crime level etc. While economic indicators include GDP, inflation rate and so on. Researchers have recognised that it is the system of indicators rather than individual indicators that is more significant for GOM (Bottero et al, 2007). Although made up of individual indicators, the system of indicators can describe and give inter-correlated information from a logical and functional view. The proposed integrated sustainability analysis approach in this paper explores a system of indicators.

3.2 Development of decision network models with ANP

In order to address the decision making challenges for GOM from an holistic perspective, it is extremely important:

1. To identify the relationships between the key components in a sustainable operations system: operations strategy, operations structural and infrastructural decisions, environmental issues and social issues. The relationships should be based on the understanding of the contents of each component. For example, how environmental issues such as waste management, reduce-reuse-recycle, and pollution control can be addressed by operations strategies and its structural and infrastructural decisions. Similarly, how social issues such as staff and customer safety, employment policy, workplace stress, price manipulation, honesty and transparency of supplier relationships can be addressed by the operations strategies and decisions;
2. To define operations decision hierarchy/network, i.e. the dependency between operations strategic decisions, structural decisions and infrastructural decisions. Within the decision network, if decision on one network node changes, what are the decision propagation paths along the network and consequences to other decisions? What needs to be done to manage the decision changes?

To address the above issues and to make sure multiple criteria including environmental and social objectives from the OLC analysis (Section 3.1) are integrated into the decision making process, Analytic Network Hierarchy (ANP) technology has been explored. The result of the process is a GOM analytical model consisting of a control hierarchy, clusters and elements, as well as interactions between clusters and elements. Six key steps have been undertaken to develop the GOM analytical model.

Step 1. specify decision goal based on the OLC analysis of the GOM decision problem, and define decision criteria clusters, sub-criteria and detail criteria.

Step 2. design alternatives for the specific GOM decision problem. It is advised that adopting alternatives from “good practices” in the filed and using preliminary elimination increases the quality of decision alternatives.

Step 3. determine the network structure and interactions. The output of this step will be a control hierarchy, as shown in Figure 4. It should be noted that in the Figure the influence between the elements are bi-directional, which means that the importance of the criteria influences the importance of the alternatives, and vice versa.

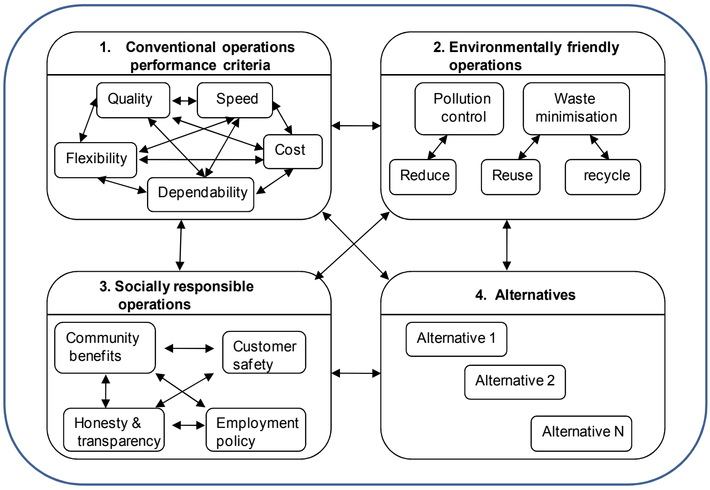


Fig. 4. The GOM ANP network control hierarchy

Step 4. create a super-matrix based on the network control model from step 3. The super-matrix is composed of ratio scale priority vectors derived from pair-wise comparison matrices. The super-matrix structure is shown as follows:

$$
W = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array}
\begin{array}{c} \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\
\left[\begin{array}{cccc}
w_{11} & w_{12} & w_{13} & w_{14} \\
w_{21} & w_{22} & w_{23} & w_{24} \\
w_{31} & w_{32} & w_{33} & w_{34} \\
w_{41} & w_{42} & w_{43} & 0
\end{array}\right] \end{array}
$$

In the above equation, subscript number 1 shows the criteria cluster belonging to conventional operations performance objectives; subscript number 2 shows the criteria cluster belonging to environmental friendly operations; subscript number 3 shows the criteria cluster belonging to socially responsible operations; subscript number 4 shows the criteria cluster belonging to alternative operations. In the super-matrix, w_{11}, w_{12}, w_{13}, and so on represent the sub-matrices. The cluster which has no interactions is shown in the super-matrix with a value of zero. Those non-zero values mean that there are dependencies between the clusters. For example, w_{12} means that cluster 1 depends on cluster 2. Similar to that in AHP, the 1 – 9 scale system developed by Saaty (Saaty & Vargas, 2006) is used in this research, and pairwise comparisons are made to create the super-matrix.

Step 5. yield the weighted super-matrix. The un-weighted super-matrix from step 4 must be stochastic to obtain meaningful limiting results. This step is to transform the un-weighted into a weighted super-matrix. To do this, firstly the influence of the clusters on each other is determined, which generates an eigenvector of the influences. Then the un-weighted super-matrix is multiplied by the priority weights from the clusters, which yields the weighted super-matrix.

Step 6. stabilise the super-matrix. This step involves multiplying the weighted super-matrix by itself until the row values convergence to the same value for each column of the matrix.

By the end of step 6, the limiting priorities of all the alternatives should be computed and shown in the matrix. The alternative with the highest priority should become transparent and will become the optimal choice to decision makers.

3.3 The integration of OLC analysis and ANP

In order to provide efficient support for holistic decision making in GOM, decision requirements need to be met to address multiple criteria across OLC stages. As shown in Figure 5, information about decision criteria and indicators derived from the OLC analysis empowers decision makers to target the most important environmental issues from a life cycle perspective, so that adverse impact of decisions from one stage to another can be minimised and mitigated. ANP addresses multiple decision criteria by incorporating decision makers' preferences and score their judgement within the ANP pair-wise comparison matrices. The dependence between multiple criteria is taken into account through the ANP network interactions. By integrating ANP and OLC analysis, efficient decision support will be provided for holistic decision making to be made to address multiple decision criteria throughout operational whole life cycle.

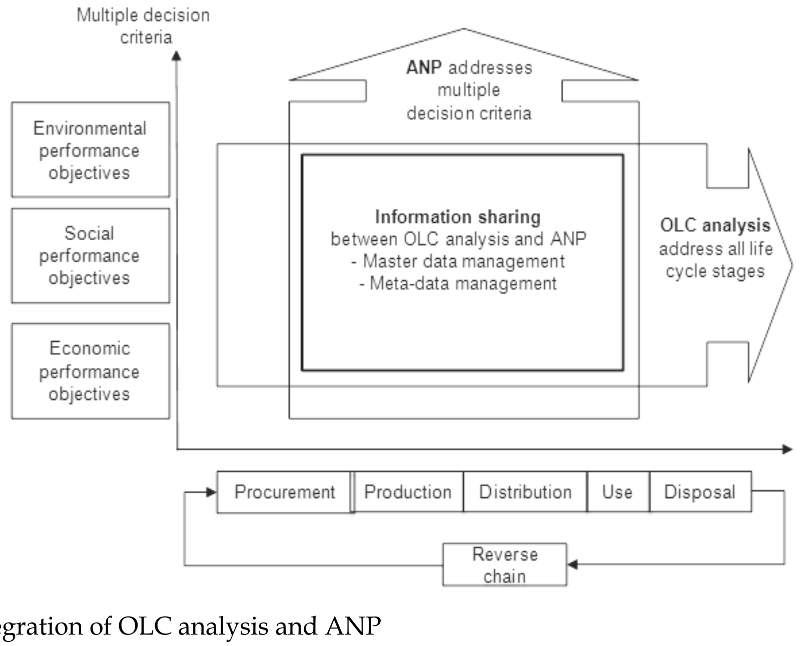


Fig. 5. Integration of OLC analysis and ANP

By integrating the information about the interactions among the three main sustainability dimensions and their cause-effect relations in the OLC analysis and ANP, it allows decision makers to measure the interconnections and the influences both horizontally (across multiple decision criteria) and vertically (across life cycle stages), which provides an integrated approach for the sustainability analysis for holistic decision making in GOM. Two strategies have been explored for the information integration between OLC analysis

and ANP model development: one is through master data management, and the other is through meta-data management.
In a GOM decision support system, master data is a very important concept which supports data integrity and consistence. Master data are persisted, long lived data which need to be stored centrally. They can be used by all business functional units and at all levels of organization (Monk & Wagner, 2009). Examples of master data in an operations system are material master, vendor/supplier master, and customer master records. Additionally, master data also includes hierarchies of how individual products, customers and accounts aggregate and form the dimensions which can be analyzed. Master data management is carried out to ensure that material master, vendor/ supplier master and customer master for example are consistently stored and maintained, so that all information users, both people (including decision makers) and computer systems, can access the right information at all times.
As the demand for business intelligence grows, so do the available data sources, data warehouses, and business reports that decision makers depend on for business decisions. While master data management can be used to effectively integrate business data across business functions, metadata management provides an extra layer of reliability when GOM decision support systems use multiple data sources. Separate departmental deployments of business solutions (resulting from being in charge of different OLC stages) have inevitably created information silos and islands, which makes it significantly more difficult to manage the information needed to support holistic decision making. This is especially the case where the data sources change, which will have significant impact on the GOM decisions. Decision makers will also tend to put various trust in the available information with various origins. Metadata management can provide powerful support for data traceability and give decision makers essential assurance of the integrity of information on which their decisions are based. A generic definition of metadata is "data about data" (Babin & Cheung, 2008). In green operations management, typical use of metadata has been identified as helping to provide quick answers to the questions such as: What data do I have? What does it mean? Where is it? How did it get there? How do I get it? And so on. The answers to these questions will have a profound impact on the decisions to be made.

4. Application of the integrated approach to case study

This section discusses the application of the proposed integrated sustainability analysis approach to a case example from Plastics Manufacturing industry.

4.1 The case

Manufacturing industry is, without a doubt, a major contributor to world's economy (e.g. GDP growth). At the same time, manufacturing has been in the centre of the root cause for environmental issues. Along with the wave of business globalisation, more and more social problems are being unfolded from the manufacturing industry. It is a common acknowledgement that the quicker to take effective means to tackle the environmental and social problems caused by manufacturing industry, the better (Nunes & Bennet, 2010). As one of the fastest developing countries on the planet, China has been branded as the world's manufacturing workshop in recent years. Its adverse impact on 3BL sustainability can no longer be ignored. According to a 1998 report of the World Health Organisation, of the ten most polluted cities in the world, seven were in China and the situation has not changed much (Chow, 2010). Therefore, Chinese manufacturing industry can provide perfect cases for researchers to study the GOM issues. This paper looks at a case from a Chinese Plastics Manufacturing company.

One of the most influential products from Plastic Manufacturers is plastic bags. Highly convenient, strong and inexpensive, plastics bags were appealing to business and consumers as a reliable way to deliver goods from the store to home. However, many issues associated with the production, use and disposal of plastic bags may not be initially apparent to most users, but now are recognised extremely important and need to be addressed urgently. By exploring the integrated OLC and ANP approach with the case study, this paper aims to help decision makers achieve better understanding of the full ecological footprint of the products, and to provide efficient decision support in dealing with the associated negative impacts on environment and social equity.

4.2 Eliciting decision criteria and indicators through OLC

It was recognised that the Plastic Manufacturing company needs to understand plastics bags life cycle impacts by undertaking streamlined OLC to elicit environmental indicators. The information can then be used to enlighten operations managers and help them make informed decisions. From the manufacturer's viewpoint, planning ahead ensures that any potential risks to business are anticipated whenever possible. A key benefit is that a proactive approach is likely to be more scientifically sound than a reactive approach, which is merely responding to government legislation or consumer concerns.

Figure 6 demonstrates the application of LCA to plastic bags, with energy inputs and emission output at each key stage of the life cycle. In terms of waste management, three potential strategies can be implemented: to make recyclable bags, reusable bags and degradable bags. Specific indicators for environmentally friendly operations obtained from the OLC process include minimum energy consumption, gas emission, and land and water pollution. Indicators for socially responsible operations include minimum damage/ threat to human health, wildlife and tourism etc.

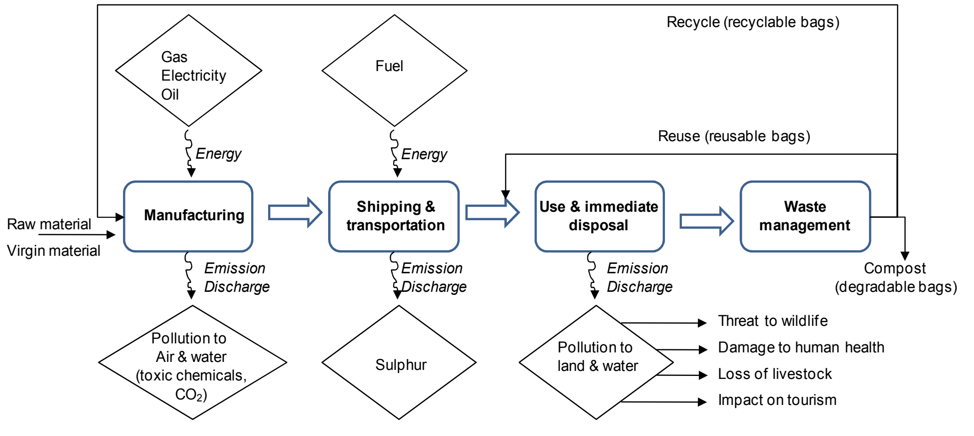


Fig. 6. OLC analysis for plastic bags

4.3 Developing the GOM analytical model and results

Plastic grocery bags were first introduced to Chinese supermarkets over 30 years ago. Today, 80 percent of grocery bags are plastic (FMI, 2008). To address the environmental and social issues resulting from plastic bags, many crucial decisions that plastic manufacturer needs to make during the whole life-cycle. Four decision alternatives can be derived from the OLC analysis:

1. To make *recyclable* plastic bags. This alternative seems to be taken at rather late stage of the life cycle, but corresponding considerations are required at early stages such as in the material selection stage so that recyclable plastic bags can be sorted into proper categories and processed later.
2. To make *reusable* plastic bags. This alternative requires appropriate actions to be taken at early stages of the life cycle. For example, at the material selection and manufacturing stages, appropriate considerations should be taken so that the reusable bags have the strengths to be reused for a certain number of times.
3. To make *degradable* plastic bags, such as those which degrade under micro-organisms, heat, ultraviolet light, mechanical stress or water.
4. To replace plastic bags with *paper* bags. For some time, manufacturers were forced to make a key decision – "plastic or paper". Research clearly showed that paper shopping bags make a much larger carbon footprint from production through recycling. For example, a paper bag requires four times more energy to produce a plastic bag. In the manufacturing process, paper bags generate 70 percent more air and 50 times more water pollutants than plastic bags (FMI, 2008).

4.3.1 Development of the network control hierarchy for the Plastic Bags case

The generic ANP models discussed in Section 3 include comprehensive factors of GOM decision situations, this Section applies the GOM analytical models to a customised situation of dealing with the Plastic Bags. Therefore, a simplified version of the generic ANP Control Hierarchy for the case has been developed, as shown in Figure 7. The analytical models discussed in the case study were developed using Super Decisions® software. As can be seen from the Figure 7, the GOM network consists of four clusters. Each cluster has one or more elements that represent the key attributes of the cluster. Elements for Clusters 2, 3 and 4 have derived from the case OLC process (Section 4.2). Connections between the clusters indicate the influence and dependency. A reflexive relationship on a cluster in the model (such as the one for Cluster 2) means that there is inter-dependency between the elements in the same cluster.

4.3.2 Pair-wise comparisons for the Plastic Bags case

In complex decision making using ANP, a series of pair-wise comparison are made to establish the relative importance of the different clusters and elements with respect to a certain component of the network, including clusters comparison and elements (of the clusters) comparison. Both cluster and element comparisons are based on a ratio scoring system.

In the pair-wise comparison process for the Plastic Bags case, a 9-scale ratio scoring system suggested by Saaty (2005) has been employed. A judgment or comparison is the numerical representation of a relationship between two elements that share a common parent. Each judgement reflects the answers to two questions: which of the two elements is more important with respect to a higher level criterion, and how strongly, using the 1—9 scale shown in Table 2.

At the level of clusters comparison, there are four 4x4 matrices containing the judgements made pairwise comparisons established from the survey and discussion with groups of

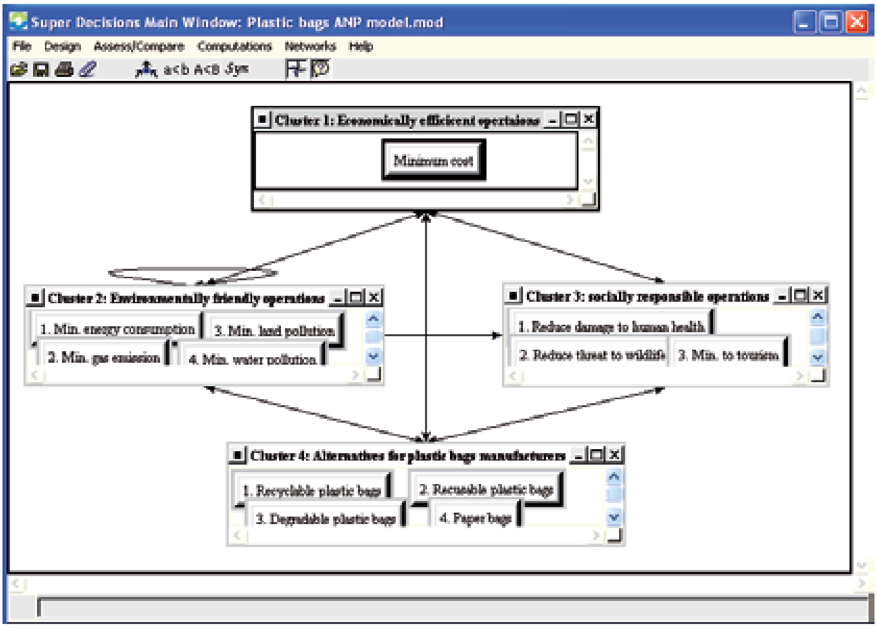


Fig. 7. GOM network control hierarchy for the Plastic Bags case

Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit.
Rationales	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9.

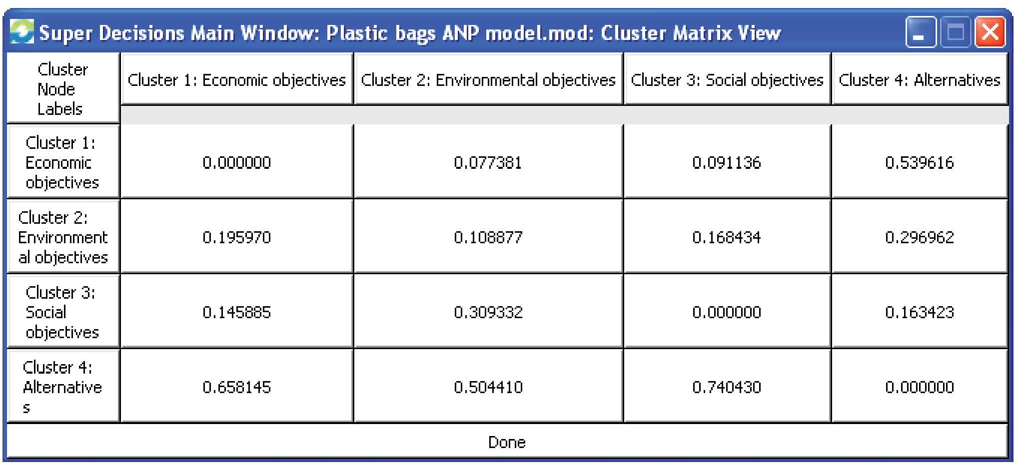
Table 2. The Fundamental Scale (Saaty, 2005)

experts of sustainability assessment. The pairwise comparison matrices at this level allow decision makers to evaluate the relationships existing between the different sustainability aspects, i.e. economic, environmental and social. For example, Table 3 represents the comparison among the four clusters from the point of view of socially responsible operations. The priority vectors are calculated and shown in the last column of the Table.

Social sustainability	Alternatives	Environmental sustainability	Economic sustainability	Social sustainability	Priority vector
Alternatives	1	7	5	3	0.740430
Environmental sustainability	1/7	1	3	1/3	0.168434
Economic sustainability	1/5	1/3	1	1/5	0.091136
Social sustainability	1/3	3	5	1	0

Table 3. Pairwise cluster comparison matrix with respect to the social sustainability

When the priority vectors for all four clusters are calculated and aggregated in one table, a Cluster Matrix is formulated for the Plastic Bags case, as shown in the Figure 8. The Cluster Matrix is used later to transform super-matrix from unweighted to weighted format.



Super Decisions Main Window: Plastic bags ANP model.mod: Cluster Matrix View

Cluster Node Labels	Cluster 1: Economic objectives	Cluster 2: Environmental objectives	Cluster 3: Social objectives	Cluster 4: Alternatives
Cluster 1: Economic objectives	0.000000	0.077381	0.091136	0.539616
Cluster 2: Environmental objectives	0.195970	0.108877	0.168434	0.296962
Cluster 3: Social objectives	0.145885	0.309332	0.000000	0.163423
Cluster 4: Alternatives	0.658145	0.504410	0.740430	0.000000

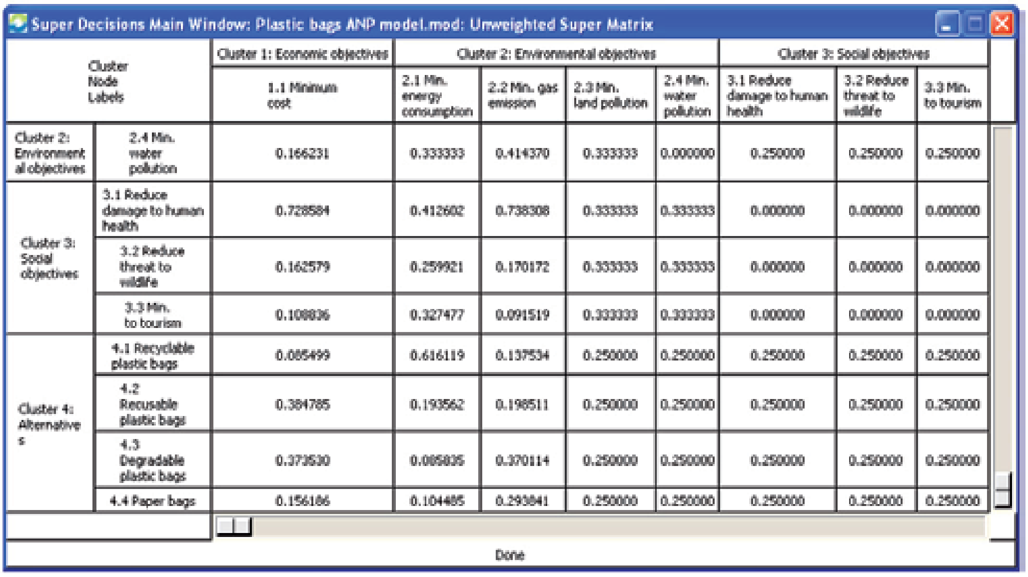
Done

Fig. 8. Cluster matrix

Once the clusters comparisons are done, it is essential to perform the pairwise comparisons at more detailed level, i.e. comparisons between elements (of the clusters). The element comparisons can be done in similar manner as for the cluster comparisons.

4.3.3 Super-matrix formation and global priorities for the Plastic Bags case

The result of all pairwise comparisons is then input for computation to formulate a super-matrix. In the Plastic Bags case, three different super-matrices have been generated: a Un-weighted, a Weighted super-matrix and a Limit Super-matrices. Super-matrices are arranged with the clusters in alphabetical order across the top and down the left side, and with the elements within each cluster in alphabetical order across the top and down the left side. An Un-weighted Super-matrix contains the local priorities derived from the pair-wise comparisons throughout the network. Figure 9 shows part of the Un-weighted matrix for the Plastic Bags case (because of the space limit, part of the super-matrix is hidden. In the real software environment, the whole super-matrix can be seen by scrolling the bars on the interface).



Super Decisions Main Window: Plastic bags ANP model.mod: Unweighted Super Matrix

Cluster	Node Labels	Cluster 1: Economic objectives	Cluster 2: Environmental objectives				Cluster 3: Social objectives		
		1.1 Minimum cost	2.1 Min. energy consumption	2.2 Min. gas emission	2.3 Min. land pollution	2.4 Min. water pollution	3.1 Reduce damage to human health	3.2 Reduce threat to wildlife	3.3 Min. to tourism
Cluster 2: Environmental objectives	2.4 Min. water pollution	0.166231	0.333333	0.414370	0.333333	0.000000	0.250000	0.250000	0.250000
Cluster 3: Social objectives	3.1 Reduce damage to human health	0.728584	0.412602	0.738308	0.333333	0.333333	0.000000	0.000000	0.000000
	3.2 Reduce threat to wildlife	0.162579	0.259921	0.170172	0.333333	0.333333	0.000000	0.000000	0.000000
	3.3 Min. to tourism	0.108836	0.327477	0.091519	0.333333	0.333333	0.000000	0.000000	0.000000
Cluster 4: Alternatives	4.1 Recyclable plastic bags	0.085499	0.616119	0.137534	0.250000	0.250000	0.250000	0.250000	0.250000
	4.2 Recusable plastic bags	0.384785	0.193562	0.198511	0.250000	0.250000	0.250000	0.250000	0.250000
	4.3 Degradable plastic bags	0.373530	0.085835	0.370114	0.250000	0.250000	0.250000	0.250000	0.250000
	4.4 Paper bags	0.156186	0.104485	0.293841	0.250000	0.250000	0.250000	0.250000	0.250000

Done

Fig. 9. The Un-weighted Super-matrix for the Plastic Bags case

The Unweighted Supermatrix has to be transformed into the Weighted Supermatrix. The transformation process involves multiply the Unweighted Supermatrix by the Cluster Matrix, so that the priorities of the clusters can be taken into account in the decision making process. The Weighted Supermatrix for the Plastic Bags case in shown in Figure 10.
However, the Weighted Supermatrix is very difficult for decision makers to use because of the distribution of vector values. This requires conducting a finishing touch in the GOM analytical model development process by transforming the Weighted Supermatrix into a Limit Supermatrix. The Limit Supermatrix is obtained by raising the weighted supermatrix to powers by multiplying itself. When the column of numbers is the same for every column, the Limit Supermatrix has been reached and multiplication process is halted. The Limit Supermatrix for the Plastic Bags case is shown is Figure 11. A graphical overview of the Limit Supermatrix of the case is shown in Figure 12, in which the consequence of all alternatives is more visualised.
Based on the Limit Super-matrix results and their visual representation shown in the Figures 11 and 12, recommendation of the decision alternatives can be drawn as follows:

1. Paper bags as a replacement of plastic bags is the least ideal choice, based on evidence from the super-matrix: a paper bag requires more energy than a plastic bag (in the super-matrix, alternative 4 Paper bags contributes a lot less to objective 2.1 Minimum energy consumption); in the manufacturing process, paper bags generates a lot more air and water pollutions than plastic bags (in the super-matrix, alternative 4 Paper bags contributes a lot less to objectives 2.2 and 2.4); paper bags also take up more landfill space.

2. Plastic bags recycling is not a preferred choice in terms of achieving economic, the cost, objective.
3. Making degradable bags is a relatively ideal choice (with an overall value of 0.98 in the Figure 12).
4. Making reusable bags is the preferred choice because it has the highest overall score based on the data collected from the company.

Super Decisions Main Window: Plastic bags ANP model.mod: Weighted Super Matrix

Cluster Node Labels		Cluster 1: Economic objectives	Cluster 2: Environmental objectives				Cluster 3: Social objectives		
		1.1 Minimum cost	2.1 Min. energy consumption	2.2 Min. gas emission	2.3 Min. land pollution	2.4 Min. water pollution	3.1 Reduce damage to human health	3.2 Reduce threat to wildlife	3.3 Min. to tourism
Cluster 2: Environmental objectives	2.4 Min. water pollution	0.032576	0.036292	0.045115	0.036292	0.000000	0.042109	0.042109	0.042109
Cluster 3: Social objectives	3.1 Reduce damage to human health	0.106290	0.127631	0.228383	0.103111	0.103111	0.000000	0.000000	0.000000
	3.2 Reduce threat to wildlife	0.023718	0.080402	0.052640	0.103111	0.103111	0.000000	0.000000	0.000000
	3.3 Min. to tourism	0.015878	0.101299	0.028310	0.103111	0.103111	0.000000	0.000000	0.000000
Cluster 4: Alternatives	4.1 Recyclable plastic bags	0.056271	0.310776	0.069373	0.126102	0.126102	0.185107	0.185107	0.185107
	4.2 Recusable plastic bags	0.253244	0.097634	0.100131	0.126102	0.126102	0.185107	0.185107	0.185107
	4.3 Degradable plastic bags	0.245837	0.043296	0.186689	0.126102	0.126102	0.185107	0.185107	0.185107
	4.4 Paper bags	0.102793	0.052703	0.148216	0.126102	0.126102	0.185107	0.185107	0.185107

Done

Fig. 10. The Weighted Super-matrix for the Plastic Bags case

Super Decisions Main Window: Plastic bags ANP model.mod: Limit Matrix

Cluster Node Labels		Cluster 1: Economic objectives	Cluster 2: Environmental objectives				Cluster 3: Social objectives		
		1.1 Minimum cost	2.1 Min. energy consumption	2.2 Min. gas emission	2.3 Min. land pollution	2.4 Min. water pollution	3.1 Reduce damage to human health	3.2 Reduce threat to wildlife	3.3 Min. to tourism
Cluster 1: Economic objectives	1.1 Minimum cost	0.239251	0.239251	0.239251	0.239251	0.239251	0.239251	0.239251	0.239251
Cluster 2: Environmental objectives	2.1 Min. energy consumption	0.068682	0.068682	0.068682	0.068682	0.068682	0.068682	0.068682	0.068682
	2.2 Min. gas emission	0.037753	0.037753	0.037753	0.037753	0.037753	0.037753	0.037753	0.037753
	2.3 Min. land pollution	0.050458	0.050458	0.050458	0.050458	0.050458	0.050458	0.050458	0.050458
	2.4 Min. water pollution	0.055038	0.055038	0.055038	0.055038	0.055038	0.055038	0.055038	0.055038
Cluster 3: Social objectives	3.1 Reduce damage to human health	0.089553	0.089553	0.089553	0.089553	0.089553	0.089553	0.089553	0.089553
	3.2 Reduce threat to wildlife	0.039760	0.039760	0.039760	0.039760	0.039760	0.039760	0.039760	0.039760
	3.3 Min. to tourism	0.034119	0.034119	0.034119	0.034119	0.034119	0.034119	0.034119	0.034119

Done

Fig. 11. The Limit Super-matrix for the Plastic Bags case

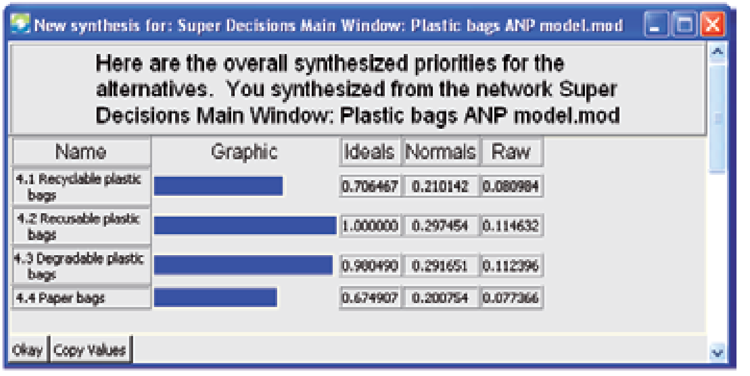


Fig. 12. Visualised representations of the global priorities of the four alternatives

5. Discussion and conclusions

The focus of the paper is on an integrated sustainability analysis for the holistic decision making in GOM. The approach integrates two core elements: an Operational Life Cycle (OLC) assessment, and Analytic Network Process (ANP) for multi-criteria decision analysis. At different stages of OLC (procurement, production, distribution, use, and reverse logistics), GOM has different strategic focus. Understanding the OLC influence on operations foci, the environmental and social sustainability issues can be better addressed in the operations decision making process.

The strengths of the integrated approach lies in that information about decision objectives and indicators derived from the OLC analysis is directly fed into the GOM analytical model development, which allows decision makers to find the optimal solution to decision problems to achieve the multiple sustainability criteria. At its highest level, GOM decision criteria include economic, environmental and social objectives. Within each of the three areas, more specific criteria have been generated from the OLC analysis. For example, economic criteria are further broken down to cost reduction, high margin, productivity improvement, maximum profit etc. Environmental sustainability includes such criteria as waste minimisation, reduce-reuse-recycle, and pollution control. Social criteria are based on labour, discrimination, mistreatment, health and safely, working hours, minimum wages etc. For operations decision making across multi-stages of OLC, there can be a huge number of decision variables and decision alternatives for each decision problem. Under such complex decision situations, GOM analytical models allow operations managers to weigh the importance of each criterion, to rate the satisfaction level of each decision alternative, to calculate aggregated score for decision choices against criteria, and to predict the consequence of each alternative (Sarkis, 2003). Therefore managers can confidently and transparently perform "what-if" and sensitivity analysis for each decision option, subsequently improve their judgements and make informed decisions. The novelty of the integrated approach is augmenting the ANP by OLC analysis so that life cycle stage impact on the green operations decisions is coherently incorporated.

The benefit of the integrated sustainability analysis approach is that it provides a formal, evidence-based justification for operations decisions that integrates environmental, social and economic sustainability objectives into operations manager's proactive decision making process. Therefore, environmental and social values are not just talked (in words) but also enacted (in actions).

The evaluation of the integrated sustainability analysis approach has been illustrated through a decision case from the plastic manufacturing industry. The case study shows that the approach has great potential in providing scientific evidence to support GOM decision making under complex situations and with multiple decision criteria.

Limitations of the approach include:

- It is developed for and evaluated in production operations case. Its applicability to service operations needs further exploration.
- At this stage, the research has not considered feedback of clusters to the decision support system yet. Further work needs to explore a mechanism and tool to manage the feedback.

6. Acknowledgement

The work reported in this paper has been undertaken at the University of Plymouth, UK, and is funded by International Research Networking and Collaboration scheme under grant number UOP/IRNC/GH102036-102/1 for the project "**G**reen **O**perations **M**anagement **-** integration challenges and decision support (also known as GOM project)"

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Part 3

Applications in Agriculture

14

Uncertainty Analysis Using Fuzzy Sets for Decision Support System

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1. Introduction

In agricultural domain application, it is becoming increasingly important to preserve planting material behavior when interact with an environment that is not under its control. However, the uncertainty always inherent such inaccurate decisions when a present of incomplete information in sampling data set (Chao, et al., 2005; Latkowski, 2002; Michelini, et al., 1995). As a result, the proper decision may need to adapt changes in their environment by adjusting its own behavior. Many different methods for dealing uncertainty have been developed. This research work proposes incomplete information with fuzzy representation in objective function for decision modeling. Firstly, we integrate expert knowledge and planting material data to provide meaningful training data sets. Secondly, fuzzy representation is used to partition data by taking full advantages of the observed information to achieve the better performance. Finally, we optimally generalize decision tree algorithms using decision tree technique to provide simpler and more understandable models. The output of this intelligent decision system can be highly beneficial to users in designing effective policies and decision making.

2. Preliminary study

The major problems in decision modeling are missing information of ecological system, such as weather, fertilizer, land degradation, soil erosion and climate variability during planting material selection in physiological analysis. This underlying obstacle will return poor results when the aggregation of all the databases in planting material. If we try to develop a decision modeling to apply knowledge to user, then we have to integrate historical records of planting material behavior, expert knowledge's perception and decision algorithm learning. From an information or knowledge provider's perspective, the challenge is to gain an expert user's attention in order to assure that the incomplete information is valued (Rouse, 2002). One of the more widely applied in representing uncertainty is fuzzy representation (Michelini et al., 1995; Mendonca et al., 2007). This representation required a mathematical support to make further treatment for interpretation of missing values as information, which is compatible with the observed data. We analyze the complexity of ecological system which have missing values caused by the uncertainty to the user, then representing the observed data into plausible values and discuss the outcome of an empirical study for the missing information in induction learning. We have observed the most commonly used algorithms for decision modeling of missing values (Tokumaru et al., 2009) and resulted in better understanding and comprehensible rules in planting material selection.

2.1 The concept of uncertainty

The uncertainty clearly shows the limitations of the currently adopted approach to the knowledge representation. In particular, it has shown that the result of a measurement represents incomplete knowledge and this knowledge can be usefully employed only if its missing value can be somehow estimated and quantified. However, we have to measure the degree of uncertainty to rank objects for presentation to a user. The approach requires a suitable mathematical theory for handling incomplete knowledge. The practice refers mainly to the probability theory to treat missing values. In the normal situation, the presence of knowledge is recognized, but the exact value is not known, even if it is possible to locate it within a closed interval. By definition, we always take the same value, although unknown, within the estimated interval. The problem of how to estimate the missing value and measure the uncertainty is still open topic in the field, despite much contribution that have been made in the literature over the years. From information or knowledge provider's perspective, the challenge is to gain an expert user's attention, which to assure that the information or knowledge content is valued. The aim of a measurement process is in fact always to take a decision. Moreover, decisions are sometimes required within the measurement process itself.

2.2 Related work

This section reviews some approaches representing missing values in information system when the decision tree is constructed. The development of measurement science has identified the uncertainty concept to quantify the incomplete information during the decision making. The measurement of uncertainty is treated in a purely probabilistic way and has been considered the available mathematical theory capable of handling incomplete information. In some case, the valuable information is obtained in incomplete decision table. The possible decomposition of information table can search possible information within the missing value (Latkowski, 2002). He addressed the degree of similarity between objects on the attributes can be measured by operator product and the imprecise attribute values are expressed in a probability distribution. When the results from possible tables are aggregated, the probabilistic values of decision table can be expressed in a probability distribution and the extended set of possible members of subset is obtained. The elimination of irrelevant features sometimes gives a little or no additional information beyond that subsumed by the remaining features (Koller, et al. 1996). They proposed an efficient algorithm for feature selection which able to compute an approximation to the optimal feature selection criterion. (Chao, et al., 2005) provided comprehensive study dealing with missing values in cost-sensitivity decision trees. He reported that cost-sensitive decision learning algorithms should utilize only known values, it is desirable to have missing values to reduce the total cost of test and misclassification and take advantage of missing values for cost reduction. A conceptual framework of modeling decision making processes with incomplete knowledge in agriculture is presented (Passam, et al., 2003). He compared with existing methodologies and claimed the result to be more realistic, since he took into account the available information without enforcing an artificial accuracy. While Schafer (1997) introduced the concept of different levels of suitability for learner biases, the fact that no algorithm biases can be suitable for every target concept, the idea that there is no universally better algorithm is fast maturing on the machine learning community. It might do better to map different algorithms to different groups of problems with practical importance.

Often cases with incomplete descriptions are encountered in which one or more of the values are missing. This may occur, for example, because these values could not be measured or because they were believed to be irrelevant during the data collection stage. Considerable attention and significant progress has been devoted in the last decade toward acquiring "classification knowledge", and various methods for automatically inducing classifiers from data are available. Quinlan (1996) had focused several approaches of measurement in high levels of continuous values with small cases on a collection of data sets. A variety of strategies are used in such domain and returned poor result as some imprecise data is ignored.

The construction of optimal decision trees has been proven to be NP-complete, under several aspects of optimality and even for simple concepts (Murthy, et al., 1993). Current inductive learning algorithms use variants of impurity functions like information gain, gain ratio, gini-index, distance measure to guide the search. Fayyad (Fayyad, 1994) discussed several deficiencies of impurity measures. He pointed out that impurity measures are insensitive to inter-class separation and intra-class fragmentation, as well as insensitive to permutations of the class probability distribution. Furthermore, several authors have provided evidence that the presence of irrelevant attributes can mislead the impurity functions towards producing bigger, less comprehensible, more error-prone classifiers.

There is an active debate on whether less greedy heuristics can improve the quality of the produced trees. Others showed that greedy algorithms can be made to perform arbitrarily worse than the optimal. On the other hand, Murthy and Salzberg (1993) found that one-level look-ahead yield larger, less accurate trees on many tasks. (Quinlan, et al., 1995) reported similar findings and hypothesized that look-ahead can fit the training data but have poor predictive accuracy. The problem of searching for the optimal sub-tree can be formulated. The coefficient matrix of the defining constraints satisfies the totally uni-modular property by solving the integer program (Zhang et al., 2005). He provided a new optimality proof of this efficient procedure in building and pruning phase. The cost is imposed on the number of nodes that a tree has. By increasing the unit node cost, a sequence of sub-trees with the minimal total cost of misclassification cost and node cost can be generated. A separate test set of data is then used to select from these candidates the best sub-tree with the minimal misclassification error out of the original overly grown tree. Besides cost-complexity pruning, a number of other pruning algorithms have been invented during the past decade such as reduced error pruning, pessimistic error pruning, minimum error pruning, critical value pruning, etc. It is clear that the aim of the pruning is to find the best sub-tree of the initially grown tree with the minimum error for the test set. However, the number of sub-trees of a tree is exponential in the number of its nodes and it is impractical computationally to search all the sub-trees. The main idea of the cost-complexity pruning is to limit the search space by introducing selection criterion on the number of nodes. While it is true that the tree size decides the variance-bias trade-off of the problem, it is questionable to apply an identical punishment weight on all the nodes. As the importance of different nodes may not be identical, it is foreseeable that the optimal sub-tree may not be included in the cost-complexity sub-tree candidates and hence it will not be selected. An interesting question to ask is whether there is an alternative good algorithm to identify the true optimal sub-tree.

Most of the data mining application reduced to search for the intervals after discretisation phase. All values that lie within this interval are then mapped to the same value. It is necessary to ensure that the rules induced are not too specific. Several experiments have shown that the quality of the decision tree is heavily affected by the maximal number of discretisation intervals chosen. Recent development of estimation uncertainty using fuzzy set theory is introduced. The fuzzy practicable interval is used as the estimation parameter for the uncertainty of measured values. When the distribution of measured values is unknown, results that are very near to the true values can be obtained in this method. In particular, the boundaries among classes are not always clearly defined; there are usually uncertainties in diagnoses based on data. Such uncertainties make the prediction be more difficult than noise-free data. To avoid such problems, the idea of fuzzy classification is proposed. The new model of classification trees which integrates the fuzzy classifiers with decision trees is introduced (Chiang, et.al., 2002). The algorithm can work well in classifying the data with noise. Instead of determining a single class for any given instance, fuzzy classification predicts the degree of possibility for every class. Classes are considered vague classes if there is more than one value for the decision attribute. The vague nature of human perception, which allows the same object to be classified into different classes with different degrees, is utilized for building fuzzy decision trees (Yuan et al., 1995). The extension of earlier work of decision tree C4.5 by Quinlan (1996), each path from root to leaf of a fuzzy decision tree is converted into a rule with a single conclusion. A new method of fuzzy decision trees called soft decision trees (Olaru et.al., 2003) is presented. This method combines tree growing and pruning, to determine the structure of the soft decision tree, with refitting and back-fitting to improve its generalization capabilities. A comparative study shows that the soft decision trees produced by this method are significantly more accurate than standard decision trees. Moreover, a global model variance study shows a much lower variance for soft decision trees than for standard trees as a direct cause of the improved accuracy. Fuzzy reasoning process allows two or more rules or multi branches with various certainty degrees to be simultaneously validated with gradual certainty and the end result will be the outcome of combining several results. Yuan (1995) proposed a novel criterion based on the measurement of cognitive uncertainty and criterion based on fuzzy mutual entropy in possibility domain. In these approaches, the continuous attributes are needed to be partitioned into several fuzzy sets prior to the tree induction, heuristically based on expert experiences and the data characteristics. The effectiveness of the proposed soft discretization method has been verified in an industrial application and results showed that, comparing to the classical decision tree, higher classification accuracy was obtained in testing. The soft discretization based on fuzzy set theory one inherent disadvantage in these methods is that the use of sharp (crisp) cut points makes the induced decision trees sensitive to noise. As opposed to a classical decision tree, the soft discretization based decision tree associates a set of possibilities to several or all classes for an unknown object. As a result, even if uncertainties existed in the object, the decision tree would not give a completely wrong result, but a set of possibility values. Experimental results showed that, by using soft discretization, better classification accuracy has been obtained in both training and testing than classical decision tree, which suggest that the robustness of decision trees could be improved by means of soft discretization.

Basically, the true value is unknown and it could be estimated by an approximation. Sometimes, we found some of the attributes may be form the similar classes with the presence of missing values. Rough Sets are efficient and useful tools in the field of knowledge discovery to generate discriminant and characteristic rules. This method provides relative reduct that contains enough information to discern objects in one class from all the other classes. From the relative reduct produced by the quick algorithm, rules are formed. If a new object is introduced into the data set with the decision value missing, one could attempt to determine this value by using the previously generated rules. Although rough set have been used for classification and concept learning tasks (De Jong et al, 1991; Janikow, 1993; Congdon, 1995), there is rather little work on their utility as a tool to evolve decision trees. (Jenhani, 2005) proposed an algorithm to generate a decision tree under uncertainty within the belief function framework.

3. Method and material

There are 3300 records of planting material had been collected in physiological analysis. These records are represented as a table of examples which described by a fixed number of features along with a predicted label denoting its class. In oil palm industry, the Elite palms with special characteristic, such as high bunch oil content, slow stem growth and short leaves were identified and selected from backcross and progeny test compact seeds. Effective breeding and selection requires a large genetic variation such as current oil palm breeding populations. Apart from targeting the primary objectives in oil palm breeding, several traits of interest include improvement of physiological traits (such as bunch index and vegetation measurement). Thus, it has become apparent to develop not only high yielding planting materials but also with novel traits. In this research study, we attempt to mine the oil palm germplasm for yield and novel traits for use in breeding and ultimately commercialization.

Total Economic Production (TEP) composites of oil yield and kernel yield per palm per year. Oil yield is derived from a composite of characters and is dependent on a number of components, the most important being fresh fruit bunch (FFB) and fruit composition, such as mesocarp to fruit (M/F), shell to fruit (S/F) and oil to bunch (O/B). The oil palm fruit is a drupe, consisting the mesocarp, shell and kernel. Within the fruit, a major component that determines a high O/B, besides M/F, is S/F. Shell and mesocarp contents of the fruit is negatively correlated, a reduction in shell content subsequently increases the mesocarp content, while the kernel remains unchanged. Among others, a strategy in developing planting materials for high oil yield is through the selection against shell thickness. Fruit size is indicated by the mean fruit weight (MFW) in bunch analysis. Generally, MFW is positively correlated with the oil-related-traits such as mesocarp to fruit (M/F), oil to dry mesocarp (O/DM), oil to wet mesocarp (O/WM), oil to bunch (O/B) and oil yield (OY), and negatively related with kernel yields and F/B. The O/B is the product of oil to bunch is strongly associated with F/B, M/F and O/WM. Beside that, we incorporate vegetation measurements which provide the height, trunk diameter, frond production and leaf area per every palm tree.

In decision modeling analysis decision tree structure refers to all the unique values which some records may contain incomplete information with discrete set of values or continuous attributes. Figure 1 shows the comparison of complete and incomplete information of physiological analysis during the initial study.

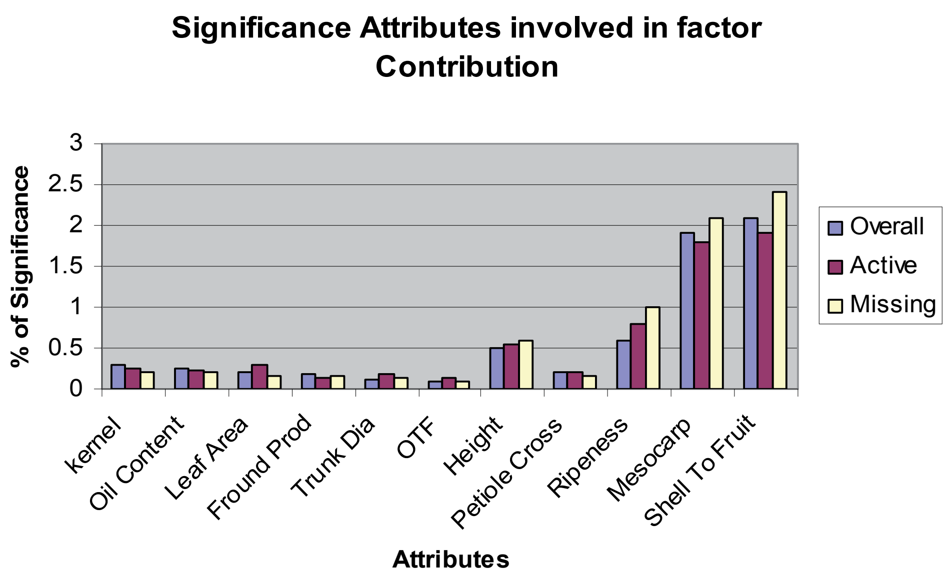

Fig.1. Number of complete and missing attributes in physiological analysis

By integration of expert knowledge and planting material, it seem reasonable to calculate the number of samples in the set *Tj* which belong to the same predicted class *Cj*., assigned as (1), then the probability of a random sample of the set T belongs to the class Cj . We estimate an attribute x_i provides data in fuzzy set and gives a membership degree as in (2), where *p* is the number of specified clusters, *k* is the number of data points, x_i is the i-th data points, $\mu_i(x_i)$ is a function that returns the membership of x_i in the j-th cluster

$$freq(C_i, T) = \sum_{j=1}^{n} \mu(C_j). \tag{1}$$

$$\sum_{j=1}^{p} \mu_j(x_j) = 1 \tag{2}$$

Some data sets can not be separated with clearly defined boundaries due to the data bases which contain incomplete information, but it is possible to sum the weight of data items belong to the nearest predicted class.

3.1 Fuzzy representation

Since fuzzy set theory can be used to describe imprecise information as membership degree in fuzzy clustering, therefore a given item sets are divided into a set of clusters based on similarity. We present fuzzy C-means based on objective function to quantify the goodness of cluster models that comprise prototypes and data partition. Fuzzy cluster analysis assigned membership degrees to deal with data that belong to more than one cluster at the same time; they determine an optimal classification by minimizing an objective function. A standard minimized objective function simply expressed as

$$l = \sum_{k=1}^{p} \sum_{i=1}^{n} (\mu_k(x_i))^m \left\| x_i - c_k \right\|^2 \qquad (3)$$

It can be seen that the characteristic functions constitute between ambiguity and certainty to the closed subsets x_i of the boundary with respect to the set interval (Heiko et al., 2004). We use more robust method of viewing the compatibility measurement for query x_i takes the weighted average of the predicate truth values. The equation show how the weighted average compatibility index is computed. The average membership approach computes the mean of the entire membership values.

$$x_i = (\sum_{i=1}^{n} (\mu_i(p_i)) \times w_i) / \sum_{i=1}^{n} w_i \qquad (4)$$

The degrees of membership to which an item sets belongs to the different clusters are computed from the distances of the data point to the cluster centers. With combination expert knowledge and most relevant ecological information, the membership degree can be calculated to determine some plausible data point lies to center of the nearest cluster. An iterative algorithm is used to solve the classification problem in objective function based clustering: since the objective function cannot be minimized directly, the nearest cluster and the membership degrees are alternately optimized. In fuzzy clustering analysis, the calculation of cluster centre value is given as follow, and each of observed data is assigned to the centre using Euclidean distance.

$$c_j = (\sum (\mu_j(x_i))^m x_i) / (\sum (\mu_j(x_i))^m \qquad (5)$$

3.2 Decision tree construction

We develop decision tree with expert knowledge and additional information in Figure. 2(a) and 2(b), the generated nodes form dynamic structure that changes when all elements remain possible to be tested. All available information is applied to derive the fuzzy maximum estimation which describes the imputation of estimates for missing values in cluster centers. In decision tree (Quinlan, 1993) the attribute depends on its entropy computation among the rest of the attributes, it can be simply formulated the uncertain subset xi from the interval of element x_o are dropped out. The entropy can be measured as the item sets are divided into subset T_j

$$\sum_{j=1}^{n} \frac{freq(C_i, T_j)}{T_j} \log_2 \frac{freq(C_i, T_j)}{T_j}. \qquad (6)$$

In the measured value xi, the possible subset is uniquely determined by the characteristic function. The measurement of the dispersal range of value xi is relative to the true value xo.

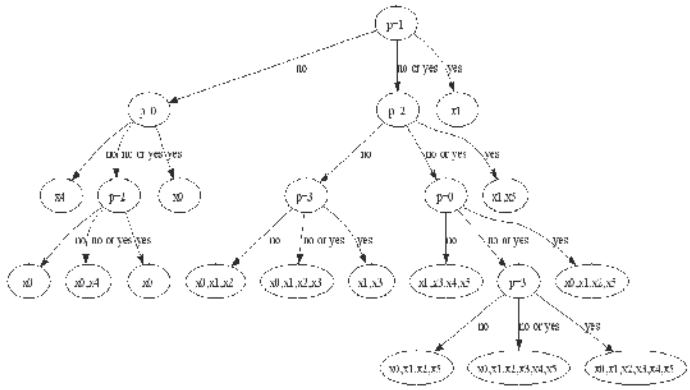

Fig. 2(a). Decision Tree Construction with incomplete information

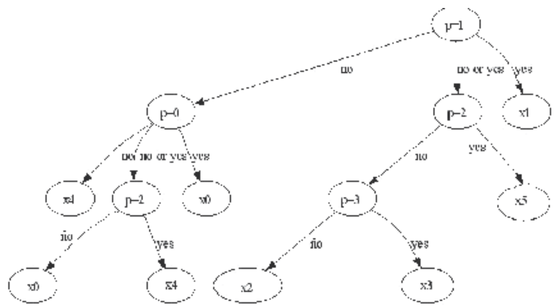

Fig. 2(b). Decision Tree Construction with expert knowledge and additional information

3.3 Proposed method

During the decision tree construction, the problem of missing values has to be dealt with both when processing the training examples and classifying a case using a learned tree. In some cases, an attribute may have associated missing values which are observed in the training examples and would appear as multiple values or null. When the decision tree is used to classify unseen cases, it is difficult to encounter a test on an attribute whose value is unknown. We present a reactive method for generalizing the decision tree into combination of binary and ternary tree, so called reactive decision tree by removing one or more inconsistence conditions of the attribute values. The method includes setting a preference ordering for conflicting attribute value and forming consistent sub trees or the exact tree leaf, which represents the predicted class at that leaf.

For each attribute, disjoint classes are separated with clearly defined boundary. These boundaries are critical since small changes close to these points will probably cause complete changes in classification. However, the imprecise and missing information often regarded as a difficult problem to define clearly about the class boundaries. This causes several problems for the selection of a test to partition the training set which require comparison of tests based on attributes with different numbers of unknown values. The comparison of the test which had been selected is sometimes in a sensible manner. The existence of imprecise information in real-world problems, the class boundaries may not be defined clearly. To obtain lower and upper approximations, it is necessary to briefly evaluate the qualitative attribute values, a set of evaluation grades may first be supplied from existing possible values. It provides a complete set of distinct standards for assessing qualitative attributes. In accomplishing this objective, an important aspect to analyze is the level of discrimination among different counting of evaluation grades, in other words, the cardinality of the set used to express the information. The cardinality of the set must be small enough so as not to impose useless precision on the users and must be rich enough in order to allow discrimination of the assessments in a limited number of degrees. We are able to make a decision when we know the exact values of the maximized quantity. However, the method has difficulties for knowledge discovery at the level of a set of possible values, although it is suitable for finding knowledge. This is because the number of possible tables exponentially increases as the number of imprecise attribute value increases. We explore the relation between optimal feature subset selection and relevance. The motivation for compound operators is that the feature subsets can be partitioned into strongly relevant, weakly relevant and irrelevant features (John et al, 1994). The wrapper method (kohavi et al., 1994) searches for an optimal feature subset tailored to a particular algorithm and a domain. This approach showed the feature subset selection is done using the induction algorithm as a black box, which is no knowledge of the algorithm is needed during the interface. We compare the wrapper approach to induction without feature subset selection and to Relief (Kira et al., 1992), a filter approach to feature subset selection, and FOCUS (Dietterich, et al., 1996). The improvement in accuracy also is achieved for some data sets in Naive-Bayes algorithm. The Maximum Acceptable Error (MAE) provides an improved estimate of the confidence bounds of concentration estimates. This method accommodates even strongly nonlinear curve models to obtain the confidence bounds. The method describes how to define and calculate the minimum and maximum acceptable concentrations of dose-response curves by locating the concentrations where the size of the error, defined in terms of the size of the concentration confidence interval, exceeds the threshold of acceptability determined for the application.

3.4 Decision rule construction

We investigate the possible of rules generated or classifiers during the classification rule development. As we had known that one of the most simple to understand, readable and manipulate is the decision tree. Decision trees represent a series of IF......THEN type rules which are linked together and can be used to predict properties for our observations based upon the values of various features. We describe approximation boundary of the attribute value process by ambiguity Ax, impossible Ix, necessary values Nx and given information attributes Wx. Generally, we derived our attribute with the values as (Ax, Ix, Nx, Wx). Initially, we assume that our domain of the attribute x is Dx = { a , b , c} and the values of attribute x is $\{\varnothing,\varnothing,\varnothing,D_x\}$.

We argue more precise as the rule being uncertainty to the expert as information when there are less information provided which represents decision tree with uncertainty. Decision-tree algorithms suggest a more focused approach to rule extraction. The rule extraction assumes that the user is interested in only one attribute as class as a consequent of every rule. This assumption significantly reduces the search space with the problem of finding association rules between any database attributes. A set of mutually exclusive and exhaustive if-then (production) rules can be easily extracted from a decision tree.

3.5 Improved algorithm and methodology

In this framework, the formal method is an approach towards the extraction of highly similar groups of subsets from a collection of elements described by a set of attributes A. The paradigm occurred within the attributes considered represent binary features with only two possible values true and false.

$$G_A(X) = \begin{cases} 1 & x_i \in A \\ 0 & x_i \notin A \end{cases}$$

We build the functions $G_A(X)$ constitute between ambiguous and certainty to the closed subsets X_i of the boundary with respect to the set inclusion. The function builds operators join and meet to provide the least upper and lower approximation in the set boundary respectively. From set theory viewpoint, the concepts represent complete maximal wide range of subsets which is described by the elements. It may be reduced to the discovery of the closed sets to the test rules. The algorithm used to discover the concept set comes from the set theory. It generates possible subsets in an iterative manner, starting by the most specific test value. At each step, new subsets are generated as members coupled, where the subset is the intersection of the intents of the already existing subsets. We define the border of a partially constructed subset through an element-wise insertion to the root node. The overall decision tree construction is supported by a structure that once the algorithm has finished its work contains the entire three-valued decision tree. Firstly, the set in the root node is a dynamic structure that changes when all elements remain possible to be tested. When the attribute depends on its entropy computation among the rest of the attributes, it can be simply formulated the new border always includes the new element whereas all elements of the old border that are greater than new elements are dropped out.

$$G_A(X) = \begin{Bmatrix} 1 & & x_p \subseteq U_p \cup N_p \cup \{v\} \\ unknown & \forall x & U_p \cup \{v\} \neq D_p \\ 0 & & v \notin x_p \end{Bmatrix}$$

To consider the universal set X and its power set P(X), let K be an arbitrary index set, it can proved that a function Nec is a necessity function if and only if it satisfies the following relationship:

$$Nec(\bigcap_{k\in K} A_k) = \inf_{k\in K} Nec(A_k)$$

While the function Pos is a possibility function if and only if it satisfies the following relationship:

$$Pos(\bigcup_{k\in K} A_k) = \sup_{k\in K} Nec(A_k)$$

for any family $\{A_k \mid k \in K\}$ in P(X).

We have analyzed through examples how to aggregate individual elements by considering the overall contributions to the agreement. We now present the considered algorithm in a general and precise way.

1. Decision makers $V = \{v_1, ..., v_m\}$ sort the alternatives of $X = \{x_1, ...x_m\}$ according to the linguistic categories of $\Gamma = \{\ell_1, ...\ell_p\}$. Then, we obtain individual weak orders $R_1........, R_m$ which rank the alternatives within the fixed set of linguistic categories.
2. Taking into account the scores $s_1, ...s_p$ associated with $\ell_1, ..., \ell_p$, a score is assigned to each alternative for each alternative for every decision maker: $S_i(x_u), i = 1, ..., m$, $u = 1, ..., n$
3. We aggregate the individual opinions by means of collective scores which are defined as the average of the individual scores:

$$S(x_u) = \frac{1}{m}\sum_{i=1}^{m} S_i(x_u)$$

and we rank the alternatives through the collective weak order R:

$$x_u R x_v \Leftrightarrow S(x_u) \geq S(x_v)$$

4. We calculate the overall contributions to the agreement for all the decision makers: $w_1, ..., w_m$.
   a. if $w_i \geq 0$ for every $i \in \{1, ..., m\}$, then we obtain the new collective scores by :

$$S^w(x_u) = \frac{1}{m}\sum_{i=1}^{m} w_i \bullet S_i(x_u)$$

   and rank the alternatives by means of the collective weak order R^w.

$$x_u R^w x_v \Leftrightarrow S^w(x_u) \geq S^w(x_v)$$

   b. Otherwise, we eliminate those decision makers whose overall contributions to the agreement are not positive. We now initiate the decision procedure for the remaining decision makers $V^+ = \{v_i \in V \mid w_i > 0\}$

We apply the method of weighted equivalence classes to information tables containing missing values. We briefly compare the method where uses of indiscernible classes with the method of weighted equivalence classes. The proposed method is based on possible values in the data sets, which consist of precise values, are obtained from an information table. Each possible subset is dealt with by applying rough sets to information tables containing precise information, and then the results from the possible tables are aggregated. In other words, the methods that are already established are applied to each possible table. Therefore, there is no doubt for correctness of the treatment.

The value selection assumes that the algorithm is interested in only one attribute as class as a consequent of the entropy estimation. By reducing the data, we generate different subset from selected condition attribute. This assumption significantly reduces the search space with the problem of analyzing the ambiguity of attribute values. When each attribute has associated a numerical score with respect to decision attribute, each alternative obtain a more focused approach to the selected values of subsets. Then, we obtain a distance between each individual preference and the collective one through the distance among the individual

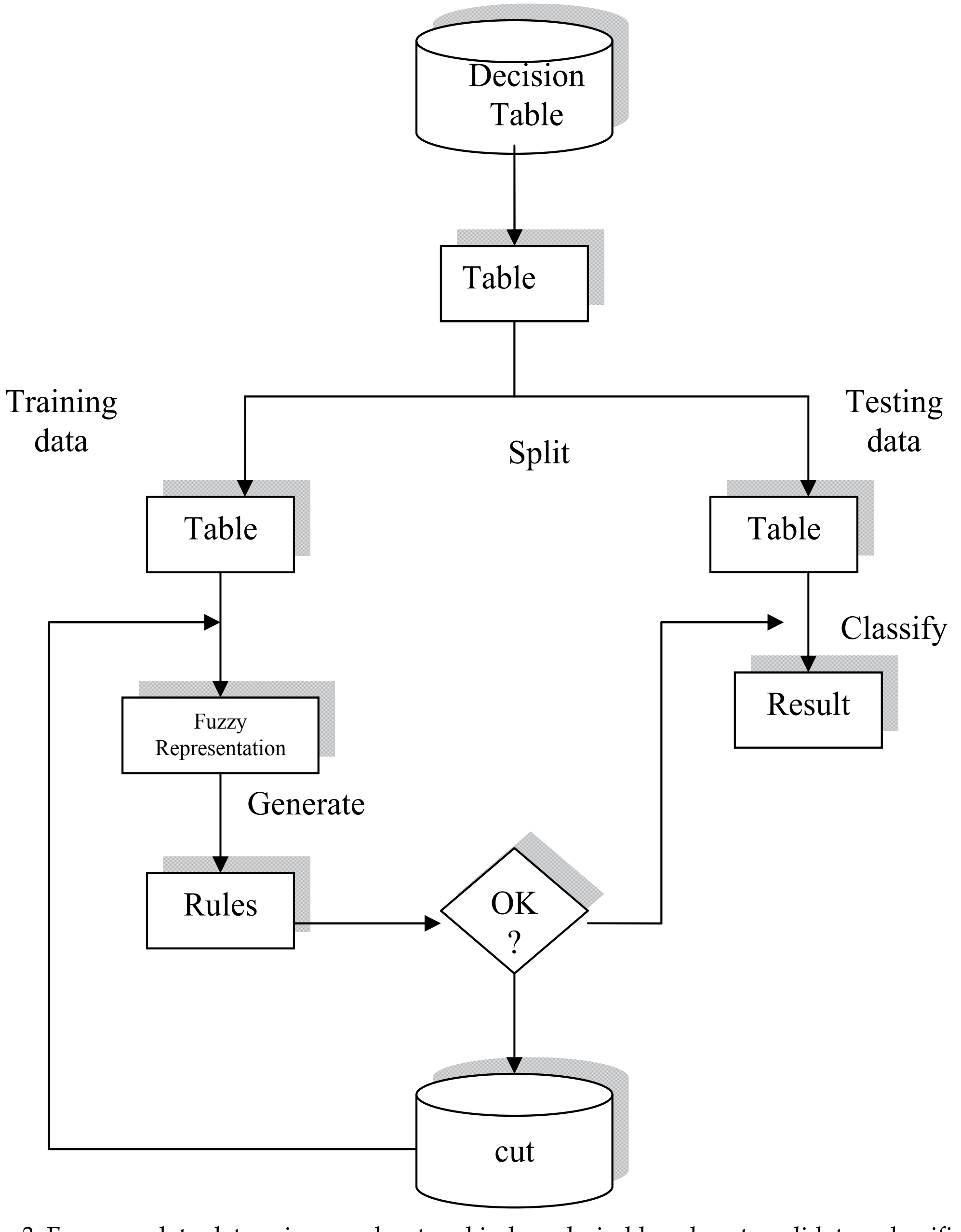

Fig. 3. Framework to determine rough set and induce desirable values to validate a classifier

and collective scoring vectors. We measure the agreement in each subset of possible values, and a weight is assigned to each decision makers, the overall contribution to the agreement. Those decision makers whose overall contribution to the agreement is not positive are expelled and we re-initiate the process with the opinions of the decision makers which is positively contribute to the agreement. The sequential process is repeated until it determines a final subset of decision makers where all of them positively contribute to the agreement.

Then, we apply a weighted procedure where the scores each decision makers indirectly assigns to the alternatives are multiplied by the weight of the corresponding decision maker, and we obtain the final ranking of the alternatives. As a result, the mutually exclusive attribute value can be easily extracted from a decision tree in the form of ambiguity reduction. Consequently, we assign the examples with missing values of the test attribute to the 'yes', 'no' and 'yes-or-no' outgoing branches of a tree node.

3.6 New decision tree construction

New extended ID3 algorithm based on T2, T3 calculates optimal decision trees up to depth 3 by using two kinds of decision splits on nodes. Discrete splits are used on discrete attributes, where the nodes have as many branches as there are possible attribute values. Interval splits are used on continuous attributes where a node has as many branches as there are intervals. The number of intervals is restricted to be either at most as many as the number of existing classes plus one, if all the branches of the decision node lead to leaves, or to be most as 2 otherwise. The attribute value "unknown" is treated as a special attribute value. Each decision node has an additional branch, which takes care of unknown attribute values. In fact, this way of treating unknown attributes is reported to perform better than that of C4.5.
In the tree-building phase, at each node, all attributes are examined, in order to select one on which a split will be performed for the node. When the attribute is discrete , the relative frequencies of all of its possible values are calculated. For continuous attributes, the same approaches would be inefficient because of the number of possible values and the resulting low frequencies of them. For that reason, local discretisation is used. Finally, a split is performed on an attribute if it results in maximum accuracy. Consequently T3 produces a tree hierarchy, which determines how important is an attribute in the classification process, in contrast to C4.5 which uses the gain ration. To carry out this local discretisation of a continuous attribute, its values have to be partitioned into multiple intervals. The set of intervals that minimizes the classification error is found by a thorough exploration instead of heuristically applying recursive binary splitting. The search for these intervals is computationally expensive, so T3 restricts decision trees to three levels tests, where only the third level employs binary splits of continuous attributes. T3 does not use a pruning technique. Instead it uses a parameter called Maximum Acceptable error (MAE). MAE is a positive real number less than 1, used as a stopping criterion during building the tree. T2 was observed to use a greedy approach when building the tree, thus further splitting at a node would stop only if the records already classified in this node, belonged to a single class. However, this greedy approach is not optimal, because minimizing the error in the leaf nodes does not necessarily result in minimizing the overall error in the whole tree. In fact, it was proved that a strategy choosing locally optimal splits necessarily produces sub-optimal trees. It should be noted here that classification error indicates how many instances of a training set have incorrectly classified, while generalization error indicates how many instances of a testing set have been incorrectly classified. Furthermore, even minimizing classification error does not always cause minimization of the generalization error due to over-fitting.
By introducing MAE, we allow the user to specify the level of purity in the leaves and stop to further building of the tree at a potential node split. We set MAE to have 4 distinct values, namely 0.0 to 0.3, meaning that splitting at a node stops even if the error in that node is equal to or below a threshold of 0 to 30 percent respectively. More precisely, building the tree would stop at a node in two cases. In the first case, building stops when the maximum

depth is reached, i.e. 3 when T3 is used or 2 when T2 is used. In the second case, building stops at that node only all the records remaining there to be classified to the same class in a minimum proportion of 70 to 100 percent. We used eight different version of T3 in our experiments, with different depth and length with MAE set to 0.1 – 0.3.
We associate a score to each value and aggregate each individual values by means of the average of the individual scores, providing a collective weak order on the set of alternatives. Then we assign an index to each value which measures their overall contribution to the alternatives. Taking into account these indices, we weight individual scores and obtain a new collective ranking of alternatives. Once the exact value is chosen, a branch relative to each value of the selected attribute will be created. The data are allocated to a node according to the value of the selected attribute. This node is declared as a leaf when the gain ratio values of the remaining attributes do after excluding the opinions of those decision makers whose overall contributions to the agreement are not positive. The new collective ranking of alternatives provides the final decision. Since overall contribution to the agreement indices usually is irrational numbers, it is unlikely that the weighted procedure provides ties among alternatives. The proposed decision procedure penalizes those individuals that are far from consensus positions, this fact incentives decision maker to moderate their opinions. Otherwise, they can be excluded or their opinions can be underestimated. However, it is worth emphasizing that our proposal only requires a single judgment to each individual about the alternatives. We can generalize our group decision procedure by considering different aggregation operators for obtaining the collective scores. Another generalization consists in measuring distances among individual and collective scoring vectors by means of different metrics.

4. Experimental result

The presence of the incomplete information in ecological system impacts on classification evaluation of planting material behavior in physiological analysis, since the semantics are no longer obvious and uncertainty is introduced. In figure 3, the graph shows the observed data are more likely to satisfy with additional information. The experiment combines planting material with expert knowledge and ecological information to generate an ROC curve. It can be seen that, in most of the data sets, the number of data belonging to the various categories do not exactly match the results of physiological analysis. This is because some of the planting material that should be classified in same type A has been misclassified into type B and vice versa.
In this experiment, we examine gradually the selected records of complete, ranked features and missing records of real physiological traits. The result, in Table 1 shows that the features in missing values compare to the others complete records. By adding additional features of ecological information to physiological trait, it shows less correlation between each feature in missing values and the others. The possible clusters rearrange their structure and rules are generated mostly come from combination of planting material and ecological information. As a result, the selected proper fuzzy values in decision tree construction provides less and simple rules. It removes some irrelevant features during the selection of subset of training data.
Figure 4 shows some of the rule production which obtained from the experiment. From it, the program obtained two decision tables for each clinician, one consisting of those with an 'induce' response and the other with a 'Don't induce' response (these tables are not shown). Rather than attempt to create a reduct from indistinguishable rules at this point we

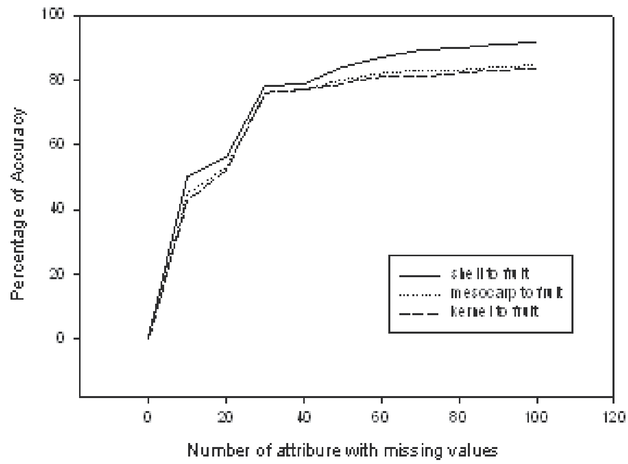

Fig. 3. Comparison of most observed attribute in missing values

	Training		Testing	
Modeling Decision with Fuzzy Set	Agree	Disagree	Agree	Disagree
	83.37%	16.63%	81.09%	18.91%
Modeling Decision with incomplete information	Correct	Wrong	Correct	Wrong
	78.82%	21.18%	76.68%	23.32%

Table 1. Summary of comparisons of agrees and disagree classification based od decision tree algorithms

generated all the possible rules from the decision table and then removed those that contradicted each other from the 'induce' and 'don't induce' set. By this means we hoped to prevent the production of spurious rules, while still producing a reasonable number of rules from a small decision table.

The analysis uses the trait set to produce good rules and is examined to see if any, and the contradicted rules are removed from the final rule - set. This is done by removing all unknown or missing values set with the same parameters that have equal or worse values than the original rule. We extracted the relevant parameters for each of these trait under their physiological analyse. Those traits induced for reasons other than our indications were removed from the database. We then calculated the 'actual' rate of induction for the relevant indications. The rules obtained above are then applied to the relevant database. Experimental results have shown that our proposed method produces relatively small sized and comprehensible trees with high accuracy in generalisation and classification. It improves the performance of existing classifier in terms of both generalisation accuracy and particularly classification accuracy. Our proposed also outperforms C4.5 in terms of tree size and classification accuracy. However, this method's generalisation accuracy remains lower than that of C4.5

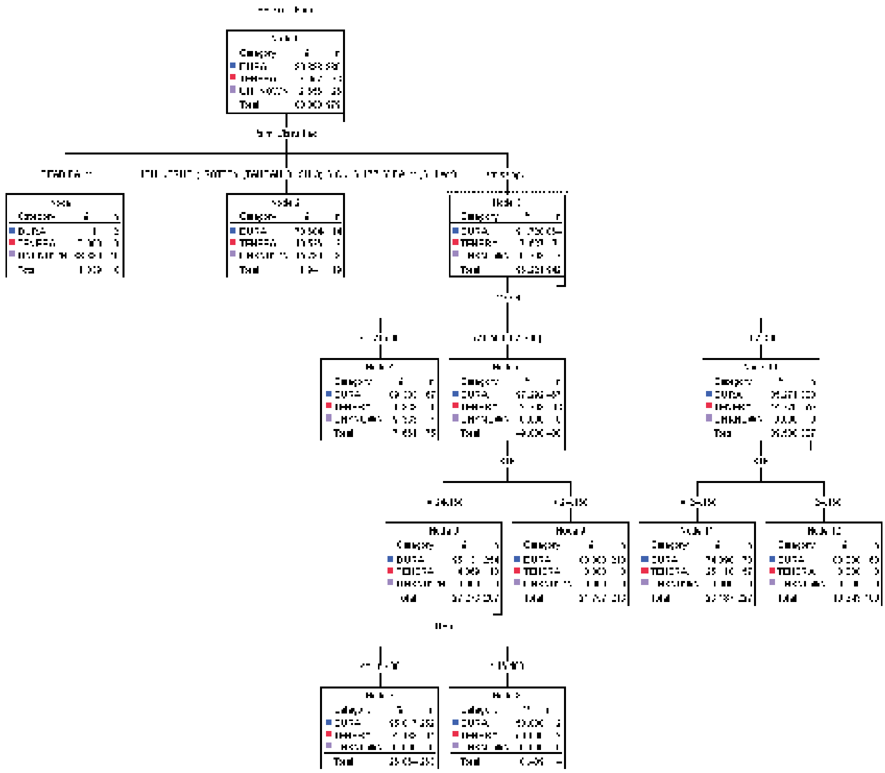

Fig. 4. The production rules by proposed method

5. Discussion and summary

This study has focused on domains with relatively high levels of unknown values and small testing set. It can be seen that the proposed method can be used for small samples and produces better result with expert knowledge and additional information. We have measured the degree of uncertainty using membership function and the proposed method is near to the true values of the uncertainty and the relative errors of the estimation are very small. However, this method still produces fairly large error after pruning with more missing values. This shows that the proposed method can only be applied to several conditions. The uncertainty estimation of measured values can be directly obtained using fuzzy representation and it is no longer necessary to estimate the standard deviation by mean value. For systems with small samples and unknown distributions, the proposed method is more suitable. When the training set is partitioned, ignoring cases with unknown values of the tested attribute leads to very inferior performance. During classification, attempting to determine the most likely outcome of a test works well in some domains, but poorly in others. Combining all possible outcomes is more resilient, giving better overall classification accuracy in these domains.

6. Conclusion

A missing value is often described as an uncertainty in the development of a decision system. It is especially difficult when there is a genuine disagreement between experts in the

field and also complex and unstated relationships between the variables that are used in the decision. The field of planting materials is particularly difficult to study because of the wide variation in environmental factors, and the differing population groups of genotypes serve. This decision support system allows the breeders or experts to make decisions in a way that is similar to their normal practice, rather than having to declare their knowledge in a knowledge engineering sense. Feedback from the experts in their domain should also be collected to refine the system especially in the evaluation of the decision trees themselves.
In this research work, we points out the extension of the splitting criterion in the missing values together. In addition to this, the splitting criterion also discards the irrelevant predictor attributes for each interior node. From the experiments reported, the classification error using our method was still low as compared to the original complete data sets by including additional attributes. It showed that discovered rules have a strong predictive power in missing values; this rule was not captured by C4.5 algorithm. On the other hand, the proposed method with his splitting criteria allows normally undeclared rules to be discovered. An added advantage here is that every expert has the opportunity to study the rules and make decisions on planting materials selection. On the other hand, the rough sets technique produce coarse splitting criterion and are often used for knowledge discovery from databases. It is also useful in any situation where a decision table can be constructed. It has an advantage in producing a set of comprehensible rules. The fact that this technique produces a lower and upper approximation of the true value, it allows a degree of uncertainty to be represented. The rules that are generated by the decision tree could be applied to a database of 'standard' procedures, or one that reflects their planting materials to obtain standard rules or drawing up guidelines for the development of an expert system in the oil palm industry.
We have focused on measurement of uncertainty in decision modeling. In this study, a special treatment of uncertainty is presented using fuzzy representation and clustering analysis approach in constructing the decision model. The uncertainty is not only due to the lack of precision in measured features, but is often present in the model itself since the available features may not sufficient to provide a complete model to the system. The result of the study shows that uncertainty is reduced and several plausible attributes should be considered during classification process. This formalization allows us to the better understanding and flexibility for selecting planting material in acceptance of the classification process.

7. Acknowledgement

The author would like to thank Universiti Tun Hussein Onn Malaysia for funding the research grant.

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15

A Web-Based Decision Support System for Surface Irrigation Design

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1. Introduction

Surface irrigation systems have the largest share in irrigated agriculture all over the World. The performance of surface irrigation systems highly depends upon the design process, which is related to the appropriateness and precision of land leveling, field shape and dimensions, and inflow discharge. Moreover, the irrigation performance also depends on farmer operative decisions, mainly in relation to land leveling maintenance, timeliness and time duration of every irrigation event, and water supply uncertainties (Pereira, 1999; Pereira et al., 2002).

The design procedures of farm surface irrigation drastically changed in recent years. The classical ones based upon empirical rules (Criddle et al., 1956; Wilke & Smerdon, 1965). A quasi-rational methodology taking into consideration the main design factors was developed by the Soil Conservation Service and based upon intensive field observations (SCS, 1974, 1979). This methodology was widely applied and adopted with optimization procedures (Reddy & Clyma 1981a, 1981b). It assumes the soil classification in infiltration families related with soil texture and obtained from infiltrometer observations (Hart et al., 1980). For furrows design, an empirical advance curve was applied relating inflow discharge, slope, length, and infiltration. Other classical methods refer to the volume-balance models using the continuity equation and empirical information (Walker & Skogerboe, 1987; Yu & Sing, 1989, 1990; Clemmens, 2007). These type of models also apply to irrigation management (Latimer & Reddel, 1990; Camacho et al., 1997; Mailhol et al., 2005).

Numerous mathematical computer models for surface irrigation simulation were developed. They originated a new age of design methods, with increased quality of procedures because they allow the quantification of the integrated effect of main irrigation factors (length, discharge, slope, soil roughness, shape, and infiltration) on performance, thus, enlarging the solution set with higher precision and effectiveness than the traditionally empirical methods. Strelkoff & Katopodes (1977) first presented an application of zero-inertia modeling for border irrigation. Further developments were applied to borders, basins and furrows (Fangemeier & Strelkoff, 1978; Clemmens, 1979; Elliott et al., 1982), and were followed by furrow surge flow modeling (Oweis & Walker, 1990). The kinematics wave and the hydrodynamics model for furrows were later adopted (Walker & Humpherys, 1983; Strelkoff & Souza, 1984). Computer models for design of basin irrigation include BASCAD (Boonstra & Jurriens, 1978) and BASIN (Clemmens et al., 1993), and for border irrigation include the BORDER model (Strelkoff et al., 1996). The models SRFR (Strelkoff, 1993) and SIRMOD (Walker, 1998) apply to furrows, basin and border irrigation and adopt various approaches for solving the continuity and momentum equations. Reviews were recently produced by Pereira et al. (2006) and Strelkoff & Clemmens (2007).

In addition to hydraulics simulation models, surface irrigation design requires the application of other type of models such as for irrigation scheduling, land leveling, distribution systems, and cost and environmental analysis. In practice, it is usually difficult to manage data for an interactive application of these models in design when they are not integrated with a common database. The decision support systems (DSS) methodology provides the framework to explore the synergy between mathematical simulation models, data and user knowledge through its integration aimed to help the decision-maker to solve complex problems. The DSS methodology makes handling data of various types easier and effective, and favors the integration of simulation models and their interactive application. It provides for a decision-maker learning process and it supports a decision process and related choices through multicriteria analysis. DSS models are often applied to irrigation planning and policy analysis (Bazzani, 2005; Riesgo & Gómez-Limón, 2006), as well as to performance assessment and water demand and delivery simulation (Raju & Duckstein, 2002; Rao et al., 2004; Oad et al., 2006; Raju et al., 2006). However, few applications are developed for irrigation design (McClymont, 1999; Hornbuckle et al., 2005; Gonçalves et al., 2009; Pedras et al., 2009).

The variety of aspects influencing irrigation performance (Burt et al., 1997; Pereira and Trout, 1999; Pereira et al., 2002) makes the design process quite complex, and a multicriteria analysis approach is then advantageous. Alternative design solutions may be ranked following various objectives and criteria, such as improving the irrigation performance, achieving water saving, attaining high water productivity, or maximizing farm incomes. Using a DSS and multicriteria analysis is helpful to produce appropriate comparisons among alternative design solutions and to perform a trade-off analysis (Roy & Bouyssou, 1993; Pomerol & Romero, 2000). In this line, the DSS SADREG for surface irrigation design was developed, tested and applied to different agricultural, economical and environmental conditions, considering several irrigation methods, equipments and practices. Applications include the Lower Mondego Valley, Portugal, improving basin irrigation for water savings and salinization control in the Upper Yellow River Basin, China, improving furrow irrigation in Fergana Valley, Aral Sea Basin, Uzbekistan, and modernizing furrows and border irrigation in Euphrates Basin, Syria. The objective of this chapter is to present the DSS model and its Web application, describing procedures to design and users support.

The development of DSS for Web allows a better application flexibility, improving the user support for database access, and enlarging the number of users, particularly in the world areas where the water scarcity demand for a better use of irrigation water. The application version here presented comprises a Web and a simulation engine module, which includes the models integrated in SADREG. The Web access of DSS allows an easier transfer of knowledge and tools to improve the procedures to evaluate and design field irrigation systems. The DSS location on a server allows data sharing and comparison of results by different users. Some examples of Web applications in the irrigation domain show its usefulness (Thysen and Detlefsen, 2006; Car et al., 2007).

The organization of this chapter considers, first, the description of DSS model, with details about the process of design and selection of surface irrigation alternative; after, in sub-chapter 3, the explanation of Web methodologies in a DSS context, referring the programming languages and the architecture of Web client and server; and, in sub-chapter 4, the description of the DSS software use and Web interface.

2. DSS model

SADREG is a DSS designed to assist designers and managers in the process of design and planning improvements in farm surface irrigation systems – furrow, basin and border irrigation. It includes a database, simulation models, user-friendly interfaces and multicriteria analysis models.

2.1 DSS architecture

SADREG is comprised of two components: design and selection (Fig. 1). The first component applies database information and produces a set of design alternatives in agreement with the user options. These alternatives are characterized by various hydraulic, economic, and environmental indicators that allow appropriate selection and ranking. The selection component is based upon multicriteria analysis for ranking the alternatives, thus, supporting the decision-maker to select the best design solution. The decision-maker participates in all decision processes through interface dialogue structures that allow expressing design and management options and priorities.

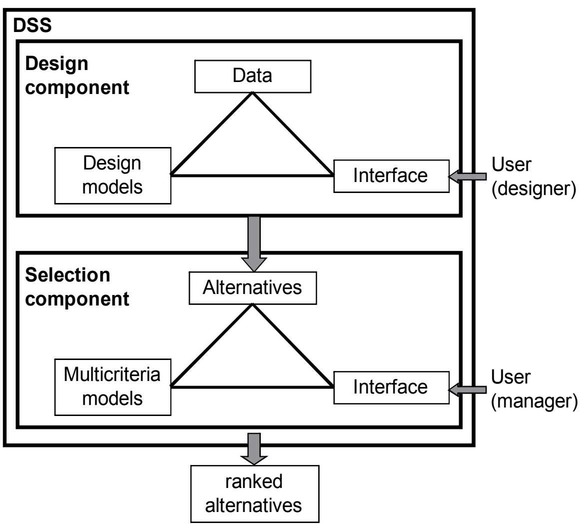

Fig. 1. Conceptual structure of SADREG

The database refers to data of various natures, some constituting input data required for computations, others are created through successive computations (Fig. 2). Main components are:

1. General field data, relative to soils and environment (e.g., soil infiltration, soil water holding capacity, soil salinity, groundwater depth, and climate), crops (planting date, yields, yield function parameters), equipment characteristics and costs, and operational costs and benefits;
2. Field data characterizing the field under design: length, width, slopes, surveying data, and characteristics of the respective water supply;

3. Data created through simulations performed with the models SIRMOD for surface irrigation simulation (Walker, 1998) and ISAREG for irrigation scheduling simulation (Pereira et al., 2003);
4. Projects data, referring to data characterizing the design alternatives; and
5. Selection data, referring to the value functions and decision priorities.

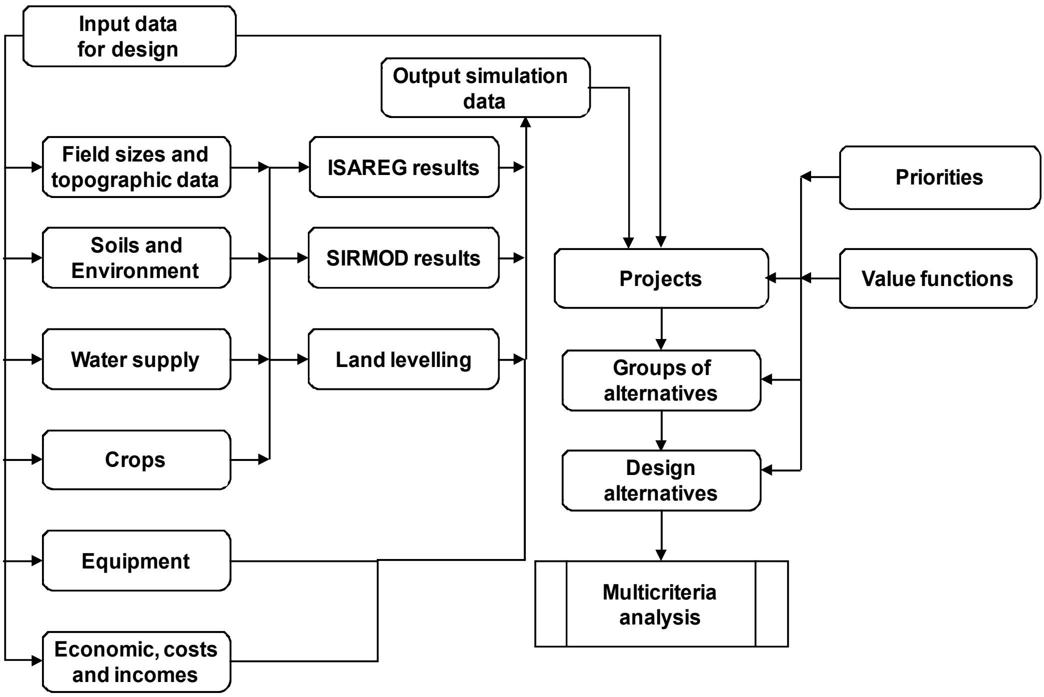

Fig. 2. Data base components in relation with respective data sources and uses in the design process

SADREG includes various computational models and tools (Fig. 3). The simulation of the surface irrigation systems – furrows, borders, and basins – is performed by the surface irrigation simulation model SIRMOD (Walker, 1998), which is integrated within SADREG. The water balance simulation to define the application depths and timings is performed by the ISAREG model (Pereira et al., 2003), which is linked (loose integration) with SADREG and explored interactively. Calculations relative to land leveling and farm water distribution systems are performed through specific built-in tools. These computational tools provide for the characterization of each design alternative, including a complete set of performance indicators. The resulting data are later handled by an impact analysis tool, so creating all data required for multicriteria analysis. The impact analysis tool performs calculations relative to crop yields and related incomes (benefits), costs, and environmental impacts as described later. Ranking and selection of alternatives are performed with composite programming and the ELECTRE II models (Roy & Bouyssou, 1993; Pomerol & Romero, 2000).

The SADREG applications scope comprises: (a) a single field analysis relative to alternative design options for furrow, basin, or border irrigation, considering several decision variables such as field slopes, farm water distribution systems and runoff reuse; and (b) an irrigation sector analysis, when a spatially distributed database relative to the farm systems is available. In this case, the alternatives are assessed jointly with modernization options relative to the conveyance and distribution network. It applies to farm land parcels or fields, of rectangular shape, with a well known geographical location, supplied by a hydrant, a gate, or other facility at its upstream end.

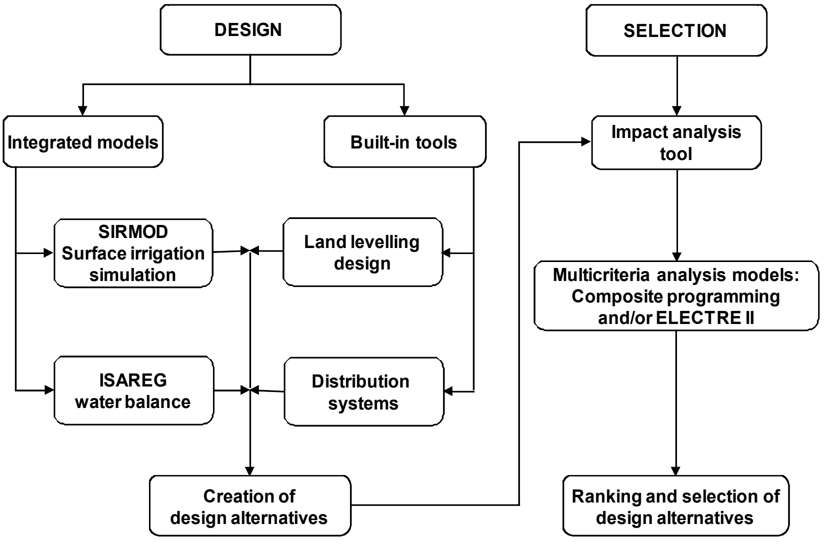

Fig. 3. Model base components

A field is characterized by its length and width, slope and land surface unevenness, soil infiltration and soil water retention characteristics, both assumed as spatially uniform for design purposes. Large fields may be subdivided into units, which are field fractions supplied by a single outlet, all having the same width, length, and slope. In addition, subunits may be considered when the water available or management constraints impose that a unit is not fully irrigated simultaneously. In order to design the upstream water distribution, the field characterization requires definition on which direction, OX or OY, the distribution system should be located. Hydrants or farm gates supply the water to the field with known discharge and hydraulic head. In large fields, farm canals or pipes supplied by those hydrants or gates may deliver the water to the upstream distribution system through various outlets, equaling the number of units. In small fields, generally only one unit is considered and the outlet coincides with the hydrant or gate.

A hierarchical approach is used to develop the design alternatives (Fig. 4). Data referring to field characteristics common to all alternatives are organized in a *workspace*. Included in the field workspace are the *projects* whose data structure is aimed at developing a set of design alternatives relative to:

1. The crop type (e.g., cereals versus row crops),
2. The irrigation method;
3. The land leveling solution, to be defined in agreement with the irrigation method, field longitudinal and cross slopes, and the selected upstream distribution side,
4. The water supply conditions that influence, together with the irrigation method, the options relative to the number and size of units and the outlet's discharge; and
5. Costs and other financial parameters.

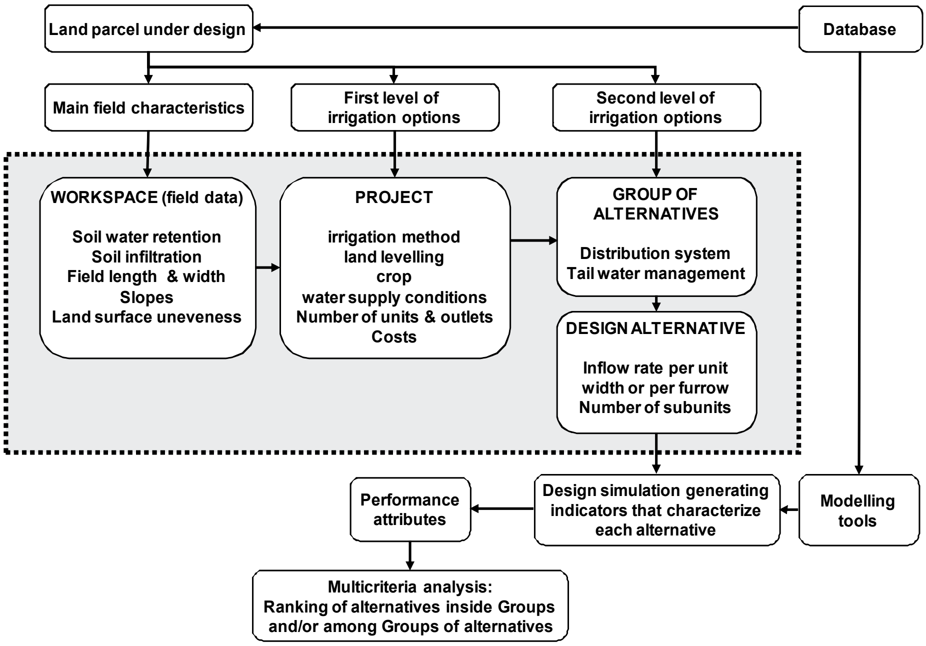

Fig. 4. Scheme of the creation of field design alternatives using a multilevel approach for design and application of multicriteria ranking and selection

The design alternatives are clustered into *groups* included in a project and relative to:
1. The upstream distribution system, which depends upon the selected irrigation method and equipment available; and
2. The tail end management system, which also depends upon the irrigation method and the equipment available.

The *alternatives* constitute complete design solutions. Within a group, they are differentiated by the operative parameters: the inflow rate per unit width of land being irrigated or per furrow, and the number of subunits.

2.2 Irrigation system design

2.2.1 Decision variables

The surface irrigation methods considered are level basin irrigation, with flat or furrowed soil surface, graded basins, borders, and graded furrows (Table 1). Level furrows are treated as furrowed level basins. For cereals, furrows of corrugated type may be considered.
The decision variables relative to the irrigation design process are described in Table 2. They depend upon the irrigation method since it influences the field layout and land leveling, the water supply and distribution, the tail water management, and the farm irrigation management.

2.2.2 Land leveling

When starting a project, the user must select the irrigation method, the upstream distribution side, and carry out a land leveling simulation adopting cross and longitudinal field slopes appropriate to the considered irrigation method and the actual field slopes. The land leveling simulation tool computes the cut and fill volumes required to change from the actual elevations $z_a(x, y)$ into the target elevations:

$$z(x,y) = z_0 + S_x(x-x_0) + S_y(y-y_0) \quad (1)$$

where x_0, y_0, z_0 = coordinates of the centre of gravity of the field (m); and S_x and S_y = longitudinal and cross slopes (m m^{-1}) along the OX and OY axis, respectively (Dedrick et al., 2007). The plan position (value of z_0) is iteratively changed until the cut to fill ratio becomes > 1.0 and < 1.2 (Fig. 5). Results include the cut and fill depths and volumes, and related costs.

Irrigation method	Soil surface condition	Field slopes	Field inflow conditions	Tail end conditions
Level basin	Flat or furrowed	Zero in all directions	Point inflow at one or various locations, or to individual furrows	Diked
Graded basin and borders	Flat or furrowed	Longitudinal slope ≠ 0 and cross slope = 0	Point inflow at one or various locations, or to individual furrows	Diked for basins and open for borders
Graded furrows	Furrowed	Longitudinal and cross slope ≠ 0	Inflow to individual furrows	Open or diked

Table 1. Irrigation methods

2.2.3 Infiltration and SIRMOD application

The modified Kostiakov equation is applied in SIRMOD model (Walker, 1998) to compute soil infiltration. For continuous flow, it takes the form:

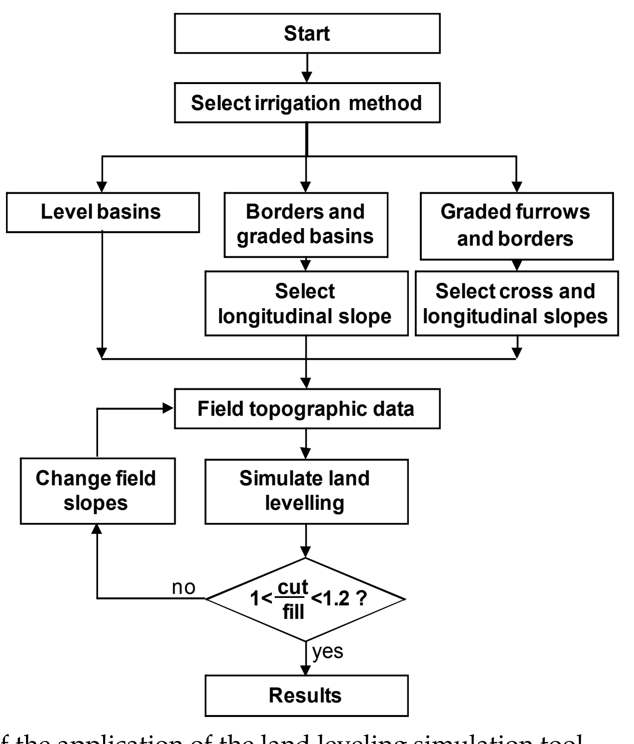

Fig. 5. Flowchart of the application of the land leveling simulation tool.

$$Z = K \cdot \tau^a + f_0 \cdot \tau \quad (2)$$

where Z = cumulative infiltration (m^3 m^{-1}); τ = infiltration time (min), K (m^3 m^{-1} min^{-a}) and a (dimensionless) are empirically adjusted parameters; and f_0 = basic infiltration rate (m^3 min^{-1} m^{-1}).

For surge-flow, the procedure developed by Walker & Humpherys (1983) is adopted:

- For infiltration on dry soil (first wetting), Eq. (2) is applied;
- For infiltration on wetted soil (third and successive wettings) the parameters a, K and f_0 in Eq. (2) are modified into K_s, a_s, and f_{0s}, thus, producing the surge infiltration equation; and
- For infiltration during the second wetting, a transition curve is applied.

This transition equation balances the effects represented by the equations for dry and wetted soil (Walker, 1998; Horst et al., 2007):

$$Z = [K + (K - K_s)\,FP]\ \tau^{[a + (a - a_s)\,FP]} + [f_0 + (f_0 - f_{0s})\,FP]\ \tau \quad (3)$$

where FP (dimensionless) = distance-based factor computed from the advance distances x_{i-2} and x_{i-1} relative to the surge cycles i-2 and i-1.

To characterize each field, SADREG includes a set of infiltration data concerning families of infiltration curves for continuous and surge flow, typical of seasonal irrigation events (first, second, and later irrigations) under flat soil infiltration conditions. Field observations of infiltration can be added to this set of infiltration curves and be used for the respective design case study. When no field infiltration data are available, the user selects the curves to be used considering the available soil data. To adjust the parameters for furrow irrigation, the procedure proposed by SCS (1979) and Walker (1989) is applied. It is based on the average wetted perimeter WP (m) and the adjusting coefficient (C_{adj}). WP is given by

$$WP = 0.265\left(\frac{q \cdot n}{\sqrt{S_0}}\right)^{0.425} + 0.227 \quad (4)$$

where q = furrow inflow discharge (l s^{-1}); n = Manning's roughness coefficient (s $m^{-1/3}$); and S_o = furrow longitudinal slope (m m^{-1}). The adjusting coefficient C_{adj} is estimated as

$$C_{adj} = 0.5, \ldots if\ \frac{\mathrm{WP}}{\mathrm{FS}} < 0.5\text{ , else } C_{adj} = \frac{\mathrm{WP}}{\mathrm{FS}} \quad (5)$$

where FS (m) = furrow spacing. The parameters K and f_0 [Eq. (2)] and the surge-flow infiltration parameters are adjusted as

$$K_{adj} = C_{adj} \cdot K \quad (6)$$

$$f_{0\ adj} = C_{adj} \cdot f_0 \quad (7)$$

SIRMOD model is applied for several input conditions that cover all situations relative to the user options to create alternatives. The continuous input variables consist of: field length

	Decision variables	
Design	Field layout and land levelling	- upstream distribution side (OX or OY) - field length (FL) and field width (FW) - cross slope (S_{oC}) - longitudinal slope (S_o)
	Water supply conditions	- number of outlets (N_o) - number of units (N_u) - total field supply discharge (Q_F) - outlet discharge (Q_o) and hydraulic head (H_o) - time duration of field delivery (t_F)
	Farm distribution system	- continuous and constant inflow rate for basins and borders - continuous or surge flow with automatic or manual surge valves for graded furrows, - lined or unlined canal, or gated pipes, or layflat tubing (for all methods)
	Tail water management	- no tail water runoff (case of basins and diked furrows) - open tail end without tail water reuse - open tail end with reuse by pumping to the upstream end - open tail end with gravity reuse on downstream fields
Management	Irrigation scheduling	- irrigation timing - required application depths - application time duration (t_{ap})
	Distribution system operation	- inflow rate per unit width or per furrow (q_o) - number of sub-units (n_s)

Table 2. Design and management decision variables

(*FL*, m), required application depth (Z_{req}, mm), field longitudinal slope (S_o), Manning's hydraulics roughness coefficient (n), furrow spacing (*FS*), and inflow rate per unit width or per furrow (q, l s^{-1}). The discrete input variables required are: inflow regime (continuous or surge flow), tail end management (diked, open, or open with reuse), cross section shape (flat or a given furrow type), and parameters of the infiltration equation.

Any run of SIRMOD produces output data including: application, advance and recession times; infiltration depths; runoff and percolation volumes; and performance indicators, mainly those defined in Table 3 (Walker & Skogerboe 1987; Pereira & Trout 1999).

Indicator	Definition	Units
Application efficiency	$E_a = \begin{cases} \frac{Z_{req}}{D} \times 100 & Z_{lq} > Z_{req} \\ \frac{Z_{lq}}{D} \times 100 & Z_{lq} < Z_{req} \end{cases}$	%
Distribution uniformity	$DU = \frac{Z_{lq}}{Z_{avg}} \times 100$	%
Water requirement efficiency	$E_r = \frac{Z_{avg\ (root)}}{Z_{req}} \times 100$	%
Infiltration efficiency	$IE = \frac{Z_{avg}}{D} \times 100$	%
Tail water runoff ratio	$TWR = \frac{Z_{run}}{D} \times 100$	%
Deep percolation ratio	$DPR = \frac{Z_{dp}}{D} \times 100$	%

Z_{req} - the average water depth (mm) required to refill the root zone in the lower quarter of the field
D - the average water depth applied to the irrigated area (mm)
Z_{lq} - the average depth of water infiltrated in the lower quarter of the field (mm)
Z_{avg} - the average depth of water infiltrated in the whole irrigated area (mm)
$Z_{avg\ (root)}$ - the average depth of water infiltrated stored in the root zone (mm)
Z_{run} - the depth of water that runs off at the tail end of the field (mm)
Z_{dp} - the depth of water that percolates below the root zone (mm)

Table 3. Performance indicators

SIRMOD is used iteratively for a given alternative to search the irrigation parameters referred to above that comply with the application of the required irrigation water depth Z_{req} (mm). This one is computed by running interactively the model ISAREG for the considered crop, soil, and climate. In SIRMOD simulation, an appropriate inflow rate q ($q_{min} < q < q_{max}$, l s^{-1} m^{-1}) is iteratively selected using increments $\Delta q = 0.1$ l s^{-1}. However, it may happen that the model does not converge and it becomes necessary to have a successful simulation trying different combinations of internal simulation parameters (Walker, 1998): time step (1-2.5 minutes), space step (1-25 m, according to the field length), time weight factor (0.60-0.65), space weight factor (0.50-0.65), and type of hydraulics simulation model (full hydrodynamic or zero inertia). When an inflow rate q is found a new iteration starts to compute the time t_{ap} (min) required to apply the water depth Z_{req}. This is performed by maximizing the water requirement efficiency (Table 3), which should become close to 100%.

Results are then saved in the database to be further applied to other alternatives. The results for intermediate values for each of the continuous input variables are calculated by interpolation between those stored in the database instead of running the model several times.

2.2.4 Generation of alternatives

The procedure to build up and characterize design alternatives for a given field is performed through the following sequential steps:

1. Selection of the irrigation method: level basin (flat or furrowed), graded basins or border, or graded furrows; for furrows, selection includes the cross section type and the furrow spacing;
2. Definition of the field side, along the axis OX or OY, where the upstream distribution facilities will be located;
3. Land leveling simulation, with selection of the field slopes more appropriate to the irrigation method, and the actual field topography;
4. Selection of the inflow regime for graded furrows: continuous or surge-flow. The surge-flow irrigation management follows the one-fourth length rule for the advance phase, i.e., with increased duration of successive cycles; after the advance is completed, a continuous flow with half-inflow rate applied to the full unit is adopted. For basin and borders, only a continuous inflow rate is considered;
5. Definition of the number of outlets and field units;
6. Selection of the water distribution system: gated pipe, lay-flat tubing, earth canal, or lined canal; when the surge-flow option is selected, the respective control system may be either manual or automatically operated;
7. Selection of a tail water management option for borders and furrows: diked, i.e., closed at the tail end, or open. When open, the tail end runoff may be reused by pumping to the upstream end, reused by gravity in downstream fields, or not reused. Basins are diked; and
8. Estimation of an appropriate crop irrigation scheduling, thus, the required application depths and timings. With this purpose, the ISAREG model is used interactively with SIRMOD for searching the application depths appropriate to the irrigation method.

2.2.5 Impact evaluation

The cost analysis considers the investment and the operation and maintenance (O&M) costs (Mjeld et al., 1990; Solomon et al., 2007). The investment cost refers to the farm distribution system equipment and the initial land leveling. The net present value of the investment cost is calculated on a yearly basis using a capital recovery factor that is a function of the annual interest rate and the lifetime of the components (Tab. 4). The annual O&M costs include land leveling maintenance, distribution system operation and maintenance, and reuse pumping costs. The database shall include the duration times relative to all irrigation tasks depending upon the irrigation method and the equipment used. The production costs not referring to irrigation (e.g. fertilization, cultivation, and harvesting) do not differ among alternatives and do not interfere on ranking and selection of alternatives. Thus, they are not included in the cost analysis.

Investment costs (IC):	Formulas
IC_{va} - Present worth cost of one given component (€)	$IC_{va} = IC \cdot \left(1 + \left[\sum_{j=1}^{N_{sub}} \left(\frac{1}{1+i_{TA}}\right)^{j \cdot N_{LT}}\right]\right)$
CRF - capital recovery factor (-)	$CRF = \frac{i_{TA} \cdot (1+i_{TA})^{N_{AP}}}{(1+i_{TA})^{N_{AP}} - 1}$
AFC - Annual fixed cost (€/year)	$AFC = CRF \cdot \sum_{j=1}^{N_{comp}} IC_{va_j}$
IC_{LL} - initial land leveling cost (€)	$IC_{LL} = a_0 + a_1 \cdot t_{mac}$
t_{mac} - time machine operation for land leveling (h)	$t_{mac} = t_{uexc} \cdot V_{exc}$ or $t_{mac} = t_{uarea} \cdot A$
IC_D - distribution system cost (€)	$IC_D = b_0 + b_1 \cdot FW$
IC_R - reuse system cost (€)	$IC_R = r_0 + r_1 \cdot A$
IC_T - total investment annual cost (€/year)	$IC_T = IC_{LL} + IC_D + IC_R$
OMC - Operation & maintenance costs:	
OMC_R - Reuse pumping system cost (€/year)	$OMC_R = r_2 \cdot VR$
OMC_{LL} - Land leveling maintenance cost (€/year)	$OMC_{LL} = a_0 + a_1 \cdot a_2 \cdot A$
OMC_D - Distribution system cost (€/year)	$OMC_D = h_0 \cdot t_{Mt}$
t_{Minst} - labour to install the distribution system (h/year)	$t_{Minst} = h_1 \cdot FW$
t_{Mrem} - labour to remove the distribution system (h/year)	$t_{Mrem} = h_2 \cdot FW$
t_{Mope} – labour to operate a sub-unit (h)	$t_{Mope} = h_3 \cdot S_U W$
t_{Mfree} - free man power time in a sub-unit irrigation (min)	$t_{Mfree} = t_{ap} - t_{Mope}$
t_{MopU} - total labour to operate a unit (h)	$t_{MopU} = t_{MopSU} \cdot ns, \ldots$ if $t_{Mfree} > t_{Mm}$ $t_{MopU} = t_{ap} \cdot ns, \ldots$ if $t_{Mfree} \le t_{Mmin}$
t_{Mt} - total labour by the distribution system (h/year)	$t_{Mt} = t_{Minst} + \sum_{j=1}^{Nirrig} (N_u \times t_{MopU})$
OMC_T – total O&M annual cost (€/year)	$OMC_T = OMC_{LL} + OMC_D + OMC$
Symbols: *A=field area (ha)* a_0 =leveling machines fixed cost (€/operation) a_1=hourly cost of the land leveling machines (€/h) a_2=unitary maintenance leveling machine	Ncomp=Number of a equipment components Nirrig=annual number of irrigation events NLT=equipment component life time (years) ns=number of subunit per unit; Nsub=number of component replacements during NAP

time (h/ha)	Nu=number of units per field
b_0=distribution system fixed cost (e.g., valves) (€)	r0=reuse system fixed cost (€)
b1=unitary distribution system (dist.syst.) cost (€/m)	r1=unitary reuse system cost (€/ha)
FL =field length (m)	r2=unitary reuse system variable cost (€/m3)
FW =field width (m)	SUW=subunit width (m);
h_0=hourly cost of the man power (€/h)	t uexc=unitary machinery for cut volume (h/m3)
h_1=unitary man power time to install dist.syst. (h/m)	tap=application time (min)
h_2=unitary man power time to remove dist.syst. (h/m)	tMmin=additional time required to other tasks relative to irrigation (min);
h_3=unitary man power time to operate dist.syst. (h/m)	tuarea=unitary machinery time to land smoothing (h/ha)
IC= investment costs	Vexc=land leveling excavation volume (m3)
i_{TA}=annual interest rate (decimal)	VR=pumping reuse volume (m3/year)
NAP=analysis period (years)	

Table 4. Cost analysis equations

A water-yield function is used to estimate the crop yield from the computed total water use during the irrigation season. A quadratic function (Fig. 6) is adopted to calculate the relative yield (Y/Y_{opt}) from the relative water application (W/W_{opt}) (Solomon, 1984):

$$Y/Y_{opt} = k_0 + k_1 \cdot (W/W_{opt}) + k_2 \cdot (W/W_{opt})^2 + k_3 \cdot (W/W_{opt})^3 + k_4 \cdot (W/W_{opt})^4 \quad (8)$$

where W = actual water available for crop use during the irrigation season (mm); W_{opt} = seasonal water required for achieving maximum crop yield (mm); Y and Y_{opt} = crop yields (kg ha^{-1}) corresponding to W and W_{opt}, respectively; and k_i (i = 1, ..., 4) are empirical coefficients typical for the crop, and environmental and agronomical conditions under consideration. The decreasing branch of this function is related with soil drainage conditions and excess water impacts on yields. To consider these effects, the user should adjust to the local conditions the descending branch of the quadratic function, as indicated in Fig. 6 where 3 types of descending branches are presented.

The environmental attributes considered for selection of the design alternatives are:

1. The total irrigation water use during the crop season;
2. The nonreused runoff volume, that represents a nonconsumed and nonbeneficial fraction of water use and is an indicator for potential degradation of surface waters;
3. The deep percolation volume, which represents also a nonconsumed and nonbeneficial fraction of water use and is an indicator for potential degradation of ground waters;
4. The potential land leveling impacts on the soil quality; and
5. The potential for soil erosion.

The total water use, runoff and deep percolation volumes are calculated with SIRMOD for every single event of the irrigation season. The seasonal values are obtained by summing up these results. The attribute relative to land leveling impacts is expressed by the average cut depth because the smaller are the cut depths, the lower are the impacts on soil quality.

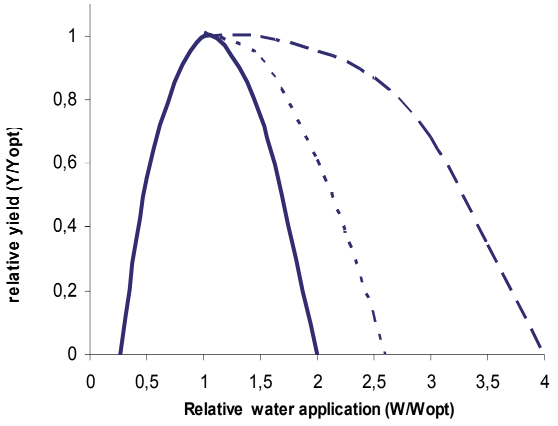

Fig. 6. Irrigation water-yield functions. Examples of quadratic equations with different descending branches for a crop susceptible to excess water in a poorly drained soil (—), for a susceptible crop in a drained soil (- - -), and for a non-susceptible crop in a well drained soil (— —)

The potential soil erosion attribute is a qualitative index, *EI*, which takes values 1-9 in an ascending scale of risk of soil erosion due to the applied irrigation water. *EI* is an empirical function of the inflow rate *q* per unit width or per furrow, the longitudinal slope S_o, and the soil type considering the empirical concept of maximum nonerosive inflow rate as proposed by Criddle et al. (1956). For furrows in a silt-loam soil, *EI* values relative to single events are given in Table 5 as a function of the product $q\ S_o$, where q in l s^{-1} and S_o in percentage. For different soil types this scale values should change similarly to the maximum nonerosive inflow rate. The seasonal *EI* is the geometric average of the single event values.

$q\ S_o$ (l s^{-1} %)	<0.30	0.3-0.5	0.5-0.62	0.62-0.75	0.75-0.87	0.87-1.0	1.0-1.25	1.25-1.5	>1.5
EI	1	2	3	4	5	6	7	8	9

Table 5. Potential erosion index *EI* for furrows in a silt-loam soil

2.3 Multicriteria analysis

The selection of the best irrigation design alternative is a multiple objective problem whose rational solution requires multicriteria analysis. This methodology integrates different types of attributes on a trade-off analysis, allowing the comparison between environmental and economic criteria (Pomerol & Romero, 2000). Multicriteria analysis supports a better understanding of the irrigation impacts while enabling us to achieve a satisfactory compromise between adversative decision-maker objectives.

The process starts with the definition of the design objectives and related attributes (Fig. 7). These attributes are then transformed into criteria through user-defined value or utility functions [Eqs. (9) and (10) presented below]. The alternatives and respective criteria are tabled in a payoff matrix, which synthesize the more relevant data for the selection analysis. A first screen of the alternatives may be done prior to the application of multicriteria using a dominance and satisfaction preanalysis.

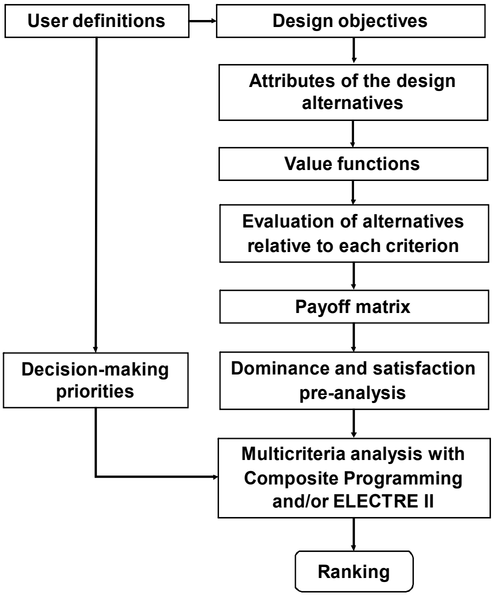

Fig. 7. Scheme of application of the multicriteria methodology

A set of design objectives and correspondent attributes are presented in Table 6.

Objectives	Alternative Attributes	units
Maximizing benefits	Yield value	€/year
Minimizing costs	Investment cost	€/year
	Operation and maintenance cost	€/year
Minimizing water degradation and the non-beneficial water use	Deep percolation	m^3/year
	Runoff	m^3/year
Maximizing soil conservation	Average land levelling cutting depth	cm
	Erosion index	index

Table 6. Objectives and attributes for design selection.

The decision criteria refer to:

1. Economic criteria relative to the yield value, the initial investment cost, and the operation and maintenance costs;
2. Environmental criteria relative to the potential degradation of groundwater and surface waters and the reduction of nonbeneficial water uses relative to tail-end runoff and deep percolation, potential erosion due to irrigation water flowing over the soil surface, and soil degradation due to land leveling cuts. Hydraulic criteria are represented in the environmental criteria through controlling runoff and percolation.

The attributes are scaled according to a measure of utility using value or utility functions, which are applied to the environmental and economic criteria. This approach enables to compare variables having different units, which is one of the primary benefits of multicriteria methodology. With this procedure, the utilities U_j for any criterion j are normalized into the [0-1] interval (zero for the more adverse and 1 for the most advantageous result).

The following linear utility function is applied for the economic criteria:

$$U_j(x_j) = \alpha \cdot x_j + \beta \tag{9}$$

where x_j = attribute: α = graph slope, negative for costs and positive for benefits; and the parameter β = utility value $U_j(x_j)$ for a null value of the attribute. A logistic utility function (Fig. 9) is adopted for the environmental criteria:

$$U_j\left(x_j\right) = \frac{e^{K_{bj}\cdot\left(x_{Mj}-x_j\right)}}{e^{K_{aj}} + e^{K_{bj}\cdot\left(x_{Mj}-x_j\right)}} \tag{10}$$

where K_{aj} and K_{bj} = function parameters; and x_{Mj} = maximum attribute value corresponding to a null utility for the *j* criterion.

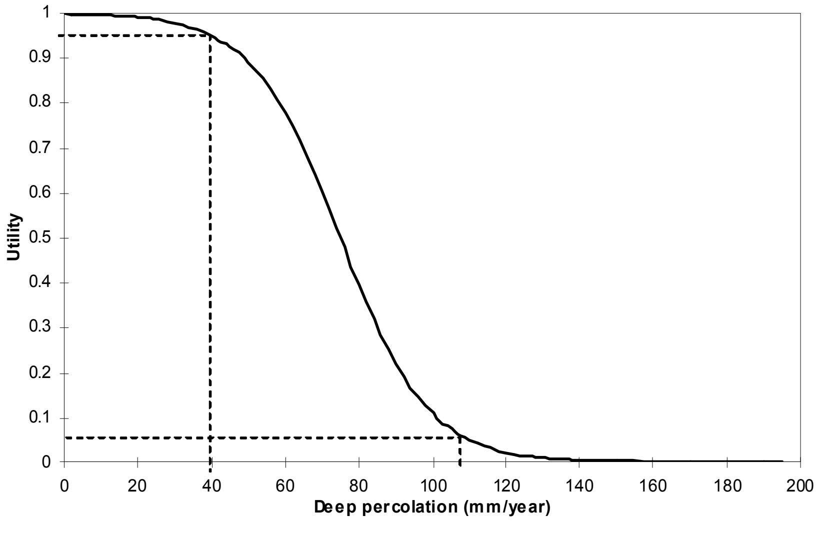

Fig. 8. Logistic utility function relative to deep percolation where x_a = 40 mm and x_b= 110 mm, and $U(x_a)$ = 0.95 and $U(x_b)$ = 0.05

To adjust this function (10) to user preferences, it is necessary to select the attribute values x_a and x_b that correspond to a very low and a very significant impact, e.g., such that $U(x_a)$ = 0.95 and $U(x_b)$ = 0.05, as shown in Fig. 8. Based on these values, and for a specific criterion, the parameters K_a and K_b are then calculated as follows (Janssen, 1992):

$$K_a = \ln\left[\frac{(1-U(x_a)).e^{K_b\cdot(\alpha_M - x_a)}}{U(x_a)}\right] \tag{11}$$

$$K_b = \frac{\ln\left[\frac{U(x_a)\cdot(1-U(x_b))}{(1-U(x_a))\cdot U(x_b)}\right]}{x_b - x_a} \tag{12}$$

The dominance preanalysis is a procedure to select the nondominated alternatives. For these alternatives do not exist any other feasible alternative that could improve the performance relative to any criterion without decreasing the performance of any other criterion. The multicriteria selection applies to those nondominated alternatives. The satisfaction preanalysis screens the alternatives set by selecting the user acceptable ones, i.e., those that for every criterion perform better than a minimum level required by the decision maker.

To apply the multicriteria methods, the user needs to assign priorities by selecting the weights λ_j that represent the relative importance of each criterion j as viewed by the decision maker. These can be directly defined by the decision maker or calculated by the Analytical Hierarquical Process (AHP) method (Saaty, 1990).

Two multicriteria methods may be applied: the composite programming (Bogardi & Bardossy, 1983) and the ELECTRE II (Roy & Boussiou, 1993; Roy, 1996). The composite programming is an aggregative multicriteria method that leads to a unique global criterion. It is a distance-based technique designed to identify the alternative closest to an ideal solution using a quasi-distance measure. This method allows the analysis of a multidimensional selection problem by a partial representation in a two dimensions trade-off surface.

The distance to the ideal point ($L_j = 1\text{-}U_j$) relative to each alternative a_k, is a performance measure of a_k according to the criterion j. The ideal point represents the point on the trade-off surface where an irrigation design would be placed if the criteria under consideration were at their best possible level. If this distance is short, this performance is near the optimum. The composite distance L is computed for each set of N criteria as

$$L = \left[\sum_{j=1}^{N} \lambda_j \cdot L_j^p \right]^{1/p} \tag{13}$$

where L_j = distance to the ideal point relative to criterion j; and p = balancing factor between criteria. Each composite distance corresponds to a distance-based average, arithmetic or geometric, respectively when $p = 1$ or $p = 2$. The balancing factor p indicates the importance of the maximal deviations of the criteria and limits the ability of one criterion to be substituted by another. A high balancing factor gives more importance to large negative impacts (a larger distance to the ideal point) relative to any criterion, rather than allowing these impacts to be obscured by the trade-off process.

The ELECTRE II is an outranking method that aims to rank alternatives. It is based on the dominance relationship for each pair of alternatives, which is calculated from the concordance and discordance indices. The concordance represents the degree to which an alternative k is better than another alternative m. A concordance index is then defined as the sum of weights of the criteria included in the concordance set relative to the criteria for which the alternative k is at least equally attractive as the alternative m. The discordance reflects the degree to which an alternative k is worse than alternative m. For each criterion from a discordance set, that includes the criteria for which alternative k is worse than m, the differences between the scores of k and m are calculated. The discordance index, defined as the largest of these differences, reflects the idea that, beyond a certain level, bad performances on one criterion cannot be compensated by a good performance relative to another criterion. The decision maker indicates the thresholds that are used to establish a weak and a strong outranking relationship between each pair of alternatives.

For every project of a given field (Fig. 4), SADREG produces a large set of alternatives as a result of numerous combinations of design and operation variables. As mentioned before, these alternatives are clustered by groups relative to different water distribution equipment and tail end management options. The multicriteria analysis allows the alternative selection for each group and the ranking and comparison of the groups of a given project. This analysis plays an important role on automatic management of large amount of data, screening the alternatives, removing those not satisfactory or dominated, and ranking and selecting the most adequate according to the user priorities.

3. Web-based DSS methodology

The Web DSS application is based on client-server architecture. It comprises a Web module and a simulation engine, which includes the simulation models of SADREG (Fig. 9). The Web module controls the simulation engine, creates the user interface, importing and showing numerical and graphical data. The architecture of DSS Web Server and Client are schematized in Fig. 10 and 11. PHP and C# languages are applied to achieve higher system flexibility, and to minimize client system requirements. The SQLServer is applied for database management, which allows a simultaneous connection of several users. The server is established by four component modules, each one responsible for a task (Jia & Zhou, 2005): (1) Communication – the interface with the Web applications using TCP/IP like transport way; (2) Logic – the control of execution and respective data flow; (3) Simulation – the computation of simulation models; and (4) Data abstraction – the isolation and optimization data model and data modifications.

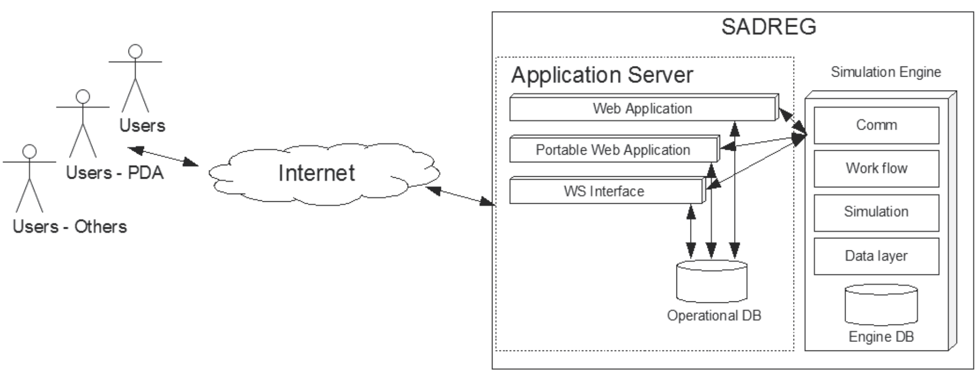

Fig. 9. Abstract system architecture

The application is multiuser, with properly warrant data protection among the several users. The user input data are provided to server that controls the simulation engine and return the output data to server that will be accessed by user. The software developed is based on first-in first-out philosophy, which uses a resources list that is being used and free up to the end of the simulation (Jia & Zhou, 2005). The communications with the server are performed in a first step of software development with TPC sockets, to avoid entropy. For normal system operation, a protection layer based on SSL protocol will be added for a better guarantee of communications security. The same procedure is adopted with the Web application that will use HTTPS connections. The protocol used in the communication with the server, without state and atomic operations, will be published to permit create other applications based on this service. The user does not interact directly with the simulation engine to shorten the time required to complete the tasks. When the user requests a simulation, the order remains in a waiting list until the simulation engine is available to process it. Then the produced results are recorded in the simulation data base, the user is notified and the output becomes available on the Web application.

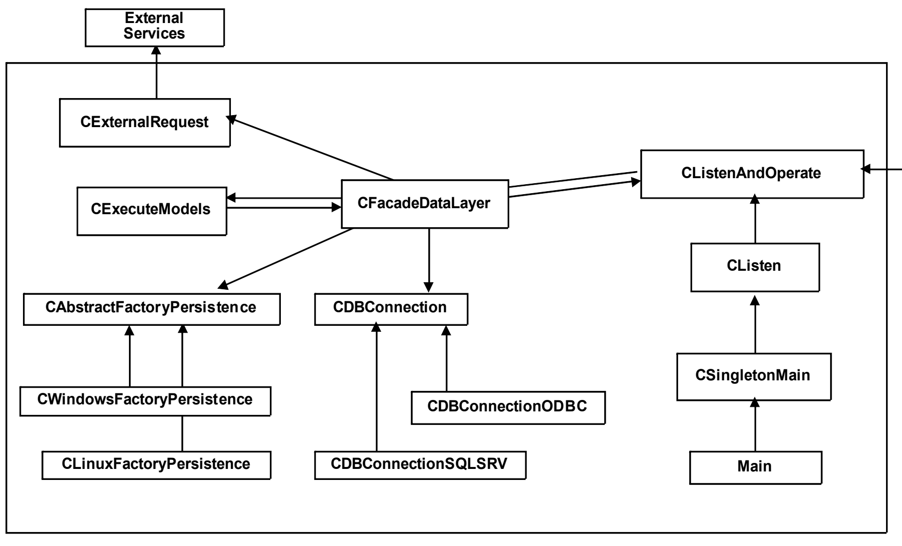

Fig. 10. Architecture of DSS Web Server

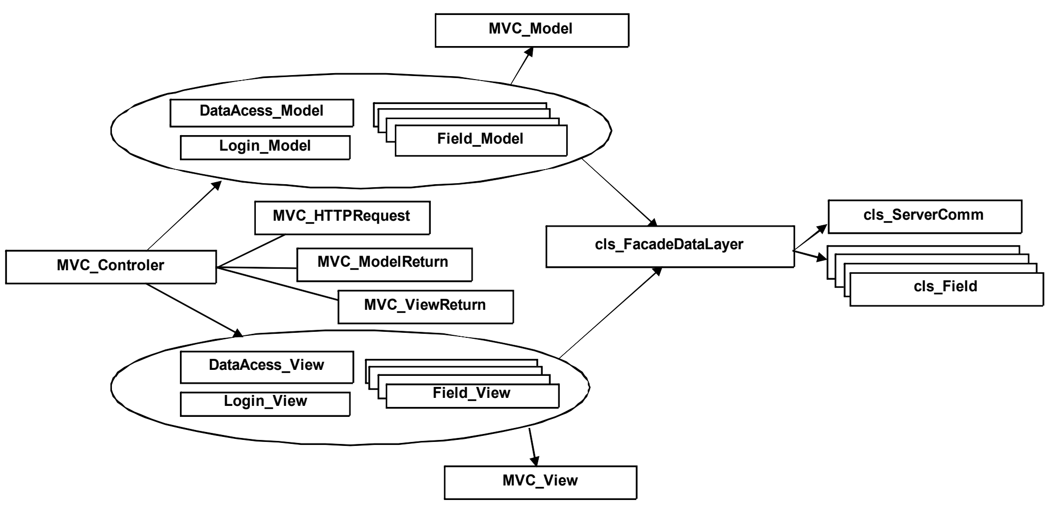

Fig. 11. Architecture of DSS Web Client

This approach confines the model relatively to Web system, allowing its reuse and maintenance without impact on system. This model could be transformed in a *stand-alone* application for off-line use. The database was designed to integrate all DSS information required, from agronomic, climatic and economic subjects. All records had specialized information to provide auditoria and controls of permissions, allowing the possibility to share data and experiences by groups of users. The access control to user data is guaranteed at level of server. In the server the data abstraction is provided by pattern AbstractFactory (Fig. 12) to guarantee without impact on models source code a platform change. The communications with server are made with TCP/IP sockets applying a protocol developed specifically. The use of norms like SOAP and WebServices will be included, in a higher layer, like a protection SSL layer, with a guarantee of security, without state and atomic operations, will be published to permit create other applications based on this service.

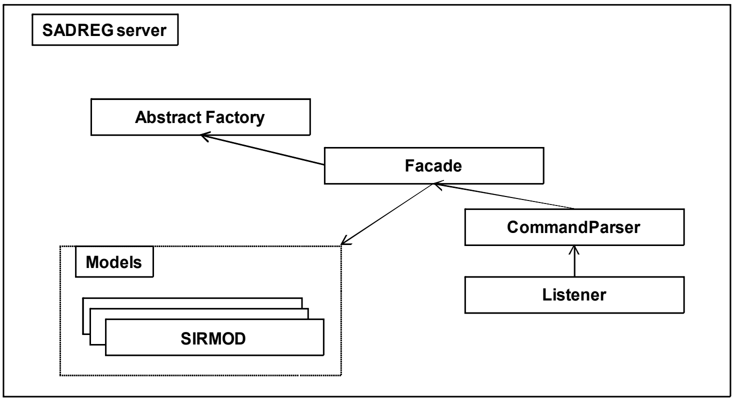

Fig. 12. Models integration on DSS Web server.

The interface includes a context online help, allowing a direct support to users. It was created a simple Web user friendly interface. The user may select the language of the interface. The system has available also a Web-service interface to integrate with other systems and a short Web version to be used with portable and limited equipments, such as PDA for field use.

4. Applying the DSS

The data flow and logic of the execution are represented in the diagram of Fig. 13. To access the application the user needs to register beforehand asked the system administrator, with the conditional access by keyword. The interface language is set in the attributes of the user, although this may change in a straightforward manner by clicking on the button.

4.1 Input data

The user can view the general options of the application, without change them, because these data are the responsibility of the administrator. These data include, for example, the technical characteristics of equipment for water supply, the classification of soils (example in Fig. 14), climatic stations and the curves of infiltration. These data will be accessed during the timely preparation of projects. In turn, the user data comprises its private information, which may have access to the group member's share with which the user has set permission. The field is the subject of spatial unit design, and its register, inserted in the field workspace, includes features such as location, soil type, and size and topography data (Fig. 15). A user can create multiple field workspaces, from a new record or copy of an existing one. Other user data refers to crops and unit costs, which may well be applied in different fields of the same user.

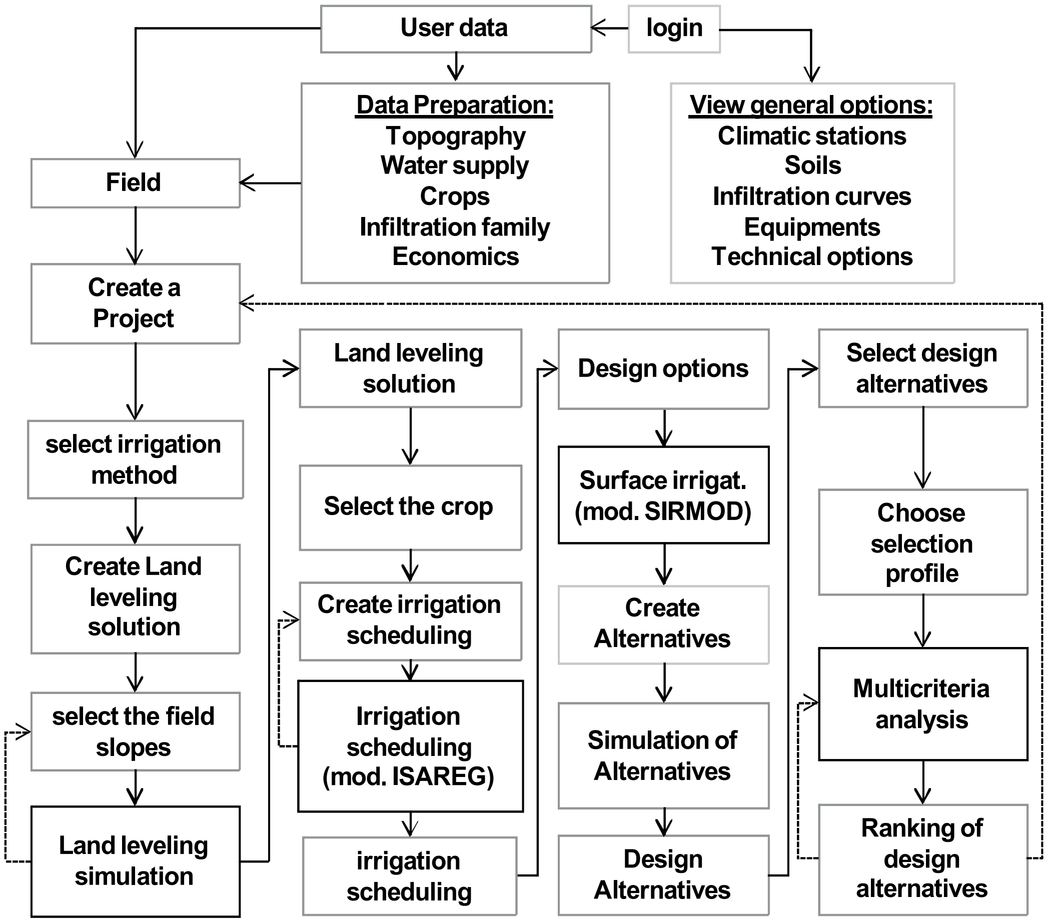

Fig. 13. Data and simulation flowchart

4.2 Projects

Once the user has completed the field data register, he(she) builds projects to create alternatives. Each project refers to a particular method of irrigation and a land leveling solution. This solution is obtained by simulation the land leveling, using the field topography of the parcel and the slopes selected by user. The user will have access to the simulation results, which included the volumes handled, the spatial distribution of the depths of excavation and fill and the estimated time of execution of work and its cost. Interactively, the user can do several simulations to find a solution that he(she) considers appropriate for the project.

In the next step, the user chooses a crop to be considered in the project within a list of options. The determination of the irrigation scheduling, i.e., the appropriate application depths and the irrigation dates along the crop period, is obtained with the ISAREG model. This calculation requires the application of climatic data from the region where the field is located, and information about the type of soil and crop characteristics. This process is also interactive with the user, because there are several possible solutions to these calendars. The user will then choose the one more appropriate to the project.

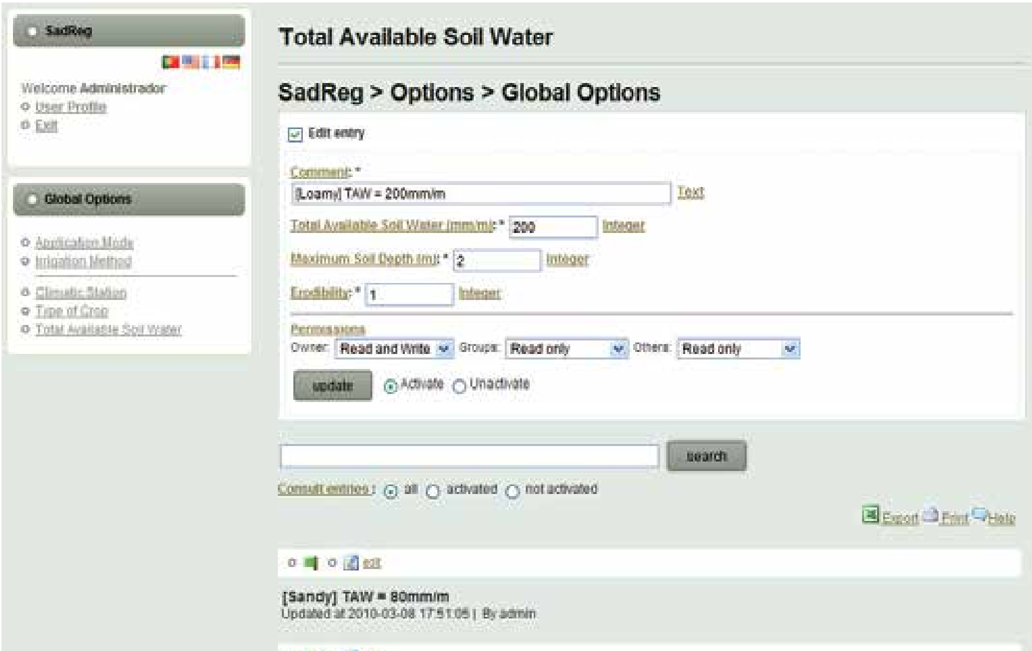

Fig. 14. Example of view access to general options data on Web interface (example of soil type)

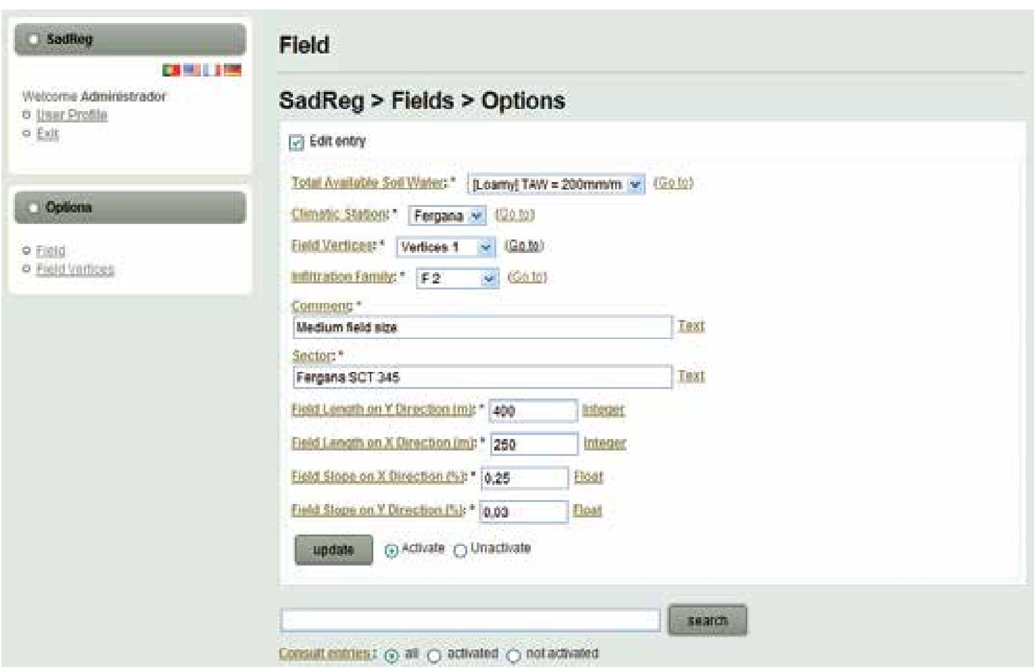

Fig. 15. Example of field input data on Web interface

4.3 Design options

The user sets the project options that will be applied in creating alternatives. These options relate to supply conditions, such as surge or continuous inflow, possible field subdivision in the longitudinal and cross directions, equipment for water distribution (e.g., gated pipes or canals), the flow conditions at the downstream end (e.g., open, closed or re-use), and the constraints in supplying water to the field (flowrate, hydraulic head, frequency). Then the application runs the model SIRMOD for hydraulic simulation of the process of irrigation or access to previously recorded results, if they exist in the database, and then proceeds to create alternatives. The user then accesses the results, refering the projects and groups (Fig. 16), view and analyses the alternatives developed (Fig. 17), and may remove them when they are unsatisfactory.

Fig. 16. Example of project results view on Web interface

4.4 Selecting alternatives

The next step is the selection of design alternatives through the module using multicriteria analysis (MCA). For this purpose the user must set the profile to apply for selection (Fig. 18), which is the set of multicriteria analysis parameters, such as the method, the value functions associated with the attributes, the decision criteria and corresponding weights defining the user priorities. The results will include the identification of effective alternatives, i.e., those that have enough quality to be selected, and the unsatisfactory or dominated, i.e., the ones that are not considered for the subsequent ranking of alternatives. This process is interactive with the user, which could generate new rankings when changing the profile selection.

Once this process is ended, the user has information to make the decision, thus choosing the alternative which he(she) prefers to see implemented, or, the user may seek for another solution to the problem by creating a new project, thus changing any of the options made. This iterative process is controlled by the user, resulting in increased number of design alternatives, which may be all together analyzed and ranked by the MCA module.

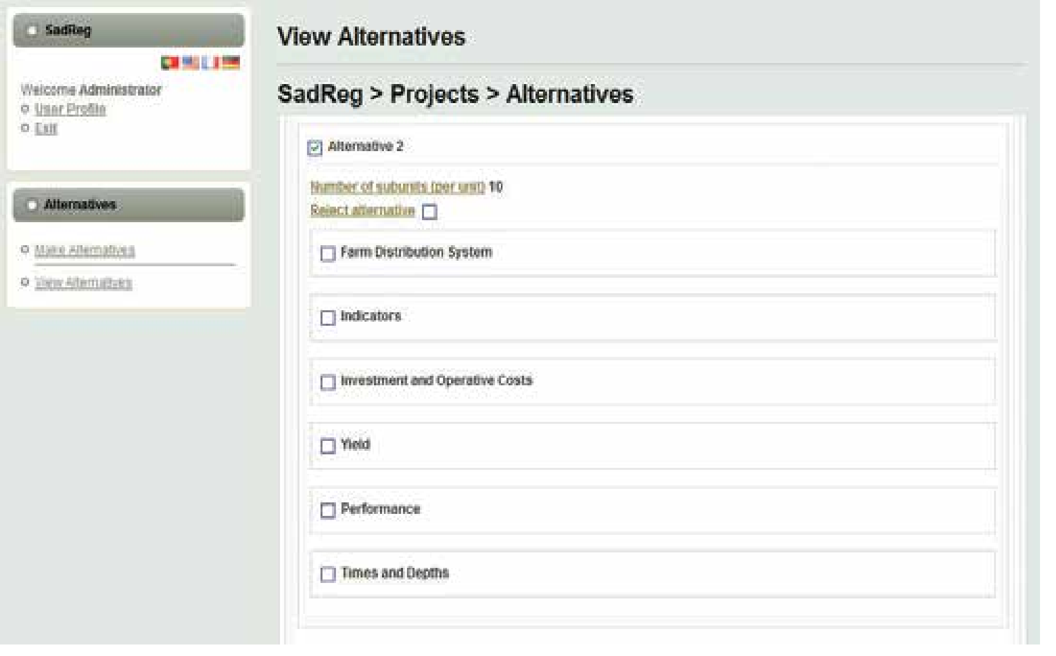

Fig. 17. Example of alternative view on Web interface, showing the main results itens

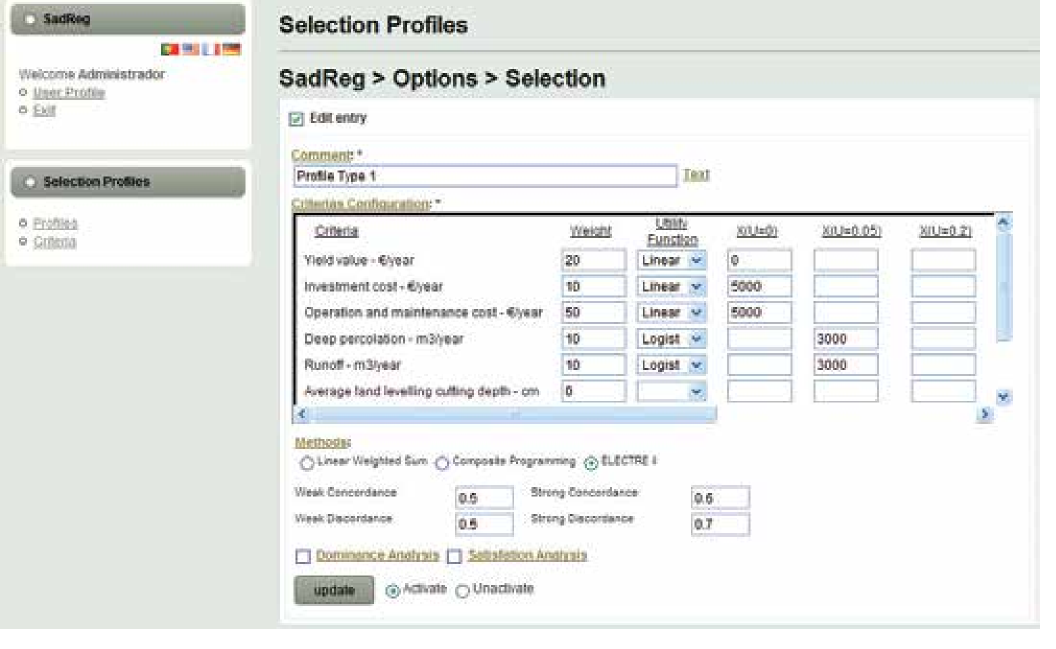

Fig. 18. Example of selection profile definition on Web interface

5. Conclusion

Appropriate design of surface irrigation systems requires a complex manipulation of data, models, and decisions. The multicriteria approach integrated in a DSS enables us to solve that complexity while creating and ranking a large number of design alternatives. The DSS SADREG has shown to be an appropriate tool for (1) generating design alternatives associated with attributes of technical, economic, and environmental nature; (2) handling and evaluating a large number of input and output data; (3) evaluating and ranking design alternatives using multicriteria analysis where criteria are weighted according to the priorities and perception of the designer and users; and (4) providing an appropriate dialogue between the designer and the user.

The Web-based DSS allows a simple way to support surface irrigation designers to improve the project procedures, particularly in the world water scarcity areas where the surface irrigation requires improvements and the expert technical support is more incipient. With a simple Web user friendly interface, with several optional languages and an online help, this tool would contribute to an effective support to enlarge the knowledge of surface irrigation, its design procedures and field practices.

In conjunction with web application SADREG, tools are available towards the resolution of specific problems such as land leveling, pipe sizing and economic calculation, as well as documents on good equipment and irrigation practices. The application maintenance and user support is the responsibility of the multidisciplinary team that developed the software, with computer engineers and agronomists, the objective being that of a dynamically adjusts the system to answer the most frequent difficulties and new challenges more exciting. This software is available on http://sadreg.safe-net.eu Web site.

6. Acknowledgment

The support of CEER - Biosystems Engineering (POCTI/U0245/2003) is acknowledged. Studies referred herein are developed in the framework of the research project PTDC/AGR-AAM/105432/2008 founded by Portuguese Foundation for Science and Technology.

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Part 4

Applications in Spatial Management

16

A Decision Support System (FMOTS) for Location Decision of Taxicab Stands

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1. Introduction

Taxi systems and their municipal organization are generally problem area in the metropolitan cities of developing countries. The locations of taxicab stands can be market-oriented and can cause chaos. A decision support system is needed for the related agencies to solve such kind of problems. In this chapter, a decision support system for taxicab stands that can be used in any metropolitan area or municipality is presented. The study attempts to create a scientific basis for decision makers to evaluate the location choices of taxicab stands in major cities with the help of GIS and fuzzy logic.

Taxi, which has been worldwide used since the 19th century, is an indispensable component of urban transport. Compared to other modes of transport, taxi has a relative advantage with the comfort and convenience that it provides 24 hours a day to its users. However, it is criticized because of its low occupancy rates and traffic burden it loads on urban streets.

Taxicab stands offer a viable service by providing an identifiable, orderly, efficient, and quick means to secure a taxi that benefits both drivers and passengers (Giuliani et.al, 2001). Stands are normally located at high-traffic locations such as airports, hotel driveways, railway stations, subway stations, bus depots, shopping centers and major street intersections, where large number of passengers are likely to be found. The choice of location for taxicab stands depends only on legal permissions. From the legal authorities' side, there is no evidence of taking some scientific criteria into account while giving the permission. The entrepreneurs willing to manage a taxicab stand have limitless opportunities to select any point on urban land. These free market conditions cause debates on location choices of taxicab stands.

In some cities, taxi companies operate independently and in some other cities, the activity of taxi fleets is monitored and controlled by a central office, which provides dispatching, accounting, and human resources services to one or more taxi companies. In both systems, the optimum organization of taxi companies on urban space is a problem. The taxi company in the system should provide the best service to the customer, which includes reliability and minimum waiting time.

As private entrepreneurs, taxi companies tend to locate in some certain parts of the city, where they believe they can find more passengers. The decision makers, on the other hand, should find an optimum between taxi companies' demands and the city's real needs. They would rather improve the effectiveness of taxicab stands as a tool to reduce congestion, while improving convenience for passengers and taxi drivers.

There are two major obstacles confronting the decision makers, who try to evaluate location choices of taxi companies: The first is about the scale of the analyzed area. Taxicab stands are the problem of major cities and managing data in this scale requires specific methods. In this study, GIS based service area analyses helped to define the area, which can be accessed from taxicab stands within a psychologically accepted time limit (and critical areas that are out of service range).

The second problem of the decision makers is the lack of a certain measure for this specific decision. An alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience, is necessary. Fuzzy logic is an organized and mathematical method of handling inherently imprecise concepts. It has proven to be an excellent choice for many control system applications since it mimics human control logic. It uses an imprecise but very descriptive language to deal with input data more like a human operator.

This study appeared as a response to the demands of the municipalities and the taxi associations in Turkey. The research is focused on both issues: how well the existing taxicab stands are located and where the most appropriate places for the incoming demand should be. The pioneering steps of the study have already been presented in a scientific paper (Ocalir, et. al, 2010). An integrated model of GIS and fuzzy logic for taxicab stand location decision is built. GIS were used for generating some of the major inputs for the fuzzy logic model. The location decisions of taxicab stands in big cities, where organizational problems of taxicab stands slow down a better quality of service, have been examined by this integrated model and their appropriateness has also been evaluated according to the selected parameters. With the fuzzy logic application, evaluation of the existing taxicab stands is done and decision for new taxicab stands is given. The equations are obtained by artificial neural network (ANN) approach to predict the number of taxicab stands in each traffic zone.

In the next section, background information for the tools used (the integration of GIS and fuzzy logic) is provided. It is followed by the introduction of a decision support system, the Fuzzy Logic Model for Location Decisions of Taxicab Stands (FMOTS), with a case study in Konya (Turkey). The applicability of the FMOTS model for big cities for the selected case study Konya (Turkey) with a population of approximately 2000000 will be examined.

The taxicab stand allocating problem came in agenda as taxi use gained importance in recent years parallel to the development of university and its facilities. Having sprawled to a large area in a plain, Konya accommodates different sustainable transportation systems. FMOTS should be applied to this city for understanding supply and demand of taxicab stands. Advanced GIS techniques on networks, fuzzy logic 3D illustrations and artificial neural network equations for new demands will be given for taxicab stands in Konya, Turkey. The paper closes with conclusions.

2. Incorporating fuzzy logic into GIS operations

Defining service areas is an important geographical application (Upchurch et.al, 2004) and with use of GIS, some studies have been performed. The service area analysis of transit services by GIS has been performed in O'Neill (1995) and Horner and Murray (2004)'s researches. In O'Neill's (1995) study, by defining a transit route's service area, walking distance and travel time were used as acceptable limits for transit users. Another study with GIS was performed (Walsh et al., 1997) for exploring a variety of healthcare scenarios, where changes in the supply, demand, and impedance parameters were examined within a spatial context. They used network analysis for modeling location/allocation to optimize travel time and integrated measures of supply, demand, and impedance.

Fuzzy systems, describe the relationship between the inputs and the output of a system using a set of fuzzy IF-THEN set theory (Zadeh, 1965). The classical theory of crisp sets can describe only the membership or non-membership of an item to a set. Fuzzy logic, on the other hand, is based on the theory of fuzzy sets, which relates to classes of objects with unsharp boundaries, in which membership is matter of degree. In this approach, the classical notion of binary membership in a set has been modified to include partial membership ranging between 0 and 1.

Fuzzy Logic will be increasingly important for GIS. Fuzzy Logic accounts a lot better to uncertainty and impreciseness in data as well as to vagueness in decisions and classifications than Boolean Algorithms do. Many implementations have proved to get better output data. In the recent years, fuzzy logic has been implemented successfully in various GIS processes (Steiner, 2001). The most important contributions are in the fields of classification, measurement, integrated with remote sensing (Rashed, 2008), raster GIS analysis and experimental scenarios of development (Liu and Phinn, 2003), risk mapping with GIS (Nobre et al., 2007; Ghayoumian, et.al,2007; Galderisi et.al, 2008), ecological modeling (Malins and Metternicht, 2006; Strobl, et.al, 2007), qualitative spatial query (Yao and Thill, 2006), data matching (Meng and Meng, 2007), site selection (Alesheikh et.al, 2008; Puente et al., 2007) and finally in road network applications (Petrik et al., 2003).

In the scientific literature, there are many studies, which implements fuzzy logic onto some transport problems. Some of these studies focus on transport networks. Choi and Chung (2002) for instance, developed an information fusion algorithm based on a voting technique, fuzzy regression, and Bayesian pooling technique for estimating dynamic link travel time in congested urban road networks. In another study (Chen et.al, 2008) used fuzzy logic techniques for determining the satisfaction degrees of routes on road networks. Ghatee and Hashemi (2009) studied on a traffic assignment model in which the travel costs of links depend on their congestion. Some other studies are on signalized junctions, which are closely related with queuing theory: Murat and Baskan (2006) developed a vehicle delay estimation model especially for the cases of over-saturation or non-uniform conditions at signalized junctions. Murat and Gedizlioglu (2005) developed a model for isolated signalized intersections that arranges phase green times (duration) and the other phase sequences using traffic volumes. In another study, Murat and Gedizlioglu (2007) examined the vehicle time headways of arriving traffic flows at signalized intersections under low traffic conditions, with data from signalized intersections.

The model brings some innovation by implementing fuzzy logic to a transport problem for an area based analysis. Point and linear analyses could not bring solutions to the mentioned problem. An area-based analysis on traffic zones is required to give transportation planning decisions about an urban area with respect to some land use data such as employment and population. An analytic process and fuzzy logic functions have been considered for the evaluation of model stages. The fuzzy logic permits a more gradual assessment of factors. The implementation of the whole model requires a big amount of information, so the model validation has been done only at the traffic zone level.

Increasing awareness about the need of designing and performing new development and site selection models has made necessary the implementation of many more new factors and parameters than those presented in traditional location models, which results major complexity for the decision making processes. That is the reason why in this research a GIS platform has been used to spatially analyze the service area of taxicab stands, bearing in mind the hierarchical structure of location factors and considering the fuzzy logic attributes. The new proposed methodology gathers the necessary tools: GIS software, to organize the datasets and to apply geo-processing functions on a clear interface; Fuzzy Logic software, to define and execute the evaluation methodology and to carry out the evaluation process. The creation of an expert system based on GIS software allows the user to query the system using different groups of criteria. This makes the planning process for the decision makers easier.

The fuzzy logic gives the system a type of evaluation closer to the complex reality of urban planning. The FMOTS is a helpful tool based on a multi-criteria evaluation methodology. Location attributes are an important source of information for empirical studies in spatial sciences. Spatial data consist of one or few cross-sections of observations, for which the absolute location and/or relative positioning is explicitly taken into account on the basis of different measuring units. Using fuzzy logic operators for modeling spatial potentials brings more sophisticated results because the information about membership values gives a more differentiated spatial pattern. A lot of the events, which are analyzed using spatial analysis techniques, are not crisp in nature. To analyze such events, it is common to commute fuzzy data into crisp data, which stands for a loss of information (Wanek, 2003).

GIS operations for data interpretation can be viewed as library of maps with many layers. Each layer is partitioned into zones, where the zones are sets of locations with a common attribute value. Data interpretation operations available in GIS characterize locations within zones. The data to be processed by these operations include the zonal values associated with each location in many layers (Stefanakis et al., 1996). A new class of data with measurement operations in this field that correspond to the area and length characterizing the traffic zones is computed. The transformation of these values is accomplished through fuzzification. This study gives a methodology to quantify taxicab stand complexity using fuzzy. In essence fuzzy logic opens the door to computers that understand and react to the language and the behavior of human beings rather than machines (Narayanan et al., 2003).

3. System design

In this study, an expert system based on fuzzy logic with related modelling software and the GIS software is developed. The model permits us generate digital suitable locations and can also be used to evaluate existing taxicab stands from a sustainable point of view. It is indeed a decision support system, which is an integrated model of GIS and fuzzy logic applications. The design of the proposed model is given in Fig. 1. After the definition of the problem, GIS application begins. The tabular data, together with geo-referenced data, are processed by GIS applications. However, some outputs of this phase needs some further process with a fuzzy logic application. In this fuzzy logic application, in addition to some former tabular data, the amount of roads which have (AND don't have) adequate taxi service, are calculated by network analysis tool of GIS and used as basic inputs.

The location analysis of the taxicab stands in Konya begins with GIS. The first level of a GIS study is the database creation process, which is necessary for network analysis. Some points should be noticed before dealing with the networking database, such as the data structure, data source and the consistency of the database.

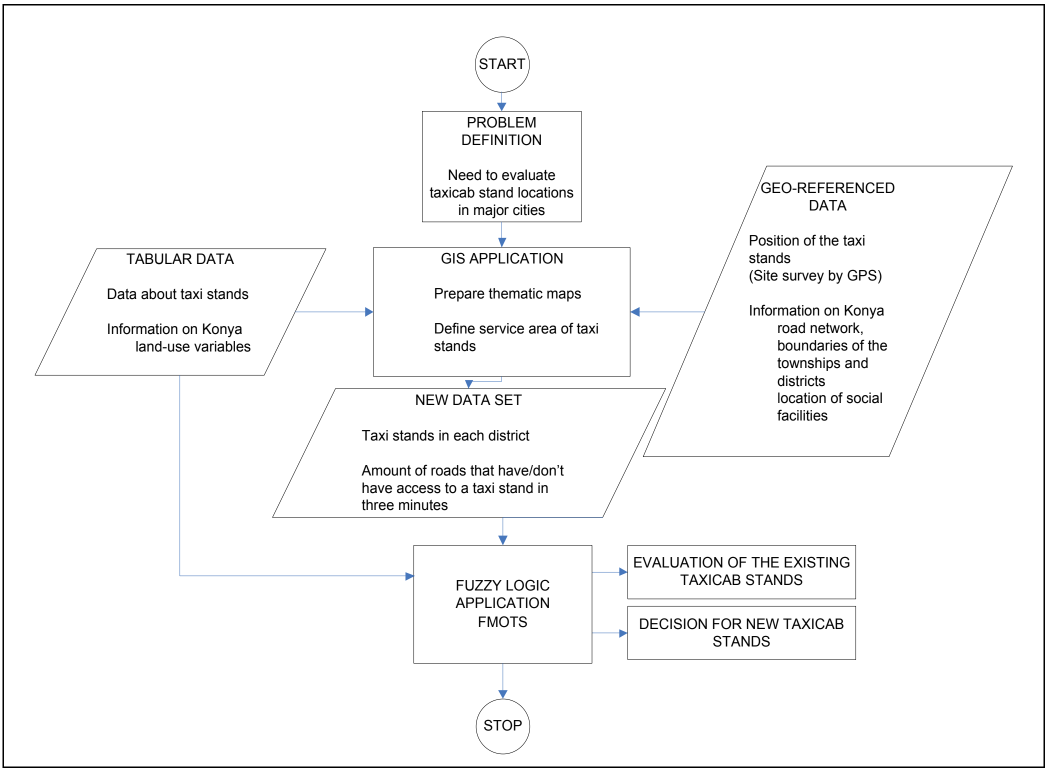


Fig. 1. The design of the decision support system

The geo-referenced data are grouped as spatial and descriptive data. Spatial data determine location, form and relationships with other features. The data of the location of taxicab stands all over Konya and the road network map have been received from a GIS software provider in Turkey (Basarsoft) as a contribution to our study. The spatial data collected for this study are: the current road network for the whole city, the district boundaries, locations of the social facilities and the locations of taxicab stands. Descriptive data are listed on the database. The database includes traffic directions and average speeds. Traffic zones are overlaid onto the road network. The data related to the traffic zones contains employment, area and population information and have been received from Konya Municipality for this study. These data are current names of the roads, the districts, population of the districts, traffic zones, car ownerships and the names and the addresses of taxicab stands.

Traffic zones are generally used as planning units for urban transportation planning processes. Many thematic maps were produced according to these geo-referenced data, such as population map, the number of taxis in the taxi stands with population, matched and unmatched taxicab stand locations. Some comparisons among the districts according to the number of taxicab stands are made. The GPS was calibrated in the most accurate way. All projections were set to UTM (Universal Transverse Mercator) and WGS84 reference systems, zone 36 referring to Konya. No overlaying and accuracy problems appeared for overlaying operations with the same projection and reference system in the metropolitan scale.

The other data about road network include directions as two-ways and one-way and speed limits. The data were compiled in GIS environment together with population, district boundaries and urban social facilities. These data were used as the criteria for the site selection of taxicab stands. The results were matched with the spatial data and overlaid with districts.

The accessibility and service area analyses were produced by network analysis tool of GIS. The road network of Konya, including all updated directions, district borders and the location of taxicab stands are overlaid as thematic maps. A psychological threshold of 3 minutes is accepted for taxi users to have access to any taxi. Service area analysis of 53 taxicab stands was performed for each of the stands in 3 minutes drive time according to the road network map. With the help of an additional network analysis tool, travel time was specified in a problem definition dialog. The defined service area and the network according to the given travel time (3 minutes) were displayed as cosmetic layers in the view. These cosmetic layers were added onto one by one and then they were turned to a thematic layer as 3 minute network from the location of taxicab stands (Fig. 2). A geodatabase was built showing the lengths of roads within and outside the service area. The obtained data were used as inputs of a fuzzy logic application.

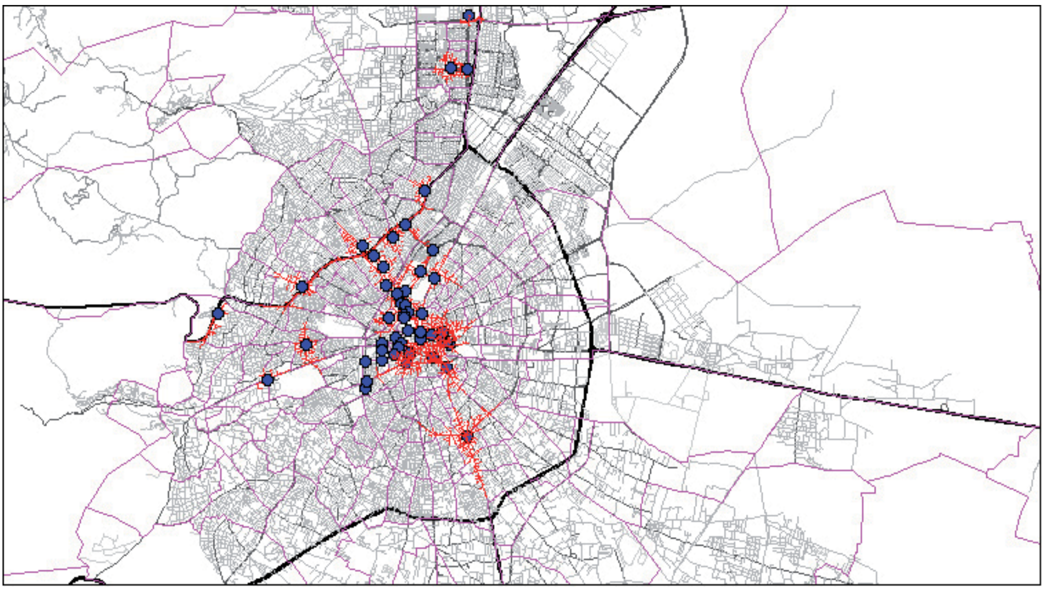


Fig. 2. The road network and three minutes psychological threshold (in red) for the accessibility of existing taxicab stands

With the fuzzy logic application, evaluation of the existing taxicab stands is done and decision for new taxicab stands is given. The equations are obtained by artificial neural network (ANN) approach to predict the number of taxicab stands in each traffic zone.

4. Background information on Konya

The area of interest is Konya, a big to medium size city in Turkey. The population of Konya by the year 2008 is 1969868 (TUIK, 2008). There are 434000 vehicles of which 185000 are cars by the year 2009 (TUIK, 2009). Total road network is 1060 km and 53 taxicab stands are determined in the field study. Land-use data are obtained from the Konya Municipality and the company Basarsoft for the year 2009. Although there are 213 districts in Konya, 99 of them, which are close to the central areas, are included in the FMOTS model.

City centre is composed of two adjacent parts, the traditional and the modern centres. The development is in industrial areas located in the northern and the north eastern parts of the city. The dense settlements are in the north western parts of Konya. Population in these districts are expected to increase in the following years. In the northern part of the city, an important university campus is located. The southern, the south-eastern and the eastern parts of the city are lower-density settlements .

Bicycle is an important mode of travel in Konya. The flat structure of the city supports bicycle networks. However, developments in the recent years have brought a more intensive use of motorised vehicles.

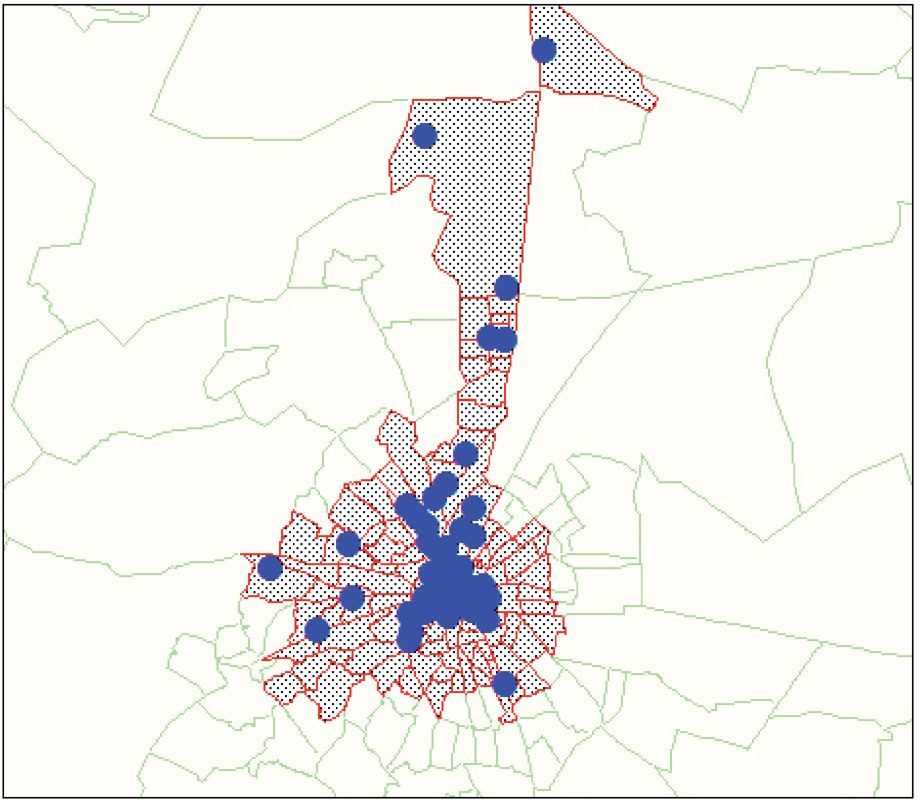


Fig. 3. The selected urban districts (esp. city center) which are included in the study and the locations of existing taxicab stands

There are no restricted conditions about site selection of taxicab stands in Konya. A fuzzy model is developed to build up a decision support system for decision makers.

5. The Fuzzy Model of Taxicab Stands (FMOTS)

For the FMOTS operation, 5 parameters, which may influence the optimum number of taxicab stands, have been defined (Fig.4). The first two of them, employment density

(Emp/km²) and population density (Pop/km²), are related with the urban morphology and describe the patterns of land use. The third parameter is the car ownership level (PCP), which is accepted as an indicator of the income level. The fourth and fifth parameters (ROSA and RWSA), the amounts of roads within and out of taxicab stands' catchment area, which are limited to 3 minutes as a psychological threshold, are the supply and the potential of taxi service respectively. The last two parameters have been determined by GIS. The proposed model is suggested to be a useful support tool for decision makers for defining the optimum number of taxicab stands especially in the newly developed regions and zones. It is assumed that each taxicab stand is available to supply necessary number of taxis when needed.

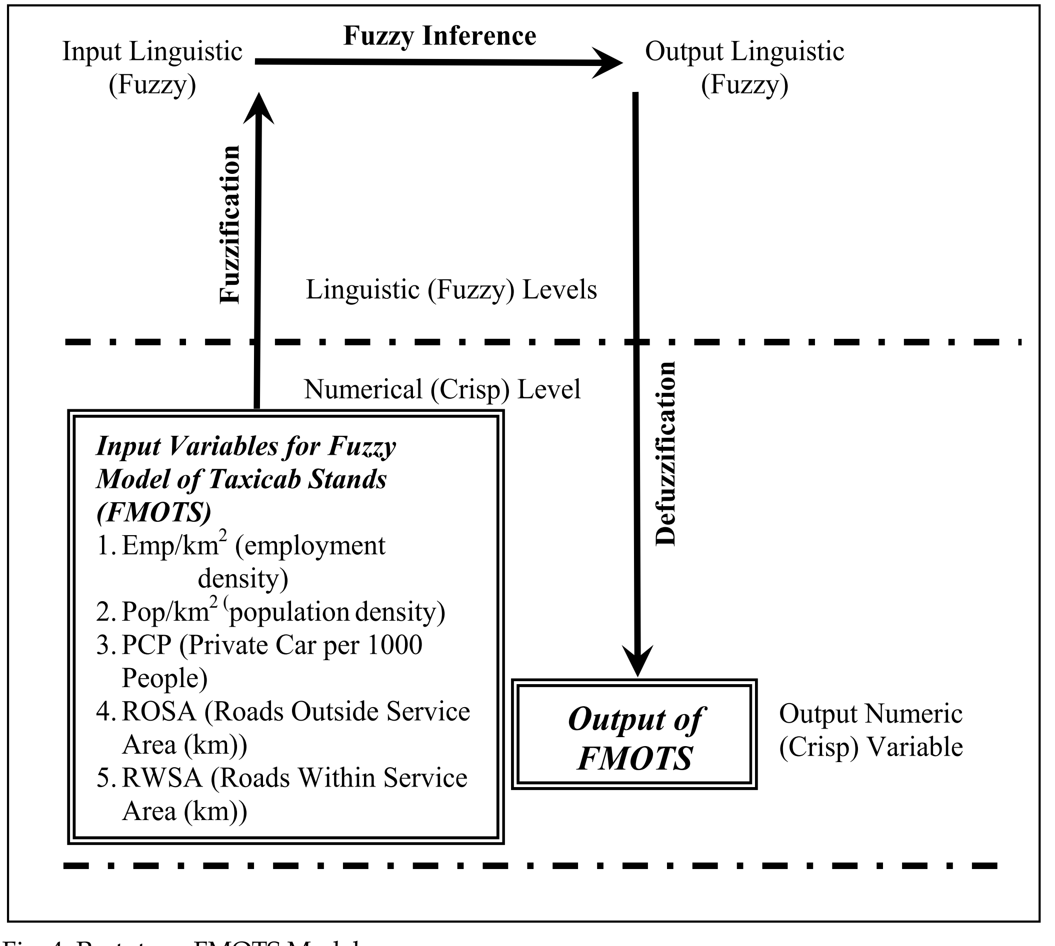


Fig. 4. Prototype FMOTS Model

Triangular membership functions have been used extensively in different applications because of their simplicity. A triangular membership function can be defined by a triplet (ϕ_1, ϕ_2, ϕ_3) , as shown in Fig 5. The membership function for a triangular membership function is defined as:

$$\mu(x) = \begin{cases} 0, & x \langle \phi_1 \\ \dfrac{(x-\phi 1)}{(\phi_2-\phi_1)} & \phi_1 \le x \le \phi_2 \\ \dfrac{(\phi_3-x)}{(\phi_3-\phi_2)} & \phi_2 \le x \le \phi_3 \\ 0, & x \rangle \phi_3 \end{cases}$$

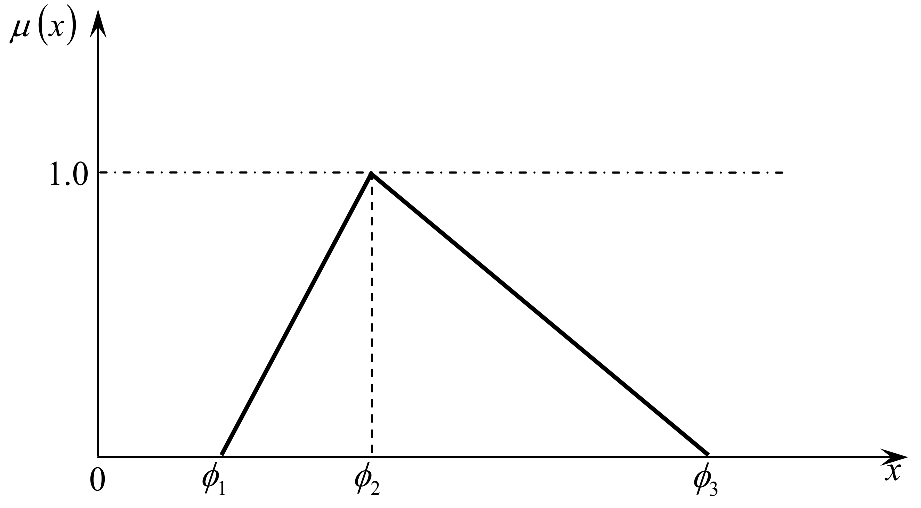
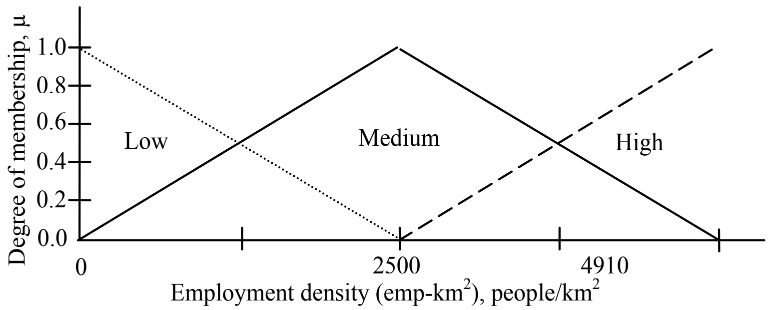


Fig. 5. Triangular Membership Function

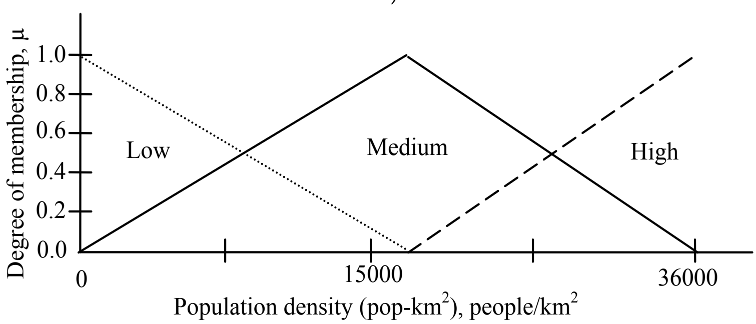
In FMOTS, each of the input parameters has been defined by three fuzzy linguistic terms: low, medium and high. The "medium" term was considered to be the mean value of the data set and, therefore, is a single point value. Based on these concepts of the data classification, membership functions were determined for employment density (Fig 6-a), population density (Fig. 6-b) and private car ownership (Fig. 6-c). Applying a similar method of data classification, membership functions were determined for the amounts of road out of service area (Fig.6-d) and amount of roads within service area (Fig. 6-e) from GIS analysis.

A triangular membership function is therefore used (Fig 6 a-e). The output parameter, on the other hand, is consisted of five linguistic terms: very_low, low, medium, high and very_high (Fig 6-f).

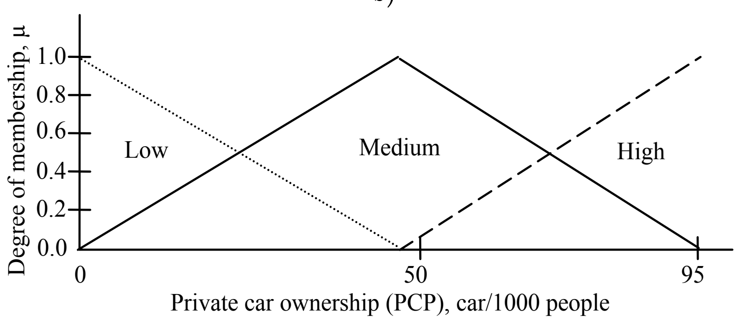
By creating a rule base for the FMOTS, the available data are used in addition to experts' knowledge. The experts are specialized in traffic and transport engineering and city and regional planning. By FMOTS, for each of the 5 input parameters, 3 linguistic terms are defined, which makes a total number (3^5 = 243) rules. However, in the model, 189 meaningful rules have been used. In Table 1, a part of the rule base is seen.


Degree of membership, μ
1.0
0.8
0.6
0.4
0.2
0.0
Low
Medium
High
0
2500
4910
Employment density (emp-km2), people/km2

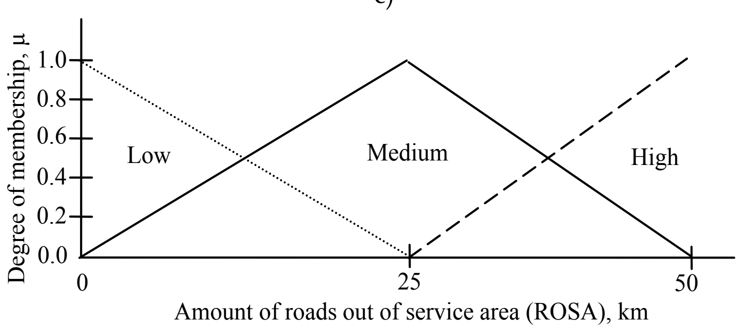
a)


Degree of membership, μ
1.0
0.8
0.6
0.4
0.2
0.0
Low
Medium
High
0
15000
36000
Population density (pop-km2), people/km2

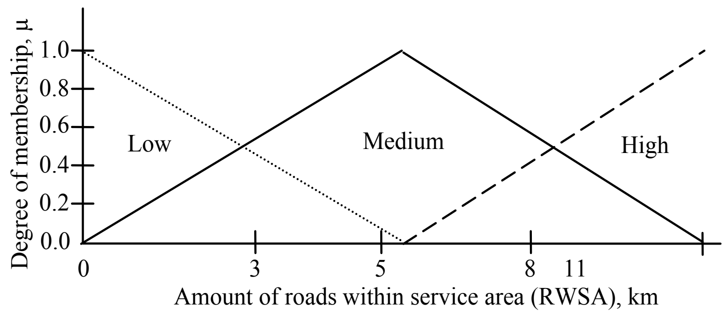
b)


Degree of membership, μ
1.0
0.8
0.6
0.4
0.2
0.0
Low
Medium
High
0
50
95
Private car ownership (PCP), car/1000 people

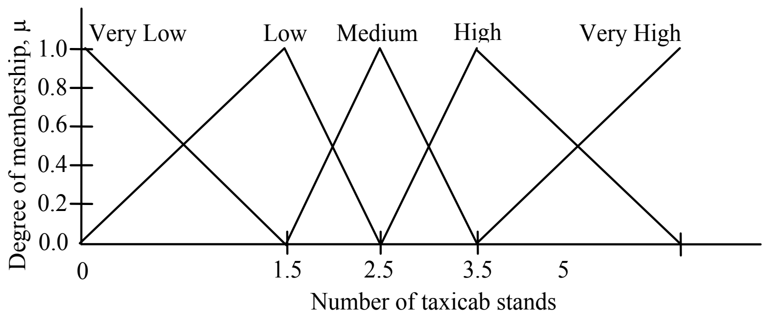
c)


Degree of membership, μ
1.0
0.8
0.6
0.4
0.2
0.0
Low
Medium
High
0
25
50
Amount of roads out of service area (ROSA), km

d)



e)



f)

Fig. 6. Membership function of input parameters (a-e) and output parameter (f)

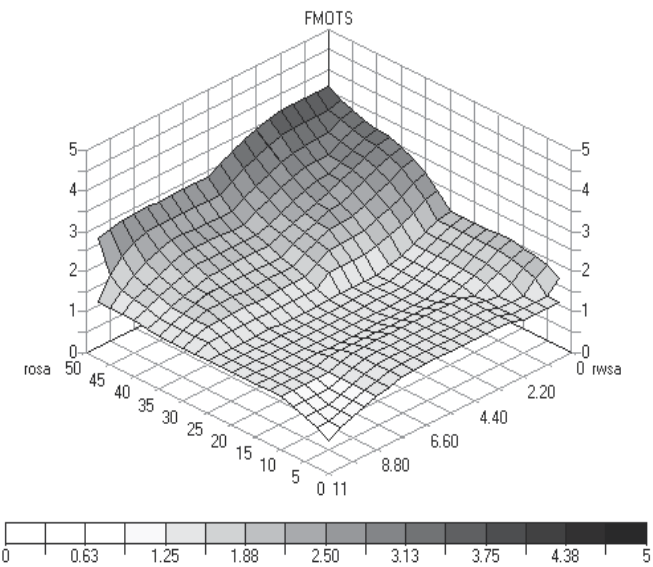
	If					Then
Number of the rule	Emp/km2	Pop/km2	Private Car per 1000 Persons (PCP)	Roads Outside Service Area (km) (ROSA)	Roads Within Service Area (km) (RWSA)	FMOTS
1	low	low	low	low	medium	very_low
2	low	low	high	low	medium	medium
3	medium	medium	medium	low	medium	medium
4	high	high	medium	large	low	very_high
5	medium	medium	high	high	low	medium

Table 1. A part of the rule base of the FMOTS

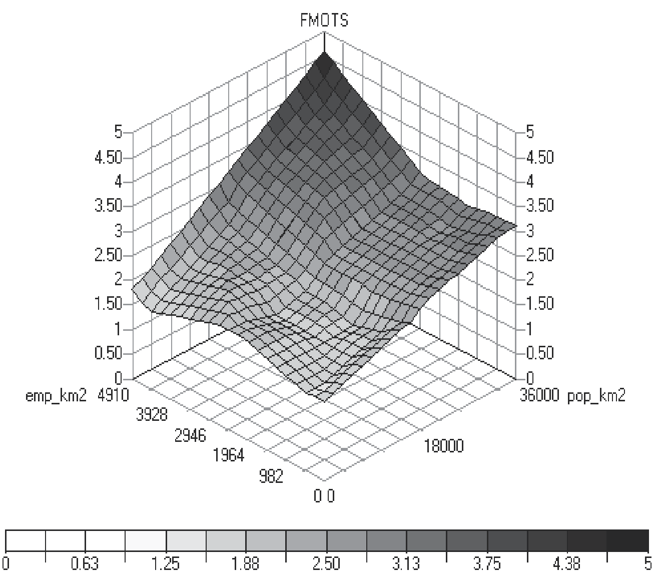
By developing FMOTS, a fuzzy logic expert system software has been used. In the model, CoM defuzzification mechanism has been managed. No weightings were applied, which means no rule was emphasized as more important than others. In this phase, a crisp value is achieved by defuzzification of the fuzzy value, which is defined with respect to the membership function. In other words, FMOTS defines the necessary number of taxicab stands for each zone, with respect to the input parameters.

5.1 Findings and comparisons

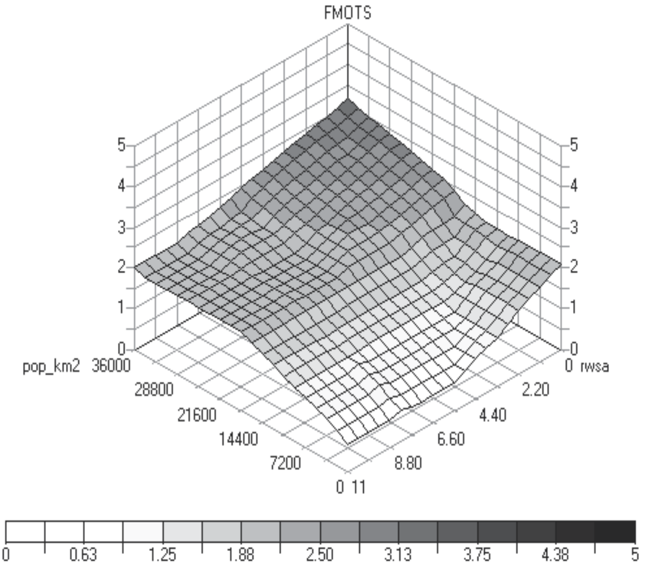
In this study, some findings are reached. In Fig.7, some main findings of the study are presented in 3D graphics. As seen in the figure, the parameter combinations have different influences on FMOTS.



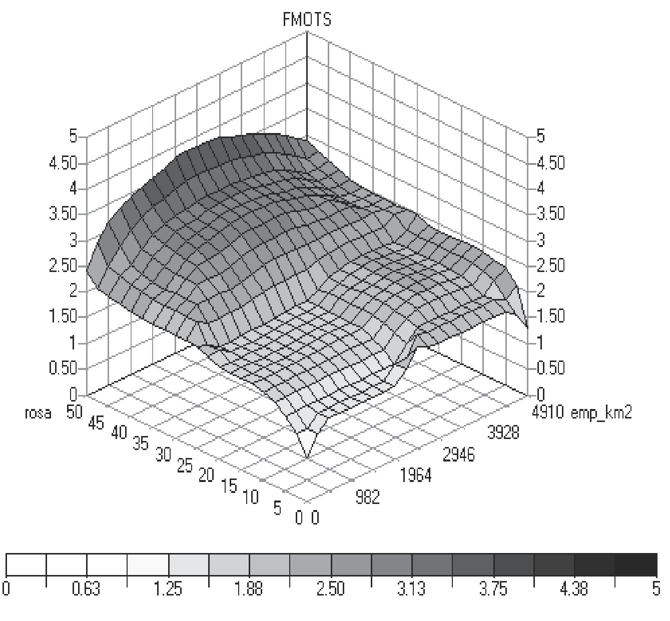
(a)



(b)



(c)



(d)

Fig. 7. Three dimensional representation of some selected variables on FMOTS: (a) RWSA–ROSA relationship; (b) Emp/km2-Pop/km2 relationship; (c) RWSA-Pop/km2 relationship; (d) ROSA-Emp/km2 relationship.

In Fig.7-a, with an increase of roads within accessed area and an increase of roads outside accessed area, an increase in necessary taxicab stands is represented. In the researched area, in the worst condition (ROSA=50 and RWSA= 0) the number of maximum taxicab stands is 4.
In Fig.7-b, population and employment potentials have a strong influence on the number of taxicab stands. Increase of both of these inputs increase also the number of necessary taxicab stands.
In Fig 7-c, increase of population density, together with a decrease in roads within service area decrease the number of necessary taxicab stands in that zone. A low population density together with a high level of roads within accessed area decrease the number of necessary taxicab stands in that zone.
In Fig. 7-d, the relationship between the employment density and the amount of roads without service area is demonstrated. In the model, if the amount of roads without service area exceed 25 km, the need for taxicab stands increase in that area. For a population density of 3000 people per km^2 and for maximum amount of roads outside accessed, 4 taxicab stands are needed.

6. Conclusions

In this study, an integrated model of GIS and fuzzy logic, FMOTS, for taxicab stand location decision is used. The model is based on fuzzy logic approach, which uses GIS outputs as inputs. The study brings some innovation by implementing fuzzy logic to a transport problem for an area based analysis, different from the others that focus on networks and queuing theory.
The model for location decisions of taxicab stands brings an alternative and flexible way of thinking in the problem of a complex set of parameters by integrating a GIS study and fuzzy logic.
FMOTS gives some results to evaluate the necessary number of taxicab stands in traffic zone level, which are consistent with the observations of the planners.
The scale of the analyzed area requires specific methods to compute the data, such as the areas which do not have adequate taxi service. GIS based service area analyses helped to define the area, which can be accessed from taxicab stands within a psychologically accepted time limit (and critical areas that are out of service range). The obtained data were useful in fuzzy operations.
FMOTS addresses many of the inherent weaknesses of current systems by implementing: a) fuzzy set membership as a method for representing the performance of decision alternatives on evaluation criteria, b) fuzzy methods for both parameter weighting and capturing geographic preferences, and c) a fuzzy object oriented spatial database for feature storage. These make it possible to both store and represent query results more precisely. The end result of all of these enhancements is to provide spatial decision makers with more information so that their decisions will be more accurate.
The location decisions of taxicab stands in Konya have been examined by this integrated model and their appropriateness has been evaluated according to the selected parameters. Despite lack of useful data in some newly developed areas, consistent results could be achieved in determining the necessary number of taxicab stands for city cells. The consistency of the model can be increased if the infrastructure of the districts is improved and some other necessary data are collected. In addition, definition of some other input parameters would help development of the FMOTS model.

The proposed fuzzy logic model is indeed a decision support system for decision makers, who wish to alleviate taxicab stand complexity in the short to medium term. Taxi and its control systems can make use of the vague information derived from the natural environment that in turn can be fed into expert systems and so provide accurate recommendations to taxi drivers, the customers, motoring organizations and local authorities.

Broad future research can be suggested with the study. The model can be developed for a decision support system for determining the necessary number of taxicabs assigned for each of the taxicab stands in an urban area.

7. Acknowledgement

The authors are grateful to the GIS software company Basarsoft (Turkey) and Konya Municipality for supply of the necessary data.

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Sensor Network and GeoSimulation: Keystones for Spatial Decision Support Systems

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1. Introduction

Natural hazards and man-made disasters are victimizing large numbers of people and causing significant social and economical losses. By developing efficient Spatial Decision Support Systems (SDSS), managers will be efficiently assisted in identifying and managing impending hazards. This goal could not be reached without addressing significant challenges, including data collection, management, discovery, translation, integration, visualization, and communication. As an emergent technology, sensor networks have proven efficiency in providing geoinformation for any decision support system particularly those aiming to manage hazardous events. Thanks to their spatially distributed nature, these networks could be largely deployed to collect, analyze, and communicate valuable *in-situ* spatial information in a timely fashion. Since some decisions are expected to be taken on-the-fly, the right data must be collected by the right set of sensors at the right time. In addition to saving the limited resources of sensor networks, this will speed up the usability of data especially if this data is provided in the right format. In order to boost the decision support process, a thorough understanding and use of the semantics of available and collected heterogeneous data will obviously help to determine what data to use and how confident one can be in the results ultimately. An appropriate representation of the geo-information should enhance this process.
Data collected by sensors is often associated with spatial information, which makes it voluminous and difficult to assimilate by human being. In critical situations, the hazard manager has to work under pressure. Coping with such collected data is a demanding task and may increase the risk of human error. In this context, Geosimulation emerges as an efficient tool. Indeed, mapping the collected data into a simulated environment which takes into account the spatial dimension may dramatically help the hazard manager to easily visualize the correlation between data collected by sensors and the geospatial constraints.
In this chapter, we first present fundamental concepts of SDSS and the most important challenges related to their development. Second, we outline the sensor network technology as an emergent tool for leveraging SDSS. Third, we present the Geosimulation approach as another keystone to enhance SDSS. In this part, we summarize the current opportunities, research challenges, and potential benefits of this technique in SDSS. Finally, for better efficiency, we propose an encoding that emphasizes the semantics of available data and

tracks events/effects propagation. Based upon conceptual graphs, this encoding will be used to increase the benefits from sensor networks and geosimulation in SDSS.

2. Spatial decision support systems

Literature about spatial decision support systems (SDSS) is abundant and covering all their facets is beyond the scope of this chapter. In this section we only introduce the main characteristics of these systems and some important challenges related to their development.

2.1 Definition and importance of SDSS

The concept of spatial decision support systems has emerged by the end of 1980's from the integration of two technologies: decision support systems (DSS) and geographic information systems (GIS) (Sugumaran and Sugumaran, 2005). Beyond the broad definition that SDSS are DSS designed to support decision-makers solving complex spatial problems, in the literature there is no consensus about what SDSS exactly are. Keenan (Keenan, 2003) attributed the disagreement on the definition of SDSS to the fact that DSS themselves are not clearly defined. Consequently, in the literature SDSS are often defined by their common characteristics rather than by what they exactly are. For example, Goel (Goel, 1999) listed the following common traits characterizing SDSS: they are designed to solve ill-structured problems, they have user interfaces, they combine models and data and they contain tools allowing users to explore and evaluate candidate solutions. They are supposed to provide an iterative problem-solving environment. However, we only develop the following main characteristics:

Class of problems

Malczewski (Malczewski, 1999) defined a SDSS as "an interactive computer based system designed to support a user or group of users in achieving a higher effectiveness of decision-making while solving a semi-structured spatial decision problem". Spatial decision problems are often ill- or semi-structured. They are multidimensional, characterised by uncertainty (which is inherent to spatial data), have decision objectives and factors that can not be fully and formally specified and do not have a unique evident solution (Densham, 1991; Gao et al., 2004; Ademiluyi and Otun, 2009). Consequently, spatial decision-making processes are usually based on the "what-if" analysis: the decision-maker defines the problem, collects and analyses data and evaluates the consequences of several alternatives (scenarios) in order to select the best one (Ademiluyi and Otun, 2009). Moreover, spatial decisions require the implication of several stakeholders; they are iterative, interactive and participative processes (Densham and Goodchild, 1989; Goel, 1999). In addition, several studies have demonstrated that human beings have several cognitive limits when reasoning about spatial data (Kahneman and Tversky, 1982). For all of these reasons, spatial decisions are inherently complex and it is very helpful to have SDSS that support them.

Main components

Decision support systems are often developed based on the "*DDM paradigm*", i.e., a DSS should provide capabilities related to *dialog*, *data* and *modeling* (Sprague and Watson, 1996). SDSS are complex systems that integrate multidisciplinary technologies, but as an extension of DSS, they should have architectural components that balance among those three capabilities (Ademiluyi and Otun, 2009). Although the number and exact description of components mentioned in the SDSS literature differs (see (Sugumaran and Degroote, 2010) for more details), a SDSS should at least integrate the following capabilities (Densham, 1991; Densham and Goodchild, 1989; Keenan, 2003):

1. Spatial and non spatial data management capabilities (SDBMS component): include tools supporting the collection and storage of data, the translation between different data models and data structures, and retrieving data from storage.
2. Analytical and spatial modeling capabilities (Modeling and analysis component): provide decision-makers with access to a variety of spatial models in order to help them in the decision-making process. Examples of models include statistical, mathematical, multi-criteria evaluation, cellular automata and agent-based models (Sugumaran and Degroote, 2010).
3. Spatial display and report generation capabilities (User interface component): support the visualization of the data sets and the output of models using several formats such as maps, graphics and tables.

Domain specific

Like DSS, SDSS are often domain- and problem specific, although there are some SDSS that are designed to be generic (Sugumaran and Degroote, 2010). SDSS have been applied to several domains, such as urban planning, environment and natural resource management, transportation and business, which led to the use of several spatial modeling techniques and technologies. Reusing modeling techniques is not always evident, and the development of SDSS is often complex, expensive and requires the acquisition of specific domain or problem knowledge.

2.2 SDSS vs. GIS

Although GIS offer spatial data management and analysis capabilities that are attributes of SDSS, they are usually not considered as SDSS (Sugumaran and Degroote, 2010) The major reasons are that GIS lack of analytical modeling capabilities and techniques for effective scenarios evaluation (Segrera et al., 2003). In addition, Malczewski (Malczewski, 1999) pointed out that GIS do not usually have tools for presenting and evaluating choices with conflicting multi-criteria and goals. These deficiencies limit the effectiveness of GIS in supporting complex spatial decision problems (Densham, 1991). SDSS are thus usually developed based on GIS software coupled with additional modeling and analysis techniques such as multi-criteria decision analysis (MCDA), artificial intelligence, agent-based modeling and simulation techniques.

2.3 Challenges for SDSS

Although SDSS have reached the maturity stage and have been successfully implemented in several domains, there are still several challenges to be addressed. Sugumaran and Degroote (Sugumaran and Degroote, 2010) identified technical, technological, social and educational challenges, but in the following we only focus on some important challenges:

1. As we previously mentioned, an important capability of any SDSS is the presentation of output and scenario alternatives to users. Evers (Evers, 2007) listed the lack of capabilities for evaluating alternatives as a major reason for the inefficacity of SDSS. Uran and Janssen (Uran and Janssen, 2003) indicated that an SDSS must allow the user creating and testing alternatives using intuitive and simple techniques for end users. In addition, it is very important for the decision-maker to be provided with the relevant

information, and any lack or over-load could potentially limit her ability to make good informed decisions. Providing the relevant and meaningful information is an important challenge. Most used techniques are visual (maps, 3D visualisations, etc.) or quantitative (tables, graphs, etc.). There is currently a lack of qualitative techniques that allow the decision-maker exploring the consequences of her alternative solutions with a simple and meaningful language.

2. Developing SDSS for environmental monitoring and crisis situations requires not only the capability of modeling dynamic spatial phenomena, but also the ability to update those models with real-time data. Moreover, the system must provide an output that is relevant and easy to understand to the non-technical decision-maker, because any misleading or ambiguity can have to catastrophic consequences. However, GIS traditionally do not handle dynamic spatial models, and in order to remedy this limit, they have been coupled with modeling techniques from several research fields, especially cellular automata and agent-based simulations. Although this has led to the emergence of Dynamic GIS (Albrecht, 2007), dynamic spatial knowledge representation and modeling is an active research field (Haddad and Moulin, 2010a), and the lack of standards and efficient representation formalisms makes challenging the development of SDSS for real-time or near-real time spatial problems.
3. Decision-makers often need to examine various situations simultaneously at different levels of detail (macro-, meso- and micro- scales of representations). This is an important issue since the modeled phenomena and observed patterns may be different from one level of detail to another, and since interferences may arise between phenomena developing in different levels of detail. The level of detail is very important and complex problem, because it does not only require modeling the problem's dimensions at different spatial and temporal levels of details but also linking these different levels of detail.
4. Most SDSS were developed independently of one another, and with the development of internet and web-based SDSS (Sugumaran and Sugumaran, 2005), there is more and more a need for sharing and accessing spatial data from several distributed and heterogeneous sources. Interoperability is then an important challenge to be addressed. The Open Geospatial Consortium (OGC) has been developing different interoperability standards for web applications, including Web Map Service (WMS) and Web Feature Service (WFS), and the issue of developing SDSS using these standards has been recently raised (Zhang, 2010). In addition, semantic interoperability is an active research field in geographic anthologies and semantic web (Wang et al., 2007), and the lack of standards makes the development and deployment of ontology-driven SDSS difficult.

In the remaining of this chapter we focus on SDSS for dynamic environmental monitoring and crisis response and we present an approach based on sensor networks and geosimulation techniques to address their related challenges.

3. Sensor network-based SDSS

3.1 Survey on sensor network-based SDSS

A SDSS embodies geomatic principles for situating decision-making in space. It often uses a GIS component to provide spatial analysis functionality (McCarthy et al., 2008). In a variety of applications, updated spatio-temporal data on current conditions in the environment of interest is decisive in making appropriate decisions. This data could be collected from the field using existing techniques, such as sensors, satellites, sonar, and radars.

Sensors are small devices, deployed in an environment for the purpose of collecting data for specific needs, such as monitoring temperature, pressure, moisture, motion, vibration, or gas or tracking objects. Since the energy and processing constrained sensors are frequently prone to failure, robbery, and destruction, they are unable to achieve their tasks individually. For this reason, they are deployed within an extended infrastructure called a sensor network. In this infrastructure, the spatially distributed sensors could implement complex behaviors and reach their common goals through a collaborative effort. Thanks to this collaboration, they are able to collect important spatio-temporal data for a variety of applications. This quality motivates the link between SDSS and sensor networks, especially when data is needed to be collected remotely and in real-time with tools which can operate in harsh environments.

In the literature, several works have proposed sensor network-based SDSS. In the oil and gas industry, Supervisory Control & Data Acquisition Systems (SCADA) are using sensors in the monitoring of the processes within a total operating environment. The sensors are connected throughout an oil refinery or pipeline network, each providing a continuous flow of information and data about the operating processes. Chien and his colleagues (Chien et al., 2010) have deployed an integrated space in-situ sensor network for monitoring volcanic activity. In addition to ground sensors deployed to the Mount Saint Helens volcano, this network includes a spacecraft for earth observation. The information collected with sensors is integrated with data collected with an intelligent network of "spider" instrument deployed to the surface of the Mount Saint Helens volcano. The resulting data are used by hybrid manual reporting systems such as the Volcanic Ash Advisory Centers (VAAC) and Air Force Weather Advisory System (AFWA). Within the same context, Song and his colleagues (Song et al., 2008) have proposed OASIS. OASIS is a prototype system that aims at providing scientists and decision-makers with a tool composed of a "smart" ground sensor network integrated with "smart" space-borne remote sensing assets to enable prompt assessments of rapidly evolving geophysical events in a volcanic environment. The system constantly acquires and analyzes both geophysical and system operational data and makes autonomous decisions and actions to optimize data collection based on scientific priorities and network capabilities. The data collected by OASIS is also made available to a team of scientists for interactive analysis in real-time.

O'Brien and his colleagues (O'Brien et al., 2009) have presented a distributed software architecture enabling decision support in dynamic ad hoc sensor networks, which enables rapid and robust implementation of an intelligent jobsite. The architecture includes three layers: a layer for expressive approachable decision support application development, a layer for expressive data processing, and a layer for efficient sensor communication. According to the authors, the implemented prototype can speed up application development by reducing the need for domain developers to have detailed knowledge about device specifications. It can also increase the reusability of software and protocols developed at all levels and make the architecture applicable to other industries than construction.

Wicklet and Potter (Wicklet and Potter, 2009) have presented three steps for information-gathering, from sensor data to decision support. These steps are: data validation, data aggregation and abstraction, and information interpretation. Ling and his colleagues (Ling et al., 2007) have proposed a sparse undersea sensor network decision support system based on spatial and temporal random field. The system has been presented as suitable for multiple targets detection and tracking. In this system, an optimization based random field estimation method has been developed to characterize spatially distributed sensor reports without making any assumptions on their underlying statistical distributions.

In (James et al., 2008), the authors have proposed an approach that aims at performing information-centric analysis within a GIS-based decision support environment using expert knowledge. By shifting towards a more information-centric approach to collect and use sensor measurements, more advanced analysis techniques can be applied. These techniques can make use of stored data about not only sensor measurements and what they represent, but also about how they were collected and the spatial context related to them. In a related work, Rozic (Rozic, 2006) has proposed REASON, which is a Spatial Decision Support Framework that uses an ontology-based approach in order to interpret many different types of data provided by sensor measurements. In such systems, binding and transforming the sensor data into timely information which is relevant to the problem is a challenging task. In order to solve this issue, we have proposed in a related work (Jabeur and Haddad, 2009) to allow sensors to autonomously cooperate and coordinate their efforts while emphasising on data semantics. By encoding causality relationships about natural phenomena and their effects in time and space with the formalism of conceptual graphs, we have proposed an approach that implements a progressive management of hazardous events. This approach would provide the decision-makers with timely valuable information on hazardous events of interest, such as floods and volcano eruption.

In (Tamayo et al., 2010), the authors have conducted the design and implementation of a decision-support system for monitoring crops using wireless sensor networks. The prototype implemented includes tools that provide real-time information about the crop status, surrounding environment and potential risks such as pests and diseases.

In (Filippoupolitis and Gelenbe, 2009), the authors have proposed a distributed system that computes the best evacuation routes in real-time, while a hazard is spreading inside a building. The system includes a network of decision nodes and sensor nodes, positioned in specific locations inside the building. The recommendations of the decision nodes are computed in a distributed manner then communicated to evacuate or rescue people located in the vicinity.

In order to support rain-fed agriculture in India, Jacques and his colleagues (Jacques et al., 2007) have proposed COMMON-Sense Net system, which aims at providing farmers with environment data. This system can provide farmers with valuable data allowing them to improve the production of semiarid regions in a cluster of villages in Southern Karnataka.

Mastering a ship in heavy seas is always a challenge, especially in night time. The officer of the watch has to "sense" the weather and waves in order to preserve the cargo and navigate the ship without undue motions, stress or strains. SeaSense (Nielsen, 2004) is designed to support the natural human senses in this respect by providing an accurate estimation of the actual significant wave height, the wave period, and the wave direction. Furthermore, and based on the measurements and estimations of sea state, SeaSense provides actual information on the sea-keeping performance of the ship and offers decision support on how to operate the ship within acceptable limits.

3.2 Opportunities and challenges in sensor network-based SDSS

Any SDSS should provide decision-makers with the right data, at the right time, from the right spatial location. In addition, the SDSS must allow the decision-makers to have a global view about what is happening in the application environment. As this environment may be large-scale, harsh, and likely impossible for human to access, the requested data could only

be collected remotely. There are several existing techniques that can help in achieving this task, such as radars, satellites, and sensors. Depending on the availability of resources and the application context, one or more technologies can be deployed.
Sensor networks afford SDSSs with opportunities along five axes (Fig. 1):

1. For which goals data are collected: The sensor network should collect the requested data depending on the goals of the application. For example, in a flood scenario, sensors should collect data on the level and movement of water, the conditions of soil slope, and water pollution. Moreover, sensors can deliver to the SDSS data in several formats including those that are compatible with widely used standards.
2. When data will be collected: sensors should be activated at the right time to collect and deliver the requested data to decision-makers through the SDSS.
3. Where data will be collected: sensors should collect data from the right location and thus decision-makers could have updated information on locations of interest.
4. Who will collect data: sensors should collect the requested data depending on their current locations. If they are not explicitly appointed by the decision-makers, they should self-organize in order to identify the subset of sensors that will be in charge of collecting the requested data.
5. How data will be collected: sensors generally follow sleep/wakeup cycles. They are programmed to collect data according to predefined schedules. Depending on the current situation, this schedule has to be adapted in order to collect data at appropriate times. Moreover, data can be collected through a collaborative effort from several sensors.

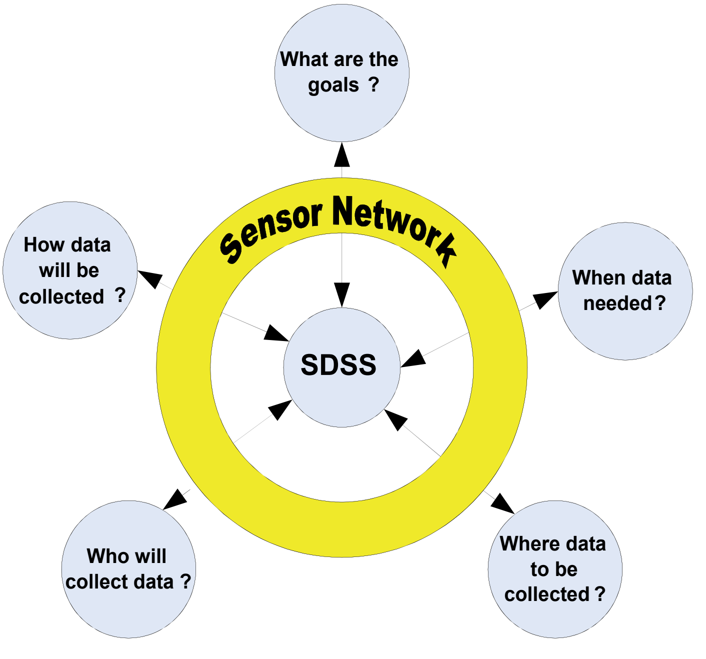

Fig. 1. Opportunities in sensor network-based SDSS

As sensors are commonly characterized with their limited processing capabilities and short-battery lives, they are commonly prone to failure and have to save their energy by following sleep/wakeup cycles. In addition, due to the characteristics of operating environments, the sensors can be destructed, lost, and even stolen. Consequently, the topology of the sensor network is frequently changing and thus pulling data from the network could be affected. This affects the fluent feeding of the SDSS with the requested data. As such, this represents the main challenge of binding SDSS with sensor networks.

Binding SDSS and sensor networks concerns several issues, including:

1. Communication: as sensors are generally spatially distributed and do not maintain reliable communication pathways, the exchange of data between the SDSS and the sensor network should not be straightforward. Thus, data should not be pulled out appropriately from the network.
2. Data format: the Open Geospatial Consortium's Sensor Web Enablement (Botts et al., 2006) working group has created an entire suite of standards related to sensor networks. In this context, SensorML could be used to describe sensors and sensor platforms, O&M (an XML schema which complements SensorML) could be used to describe measurements made by sensors, and SOS (Na and Priest, 2006) can make use of SensorML and O&M to provide an interactive, useful view of current and historical conditions at a site. In spite of such standards, some SDSSs may use proprietary data formats that may cause some incompatibility with sensor data.
3. Synchronization: in some real-time applications, communication between the sensor network and the SDSS must be in timely fashion. This could not be guaranteed all the time, particularly due to sensor network constraints.

4. GeoSimulation-based SDSS for crisis response

Hardly a day passes without some form of crisis, disaster or tragedy hitting the headlines. At the same time, new technologies have made great steps, which, in theory at least, have been accomplished for the safety of human beings and the environment. Unfortunately, many technological achievements are responsible for most of the disasters occurring today. Paradoxically, we need technology to better deal with these disasters when they occur.

When problems are well-structured and relatively static (e.g., resource allocation), mathematical programming methods can be built into the SDSS. For dynamic situations, such as crisis management, simulation is a better tool (Fedra and Reitsma, 1990; Zhang and Grant, 1993). In this section we first make an overview of SDSS used for crisis response with a particular emphasis on those based on geo-simulation. We then enumerate the main challenges and opportunities of geosimulation-based SDSS for crisis response.

4.1 Review

SDSSs have been successful in addressing the spatial component of natural and technological hazards (Fedra, 1997). As a result, several specialized SDSS have been developed that assist decision-makers with hazards. For instance, regarding wildfires, a multidisciplinary system has been developed by Keramitsoglou and his colleagues (Keramitsoglouet al., 2009) to provide rational and quantitative information based on the site-specific circumstances and the possible consequences. The system's architecture consists of several distinct supplementary modules of near real-time satellite monitoring and fire forecast using an integrated framework of satellite Remote Sensing, GIS, and RDBMS technologies equipped with interactive communication capabilities. The system may handle multiple fire ignitions and support decisions regarding dispatching of utilities, equipment, and personnel that would appropriately attack the fire front.

Garbolino and his colleagues (Garbolino et al., 2007) proposed Computer-Aided Management of Emergency Operations (CAMEO) which is a SDSS for assessing the impact of a gas release from a hazardous material transportation accident on the population in a dense urbanized area. The SDSS uses a database that centralizes, in real time, the data on hazardous material transportation coming from both embarked sensors monitoring the physical conditions of the material in the tank of the truck, the truck route, its speed etc. and an installed optical sensor placed in a highway station which detects orange plates of the hazardous material trucks crossing the highway station. CAMEO is associated to the GIS platform in order to integrate the databases on the stakes of the territory (population, housing, companies, etc.) with the maps of the atmospheric dispersion distances of toxics coming from the simulations computed with CAMEO. The overlapping of the maps of these gas release distances and the data on the stakes allow the user to identify the exposed (or impacted) stakes.

Many other SDSS were developed for droughts and agricultural pestilence (MacLean et al., 2000; Agatsiva and Oroda, 2002), floods, hurricanes, wildfires, and earthquakes (Fulcher et al., 1995; Radke, 1995; Sanders and Tabuchi, 2000; Jaber et al., 2001; Hodgson and Cutter, 2002; Jensen and Hodgson, 2006). Most of these SDSS were designed to help human decision-makers to take the right decisions. However, more sophisticated SDSS can also assist these decision-makers in planning interventions during crisis situations. These SDDS are called geosimulation-based SDSS as they use geosimulation to support human planners. To better understand these SDSS, we discuss the necessity of the geosimulation process in what follows.

Human planning requires the simulation of plans, which is itself based on anticipation and schematisation (Hoc, 1987). When facing a new situation, a human being is able to detect similarities with well-known situations and to anticipate events or properties which are not yet totally identified (Hoc, 1987) thanks to his sense of anticipation. According to Craik (Craik, 1946), planning is a very refined activity implying a mental formulation of future states of the world in order to simulate the real world behaviour and then to predict future events. However, human planning capabilities are limited. In (Kahneman and Tversky, 1982), the authors claim that simulation is difficult for humans, which is proven by Forbus' experiences (Borbus, 1981) which show that simulation cannot be done by humans, expect in trivial cases.

Planning becomes more complex when addressing uncertain situations such as during crisis response interventions. In such cases, accurate predictions about plan executions remain a hard task for human planners. The AI community proposed solutions such as the *Simulation-Based Planning* approach SBP which consists in associating planning and simulation. Each generated plan is simulated in order to be tested and evaluated. The most appropriate plan is kept. As we focus on crisis situations, the spatial component is crucial which makes the problem even more complex.

In order to plan within a large-scale space, a person relies on a sophisticated mechanism based on *cognitive maps* which are mental constructs that we use to understand and know environments and use to make spatial decisions (Kitchin, 1994). Despite its sophistication, it remains very limited as many errors, mainly metrical, can occur. Sources of these metrical errors include distortion, d*istances,* and *directions.* Consequently, and despite his exceptional cognitive capabilities, a human being has several limitations when trying to plan in a real large-scale geographic space. An SDSS based on a geosimulation (simulation using GIS data) approach would help overcome some of these limitations. Simulation is even more important for emergency planning. Indeed, when based on realistic assumptions, simulation offers an efficient way of modeling crisis response tasks.

In the domain of forest firefighting for example, we developed a geosimulation-based SDSS which relies on a four-layer architecture (Sahli and Moulin, 2009; Sahli and Jabeur, 2011). An adaptation to this architecture is discussed later (see Subsection 4.3). In the air navigation domain, (Ozan and Kauffmann, 2002) developed a practical tool for tactical and strategic decision-making in aircraft-based meteorological data collection called TAMDAR (Tropospheric Airborne Meteorological Data Reporting). This onboard system gathers meteorological data (using airborne sensors) as aircraft fly in the troposphere and transmit this data to the National Weather Service. Collected data will help decision-makers to process different operational alternatives (by conducting various what-if analyses using a GIS-based user interface) and to determine the best strategy for system operation. The SDSS is composed of a customized simulation-optimization engine, a data utility estimator, a GIS-based analysis layer, and a user interface. They can also conduct various what-if analyses effectively by using GIS-based user interface.

In the domain of civilian evacuation, and as evacuees move, a specialized SDSS can continuously track evacuees using their current spatial location coordinate. In this context, Nisha de Silva designed a prototype of a geosimulation-based SDSS named CEMPS (Configurable Evacuation Management and Planning Simulator) (Nisha de Silva, 2000). The aim was to produce an interactive planning tool to produce simple scenarios wherein emergency planners are able to watch a simulation proceed and provide limited interaction to obtain information on the progress of the evacuation. CEMPS integrates a dynamic and interactive evacuation simulation model with a GIS which defines the terrain, road network, and related geographical elements such as the hazard source and shelters, as well as the population to be evacuated.

4.2 Challenges and opportunities for GeoSimulation-based SDSS

In the following, we briefly enumerate the main challenges that geosimulation-based SDSS is facing as well as the opportunities that it represents.

1. Simulation models are difficult to integrate in the SDSS: In many crisis domains, experts have done a lot of effort on model development. The difficulty in developing the DSS is not then a lack of available simulation models but rather making these models available to decision-makers (Muller et al., 2003). These simulation models are usually used in research labs without being integrated into the decision-making process. Muller and his colleagues (Muller et al., 2003) explained this gap by the following reasons: data requirements are usually only attained in a research setting; models are complex and assumptions are not well understood by managers; and deriving model input parameters is extremely time consuming and difficult.
2. Multi-disciplinary problem: To integrate simulation models in SDSS, one needs expertise in database management system, geographic information systems, computer operating systems, remote sensing and Internet searching for data gathering, graphics, as well as specific domain knowledge. Unfortunately, only few professionals/researchers have all these skills. Cross disciplinary research groups have to be set and collaborate more in order to achieve better geosimulation-based SDSS.
3. Granularity: The accuracy of predicting entities (resources and actors within the environment) behavior depends on whether the SDSS simulator uses a micro, meso, or

macro modeling approach. The choice among the three levels of granularity depends on the trade-offs that must be made in order to maintain realistic computing power when processing large amounts of data.

4. Validation of simulated models: A simulator is intended to mimic a real-world system using actual data associated with that system. It uses assumptions that generally simplify the complex behavior of the real-world. When the SDSS simulates a highly dynamic environment as during crisis response, it is a big challenge to validate the simulation models in use.
5. Integrating data reported by citizen: Many governments are implementing large-scale distributed SDSS to incorporate data from a variety of emergency agencies in order to produce real-time "common operational pictures" of crisis situations. This goal remains a very hard task. In this context, social networks have the potential to transform emergency response by providing SDSS with data collected by citizens. Individuals are often in the best position to produce immediate, empirical and real-time observance of events simply because they are *there*. Pictures or videos taken by citizens from a cell phone can provide invaluable information. Integrating these data and media generated by citizens and other non-state actors with the main SDSS can enhance governmental response to crisis. This will not only imply reviewing the command and control strategies and the communication infrastructure, but also opening new research avenues on how to collect, filter, and integrate these new data into the SDSS.
5. Including a full Emergency Management Cycle: The emergency management community has long recognized that society's response to disaster events evolve through time. The succession of emergency response stages after a disaster event, known as the Emergency Management Cycle, includes a phase of response/rescue operations, a later phase of recovery/reconstruction, and a stage focused on mitigation and monitoring for future events (Cutter, 1993). Most of existing SDSSs only focus on one stage. It would be a considerable improvement if SDSS can address all stages involved in emergency response.
6. Web-based SDSS: As with other applications deployed via the web, the Internet based SDSS provides advantages over traditional desktop applications. First, the application is centrally located, simplifying distribution and maintenance. In addition, the Internet based approach increases the user base by reducing costs of access to users. However, Internet standards have some limitations for use in spatial applications, but new software and plugins continue to be developed. Current applications offer map display, but frequently fall short of providing comprehensive GIS functionality. Future developments offer the possibility of a distributed SDSS that could connect with datasets held at distant locations on the Internet.

4.3 Combining sensors and GeoSimulation-based SDSS

When facing a natural disaster or a crisis situation, decision-makers need to monitor the situation and then plan interventions (evacuation, rescue, etc.) while taking into account the constraints of the real word (real large-scale, dynamic, and uncertain environment).Sensors are of course one of the possible means of monitoring the environment. However, a 'deploy and ignore' approach of sensors is not appropriate in this context. In remote areas, where human interventions cannot be provided appropriately, sensors must have reasonable intelligence and autonomy to reconnoiter their surroundings, respond to changing environmental conditions, cope with frequently changing communication pathways and network topology, and carry out automated diagnosis and recovery.

Static sensors are used to monitor the environment and send sensed data to the SDSS, which may use this data in different ways. For example it can map the data (usually after treatment) on the geo-referenced map (Sahli and Moulin, 2009). A human user can visualise the data before taking any decision. The sensed data can also be used to feed a simulated model (within the SDSS) of the event occurring in the dynamic environment. We have already followed this approach for the forest fire problem in (Sahli and Moulin, 2009) and the train derailment problem (caused by rock falls) in (Sahli et al., 2008).

In this section we are going to focus on another type of sensors which is very useful during crisis response but much more difficult to manage. These are mobile sensors (whether autonomously or embedded in moving vehicles). They offer more flexibilities and opportunities for data acquisition and tracking events of interest in a highly dynamic environment. However, connectivity and coverage among the network components have to be maintained. To this end, it is important to prevent mobile nodes to move freely, anywhere and anytime, creating communication holes. Holes can also result from the absence of communication connectivity (sleep, robbery, or shutdown of some sensors) as well as from heavy network activities. The goal of maintaining a WSN without communication holes cannot be always guaranteed due to simultaneous movements, sleep/shutdown of some nodes, or jamming factors.

In the particular cases of natural disaster (forest fire, oil slick, flood, etc.) or crisis situations, mobile sensors have to deal with the constraints of the real world (real large-scale environment, dynamism, and uncertainty). The "real large-scale environment" constraint implies that the geographical aspects of the terrain could affect the sensors move. For example, moving a sensor in a forest in fire is not always possible as movements depend on the vegetation and the natural obstacles in the surrounding geographic space. The "uncertainty" and "dynamism" constraints imply that the plan of sensors relocation could fail at any time. For instance, a sensor which was moving to a safe place during a forest fire, could realize that fire has changed its direction and thus his destination is no longer safe.

Under the constraints cited above, the real environment is not necessary the best place to plan sensors relocation for the following reasons:

1. The relocation process needs the collaboration of several sensors which implies a high volume of exchanged messages between the physical sensors. Given the nature of the environment (natural disaster) and the commonly limited resources of sensors, such communication should be avoided.
2. The movement of each sensor strongly depends on different parameters, namely, the spatial characteristics of the surrounding space (elevation, slope, etc.), the evolution of the situation (e.g., fire progression in a forest), and the position of the other resources/sensors. These parameters are partially or totally unknown for individual sensors.
3. Individual sensors have only a partial vision of the situation. Each sensor is only aware of its neighborhood. Thus it lacks of the global vision of the situation, which is in this particular case necessary to find a global relocation strategy.

The artificial intelligence community has proposed solutions to similar problems through the *Simulation-Based Planning* approach (SBP) (Lee and Fishwick, 1994) which consists of associating planning and simulation. Each generated plan is simulated in order to be tested and assessed. The most appropriate plan is kept. However, when applied to real world problems, the current SBP approach does not suggest an efficient interaction between the real world and the simulated environment. In addition, monolithic planning turned out to be ineffective (Desjardins et al., 1999). Agent-based planning appeared then as a good alternative. Combining both techniques (simulation-based planning and agent-based planning) may then help to solve such problems. The SDSS which supports this idea should be able to build a synchronous parallel between the real world and the *simulated environment* (which is mainly the geo-referenced map) of the SDSS.

The sensor relocation application can be thought of as a layered architecture as illustrated in Fig. 2. This design philosophy is inspired by the layered simulation model we proposed in (Sahli and Moulin, 2009). The real sensors are of course located in the real world. Each of these sensors has a representative in the simulated environment. This representative is a software agent. Sensor relocation is thus planned by these agents in the SDSS and then communicated to the real sensors. The SDSS should include four layers as shown in Fig 2. A full description of these layers can be found in (Sahli and Jabeur, 2011).

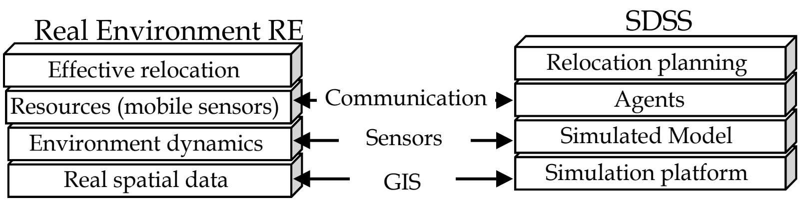

Fig. 2. Four-layer architecture of geosimulation based SDSS for sensors relocation

As the relocation planning takes place in the SDSS, the SDSS needs to be continuously updated by the real environment to maintain the coherency and synchronization between the two environments. In this context, the communication between the physical sensor and its agent representative is crucial. As for communication within the SDSS, heavier message traffic is to be exchanged between different representatives in order to: (i) inform each other about corresponding sensors status; (ii) check the status of others' sensors; (iii) coordinate relocation. Coordinating the relocation is not an individual decision. Indeed, a sensor having the intension to move must inform and get the approval of the surrounding sensors especially that the movement must be for the sake of achieving a common goal. Besides, all moves should be aligned with a strategic action which may be dictated by a human decision-maker.

An SDSS supporting these four layers of Fig. 2 offers the following advantages: (i) Most of the interaction messages between agents (sensors' representatives) are taking place in the SDSS (locally). Even a high traffic of exchanged messages will not really affect the performance of the relocation process; (ii) Since the relocation planning will be conducted by the representative agents in the SDSS, each agent will have access to all relevant data (spatial data of the surrounding space from GIS, the last evolution of the situation from the simulated environment, and the position of the other resources and sensors from the other co-existing agents). More details about the internal architecture of these agents can be found in (Sahli and Moulin, 2009); (iii) As all agents are in the SDSS, a human decision-maker can have a global idea about the current situation. Therefore, he/she can take part in the relocation planning process by dictating strategic actions.

Moreover, planning in a highly dynamic environment using a simulation-based approach implies dealing with another problem: when should the simulation process be launched in the SDSS and how the simulation process should be coupled with the effective relocation? Early planning applications were based on the assumption that a planner's environment is stable and that it is possible to create a complete plan before executing it (Russel and Norvig, 1995). Such an assumption is inappropriate when considering dynamically changing environments. Instead, it is necessary to adopt a continual planning (CP) approach in which the activities of planning and execution are interleaved and in which re-planning is triggered by changes in the environment or when the executed actions abort (Ambros-Ingerson and Steel, 1988). Nevertheless, deciding when and how to interleave planning and execution is one of the most complex problems of CP. In this context, we have already proposed a dedicated planning approach, named Anticipated Continual Planning (ACP) in (Sahli and Moulin, 2009). Our ACP is based on the Continual Planning paradigm but enhanced by a preventive re-planning step (anticipating and periodic) and by a corrective one (following an unexpected event). In both cases, a global plan is elaborated in parallel and by both software agents and human decision-makers. Our approach enhances the interleaving process of the classical CP (agents are not forced to stop the planning process in order to wait for the execution), increases the quality of the plan (the plan is periodically updated and eventual problems are anticipated and taken into account before having repercussion on the plan), and gives more guarantees about reaching a final solution (since a global plan is always available and in which human decision-makers have taken part).

5. Towards better efficiency in sensor network-based SDSS

As we previously mentioned, geospatial semantics is currently an active research topic which would resolve the problem of interoperability between different SDSS using heterogeneous spatial data sources and formats. Geospatial semantics is also very valuable for improving the efficiency of SDSS as this would help in providing the decision-makers with the right data, in the right format, at the right time. In this section we argue this idea and illustrate it with two of our previous works on sensor network-based SDSS and geosimulation-based SDSS.

5.1 Semantic aspects for better efficiency in SDSS

Maximizing the benefits from a sensor network-based SDSS would require to feed the SDSS with the right data, in the right format, from the right locations, with the right sensors, at the right time. This could be reached by a thorough examination of data semantics. Data semantics could help in delimiting the sensing areas and sensing resources (Jabeur and Haddad, 2009; Jabeur et al., 2008). In addition to preserving the sensor network resources, this would speed up getting data from the network.

Once data is pulled out from the sensor network, we can maximize the benefits from the semantics of geo-information by finding effective methods to: (1) encode data for different purposes, and (2) transform this data from one representation to another. The use of the appropriate data representation at the right time would improve the analysis of the current situation, pose the right queries to the network, increase data sharing, and reduce the consumption of the limited resources (Jabeur and Haddad, 2009).

Several approaches can be used for data representation in sensor network while increasing the benefits from the semantics of data. Semantic networks (Lehmann, 1992) and Frames

(Minsky, 1974) are examples of these approaches. The use of the XML and GML (Cox, 2006) languages provides a standard and common ways of cataloguing and exchanging sensor network information. The Open Geospatial Consortium (OGC) proposes the Observations and Measurements (O&M) standard (Cox, 2006) that defines a conceptual schema and XML encoding for observations and for features involved in sampling when making observations. OGC also proposes the Sensor Observation Service (SOS) (Na and Priest, 2006) standard that defines a web service interface for the discovery and retrieval of real time or archived data produced by all kinds of sensors. By using GML, O&M documents can be generated in SOS software. In this case, measurement records are stored to a database with a schema based on the O&M specification. When this database is queried, the SOS server pulls the relevant records from the database and automatically generates the O&M document in XML format based on a template that is stored on the server (McCarthy, 2007).

5.2 Encoding data using conceptual graphs

Knowledge about the semantic of hazardous events and their behaviours are extremely valuable for developing SDSS that can predict situations evolution and prevent dangerous consequences before they occur. For example, rising water levels indicate that flooding may be occurring, and the sudden motion of a slope can signify a slope failure. Due to complex chain reactions of concurrent events, there is an urgent need to automate the sensor network activities while preventing the waste of its limited resources. The representation of available data in the appropriate format and the encoding of expert knowledge in a machine-usable form serve to reinforce any decision support that a monitoring system may draw.

In (Jabeur and Haddad, 2009) authors proposed an approach that takes benefit from the semantics of data on natural phenomena conceptualized as *spatio-temporal events* and formalised using conceptual graphs (CGs). Based on Peirce's existential graphs and semantic networks of artificial intelligence, CGs were introduced by Sowa (Sowa, 1984) and provide an extensible system of logic to capture, represent and reason with the semantic of real-world knowledge. The approach proposed in (Jabeur and Haddad, 2009) uses causal knowledge about hazardous events and their effects in time and space to implement a progressive hazard monitoring. Hazardous events (events of interest, such as flood and rain fall) are explicitly conceptualised as static states and dynamic changes (punctual and durative) which are delimited in space and time (Haddad and Moulin, 2010a). The effects of a given hazardous event are formalised using causality relationships that define semantic, spatial and temporal causal constraints between cause and effect situations. These constraints are derived from the fact that human recognition of causal relations is based upon recognition of precedence and contiguity between the cause and the effect (Kitamura et al., 1997). Knowledge about hazardous events, their effects and risk levels were formalised using CGs and used to improve the efficiency of the sensor-network. When an event of interest is triggered by the sensors, the system first identifies what are its possible effects, their associated level risk, and where and when they may occur and then reserves the relevant sensor network resources in order to collect data in right place and time (Jabeur and Haddad, 2009).

In a related work (Mekni and Haddad, 2010) authors used semantic knowledge about events and their spatio-temporal effects to develop an integrated knowledge-based multi-agent geo-simulation framework for intelligent sensor web deployment. Figure 3 illustrates the main components of the framework.

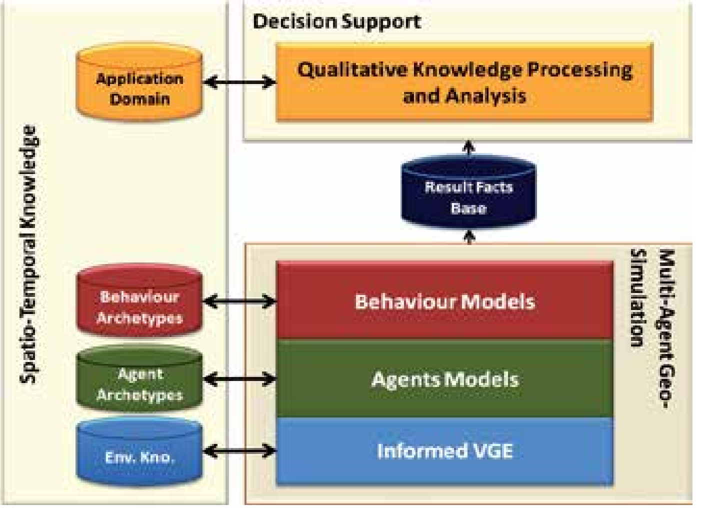

Fig. 3. Architecture of the knowledge-based multi-agent geo-simulation framework for intelligent sensor web deployment (Mekni and Haddad, 2010)

Multi-Agent Geo-Simulation is used to simulate the behaviour of a sensor network in a dynamic virtual geographic environment. Sensors are modeled as intelligent agents embedded in an informed virtual space where dynamic phenomena can occur. Sensor agents have reasoning capabilities allowing them to reason about the virtual space and to react to its dynamic phenomena. They have perception ranges and can be active or sleeping. Spatio-Temporal knowledge encoded in CGs is used for two main purposes. First, it is used during the geosimulation to support sensor agents reasoning capabilities. In the beginning of the simulation only some sensor agents are active. When an active sensor agent detects the occurrence of a situation of interest (such as a storm) in its perception range, it asks the knowledge base for its consequences, delimits when and where they may occur and then wakes up the relevant sleeping sensors within certain distance. Once the situation of interest is out the perception range of the sensor agent it switches to the sleeping mode. Second, the Spatio-temporal knowledge is used to analyse the results of the geo-simulation and to offer decision support to users (evaluation of different sensor deployment plans).

6. Conclusion

When considering any DSS, it is very important to know the degree of involvement of human experts in the process of taking decisions. This issue is more crucial during crisis response, especially when decisions are to be taken in real-time. As the spatial component arises, the trust of decision-makers in SDSS needs a longer discussion. In this chapter, we discussed briefly the problem from the cognitive point of view. A longer investigation supported by a real example can be found in (Sahli and Moulin, 2006). The cognitive aspect helps in understanding the limits of SDSS and pinpointing the issues where human decision-makers could not be overlooked.

When dealing with geographic reasoning, which is typically based on incomplete information, a human planner is able to draw quite accurate conclusions by cleverly completing the information or applying certain default rules based on common sense. Despite these cognitive capabilities, the planner has limitations when it comes to simulate complex events, particularly in a real large-scale geographic space. This task could be achieved properly by an SDSS. While the SDSS "knows" better the spatial environment as it uses GIS data, it does not have a refined sense of anticipation and judgment as a human expert does. Even if a plan generated by the SDSS seems to be well-grounded, it may not be feasible in reality or may go against certain doctrines. Human experts can propose to adjust/change the SDSS' recommendations according to their own experience and anticipation sense. For these reasons, we draw the conclusion that geosimulation based SDSS complements human planning skills when addressing complex problems such as crisis situations. It is worthwhile to investigate this degree of complementarities and come up with some general guidelines that could be customized depending on the application domain.

7. Acknowledgement

The research leading to these results has received Research Project Grant Funding from the Research Council of the Sultanate of Oman Research Grant Agreement No [ORG DU ICT 10 003]

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Part 5

Applications in Risk and Crisis Management

18

Emerging Applications of Decision Support Systems (DSS) in Crisis Management

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1. Introduction

The recent financial crisis, the growth of the frequency of extreme risk events are motivations for a new analysis of the mechanisms and processes that implies high risk and high uncertainty. The new dynamics and the severe impact of the extreme events (natural hazards, terrorism, technological accidents, and economic/financial crises), but also the complexity of interventions have motivated the scientific community to find new efficient solutions for decision making process dedicated for crisis management, especially for solving the following aspects: time urgency, the complexity of event, the volatility/ rapidly changing of event/ decision conditions, the chaotic surrounding environment ingredient, the human behaviour in critical situations (emotional stress), the consequences for decision failure, poor data, frequent interruption during the decision making process.

Extreme risk events are no longer only high impact - low probability events. Indeed, the literature demonstrates that these types of events are more frequent and also their impact is also more critical. The governments are responsible not only for the post crisis management of extreme events. In this case, better knowledge could offer opportunities to reduce the impact.

Emerging aspects regarding the integration of the concept of hybrid DSS in the treatment of extreme risk management will be presented. The efficiency of using intelligent ingredients in decision support systems (DSS) is linked to the human limits but also on the dynamics of huge data in the context of imprecision and uncertainty. Different applications for the use of hybrid DSS in flood and drought risk management, asymmetric risk and crisis management exercises will be also presented.

Many extreme risk events are associated with modern human environment and in this case the spectrum of risks is changed with a difference between the perceived possibility and reality (Renn, 1992). Extreme risk is expressed by the potential for the realization of unwanted, adverse consequences to human life, health, property, or the environment. In Kaplan, Garrick (1981) is proposed the risk triplet (S-scenario, P-likelihood, D-possible consequence), a framework that responds to the nature of disaster events that can occur, how likely is a particular event, what are the consequences.

Decision makers in extreme risk environments should respond in a new different manner because modern crisis management requires urgent developments toward better, more elaborated and appropriate means for extreme risks. Extreme risk management needs to ensure a better interoperability of different emergency services (police, fire chief, health sector, civil protection) to provide the appropriate information (of course, after data fusion and data filtering) at the right place in the critical moments. The new global environment is very complex and the dynamics of changing is difficult to understand. Decision making in critical or special situations is very complex because the systems are complex, the dynamics is difficult to understand, and adaptability is essential. Even the technologies to cope with the crisis and high risk events have developed considerably there are some underlying problems that complicate high risk prevention and multiple crisis response: an inadequate communication between different actors and different levels; the relative inadequate data fusion, selection, filtering and standardization impacted information database; the difficulty to update information about the development of the extreme risk (victims damages, rescue team technologies, in the case of natural/man-made hazards, or specific information in the case of financial crushes and crises); the access to existing databases and action plans it is relatively slow.

The interest is to develop an integrated framework capable to support emergency decisions via a better understanding of the dynamics of extreme events and a better detection and management of new risk situation. In this case, the focus is on the characteristics of genericity and adaptability of the framework in order to build a flexible, adaptive, robust and efficient system that does not depend on a particular case and it is easy to be extended in a creative manner.

In an uncertain and highly dynamic environment this type of applications could offer a robust but adaptive support for all decision making factors. Based on this type of applications is possible to build a generalized framework capable to support different types of decisions, not only in economy and finance, but also in military and law enforcement applications, in critical periods, or in high risk events.

2. An introduction in extreme risk modelling

First step in management of extreme risk events is to identify the most critical endpoints assessed in terms of the possible impacts on humans, communities, and environment. Then, it is necessary to specify the particular nature of each risk that could affect the endpoints in both terms of the likelihood and the degree of damage. The exploration of possible external impacts which might occur is based on the following aspects related to the risk triplet $R=R(S_i, P_i, D_i)$: the impacts/damage position outside/inside our control area; the scale of these impacts and their degree of irreversibility; the trans-boundary characteristics of these impacts; the potential threat to human ethics/morality.

The typical risk scenarios require an integrated perspective in selecting the adequate mix of risk reduction measures such as increased natural hazards damage potential due to urban development and agglomeration; increased systemic risk due to cascaded facilities or organizations; a severe decline in preparedness of local communities that wait for the government action (via public warning systems) and a low ability to minimize losses; a critical environmental degradation.

An extreme risk framework could be build considering the following processes: the problem formulation (potential risk events examination); risk assessment (provides an objective and integrated judgment in terms of scientific evaluations regarding extreme risk events identification, pathways, exposure assessment, exposure-damage response assessment); risk management and first subjective decision making process to select regulatory measures from alternative options. There exist conceptual/functional separations between risk assessment and risk management. The explicit representations of risk scenarios can provide a better assessment and permits regulatory decisions under volatility and uncertainty. In the literature is underlined the critical role of risk communication and stakeholders participation in extreme risk analysis.

Another branch of the literature is focused on the relationships between hazards and damages in terms of risk or vulnerability (Wisner, 2004). In the "pressure and release" (PAR) model the aim is to understand risk in more realistic terms of vulnerability in the field of disaster sciences based on the disaster risk model of Alexander (1993) expressed by:

$$\text{Risk} = \text{Hazard x Vulnerability} \quad (1)$$

In Smith (2001), the risk is modelled in a similar way:

$$\text{Risk} = \text{Hazard (Probability) x Loss (Damage)/Preparedness (Resilience)} \quad (2)$$

In Wisner (2004) "risk" is viewed as "hazard time's vulnerability" or a unit measure of the possible damages under an exposure probability to the hazards. The overwhelming tendency in both theory and practice is to view extreme risk management as a holistic process involving prevention, planning, acute response, recovery, and learning (Comfort, 1988; Nudell, Antokol, 1988; Coombs, 1999; Fink, 2002; Regester, Larkin, 2002; Curtin, Hayman and Husein, 2005). Preventing all extreme threats from materializing is not only implausible; it is simply impossible (Wildavsky, 1988). Prevention requires that one knows the source and dynamics of threats, but the literature shows this is impossible (Reason, 1997; Pauchant, Mitroff, 1992; Anheier, 1999; Gauld, Goldfinch, 2006). The decision maker will take into account the following operational steps: size up the event situation; activate the DSS; add the real time information and select the type of event scenario; adapt the base event scenario; simulate and evaluate the final scenario and the recommended decision; implement decision.

In principle, an integrated framework for extreme risk analysis should include the following four steps: scenario formulation - collection and analysis of data related to hazards in terms of their possible origins, pathways, and mitigation; extreme risk assessment – the list of potential extreme events together with their exposure or vulnerability; extreme risk management - with development of mitigation measures and procedures based on the output from the risk characterization; communication by using a dedicated platform to enable a better understanding of the rationale behind the categories of risk assessment.

In the modern literature are presented a lot of applications, procedures and activities capable to anticipate, prepare for, prevent, reduce different types of risks/losses associated to different type of crises, but there are only few integrated frameworks to deal directly with the extreme event. In this case, the decision makers need a huge technical assistance to support decision making process before, during, and after extreme events.

All these applications are based on a huge quantity of data, a dynamic or real time selection between alternatives and the implementation of the final solution should be define with precision, but also with adaptability and creativity. Other aspects are related to the possibilities to integrate and to mix different types of models, methods and techniques/decision tools and to understand the limits of acceptability. DSS is one of the most efficient technologies in the treatment of extreme risk and crisis, because it offers adaptability, robustness and is easy to use in a modular-adaptive framework. Soft computing techniques could be used together withy DSS/ IDSS not only as a mathematical ingredient, because its efficiency is given by a better capability of selection, a higher speed of analysis, and also on adding the advantages of adaptability, flexibility, and modularity.

3. Emerging techniques to understand extreme risk management (ERM)

Extreme risks are high impact, high uncertainty, and low probability emergency events with high negative impact/losses due to uncertainty spread to different levels; in the case of financial events appear also the contagion phenomenon. Extreme events demand immediate action because of serious threats to the environment; contagion brings a new dynamics in recent financial events. The urgent need for action is to respond hints that the time interval is very short. Managers should act in time, but with surgical precision because crisis represents critical turning points with decisive changes. Extreme risk and multiple crises could be describes as the manifestation of an unexpected risk that develops very quickly in to an emergency/disaster situation. An emergency/disaster situation contains also surprise and response elements. Emergency response represents the synthesis of knowledge based on experience, procedures and activities to anticipate, prepare for, prevent, reduce or overcome all the risks associated with extreme events. The interest is to offer framework easy to use, but efficient in reducing the negative consequences. A complex system supports a variety of key decision across a wide range of decision making and integrates two processes: how to recognize and size up a situation and how to evaluate the course of action (CoA).

The steps supported by an intelligent system are: size up the situation using the embedded information; search a knowledge base and recognize the first type of similar situations; diagnose the historical experience against the problem; adapt and modify the solution of the historical data base to work in the new context; rehearse the solution to verify that it is likely to realistically work; the implement of decision.

The literature reveals that decision makers do not normally use the classic rational choice techniques, but they rely on experiences; it is not the intention to find the mathematical best way, but to find a first good enough solution implemented and move to the next step (this natural style is called recognition-primed decision making, RPDM). Modern decision makers face specific gaps: some decision makers are afraid to apply RPDM based on past experiences, but others do not have a personal knowledge base of past experiences enough to cover unfamiliar extreme events. A simple framework capable to rapidly support the decision maker with experience for the past or from others scenarios and to guide the decision maker to rapid near optimal decision, is useful for small scale events, but an intelligent tool is needed for complex systems.

The decision support system (DSS) concept, launched before PCs, was focused on the use of interactive computing in unstructured/quasi-structured decision making activities. Sprague (1980) argued this limitation for solving only unstructured problems and proposed an extension that includes every system. Druzdel and Flynn (2002) define DSS as an interactive system based on computer, capable to assist the user in selection activities; in this concept DSS provide data based management and refined the conventional access to information and the capability of find function via a support in building rational models. McNurlin and Sprague (2004) described DSS as "computer based systems that help decision-makers confront ill-structured problems through direct interaction with data and analysis models".

The decision support system (DSS) concept, related to an interactive, flexible, and adaptable system developed for an intelligent decision making support, offers a better information management for a better coordination of activities. DSS are very efficient instruments in complex situations/complicated environments, where decision makers need a robust support to analyse multiple sources of knowledge (Martinsons, Davison, 2007). DSS was used with success in management and the evolution was always linked to the dynamics of informatics systems, databases and expert systems. The new IT application has decisive influence DSS, with application that spread in all domains of activities. Modern DSS are able to support operational capability and strategic decision making in complex systems. A decision making framework for extreme risk should consider a structure based on quantifying decision variables decoupled in their own control systems. These variables are combined through the practical conditions offered by knowledge based infrastructure to include all decision scenarios. Because each decision scenarios affect the system in a different way, these effects can be also used to rank decisions and, in this way, to offer a better adaptability of the global framework. The main objectives of DSS are related to a better adaptability of decision making and the build of a preliminary study for decision making in technical case where is not possible an efficient planning of such activities.

The characteristic elements of a dedicated DSS are: addressing unusual problems and assist in improving the quality of decisions to resolve them; DSS is a productivity enhancement tool for decision-making activity of the expert who holds an active control system; construction and development cause an evolutionary DSS - makers, system developers that are influencing each other in a process that does not end at a specified time; DSS has a data integrator and is adapted to the particularities of the individual application and user, limited to just one method or information technology; DSS may have several stages of completion, from the core of system to application systems; DSS can be addressed according to its stage of development and more users (decision makers, analysts, and developers of tools).

DSS is a technology capable to improve the ability of managers in decision making to better understand the risks and the dynamics of the extreme events within the constraints of cognitive, time, and budget/liquidity limits. In principle, DSS design is based on the following three capabilities: a sophisticated database management tool with real time access to internal and external data, information, knowledge; powerful modelling capabilities accessed by the portfolio of models used by the management; friendly, but powerful interface designs that enable interactive queries, reporting and interface graphical user.

Since a crisis begins with events, first step in decision making process is to categorize/ rank the events and propose a first selection of the proper models. Let a knowledge base with N different cases corresponding to N different events, each having its own model, and a situation vector filled with environmental and costs parameters. Based on situation vectors, some cases are selected as possible candidate events that are associated to the portfolio of models; the models get the necessary information from the corresponding database (online data entered in the infrastructure through human user or automated systems and offline data collected for corresponding similar situations/ events). Models are equipped with controllers that compute the performances of decision variables. It results scenarios for solving the problem with different performances (time, costs). The interest is to find the optimal solution that offers a few numbers of ranked possible scenarios, with their effect degree and the decision maker can select one of them. It is useful to introduce a system capable to gets the decision maker idea about the scenarios, to refine the decision for the future same cases and to allocate the higher degrees.

The purposes of a DSS (Fig.1) is to offer a better support for decision makers, allowing better intelligence design, or selection via a better understanding of the whole problem and its dynamics, a better managing knowledge via efficient solutions for non structured decisions.
The main characteristics of a special purpose DSS are the following:

- a structured knowledge that describes specific aspects of the decision makers environment, how to accomplish different tasks;
- it incorporates the ability to acquire and maintain a "complete" knowledge and its dynamics;
- it incorporates the ability to select any desired subset of stored knowledge and to present the global knowledge in different customized ways/reports;
- it offers a direct interaction with the user (decision maker) with adaptability and creative flexibility to the situation and users.

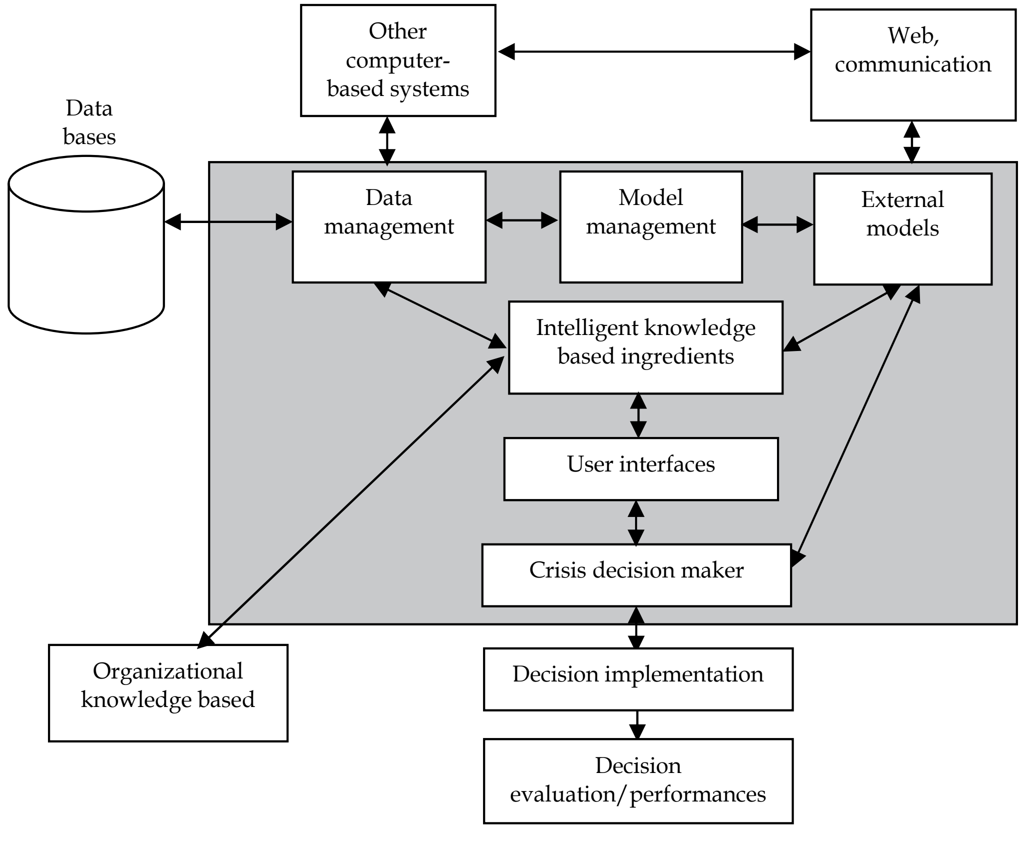

Fig. 1. The decision making process in crisis management

DSS-ERM should offer an intensive level of use in decision making process, both in the case of a crisis and before/after the crisis. This ability is based on the dynamic analysis of the current situation and „similar" past situation. The output of using this instrument could be represented by direct effects (a better decision capability, better efficiency, better objectivity in decision making process, less errors and ambiguities in communication, a good stimulus to adopt excellence and the new style of work, a better use of creativity and innovation) and indirect effects (creation of new skills and new jobs, more efficient, better competitive, better adaptability of the structure to critical situations).

4. Principles to construct an integrated DSS for extreme risk/ crisis management (DSS - ER/CM)

The system should be built and implemented in a flexible and evolutionary philosophy. It should be considered good knowledge of different applications that implies extreme risks, a good identification of the task linked to the capabilities of decision makers, a capability to refresh data/knowledge bases, a good knowledge and selection of adequate methods for the design. The basic aspects regarding the building of DSS-ER/ CM architecture is presented in Fig. 2. In this case, the system is modular and should be evolved. The flexibility will add good capability to modify in an efficient manner and the better adaptability to the treatment of new risks/events.

Decision makers that deal with crisis situations need intelligent instruments like software tools capable to deal with the questions related to the global perspective thinking, the response to unpredictability of human reaction under stress, and the impact of communication systems failure. In crisis management, the interest is to integrate different types of risk, the interactions between these risks at different levels to provide a dynamic complete picture that take into account all possible hazards and the phases of related planning including mitigation, preparedness, response, recovery after extreme event with the aim to express a structured solution. Automation, networking, systems integration and intelligent decision support improve the performance of complex decision, such typical for crisis management. The use of vague concepts is important in the context of uncertainty/ imprecise information and artificial methods (knowledge bases, fuzzy logic, multi-agent systems, natural language, genetic algorithms, and neural networks) could develop emerging capabilities that mimic human characteristics (approximate reasoning, intuition, and just plain common-sense). The main features of a dedicated DSS for crisis management are: real time data, efficient response, a user friendly interface to support decision makers that work in difficult conditions, a good quality of information, data recovery capabilities.

In the concept of Intelligent Decision Support Systems (IDSS) (Gadomski, 1998; Guerlain, Brown, 2000; Turban, 2004) are developed effective smart systems for problem solving and decision-making (Turban, 2004; Dahr, Stein, 1997) that deal with complex, imprecise and non-structured situations. IDSS are dynamic because they develop and implement more effective and productive support systems. The need for IDSS arrives from the growing need for relevant/effective DSS to deal with a dynamic, uncertain, complex management environment, the need to build context-tailored, not general purpose systems, the increased acceptance that intelligent technologies can improve decision quality and work productivity. In order to obtain an optimum solution, this type of DSS should be real-time, distributed, robust, and fault tolerant. The assistance process is provided by taking into account the elements or subsystems of high uncertain/ vague information in a changing dynamic and stochastic scenarios. The main generic capabilities are related to the independence from specific database management systems, the data fusion capability, the level of integration of resources management, the accuracy of the graphical interface, the way to detailed in time information, the use of post-action verification procedures and an efficient access to the technical documentation and history.

The critical need for the integration of intelligent ingredients in DSS is linked to the human decision makers limits: cognitive, economic, time and competitive demands. Both data management and knowledge management (facts and inference rules used for reasoning) are very important. The decision maker do needs a robust framework capable to capture imprecision, uncertainty, learn from the data/information and continuously optimize the solution by providing interpretable decision rules (Sousa, 2007).

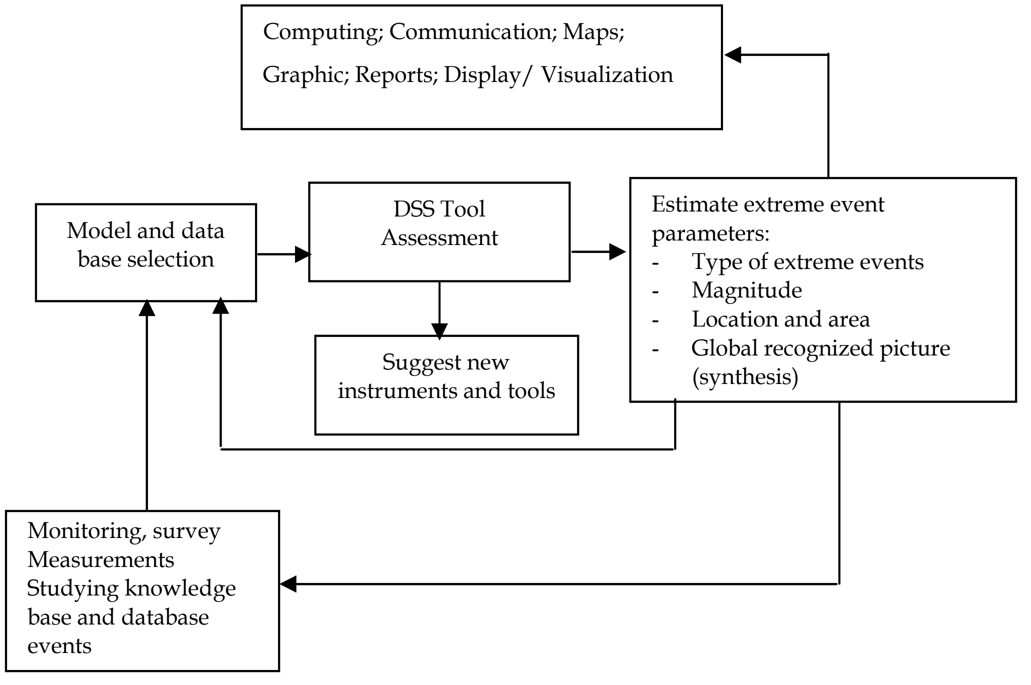

Fig. 2. Basic steps in building a DSS-ER/CM architecture

Fuzzy logic (FL)/fuzzy inference systems (FIS) applied to DSS provide formal methodology to capture valid patterns of reasoning about uncertainty. Artificial neural networks (ANN) use the capabilities of rule extraction from a trained network positions. Evolutionary Computing (EC) is a powerful global optimization instrument based on the simulation of evolution by iterative generation and alteration processes operating on a set of candidate solutions (Abraham, 2002). Due to the complementarities of these instruments (ANN, FIS, EC), the interest is to integrate various type of intelligent instruments to form a synergic integrated framework system.

ANN is defined by the architecture, the connection strength between neurons, node properties, learning rules and the objective function of the ANN represents the complete status of the network. After initialization, the learning process adapts the weights to changes for handling imprecise information. The training patterns can be thought of as a set of input pattern - output pattern pairs. The generalization represents the capability of the network to provide a correct matching in the form of output data for a set of previously unseen input data. In the Conjugate Gradient Algorithm (CGA) the search is proceeds along the conjugate gradient direction to determine the step size, which optimize the performance function along the line. The next search direction is determined so that it is conjugate to the previous search direction. The interest is to combine the new steepest descent direction with the previous search direction.

FIS are based on the concepts of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. The architecture of FIS contains a rule base, which contains a selection of fuzzy rules; a database, which defines the membership functions used in the fuzzy rule; a reasoning mechanism, which performs the inference procedure. FIS employ different inference models: Mamdani-Assilian, with the rule consequence defined by fuzzy sets, Takagi-Sugeno, with an inference in which the conclusion of a fuzzy rule is constituted by a weighted linear combination of the crisp inputs.

EAs are population-based adaptive methods for optimization, based on the principles of natural selection and survival-of-the-fittest. This dynamics of populations could be expressed by:

$$x[t+1] = s(v(x[t])) \tag{3}$$

Fuzzy controllers use a model of the expert knowledge that specifies the most important properties of the process. Adaptation of FIS using evolutionary computations has been widely explored in the literature (Abraham, 2000).

The contingency management tool (CMT) is a distributed system based on fuzzy logic; knowledge based systems and distributed systems concepts that provide decision support for a global picture of critical situations. The advantages of using an intelligent decision support tool for contingency management, as the CMT, are: reduction of the global risk, an overall increase of efficiency and reliability, a global view of the recognized picture based on a better quality of information, DSS for human resources in real-time in critical situations, DSS for training and experimentation. The use of soft computing techniques is welcome because it results a better capability of selection, a higher speed of analysis, and also on adding the advantages of adaptability, flexibility, modularity.

Fuzzy set theory (Zadeh, 1965) is a generalization of the conventional set theory that provides a strict mathematical framework to deal with the uncertainty inherent to phenomena whose information is vague/ imprecise and allows its study with some precision and accuracy. Fuzzy logic allows expressing knowledge with linguistic concepts (Ross, 2004; Zimmermann, 1996) and provides a good way to express imprecision that is inherent in the vagueness of such concepts (Jackson, 1999; Ross, 2004). Expert Systems (Turban, 2004) proceeds knowledge intensive tasks to perform inference for determining a priority list of which subsystems should be fixed and in what sequence. In crisis management it is difficult to decide which systems should be fixed first. Expert Systems allow different reasoning processes such as the fuzzy multi-criteria. The advantage of using cooperation supported by communication networks enables the separation of data, the transparent access, the sharing of computational power, decentralized decision processes, thereby enabling the increase of robustness, redundancy and efficient resource usage (Sousa, 2006).

There are a lot of efficient applications of CMT: DSS for management of actions in crisis context, DSS for management of equipment repair priorities under disaster/emergency situations, DSS for in time advice on the selection of resources for increase reliability and prevention of failures/ incidents, human resource training for contingency situations. Any critical facility subject to extreme events is a possible candidate for using the CMT. The application for risk management responds to a hierarchical and distributed decision making process that offers a specific infrastructure (libraries, knowledge bases, databases, and inference engine) and a set of generic templates that reduce the time to market a customized application. CMT collects and compiles input information on the status of the subsystems and the dynamics of risks (Sousa, 2006).

The analysis of the performances of a DSS is very important because it offers the possibility to compare, to select, to update, to improve the knowledge (models, database), but also the time to response and the capability to adapt to rapidly changing conditions. The main performance parameters for an integrated DSS-ER/CM are focused on the following aspects:

- employ a naturalistic decision model (allow decision maker to characterize event size up information as a starting point; support user in recognizing a similar problem; support user in analyzing recognized case; support the user in customized the selected analogous problem to better fit the real time conditions; support the user in implementing the final decision as an efficient CoA);
- employ case based reasoning to take advantages of expertise and historical database experiences (implement an intelligent capability; implement a knowledge base of observation; allow flexible/ adaptable observation knowledge base modules; allow revision of observation);
- trigger recognition with partial characterization of an event is limited (allow fuzzy input; recognize an event with limited information; allow a mixture of known/ unknown information; fusion capabilities);
- use system parameters that end user is likely to have available (operate on a standard laptop/ PDA; the use of an Internet connection);
- establish a central network based capability for training and experimenting (establish an web based, game oriented version for multiple applications; implement a training mode; implement a capability to improve the performances to predict decisions from each web based training session; capture web based gaming statistics; implement a capability to improve the performance to predict decisions from each web based gaming session).

In Fig. 3 are presented a simplified view regarding the performances of a dedicated DSS for crisis management.

For a better efficiency, DSS - ER/CM should operate on a standard IT infrastructure (windows based PDA/ laptop, Internet connection) and will employ a user friendly GUI (Graphical User Interface). Once the application is downloaded (with known expertise condition), direct human interface with the system will be limited to interaction during performance. Output data are provided in typical reports (both for training and experimentation) designed by the user, according to the user preferences.

Maintenance will be provided through automatically updates accessible for different type of end users. Real time diagnostics should be performed by experts to ensure the properly operation, but no support equipment will be required (updates ensure that the performance is optimal via a permanent adaptation).

5. Applications regarding the use of DSS in extreme risk management

5.1 Applications of DSS in flood risk management

Flood risk is the most frequent extreme risk event especially in the last decades. Modelling flood dynamics could be expressed by a warning system as a technical way to reduce flood risks, but also to manage adverse situations. The potential benefit of a flood forecast depends on the accuracy/precision of data/ models, the efficiency of users to build decision based on the large spectrum of information for monitoring and warning, the efficiency of operation for protection and evacuation. The situation could change the thinking of risk manager and real time information is not sufficient because a huge quantity of data should be fused, filtered and proceeded.

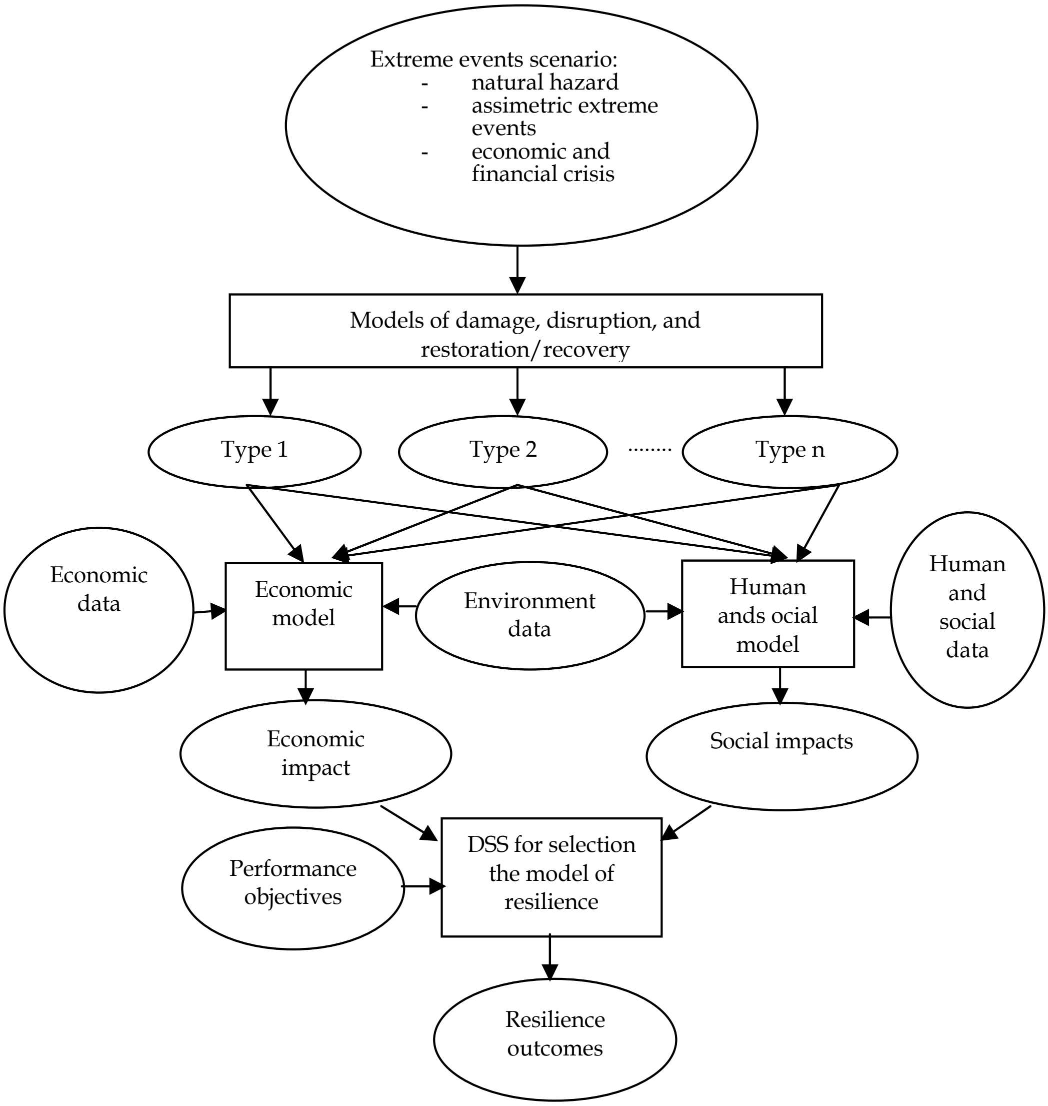

Fig. 3. The performances of dedicated DSS-ER/CM

The classic literature on prediction of flooded areas was focused mainly on deterministic models. A new branch of literature uses soft computing (especially artificial neural networks - ANN) to simulate the critical level or the dynamics of flood in a real-time monitoring framework. ANN is an empirical modelling instrument that has an ability to identify highly complex relationships input - output in a black box type model which does not require detailed information about the system. Nevertheless it learns about the relationship between input parameters and controlled and uncontrolled variables by studying previously recorded data. The advantages of ANN lie in its ability to handle huge quantity of data from nonlinear dynamical systems and, especially, when relationships are not fully understood.

The advantage of DSS in modelling flood risk management is given by its interactive nature, flexibility in approach and also on the capability to provide graphic interfaces. It also allows the identification of the critical training/testing of the model by simulating different input data. The use of DSS is efficient in the estimation of the critical level of flood warning. Flood warning system (FWS) based on DSS can immediately inform the people living downstream to take precautions and evacuation/rescue before the event. The FWS developed by the Khetchaturat and Kanbei is based on the following steps: the selection of areas that flood frequently occurred; prototype system design and data modelling flood phenomenon; the development of an early warning network between the web server and users in the area via the Internet; the development of DSS for flooding. In this framework, the authors had obtained good results.

DSS-ANN for flood crisis management is represented by a parallel, distributed processing structure composed of three layers: an input layer for data collection, an output layer used to produce an adequate response to entry, and intermediate layers capable to act as a collection of features detected. Network topology consists of a set of neurons connected by links and organized in layers. Each node in a layer receives and processes weighted input from the previous layer and sends its output to nodes in the next layer through links. For each link is assigned a weight that represents an estimator of the force connection. Weighted summation of inputs is converted to output according to the transfer function.

DSS-ANN for flood warning is efficient in the monitoring process of a flood risk zone, meaning that the orderly evacuation can occur before the actual onset of flooding and require long term sustainability. Integrating human knowledge with modelling tools lead to the development of DSS-ANN to assist decision makers during the different phases of flood management. DSS-ANN is developed as a planning tool to address both virtual and specialists, but also all those who have different positions in the management of flood risk management and also contributes to the selection of the options to reduce damages (using an expert system approach), forecasting floods (using ANN), and modelling operations according to the impact of flooding.

5.2 Applications of DSS in drought risk management

Drought is another extreme event with a major impact on economic, social, and environment. In this case, management is only a reactive one. DSS tools should address multiple risks related and, also, build the global picture of vulnerable areas to effectively manage this type of events. In the literature are presented different frameworks based on DSS instruments to help farmers to assess this type of risk. In the classic architecture built on four levels (knowledge, information, data, and presentation), experts use the knowledge base as a tool to express the interpretations of the problem and permits the interaction with users in a simple way. Knowledge base used to develop specific knowledge domain includes sequential techniques, data mining, modelling and simulation techniques, and other innovative knowledge-based models.

DSS based on geo-spatial information provides real-time drought assessment, in an easily accessible online interface. The algorithms based on data mining permits an effective identification of the correlation between global climate events and local drought conditions. Methods based on knowledge discovery in DSS are based on association rules that identify relationships between the influenced parameters. Association rules are easy to understand; experts in the field can use this joint decision making process. This framework enables each level to make application for any lower level using an open standard interface. For example,

the database knowledge permits the construction of a drought index. If data base are limited, data layer can retrieve data from relational databases to distributed space and standard queries on the data layer to give a response to the request higher.
Web-based DSS is another interesting instrument for drought risk management. It provides information for farmers, experts, end users, capable to improve the efficiency by allowing resources to better manage this type of risks.

5.3 Applications of DSS in asymmetric extreme risk management

Asymmetric threats refer to weapons/tactics used to circumvent the technological superiority and include the use of surprise or the use of weapons/tactics in an unplanned/unexpected manner. Asymmetry is present on each side: open information on the potential targets/victims, versus highly secretive, compartmentalized behaviour of terrorists. Asymmetric attacks exploit vulnerabilities outside of the accepted laws arm conflicts. Terrorism is the main asymmetric threat and represents a calculated use of violence to destroy human life and critical infrastructure/key resources or/and inoculate fear for intimidation societies. The specific characteristics of terrorist threat are related to the key role of uncertainty, limited deterrence, and the private - public good nature for providing security. A key feature is represented by the generalized, diffused nature of it (where, when and how terrorist may strike) also linked to the degree of uncertainty. If the authorities had advance knowledge of the timing and location of a future asymmetric attack, actually thwarting it would be a relatively minor affair, involving the deployment of limited police/military power. Antiterrorism represents the defensive measures to reduce the vulnerability of people and property, while counter-terrorism represents the offensive response to prevent, deter, and interdict terrorist tasks.
Operational trends are continuously changing. The technological evolution increase the knowledge of the operational theatre and the speed of response, but a huge load of uncertain data and information generated by environment still remains a problem. DSS is a computerized system capable to complement human decision in the context of human limitations. Situation awareness (SA) is essential for decision makers and the improvement of decisional process enhances also the performance of SA via the concept of the right information, at the right place, at the right time (Endsley, 2005). In the literature, there are presented solutions on contextualized user centric task oriented knowledge services (web and portal techniques) and the progress on visualization and human computer interaction devices. A new architecture developed along with information management concept and typical mechanism for special forces to effectively interoperate with IT between joint environments and with different other government departments. The critical issues (common data and service access, information exchange/ sharing, infrastructure security, privacy/ confidentiality) should be also integrated in this architecture.
MUSKETEER (MUlti environment decision Support and Knowledge Exploitation TErrorism Emergency Responses) is a complex program capable to identify, refine, develop, and integrate decision support and knowledge exploitation tools and demonstrate the efficiency of improving, the forces ability to respond to the asymmetric attacks. The interest is to build a framework to support the creation maintenance and sharing SA (common operational picture – COP, and to assist complex problem solving and decision making at different levels and different locations).

5.4 Applications for crisis management exercises (DSS-CME)

The objectives of CME are: to enhance the efficiency and operability of structure in crisis situations; to enhance the capability of all actors involved and their confidence to act adequately in crisis situations; team-building – partners should trust one another in terms of communications and valuable contacts are facilitated and consolidated; capabilities to gain additional awareness of the necessity for collaboration; it permits the identification of vulnerabilities of strategies; CME reveal where and when it is necessary to work together; it permits the identification of vulnerabilities in interdependencies of critical infrastructures across sectors; training for design new structures concepts and measures of performances.
The content and form of exercises depend on the type of extreme risks involved, the level of exercise, and the types of actors involved.

a. Discussions based exercises address possible mechanism, processes, plans and policies for any given DSS-CME on a theoretical level. Procedures and possible solutions are analyzed and different strategies are compared. Even if these exercises are less about testing existing procedures, then developing new responses to crises they imply the introducing a new innovative topics.
b. Action oriented exercises are focused on realistic scenarios and represents an important experience for actors, because it permits the identification the deficiencies. This type of CME provides an interesting way for intensive training at very low resources.
c. Target oriented levels of CME:
   - in implementation level mechanism are clearly organized; it is easy to be implemented in a real world situations;
   - in tactical exercises the priorities are coordination, collaboration, and decision making, including joint-exercises;
   - the strategic exercises is focused on the interaction between the organizations involved and the complex decision associated.

CME are efficient because they permit an important gain of knowledge with very low allocated resources. In the case of formation of decision makers the exercises begin with simple basic, low level of complexity exercises with the interest to test the efficiency of communication channels. Next step is to add value through more complex exercises, including networking and joint-exercises.

6. Conclusion

There is an emerging interest for different applications of DSS in critical decision making for extreme risk and crisis management. The nature of DSS tools have changed significantly and are equipped now with a variety of intelligent tools such as graphics, visual interactive modeling, artificial intelligence techniques, fuzzy sets, and genetic algorithms that adds new capabilities, well adapted for extreme risk and crisis management. The focus is to demonstrate the efficiency of using DSS in an extended list of applications, including all the phases in the management of natural hazards, terrorism, technological accidents, but also financial crises and multiple crises. All these problems should be treated in a multidisciplinary, modular and scalable framework, flexible, adaptive, and robust. This framework should be also design in a friendly manner, so that users can input new data/task easily. DSS-ER/CM is flexible so that new risks and impact functions can be easily incorporated by users and it should incorporate also financial-economic modules. In this philosophy, DSS-ER/CM could improve decision making process in extreme risk management with impact on the global efficiency in multiple crises management.

DSS-ERM/CM supports real time decisions based on a high number of parameters and criteria, where knowledge is expressed using vague and uncertain concepts, difficult to asses for human knowledge. Fuzzy logic, artificial neural networks, genetic algorithms are appropriate ingredients capable to support the objective to represent human knowledge. An innovative solution is the integration of the contingency management tool (CMT), a powerful knowledge-based system tool. To cope with the need of decentralised decision-making, it requires the development of an inherently distributed system. DSS mixed with CMT system ingredient enables the following features: the support decision under critical situations reducing the risk of questionable decisions; risk reduction through preventive actions; increased level of response supported by better training; it overcomes critical cases when experts are not available; give the information availability for an effective support to decision makers with a global perspective, in real time. The use of CMT in extreme risk management responds efficiently to a hierarchical and distributed decision making process that offers a specific infrastructure (libraries, knowledge bases, databases, and inference engine) and a set of generic templates capable to reduce the time to market a customized application. In this philosophy, DSS-ERM could improve decision making process in extreme risk management with impact on the global efficiency in multiple crises management.

In this chapter are presented the aspects regarding the integration of the concept of hybrid DSS in the treatment of extreme risk management. The critical need for a more efficient use of intelligent ingredients in DSS is linked to the human decision makers limits: cognitive, economic, time and competitive demands. Both data management and knowledge management (facts and inference rules used for reasoning) are very important and decision makers need a better framework, capable to capture imprecision or uncertainty. More than that they learn from the data/information and optimize the solution in order to provide interpretable decision rules. In chapter four some applications for the use of hybrid DSS in flood and drought, asymmetric extreme risk management together with the treatment of crisis management exercises (CME) are also presented. Future work should be more focused on the valuation of these types of frameworks in a way that permits better networking capabilities, costs reduction and the minimizing of the duration for periodic updates.

7. Acknowledgment

This work is supported partially by the National Centre for Programme Management, Romania.

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Risk Analysis and Crisis Scenario Evaluation in Critical Infrastructures Protection

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1. Introduction

Critical Infrastructures (CI) are technological systems (encompassing telecommunication and electrical networks, gas and water pipelines, roads and railways) at the heart of citizen's life. CI protection, issued to guarantee their physical integrity and the continuity of the services they deliver (at the highest possible Quality of Service), is one of the major concern of public authorities and of private operators, whose economic results strictly depend on the way they are able to accomplish this task .

Critical Infrastructure Protection (CIP) is thus a major issue of nations as the impact of CIs malfunctioning or, even, their outage might have dramatic and costly consequences for humans and human activities (1; 2). EU has recently issued a directive to member states in order to increase the level of protection to their CIs which, in a EU-wide scale, should be considered as unique, trans-national bodies, as they do not end at national borders but constitute an unique, large system covering all the EU area (3).

Activities on CI protection attempt to encompass all possible causes of faults in complex networks: from those produced by deliberate human attacks to those occurring in normal operation conditions up to those resulting from dramatic events of geological or meteorologic origin. Although much effort has been devoted in realizing new strategies to reduce the risks of occurrence of events leading to the fault of CI elements, a further technological activity is related to the study of possible strategies to be used for predicting and mitigating the effects produced by CI crisis scenarios. To this aim, it is evident that a detailed knowledge of what is going to happen might enormously help in preparing healing or mitigation strategies in due time, thus reducing the overall impact of crises, both in social and economic terms.

CIP issues are difficult to be analyzed as one must consider the presence of interdependence effects among different CIs. A service reduction (or a complete outage) on the electrical system, for instance, has strong repercussions on other infrastructures which are (more or less) tightly related to the electrical system. In an electrical outage case, for instance, also vehicular traffic might have consequences as petrol pumps need electrical power to deliver petrol; pay tolls do need electrical current to establish credit card transactions. As such, also

vehicular traffic on motorways might strongly perceive the effects (after a certain latency time) of an outage on the electrical system. This is a less subtle interdependence than that present for CI which are more directly related to the electrical power delivery, such as railway traffic; nevertheless, all these effects must be taken into account when healing and mitigation strategies must be envisaged for the solution of a crisis event (4).
This work reports of a new strategy aimed at realizing tools for the prediction of the onset of crisis scenarios and for a fast prediction of their consequences and impacts on a set of interdependent infrastructures, in terms of reduction of the services dispatched by the infrastructures and the impact that services unavailability might have on population. All that in order to provide a new generation of Decision Support Systems which can support CIs operators in performing preparedness actions and to optimizing mitigation effects.
The present chapter is composed of 3 sections: in the first, the general layout of the system is proposed, where each task of the system is described. This section contains the general description of the risk analysis and the tools which are used to make quantitative evaluations. The second section will encompass a general description of the meteo-climate simulation models which provide an accurate evaluation of the precipitation level expected on short- and medium-long period. The last section will be entirely devoted to the description of the impact evaluation of crisis scenarios.

2. General description of the DSS layout

The chapter will report on the main ideas at the origin of a new class of Decision Support System (DSS) which attempts to combine data (of several types and sources), dynamic data (from field sensors), dynamical predictions (weather, climate) in order to produce a dynamical risk assessment of CIs and a subsequent evaluation of the impact that predicted crises scenarios might have of technological infrastructures, services, population.
MIMESIS (Multi Infrastructure Map for the Evaluation of the Impact of Crisis Scenarios) is an example of this new DSS concept, realized to evaluate the risk to which CIs present on a given area are exposed, and to study physical interdependencies among different networks.
The tool can be used by CIs holders, Regional and National Agency for Civil Protection, Land Control Agencies.
MIMESIS is composed of the following components:

1. a geo-database designed to store, query, and manipulate geographic information and spatial data which contains stored land e CIs data;
2. a "static" analysis tool which, combining topological information with land data, is able to evaluate a *static risk* exposition index to each constitutive element of all CIs;
3. a "dynamic" analysis tool which, combining information from land sensor networks, satellite images, weather forecast, is able to evaluate a *dynamic risk* through the acquisition of dynamic real-time data;
4. the crisis scenario generator that inputs data to the DSS which evaluates the impact of faults at the topological and functional level of the CIs by using CI federated simulators;
5. a GIS user interface which allows to view crisis scenario and its evolution.

The general layout of the MIMESIS DSS is reported in Figure1
MIMESIS's goal is to predict crisis scenarios, to evaluate their impact in order to achieve prompt response and to help mitigating their effects.

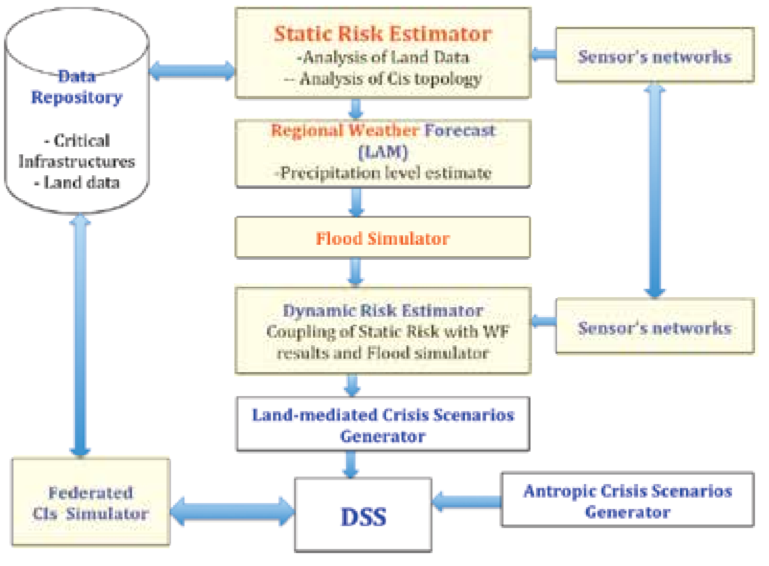

Fig. 1. General workflow of the MIMESIS DSS.

2.1 Geo-database

A major problem that risk assessments and mitigation strategies must cope with is the lack of a centralized data repository allowing comprehensive risk analysis and risk prediction of CI in a given region. Without a mean to consider, on the same ground, all CIs and their mutual interdependencies, any efficient way to predict and mitigate crisis scenarios could be realized. Impact mitigation strategies should, in fact, consider the different responses of the different CIs, their perturbation in relation to the crisis, the different latency times for perturbation spreading, the different timings in the healing actions.

To consider all these issues, the first necessary action is to constitute a control room where data of all CIs should be made available. For this reason, the geo-referenced database plays a central role in the MIMESIS tool. It contains a large set of data of different kinds: (1) regional nodes of critical infrastructures, such as electrical stations, power generators, high-to-medium-to-low voltage electrical transformers, telecommunication switches and primary cabins, railways and roads with the specific access points, gas and water pipelines and their specific active points; (2) geographic and elevation maps of the region with the highest possible accuracy; (3) position, flow rates, hydrographic models of all water basins (rivers, natural or artificial lakes, hydroelectric reservoirs etc.); (4) landslide propensity of the different areas according to historical repositories, where dates and landslides types are recorded; (5) geo-seismic data provided by the soil geo-seismic national agency, supported by real-time data provided by in-situ accelerometers (where available); (6) geo-seismic data on geological faults ; (7) social (cities, population densities), administrative (counties, districts) and economical (industrial areas classified in terms of energetic consumptions, produced GDP, types of resources the area is dependent on, etc.) data of the region; (8) agricolture's maps, fisheries etc. (9) traffic data on motorways and major urban roads (Origin-Destination matrices, if available) (10) railways data with passengers and goods traffic; (11) any other data related to other infrastructures (water, gas-oil pipelines, wherever present in the territory). Such a huge database should be provided in a GIS format, allowing a precise geo-referenced of each constitutive network's elements.

2.2 Static risk analysis

MIMESIS workflow starts with a periodic (yearly) evaluation of the "static" risk to whom each constitutive element of CI is submitted because of its geographical position. It is possible, in fact, to determine a number of risk indices, each related to a specific risk threat, which could be evaluated on the base of historical, geographical, geo-seismic data. In all cases, the risk function $R_i(r)$ of the site r related to the risk agency i, say $R_i(r)$, can be expressed as follows:

$$R_i(r) = P_i(r)I(r) \int V_i(r)dr \quad (1)$$

where $V_i(r)$ is a suitable, normalized function estimating the weight of the specific agent i in resulting a threat for the infrastructures (seismicity, presence of water basins, historical propensity of the terrain to landsliding etc.) integrated over a suitable area surrounding the CI element; $P_i(r)$ represents the sensitivity of the specific CI element to the threat i (for a given CI element located in the point r, the value $P_i(r)$ might be larger if i is the seismic threat rather than the flood threat caused by the nearby presence of water basins); $I(r)$ (which is essentially independent on the threat i) is the sum of the impacts that the absence of the CI element in r produces upon failure in its network and in the other CI networks which are functionally related to that.
We have distinguished a number of agents which could produce risk evidences for the CI elements. Among them:

- geo-seismic risk; each CI element is evaluated as a function of its position in the seismicity map. In our database, we have the update italian seismic which is periodically updated by the National Institute of Geophysics and Volcanology (INGV) (5).
- landslide risk; each CI element is evaluated as a function of its position in the italian inventory of landslides (resulting from the ISPRA project IFFI (6)).
- water basins proximity risk; each CI element is evaluated as a function of its position with respect to the regional water basin. Integration in Eq.(1) is performed over a circle of a radius which could be varied (from few hundreds meters up to a few kilometers, in the proximity of rivers with large discharge.

The impact value can be estimated as being the reduction of the Quality of Service (QoS) of the specific service provided by the network containing the faulted element. However MIMESIS attempts to evaluate also the economic and social impact that the QoS loss implies.

2.3 Dynamic risk analysis

Analogously to "static" risk analysis, a time-dependent assessment of the risks to which CI elements are exposed can be performed by predicting, at the short- and medium-time scales, the amount of precipitations expected in a given area. Severe rainfalls are, in fact, meteorological events which can produce flooding of water basins and/or determine landslides in prone grounds. The MIMESIS system daily produces an high-resolution weather forecast with precipitation mamaps of 1 square kilometre. The numerical models involved in weather and climatological predictions will be will be described in section 3. Then, static analysis should be updated by evaluating the risk values upon the application of precipitation data. In fact, the value $R_i(r)$ of Eq. 1 could be recalculated by modifying the function $V(r)$. Let consider $V(r)$ as the current flow of a river. Upon consistent precipitations, the river flow could increase and the integration of the function $V(r)$ over a given area could produce an higher, over-threshold value for the risk value $R_i(r)$. For the landslide risk threat, the $V(r)$ function could measure the extent of the correlation (captured from historical data) precipitation abundance/landslide propensity. When precipitations are abundant, a large landslide probability could be triggered in a specific area (that comprised in the integration of $V(r)$ in Eq. 1) and the risk function $R_i(r)$ consequently increase.

2.4 GIS database and the interface

The GIS database is designed to store, query, and manipulate geographic information and spatial data. Inside a geodatabase, the feature classes are organized as datasets, a collection of data presented in tabular form.

Data are stored together in a relational database where geospatial data are defined by vectorial representation. In the vector based model, the basic units of spatial information are points, lines and polygons, each of these is made up only as a series of one or more coordinate points. The database contains also the topological information of a network which is necessary for the topological algorithm analysis network developed in MIMESIS.

The application is based on Intergraph's GeoMedia Object Model, which supplies the function for representation and analysis of GIS data. The interface presents a layer-based representation shown in Figure 2

In the layer-based approach, the spatial data are presented in a set of thematic maps, called *layers*, which denote some given theme such as electrical network, telecommunication network, rivers, railways, roads etc. Each *layer* is a geo-referenced data set and associated with a table of the geodatabase containing also the attributes of geographic data. MIMESIS proposes a dynamic GIS representation adding space-temporal information to represent the evolution of a scenario. Indeed, the interface allows to control the DSS and to show the results. As the DSS evaluates the impact of faults at the topological and functional level of the CIs by using federated simulators, the interface shows the consequences of crisis scenarios enabling to detect hidden interdependencies between the different infrastructure.

3. Meteo and climatological forecasts

3.1 Weather and climate numerical models

Weather forecast and climate prediction must be considered as a key component of the new class of Decision Support System described in this work of Decision Support System.

Weather forecast provides detailed and reliable short-term spatial analysis of mesoscale weather events, while climate predictions provide long-term climate change indicators at a lower spatial resolution. Weather forecast will be used in the MIMESIS DSS for the assessment of the so called dynamic risk, while climate predictions are more suitable for the generation of crisis scenario at a larger time scale and for assessing the impact of climate for designing new interventions and extension of the existing infrastructures.

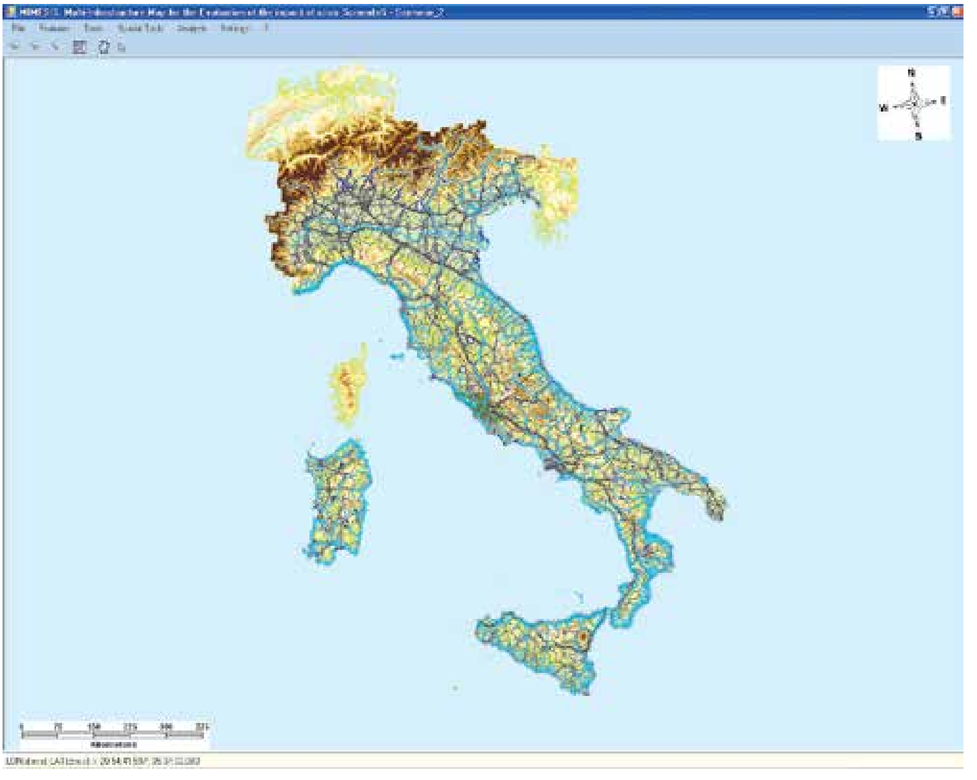

Fig. 2. MIMESIS Graphical User Interface.

Both numerical weather forecast and climate prediction involve the use of mathematical models of the atmosphere, represented by a set of discretized dynamical equations and by local deterministic parameterizations of physical processes occurring at sub-grid scales. Such processes are supposed to be in statistical equilibrium with the resolved-scale flow and are, therefore, treated as to their mean impact on the resolved scales.
Climate, seasonal and weather models are basically identical in structure, independent of the specific time scale for which they have been developed, and often share the dynamical core and physical parameterizations. Differences only lie in the resolution at which models are run, which may imply specific tuning of the sub-grid representation, although the mathematical core of the two approaches is conceptually distinct.
Climate is, by definition, the statistical mean state of the Earth system with its associated variability. Therefore, numerical simulation of climate, as performed by General Circulation Models (GCMs), is a boundary condition problem, and changes in the system equilibrium derive from slow changes in boundary forcing (such as the sea surface temperature, the solar constant or the greenhouse gas concentration). On the other hand, Numerical Weather Prediction models (NWPs) are used to predict the weather in the short (1-3 days) and medium (4-10 days) range and depend crucially on the initial conditions. For instance, small errors in the sea surface temperature or small imbalances in the radiative transfer have a small impact on a NWP model but can dramatically impair GCM results.
To partly overcome this problem, coupled Atmosphere-Ocean models (AOGCMs) have been developed. In order to allow an adequate description of the system phase space the GCM

simulation runs would last tens of years. The consequent computational cost limits the spatial resolution of climate simulations, so that local features and extreme events, which are crucial to good weather predictions are, by necessity, embedded in sub-grid process parameterizations.

A similar restriction holds for global Weather Prediction Models (WPMs) that are currently run at different meteorological centers around the world, whose prediction skill is enhanced by performing several model forecasts starting from different perturbations of the initial conditions (ensemble forecasting), thus severely increasing computational requirements. Future high resolution projections of both climate and weather rely on three classes of regionalization techniques from larger scale simulations: high-resolution "time-slice" Atmosphere GCM (AGCM) experiments (8), nested regional numerical models (9), and statistical downscaling (10), each presenting its own advantages and disadvantages.

At present, dynamical downscaling by nested limited area models is the most widely adopted method for regional scenario production, its reliability being possibly limited by unavoidable propagation of systematic errors in the driving global fields, neglecting of feedbacks from the local to the global scales and numerical noise generation at the boundaries. This technique, however, possesses an unquestionable inherent capacity to fully address the problem of weather prediction and climate change at finer resolutions than those allowed by general circulation models, as it allows local coupling among different components of the Earth system at a reasonable computational cost.

3.2 Impacts and risks prediction

Recently there has been a growing concern for the quality and reliability of both weather and climate predictions, which are expected to improve the planning and management of several economic, social and security sectors (i.e. agriculture, energy production, tourism, transport). Either on long or on short time scales, our ability to predict atmospheric phenomena clearly has a direct impact on sensitive issues, such as water resource management and hydro-geological risk assessment. However, these issues intrinsically depend on a variety of additional phenomena, e.g. processes determining soil quality, vegetation type and extension, and water demand and distribution. Therefore, resource availability and risk control are the integrated result of natural events, socio-economical interactions and political decision, and only interdisciplinary strategies can tackle the definition of priorities and means of intervention.

Following this approach, the UK Met Office has addressed, in conjunction with key energy players, the problem of responding to the challenge of climate change in the areas of energy transmission and distribution, network planning, energy trading and forecasting (11). The main findings of the project regarded network design standards, including changes in risk profiles for critical elements such as transformers, cables and conductors, the reduction in thermal plant output, the wind power potential and the vulnerability of infrastructures to extreme events such as snow and windstorms. The project also assessed changes in energy demand (gas and electricity). On the long time scale the analysis provided energy companies with guidelines on how to deal with climate projections and their related uncertainties.

This approach is also advisable for the rest of Europe, recognized as a hot spot in the last Intergovernmental Panel on Climate Change (IPCC) report (12), (13), which further urged the scientific community to undertake the difficult, but inescapable, task of supporting governments and authorities for a responsible environmental and economic planning. The IPCC report states that nearly all European regions are expected to be negatively affected by future impacts of climate change and these will pose challenges to many economic sectors. Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods, and more frequent coastal flooding and increased erosion (due to storminess and sea-level rise). In Southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. It is also projected to increase health risks due to heat waves and the frequency of wildfires (14).

Such dramatic changes are attributed to the anthropogenic warming arising from augmented carbon dioxide emissions, which have a discernible influence on many physical and biological systems, as documented in data since 1970 and projected by numerical models. Carbon dioxide and the other greenhouse gases affect the atmospheric absorption properties of longwave radiation, thus changing the radiation balance.

An immediate impact of this altered energy balance is the warming of the lower troposphere (an increase of the global temperature of about 0.6°C has been observed over approximately the last 50 years) that, in turn, affects the atmospheric hydrological cycle. Although extremely relevant as to their effects on human activities, hydrological processes are still poorly modeled, and projections are affected by severe uncertainties. Climate models can hardly represent the occurrence probability and the duration of extreme rainfall or drought events, even in today's climate conditions (15), so that governmental authorities now explicitly demand innovative science-based approaches to evaluate the complexity of environmental phenomena.

3.3 Hydrological impacts

From the point of view of weather forecast on shorter time scales (from daily to seasonal), a reliable representation of the hydrological cycle is also essential for the early warning of extreme events and the evaluation of their short-term impacts. Heavy rain may cause considerable compaction and erosion of the soil by its force of impact, sealing the soil surface and channeling the water to run off the surface carrying away the topsoil with it.

Considering hilly and mountainous areas, heavy rain may produce enormous erosion by mudflow generation, while rainwater running off hard impervious surfaces or waterlogged soil may cause local flooding (16). At the other extreme, the early prediction of drought events deriving from extreme rainfall deficits would also greatly benefit from accurate forecasts of the relevant hydrological variables. As a matter of fact, drought is, unlike aridity, a temporary phenomenon characterized by high spatial variability (17), whose representation could be effectively approached with high resolution regional models.

In order to extend their ability to describe the hydrological cycle, river routing modules are currently being incorporated in atmospheric models in order to link the meteorological forcing (in particular rainfall) to the hydrological response of a catchment. Together with land modules (which mimic the interactions between the atmosphere and the biosphere) they represent an alternative to the rainfall-runoff models which, in recent years, have been employed in a wide range of applications to assess impacts of weather, climate or land-use change on the hydrological cycle (18), (19). As atmospheric models are routinely run in either meteorological or climatological applications, such an extension is likely to be a feasible and economic way to help hydrologists to derive quantitative figures about the impacts of the observed or expected environmental changes. It should be stressed again, however, that the

impact studies, which follow up model projections, are definitely in need of complex systems capable of crossing information from different disciplines and of managing huge amounts of data.
The uncertainty involved in this type of impact assessment limits the value of the results and great care should be taken in evaluating model skill in predicting the driving meteorological variables. Precipitations, the main atmospheric driver of hydrological catchment response, are unfortunately still a critical output of model diagnostics (20). Although the complexity of cloud parameterizations is always increasing, this is no guarantee of improved accuracy, and better representation of clouds within NWP models has been the focus of recent research (21),(22), (23), (24). Numerical models explicitly resolve cloud and precipitation processes associated with fronts (large scale precipitation), while parametrizing small scale phenomena by means of the large-scale variables given at the model's grid points. The most important parameters are humidity, temperature and vertical motion. The vertical velocity determines the condensation rate and, therefore, the supply of liquid water content. Temperature also controls the liquid water content, via the determination of the saturation threshold. Moreover, the temperature distribution within a cloud is also important in determining the type of precipitation - rain or snow. The complexity of the parameterization of cloud processes is limited by the associated numerical integration time (25). Model spatial resolution is crucial for a reliable treatment of condensation processes, as vertical motion of air masses is often forced by orography, whose representation therefore needs to be as accurate as possible. Again, regional models, due to their higher spatial resolution and reduced computational costs, seem to be the most appropriate tool for downscaling precipitation fields, at the same time preserving the complexity of convection parameterization. However, the reliability of precipitation forecasts provided by state-of-the art meteorological models also depends on their ability to reproduce the sub-grid rain rate fluctuations which are not explicitly resolved. In particular, the assessment of precipitation effects on the hydrological scales requires an accurate characterization of the scaling properties of precipitation, which is essential for assessing the hydrological risk in small basins, where there is a need to forecast watershed streamflows of a few hundred square kilometres or less, characterized by a concentration time of a few hours or less.
At these smaller space time scales, and specifically in very small catchments and in urban areas, rainfall intensity presents larger fluctuations, and therefore higher values, than at the scale of meteorological models (26). In order to allow a finer representation of land surface heterogeneity than that allowed by nominal grid resolution, mosaic-type schemes are being investigated, which account for topographical corrections in the sub-grid temperature and pressure fields and downscale precipitation via a simple statistical approach. Such schemes allow simple implementation of space dependent probability distribution functions that may result from ongoing research on statistical downscaling of precipitation (27). As already mentioned, a stochastic approach has also been successful in improving precipitation forecast reliability as to its large scale statistical properties. In the last decade, ensemble prediction systems have substantially enhanced our ability to predict precipitation and its associated uncertainty (28). It has been shown that such systems are superior to single deterministic forecasts for a time range up to two weeks, as they account for errors in the initial conditions, in the model parameterizations and in the equation discretization that might cause the flow-dependent growth of uncertainty during a forecast (29), (30), (31). At the same time, multi-model ensemble approaches have been indicated as a feasible way to account for model errors in seasonal and long-term climate studies (see Figure 3).

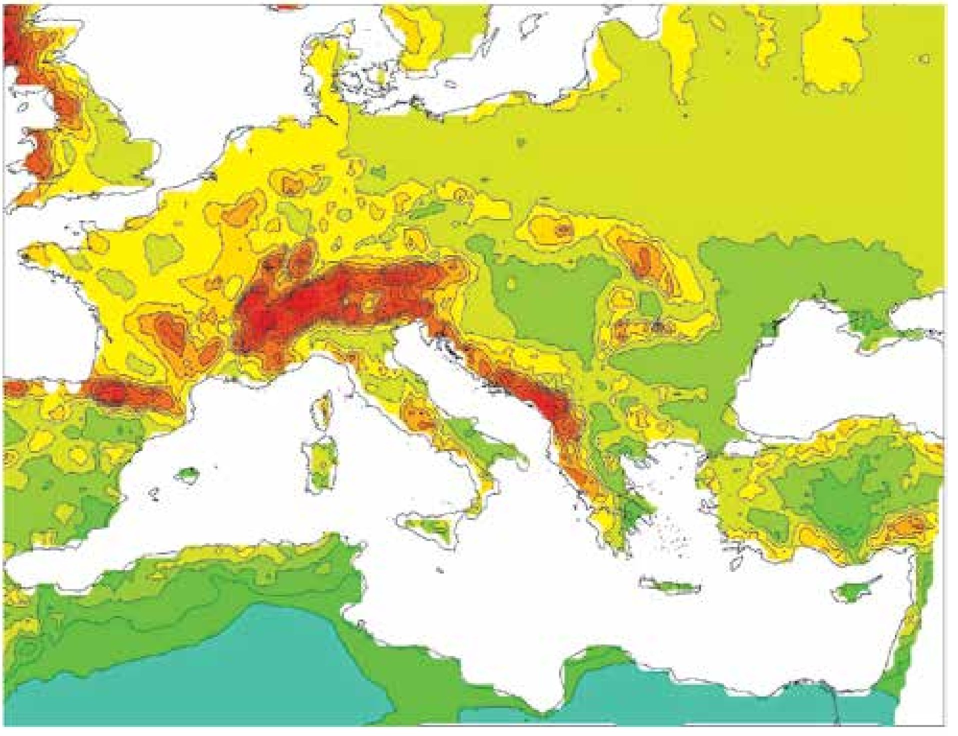

Fig. 3. Climatological precipitation field representing the period 1958-1998. The map has been produced analyzing the output of the 9 models involved in the EU ENSAMBLE project.

It has been proved that, under the assumption that simulation errors in different models are independent, the ensemble mean outperforms individual ensemble members (29), (32), (33). By sampling modeling uncertainties, ensembles of GCMs should provide an improved basis for probabilistic projections compared to an ensemble of single model realizations, as the latter only samples different initial conditions, i.e. a limited portion of a specific model phase space. Ensemble predictions are therefore increasingly being used as the drivers of impact forecasting systems (34), (35), (20), thus reinforcing the already pressing demand for complex numerical systems that allow rapid inter-comparison between model realizations and multivariate data analysis.

4. Evaluation of impacts of crisis scenarios on CIs

4.1 Crisis scenario generator and impact evaluation

Once the risk assessment of the different CI elements is concluded and, after that, the state of risk of one (or more) elements of one (or more) infrastructures have taken over a pre-defined threshold, the system produces an alarm and defines a "crisis scenario". If one defines the generic k-th given infrastructure the set $G_k(\Omega)$ of elements (nodes and arcs, together with the network which connects them), we define a "crisis scenario" a new set $G_k(\Omega')$ where Ω' is the set of constitutive elements of the infrastructure k *without* the elements (nodes and/or arcs) which have been supposed to be lost (or damaged) because the above threshold risk value. MIMESIS first performs a topological analysis in order to see whether the network of the infrastructure is still topologically connected and determines which are the new topological "critical" points of the network. Topological analysis of the network is carried out through the evaluation of the following quantities (7):

- nodes and links centrality indices (Betweenneess centrality, Information centrality);
- network's diameter, min paths, min cuts;
- spectral analysis of the Adjacency and Laplacian matrices associated to the network.

Topological analysis is a first mean to assess the integrity of the network. The presence of disconnected components of the graph can be easily seen by evaluating the eigenvalues of the Laplacian matrix associated to the network. If the graph G(associated to the network) has n vanishing eigenvalues, the graph has n different disconnected components. Centrality measures tend to identify which are the most relevant elements (nodes, arcs) of the network. Node i Information centrality, for instance, determines which is the increase of the min paths among all the other nodes if node i is lost (when network i is lost, the min paths connecting all other nodes originally passing through i should be re-evaluated and they will produce new min paths larger than the original ones). As far Information Centrality is concerned, larger is the Information Centrality, larger is the importance of the node to provide "good connections" among all the others.
After a first assessment of the perturbed network upon topological analysis, the MIMESIS tool performs the most relevant action: the estimate of the reduction of the Quality of Services produced by the perturbation occurred to the network due to the faults in one or more of its elements. This task is accomplished by using "domain" or "federated" simulators of CIs. For domain simulators we intend commercial or open source simulators of specific infrastructures: electrical (such as Powerworld, E-Agora, Sincal etc.), telecommunications (NS2), railways (OpenTrack) etc. Federating domain simulator is one of the major achievements granted by a strong collaboration among the european CIP scientific community (e.g. the projects IRRIIS (36) and DIESIS (37)). For federated simulators we intend a new class of simulators which "couple" two or more domain simulators through some specific synchronization mechanisms and some interdependency rules which allows to describe how, and to what extent, a CI determines the functioning of another. MIMESIS integrates the outcome of one of the most successful EU FP7 projects, the DIESIS project (37) which has attempted to design a general model which could allow to integrate more domain simulators in an unique framework. The key role in the DIESIS mode is played by the ontology model (KBS) which is able, to an abstract level, to describe a generic Critical Infrastructure and its links with other Infrastructures. A generic element of a network from this abstract space can be subsequently "mapped" into the real space of a specific Critical Infrastructure (electrical, telecommunication or others) by adapting the generic elements to the specific case. The ontology model allows to avoid the problem of directly connecting systems which have different structures, different constitutive elements, different functioning laws: Integration is firstly performed in a "meta-space" (the abstract space of Critical Infrastructures) (38) and then mapped into the spaces of the single infrastructures. A brief sketch of the KBS approach is outlined in the following section.

4.2 The DIESIS ontological approach for CI simulators integration

Within the DIESIS project, a framework for CIs simulators integration has been proposed that allows the separation of the scenario representation (*Scenario Definition Phase*) from the simulation framework (*Federated Simulation Phase*). The main idea is to develop a Knowledge Base System (KBS) based on ontologies and rules providing the semantic basis for the *federated* simulation framework (40), (41).

In particular, a federation of simulators can be considered as a System of Systems where each simulator represents an independent entity with its own behavior and purpose. The super-system considers the interaction of these entities and puts in evidence an emergent behavior that does not reside in any component system (42). Therefore, in a federated simulation, the stand-alone simulators must be linked together so that an understandable and meaningful information exchange could be performed. This requires that simulators could interact and cooperate. The proposed ontological approach allows both an uniform modeling of heterogeneous infrastructures and the easy representation of inter-domain dependencies.
The DIESIS KBS establishes a common formalism, for scenario and domain knowledge experts, to represent the main aspects, elements and properties of the considered domains and their interconnections. The KBS is based on the Ontology Web Language (OWL) and the ontologies are defined through proper specifications of *classes*, *properties* and *individuals* (instances of classes). The individuals represent the physical/logical entities that form the universe of a specific domain. For instance, a specific electrical load is an individual of the electrical ontology. The OWL allows to group individuals in classes that define the properties shared by all their individuals. The properties can be used either to specify relationships between individuals and data type values (*Datatype Properties*) or to describe relationships among individuals (*Object Properties*). Then, if we denote with *Pr* the set of properties we have

$$Pr = DP \cup OP \tag{2}$$

with

$$DP = \{p \mid p \; Datatype\; Property\} \tag{3}$$

and

$$OP = \{p \mid p \; Object\; Property\} \tag{4}$$

The KBS architecture includes the following ontology definitions:

- World ONTology (WONT);
- Infrastructure domain ONTologies (IONTs);
- Federation ONTology (FONT).

The WONT is a general template providing the basic structures and rules to define CI domains. In particular, the WONT allows the definition of CI domain elements (through the WONT class *Component*), their physical and logical interconnections (through the WONT object property *isConnected*) and the dependencies among different CI domains (through the WONT object property *dependsON*).
The IONTs inherit the basic template from the WONT and represent the specific knowledge of the critical infrastructure domains. For instance, the electric IONT class *Load* (that models the electric load element) and the telecommunication IONT class *Switch* (that models the telecommunication switch element) are subclasses of the WONT class *Component*. In addition, the railway IONT property *isLinked* that models the connection between two railway stations is a sub-property of the WONT property *isConnected*; similarly, the telecommunication IONT property *transmits* that models the connection between a transmitter and a receiver is another

sub-property of the WONT property *isConnected*. Analogously, all dependencies among the considered CI domains are modeled through ad-hoc designed sub-properties of the WONT property *dependsON*.
In the following, given a CI domain X_i, C_i indicates the set of all components of X_i and Pr_i indicates the set of properties related to the components of X_i. Then, a generic IONT can be represented as $IONT_i = \{C_i, Pr_i\}$.
Once the IONT has been defined to model a particular domain, it is possible to create individuals (instances of IONT classes) to represent actual network domains (for example the electrical power network or the telecommunication network of a specific city district). Similarly to the IONT definitions, we indicate with C_i^* the set of the all instantiated components belonging to the domain X_i and with Pr_i^* the set of instantiated properties related to X_i. Then, the IONT instance $IONT_i^*$ can be expressed as $IONT_i^* = \{C_i^*, Pr_i^*\}$.
The FONT includes all IONTs of the domains involved in the considered scenario (e.g. electrical, telecommunication, railway domains). The FONT properties (sub-properties of the WONT property *dependsON*) allow to model dependencies among components of different domains (e.g. the FONT property *feedsTelco* models the electrical supply of telecommunication nodes). The sets of the FONT properties and of the FONT instantiated properties are defined respectively as:

$$FPr = \{sp(a,b) \mid sp \text{ sub-property of } dependsON, a \in C_i, b \in C_j, i \neq j\} \tag{5}$$

and

$$FPr* = \{sp(a,b) \mid sp \text{ sub-property of } dependsON, a \in C_i^*, b \in C_j^*, i \neq j\} \tag{6}$$

The Figure 4 summarizes the proposed KBS architecture
The FPr^* allows the definition of FONT rules that express the semantic dependency. The FONT rules, expressed using the Semantic Web Rule Language (SWRL), have been actually translated into their JAVA counterpart and implemented through "if-then-else" constructs embedded within the Federation Managers which incapsulate the simulators of each CI domain ((39)).
The DIESIS distributed simulation framework using the KBS allows the components (involved in the defined FONT properties) to exchange the functioning status values.

5. Conclusions

CIP is a major concern of modern nations. EU has issued a Directive (3) to increase awareness of this duty as CIs are become transnational bodies whose care must be a shared concern.
Whether markets liberalization has produced, at least in principle, benefits for the consumers, it has *de facto* imposed a deep revision of the governance strategies of the major national infrastructures. In many countries, there has been a (sometimes sudden) fragmentation of the ownership and the management of relevant parts of infrastructures (see, for instance, those of gas and oil distribution, telecommunications, electrical transmission and distribution, motorways and railways) which has strongly weakened the centralized governance model which has been substituted with a model of "diffused" governance of the infrastructures. Many different industrial players autonomously own and manage parts of the infrastructures, leading its global control more complex. The lack of information sharing among operators of different parts of the infrastructures, due in some cases to industrial competition reasons, reduces the technical control of the whole infrastructure and, even more, reduces the

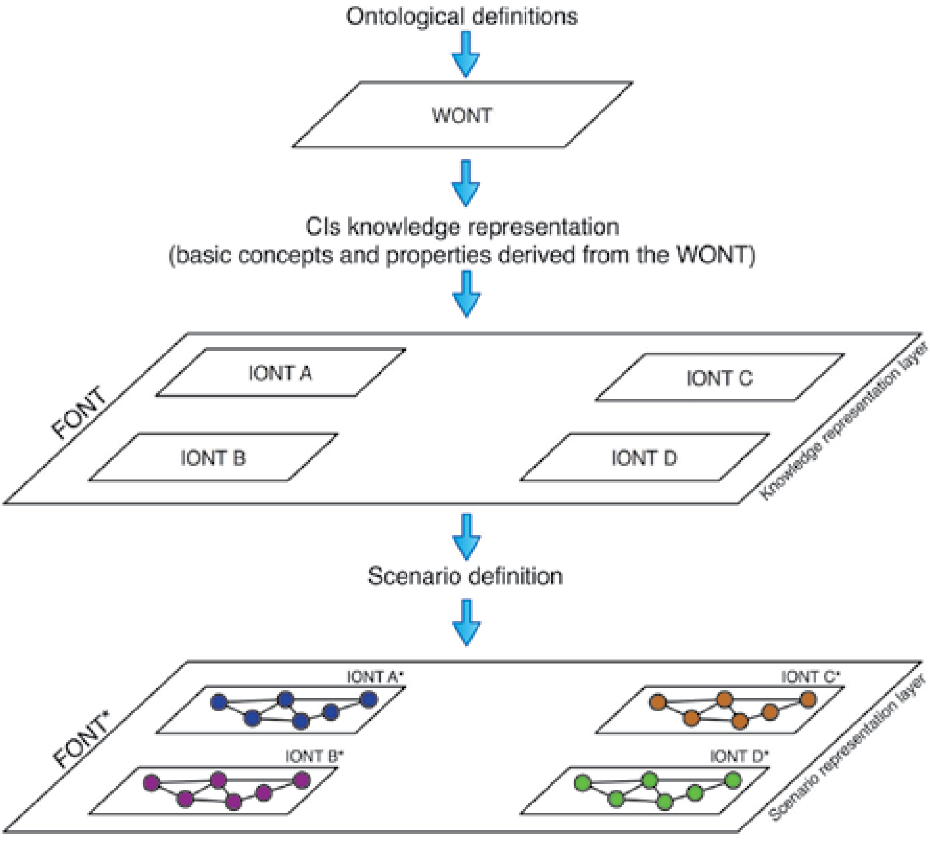

Fig. 4. KBS architecture.

possibility of a control of the "systems of systems" defined by the entanglement of all interconnected CIs.

The new generation of analysis and risk prediction of CIs, whose the system MIMESIS would be a prototype, is intended to overcome the above mentioned drawbacks imposed by modern market policies and the increased CIs interdependency. The MIMESIS system has its core in weather and climate predictions and by new hydrological models. In a future perspective of rapid and (sometimes) strong climatic changes and the occurrence of a large fraction of extreme events, prediction capabilities will be a winning asset against the occurrence of large and uncontrolled outages of one or more CIs.

Far from being usable only for assessing risk prediction related to meteo-climatic events, MIMESIS could also be used for "reverse engineering" actions related to CIP against external malicious attacks. MIMESIS could, in fact, be used to estimate the most vulnerable points of the networks, not only in relation to their single topology and functions, but also with respect to the role they play in the wider context within the cited "system of systems". An attentive "off-line" use of the tool through the insertion of random faults could reveal which types of faults produces largest perturbations to the systems, leading to suggestions in the network's Security area.

Other than being a prediction tool for external events, MIMESIS could also be used to correctly design new branches of existing infrastructures, by allowing the *ex ante* evaluation of their impact on the Quality of Services of all the system of interdependent infrastructures. We do believe that data availability by CI owners, their integration with other types of data (geophysical, economic, administrative etc.), the use of advanced numerical simulation tools for weather and climatic predictions, the use of CI simulators (both single domain or "federated" simulators) could represent an invaluable clue to realize a new generation of tools for increasing protection and enhancing security of CIs.

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Part 6

Miscellaneous Case Studies

20

Applications of Decision Support System in Aviation Maintenance

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1. Introduction

The basic purpose of aviation maintenance is to prevent the decreased levels of original aircraft airworthiness, safety and reliability design at the lowest cost, which is of great significance to the running of air transport enterprises. According to statistics, aviation maintenance accounts for approximately 20% to 30% of direct operating costs, not including indirect costs caused due to maintenance, such as flight delays, material and spare parts, corporate image.
In recent years, as the rapid development of civil aviation industry, a large number of new technologies have been used in airplanes, which increase the complexity of the civil aviation maintenance, especially the application of digital information technology. In response to modern aviation maintenance of the new situation, so as to adapt to the future development trend of digital maintenance and improve the efficiency and quality of modern aircraft maintenance, establishing the necessary modern air transport aircraft maintenance decision support system becomes increasingly urgent. For this reason, this paper in-depth analysis the problem of how to build the aviation Maintenance Decision Support System (MDSS).

2. The components of aviation maintenance decision support system

With modern communication technology, fault diagnosis technology and modern control technology, aviation maintenance decision support system can achieve real-time data exchange between air and ground, and it is able to provide effective decision support for rapid fault diagnosis and digital maintenance. This system should be composed of information acquisition and processing, aircraft maintenance support, material management, maintenance management, maintenance event evaluation, etc. As shown in Figure 1.

2.1 Information acquisition and processing

Aviation maintenance decision support system needs a variety of real-time data and historical data for decision support judgments, and all these data are collected by information acquisition and processing module.

2.1.1 Real-time data acquisition and processing

With the large number of information technology applied in civil aircraft, modern aircrafts are equipped with central maintenance computer, aircraft condition monitoring system and other real-time aircraft state parameters acquisition and monitor systems, which make it possible to monitor aircraft state parameters during the whole flight. Specifically, the collected aircraft state parameters are inputted to the aircraft online fault diagnosis system, which diagnoses the fault of aircraft by the established online fault diagnosis model. The result should be real-time transmitted to the ground system through the air-ground data link (such as Aircraft Communications Addressing and Reporting System(ACARS)), so as to provide decision support for ground maintenance and achieve rapid repair of aircraft failure, thus improving efficiency in the use of aircraft.

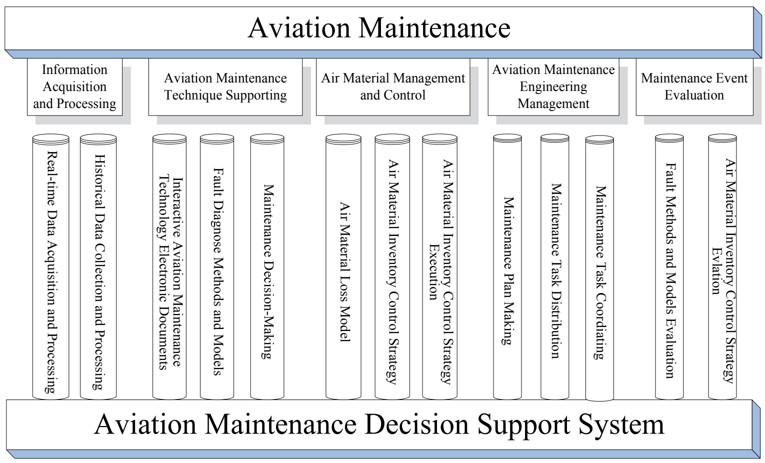

Fig. 1. Aviation maintenance decision system diagram

2.1.2 Historical data acquisition and processing

The process of aviation maintenance will accumulate a large amount of historical data. These data can be divided into three types, as shown in Figure 2.

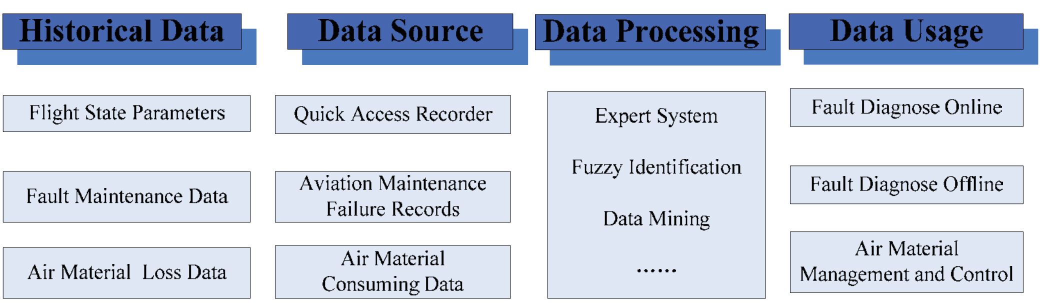

Fig. 2. Historical data acquisition and processing diagram

1. *State parameters information of the flight* is usually closely linked to aircraft failure recorded by Quick Accesses Recorder (QAR), through the in-depth analysis of recorded flight status parameters, we can learn the condition of airplane in flight. Using the causal relationship between the system failure symptoms and the cause of the malfunction, we can create online aircraft fault diagnosis model to provide decision support for online aircraft fault diagnosis, and based on which establish a on-board fault diagnosis system.

2. *Aircraft maintenance records* are the depiction of the overall evolution of the aircraft and systems. Aircraft maintenance record data can be used to obtain deep relationship between the system failure symptoms and the cause of the malfunction, it becomes particularly useful when comes to learn the relationship between system and environment, and the interaction chain relationships between system and system, that makes it possible to conduct more comprehensive and in-depth fault diagnosis on the basis of online fault diagnosis, so as to provide firm decision support for the ground maintenance.
3. *Air material is the material of aviation maintenance*, in order to achieve the complexity capabilities and high-performance of modern aircraft, there are many types of aircraft systems, while different types of air material have different price, different loss of regularity and different storage conditions (the required temperature, humidity, storage time). Thus the improper selection of air material control strategy may lead to deficiency or excess of air material, on the other hand, if make good use of air material historical consumption data, then we can understand the status of air material loss and establish an appropriate procurement strategy to maintain a reasonable level of air material reserve, to improve aviation material utilization and the efficiency of enterprises.

2.2 Aviation maintenance technical support

Aviation maintenance technical support modules are based on the collected and processed data and the existing maintenance resources. Specifically, it can be divided into two aspects:

2.2.1 The fault diagnosis model and method

Fault diagnosis model is divided into on-line and off-line diagnosis model. On-line diagnosis model receives history aircraft state parameters from data acquisition and processing module, through data acquisition and processing module for the aircraft state parameters of the process history data, using more sophisticated expert system, fuzzy identification and other traditional fault diagnosis, established to identify different systems and components of the on-line fault diagnosis model based on the case of actual operation, can be used time of diagnosis, diagnostic accuracy and other parameters on-line fault diagnosis model to evaluate the results based on evaluation of diagnostic model of the online database to be updated. In addition, based on economic considerations, it should also be established on-line diagnosis based on Minimum Equipment List (MEL), Maintenance Steering Group 3 (MSG-3), etc. to develop appropriate law judge to determine the "serious failure" of the fault code list immediately through the ACARS system, then it will be transferred to the fault code list issued ground, or for storage, such as the plane landed using WirelessFidelity /Personal Digital Assistant (WiFi/PDA) and other technical means of transmission fault code list, reducing the flow of ground data link and improve the efficient use of ground data link.

Off-line fault diagnosis model based on information acquisition and processing module of the aircraft maintenance record information obtained through in-depth analysis of the system fault laws, particularly between the system and the environment, systems and cross-linking between the laws of the system, the establishment of fault symptoms, and the causal relationship between the fault types, the use of artificial neural network, Petri net fault diagnosis technology of modern aircraft comprehensive diagnostic data. Diagnosis entered

into the aviation maintenance technical documentation for the interactive system, direct access to a viable maintenance program.
In addition, according to the system with historical fault data can also use trend analysis, curve fitting, time series and other methods for different types of faults predict the trend predicted results using the fault diagnosis can be assessed for failure diagnostic support.

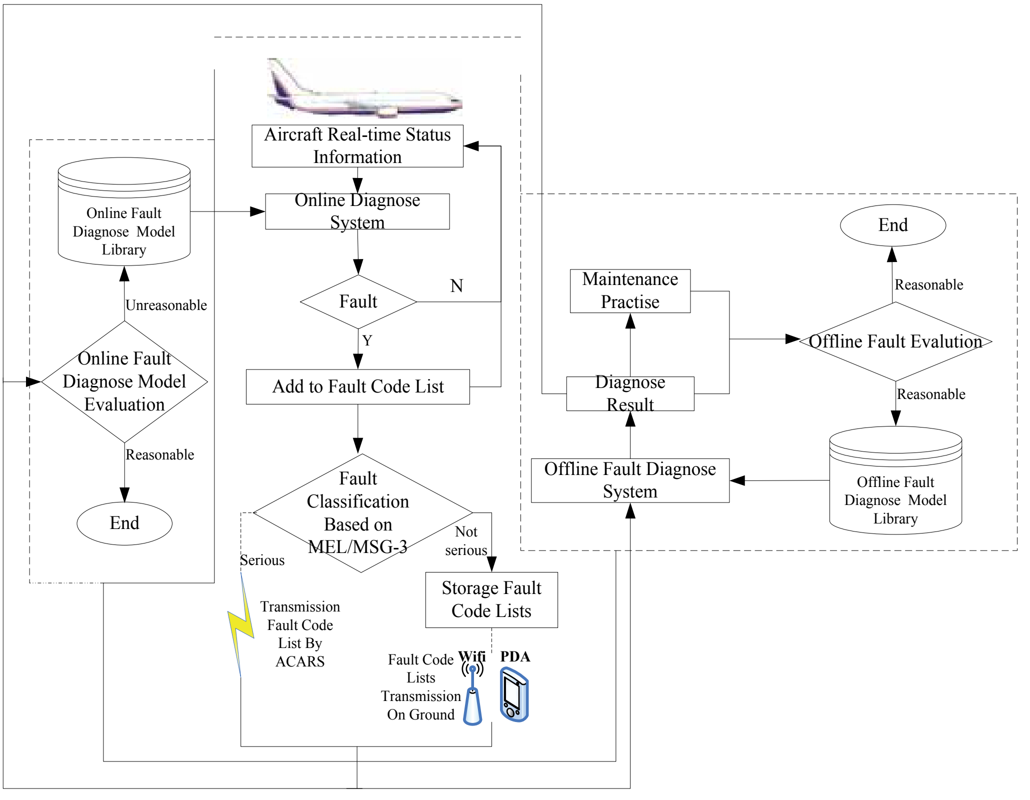

Fig. 3. Diagram of air-ground fault diagnosis

2.2.2 Maintenance technical documentation

The aviation maintenance technical documentation is another important aspect of aviation maintenance technical support, In particular, maintenance of aviation interactive electronic documents. Modern aircraft is an integrated body of advanced manufacturing technology, process technology, and information technology. It produces and uses lots of technical information in the design, production, use and maintenance process, for example, data from the manufacturer including Aircraft Maintenance Manual(AMM), Fault Reporting Manual (FRM), Fault Isolation Manual (FIM), Wiring Diagram Manual (WDM), System Scheme Manual (SSM), Illustrated Parts Catalogs (IPC), Master Minimum Equipment List (MMEL), etc; technical data from time to time update including Service Bulletin (SB), Service Letter (SL), etc; council documents including Federal Aviation Regulations (FAR, CCAR),Advisory Circular (AC), Airworthiness Directives (AD), etc. According to their own conditions, Airlines refer to the manufacturer and the requirements of the council to develop various documents, which are the important tools and resources to support the maintenance, for example, Minimum Equipment List (MEL), Operations Specifications (OS), Technology Policy and Procedures Manual (TPPM), Check Manual (TM), Outline Reliability Manual (RPM). Traditionally, many of these technical documents use paper for the storage medium, or in part, have been digitized, but a large number of technical documents have problems of queries difficult, not easy to carry and preservation and difficult to update.

Interactive aviation maintenance technical manual integrates advantages of technology of application computer, multimedia, database and network, organize and manage complex content operating manuals and maintenance information according to relevant standards, implement accurate performance of required information of maintenance staff with optimized way. The purpose of it is to accelerate the progress of aviation maintenance, enhance the effectiveness of maintenance.

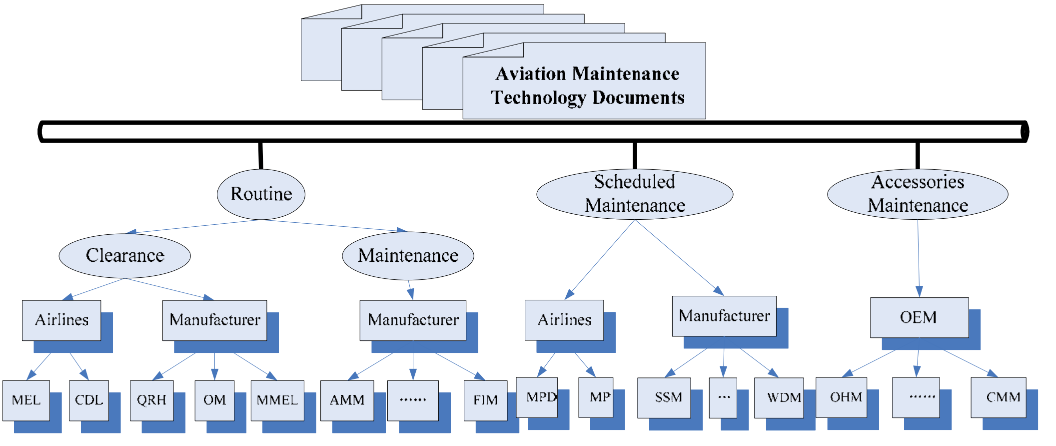

Fig. 4. The type of maintenance technology documents

2.3 Management and control of air materiel

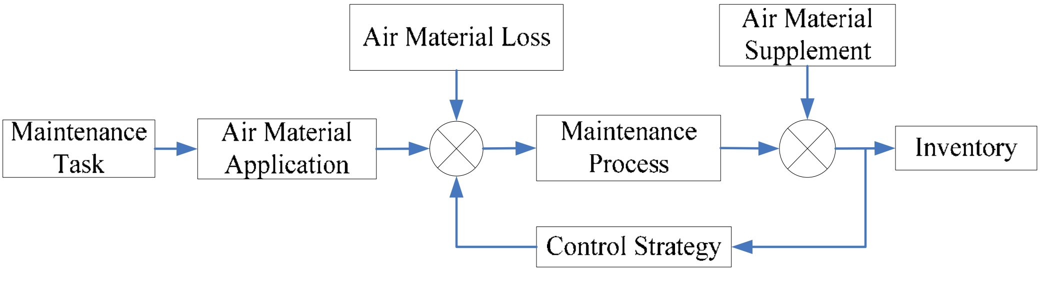

Fig. 5. Management and control of air materiel modelling

Air material inventory, which is the highest cost in aviation maintenance process, is an important component of aviation maintenance process for the complexity of modern aircraft components, variety of aircraft types and materials, and the use of different rules of air material, different storage requirements and flight safety. Therefore, control of air material has great influence on the efficiency of enterprises. Through we use historical information for information acquisition and processing module to get air materiel, it can gain the regularity of loss and buy of air materials using techniques of statistical analysis and data mining, such as the loss regularity of repairable air materials and unrepairable air materials, the maintained regularity of maintained air materials, etc., then through the rational control strategy, it establishes the corresponding loss mode, implements optimization of air material inventory and improve the quality of maintenance.

In addition, air material inventory control should consider the method of shared regional aviation maintenance units, especially with high value, and there may be more serious problems with lack of critical flight equipment, such as aircraft engines, etc. Through modeling and analysis of historical data, it can construct a reasonable model for regional air material sharing, and then contribute to enhance the efficiency of the industry for the whole region.

2.3.1 Aviation maintenance management

Aviation maintenance management is divided into maintenance program development, allocation of maintenance tasks, and maintenance tasks scheduling. Under the premise of security, the main goal of aviation maintenance is economic. A fast, highly reliable maintenance can increase the number of aircraft flight hours, thereby enhancing economic efficiency. Aviation Maintenance Management Module manages and controls the maintenance project based on the summarization of maintenance tasks from technical support module.

Maintenance plan is the core of maintenance tasks. It determines the implementation of maintenance methods based on the level of maintenance tasks, the existing maintenance resources (manpower, equipment, facilities, material, etc.) and the aircraft status. Maintenance plan includes many aspects, such as carrying out step by step or in parallel ways, the name of maintenance, repair content, maintenance workers, and materials required for the maintenance, etc. Maintenance plan makes reasonable arrangements for the future state of repair to ensure the smooth implementation of aviation maintenance.

Concrete repair work is completed by mechanical, electronic, structural, accessories maintenance workshop. The allocation of maintenance tasks are to maintain a reasonable distribution of work to the appropriate workshop, to enable the repair shops carrying out the maintenance work step by step or in parallel way and ensure the smooth progress of maintenance projects.

In the actual maintenance projects, maintenance programs will inevitably be adjusted, because the schedule might be unreasonable, or something's comes up as emergency or accident. Maintenance scheduling is to use reasonable scheduling strategy and appropriate decompose or combine maintenance tasks or just change the sequence to ensure the smooth implementation of maintenance works in accordance with the progress of the plan.

2.3.2 Maintenance results evaluation

Aviation maintenance decision support system is an open system. To achieve an objective and reasonable assessment, there should be a reasonable maintenance event parameters evaluation system, thus achieving optimal and update maintenance decision support system. Evaluation of maintenance events should contain at least three aspects: (1) Applicability of on-line fault diagnosis model. On-line fault diagnosis system is an on-board system, so its diagnosis should be real time and needs clear failure description while its relative diagnosis accuracy is not high. (2) The applicability of off-line fault diagnosis model. Off-line fault diagnosis system has sufficient resources and time to judge the on-line diagnosis system's results in detail, therefore, off-line fault diagnosis system is not critical on the diagnosis time, but the accuracy of diagnosis must be high, thus reasonable maintenance tasks can be determined, therefore, the effectively maintenance can be implemented and maintenance costs will be reduced. (3) Reasonable air materiel control model. Air material involves in various aspects, such as mechanical components, electronic components, and there are repair materials and maintenance consumables. Reasonable air materiel configuration not only meets the maintenance requirements, but also reduces the cost from procurement, storage, transportation, etc. Otherwise the airline may have a very negative impact on operations.

3. Theory and examples of decision support system of aviation maintenance

The decision support system of aviation maintenance, which has the properties of discrete event dynamic systems and continuous time dynamic system, is a typical hybrid system. The system of acquisition and processing of real-time data should contain functions of the acquisition of parameters information, filtering, transformation and so on, and it should use theory of continuous variable dynamic systems to construct, while acquisition and processing of history data mostly use relevant theories of statistics and analysis. It contains a lot of people work in the system of management and control of air materials, such as maintenance process, procurement process, etc., and has obvious properties of discrete event dynamic system, but through reasonable conversion, it can use a variety of modern control methods of minimum variance control, optimal control, stochastic control, adaptive control and robust control to implement. Aviation maintenance technical documents may pay more attention to technology and theory of multimedia, database/data warehouse. Simultaneously, because systems using discrete event dynamic system property can not be expressed using the traditional problem of parsing, it can use intelligence theory to solve, for example, fault diagnosis can use theories of neural network, Petri nets, fuzzy reasoning, agent, and so on.

With the development of theory and technology of computer simulation, it can use more approaches for the research of the model and method of aircraft fault diagnosis, the model of air materiel use and the air material inventory control, decision support system of aviation maintenance, and use full-simulation analysis of the system to establish a rational and efficient decision support system for aviation maintenance. The following is a certain type of aviation turbine jet engine fault diagnosis model of aircraft tire building process and inventory control process as an example.

3.1 Aircraft fault diagnose based on adaptive FPN

Aero-engine, which has structural complexity, possesses a number of components, works in the high temperature and harsh environment, so it may be fault anytime. When there is fault, because of the number of similar fault, it makes difficulties for aero-engine troubleshooting. For example, a certain type of air carrier turbojet has the fault of fuel consumption of large slip, it can use adaptive Fuzzy Petri Nets (FPN) to establish fault diagnosis model to position the cause of such fault. The process of model setting up as follows:

(1) The definition of model input variables and output variables, the model input variables is the logic state of fault symptoms, defining as

$$X = [x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5 \quad x_6 \quad x_7],$$

The meaning as shown in table 1; model output variables is degree of confidence of fault causes, defining as

$$Y = [y_1 \quad y_2 \quad y_3 \quad y_4 \quad y_5],$$

The meaning is as shown in table 2.

Variable name	x_1	x_2	x_3	x_4
Symptom of Phenomenon	Oil in nozzle at the bottom of turbine	Oil at compressor entrance, fore tank bottom skin	Oil at airplane tail cone	White smoking at aft pressure reducer
Variable Name	x_5	x_6	x_7	
Symptom of Phenomenon	Oil beads at centrifugal ventilator's vent	Ejector tube emitting purple smoke	Flight in the air, oil consumption heavy	

Table 1. Definition of fault symptom and input variables

Variable Name	y_1	y_2	y_3	y_4	y_5
Fault Cause	Oil pump's one-way valve not sealing	One-way valve of radiator interface not sealing	Centrifugal valve membrane rupture	In bearing cavity, pressure too high	Three class scavenging pump inefficient

Table 2. Definition of fault cause and output variables

(2) Initializing the model parameters, membership parameters of input fault symptoms and fault cause, this is given by the expert system and repair factory's statistical data, respectively set to

$$D_0 = [d_{01} \quad d_{02} \quad d_{03} \quad d_{04} \quad d_{05} \quad d_{06} \quad d_{07}] \text{ and } D_0 = [d_{11} \quad d_{12} \quad d_{13} \quad d_{14} \quad d_{15} \quad d_{16} \quad d_{17}],$$

as shown in table 3 and table 4.

(3) According to the fuzzy inference rules of FPN, it defines network algorithms on each floor, uses the maximum degree of membership and the principle of membership grade threshold (γ>0.8) and combines with the definition of fuzzy algorithms to construct the fault diagnosis model FPN.

(4) According to the actual maintenance condition, amend membership between fault symptom and fault causes in initial model parameters, and the amendment formula is as follows:

$$d_{1i} = \{\frac{\text{times of } i \text{ symptom which belong to } j \text{ reason}}{\text{the total times of } i \text{ symptom}}\} \quad (1)$$

The parameters mean $i = 1,2,\cdots,7; j = 1,2,\cdots,5$. It can make FPN amend model parameters online in accordance with fault occurrence.

Fault Symptom x_i							Membership Grade d_{0i}	Fault Cause y_i				
x_1	x_2	x_3	x_4	x_5	x_6	x_7		y_1	y_2	y_3	y_4	y_5
1	0	0	0	0	0	0	d_{01}	0.65	0.35	0	0	0
0	1	0	0	0	0	0	d_{02}	0.30	0.50	0	0.20	0
0	0	1	0	0	0	0	d_{03}	0	0.20	0.75	0	0.05
0	0	0	1	0	0	0	d_{04}	0.30	0	0	0.56	0.14
0	0	0	0	1	0	0	d_{05}	0.20	0	0.50	0.30	0
0	0	0	0	0	1	0	d_{06}	0.47	0	0.28	0	0.25
0	0	0	0	0	0	1	d_{07}	0.10	0.30	0	0	0.60

Table 3. The membership grade relationship statistics between fault symptoms and fault causes in the repair factory

Fault Symptom x_i							Membership Grade d_{0i}	Fault Cause y_i				
x_1	x_2	x_3	x_4	x_5	x_6	x_7		y_1	y_2	y_3	y_4	y_5
1	0	0	0	0	0	0	d_{11}	0.80	0.20	0	0	0
0	1	0	0	0	0	0	d_{12}	0.20	0.65	0	0.15	0
0	0	1	0	0	0	0	d_{13}	0	0.20	0.80	0	0
0	0	0	1	0	0	0	d_{14}	0.25	0	0	0.70	0.05
0	0	0	0	1	0	0	d_{15}	0.12	0	0.20	0.68	0
0	0	0	0	0	1	0	d_{16}	0.22	0	0.66	0	0.12
0	0	0	0	0	0	1	d_{17}	0.22	0.10	0.10	0	0.58

Table 4. Expert database of membership grade relations between fault symptoms and fault causes

According to the above flow, adaptive FPN fault diagnosis model is set up as shown in Figure 6. Using MATLAB and 18 fault symptom state vectors, simulation is carried out, simulation results and the actual cause confirmed in maintenance as shown in Table 5, the diagnostic accuracy rate is 100%. This shows that the reliability of model diagnosis is relatively high. On the other hand, item 7 and 10, there are some deviation between output of fault model diagnosis and result of actual maintenance, because take method of threshold membership grade to eliminate fuzzy, diagnostic efficiency little decreases, but at the same time to avoid impact of random factors, which could result in the deviation of diagnostic results.

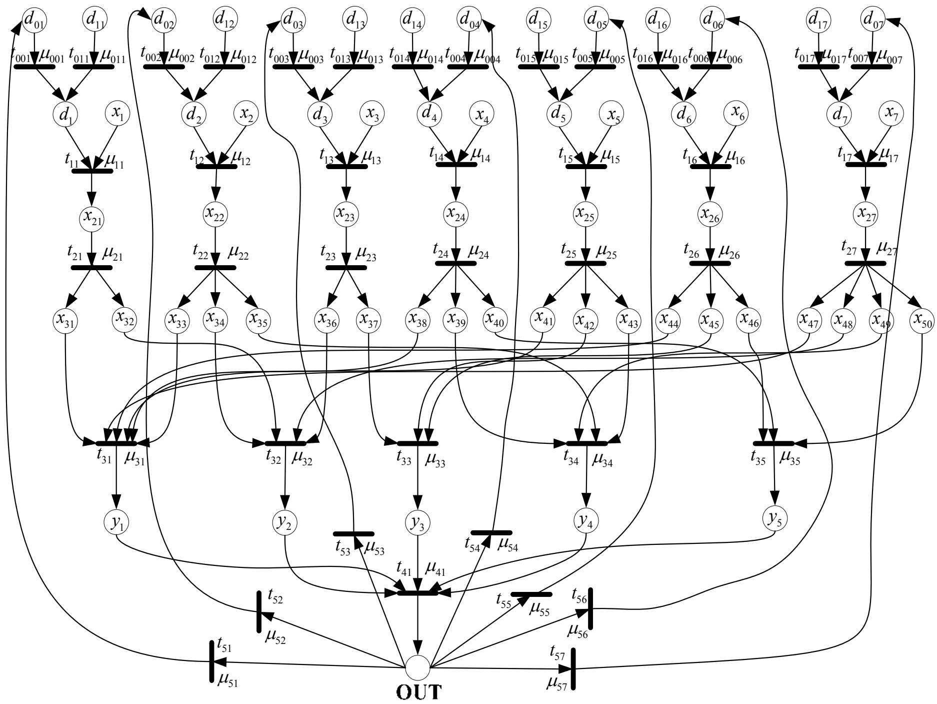

Fig. 6. Fault diagnosis model of adaptive FPN

Serial Number	1	2	3	4	5	6
Fault Symptom Matrix X	[0 1 0 1 0 0 0]	[1 0 0 0 1 0 0]	[0 1 1 0 0 0 1]	[1 0 0 1 0 0 0]	[1 0 1 0 0 0 0]	[1 0 0 0 0 0 1]
Diagnosis Cause	y_4	y_4	y_2	y_1	y_3	y_1
Actual Cause	y_4	y_4	y_2	y_1	y_3	y_1
Serial Number	7	8	9	10	11	12
Fault Symptom Matrix X	[1 1 0 0 0 0 0]	[0 0 1 0 0 1 0]	[1 0 1 0 0 0 1]	[0 1 0 1 0 1 0]	[1 0 0 0 0 1 0]	[0 0 1 0 1 0 1]
Diagnosis Cause	y_1 , y_2	y_3	y_1 , y_3	y_1 , y_4	y_1	y_3
Actual Cause	y_2	y_3	y_1 , y_3	y_4	y_1	y_3
Serial Number	13	14	15	16	17	18
Fault Symptom Matrix X	[0 0 1 1 0 1 0]	[1 0 0 0 1 1 0]	[0 0 0 1 0 0 1]	[0 0 0 1 0 1 0]	[0 1 0 1 1 0 0]	[0 0 1 01 0 1]
Diagnosis Cause	y_3	y_1 , y_3	y_5	y_4	y_4	y_3
Actual Cause	y_3	y_1 , y_3	y_5	y_4	y_4	y_3

Table 5. Comparison table of model diagnosis result and actual cause

Through the theory of adaptive FPN, it analyzes the cause of turbojet engine heavy oil consumption, sets up a heavy oil consumption fault symptoms - fault cause diagnostic model, and gives an intuitive expression of complex relationship between the fault cause and fault symptoms. It has reality significance to the aviation maintenance factory fast locating fault cause, improving maintenance efficiency and reducing maintenance costs of enterprises. And it also provides a new idea for the further development of the aviation maintenance decision-making support system.

3.2 Tire inventory management and control model

Suppose that the same type of aircrafts in a fleet of airline "A" consume and replace tires everyday, amount of which is X_1 (k) (k is a date serial number),and X_1 (k) is the random process. Considering the regularity of flights, we can think that there is no relationship between loss of statistical laws of tires and dates from the engineering point of macro view. At the same time, it is considered that the amount of tire loss of any day does not affect the amount of tire loss of any day in the future, that is, X_1 (k) and X_1 (k+1) (h $\neq$ 0) are independent.

Based on above given conditions, obviously, tires required changing everyday is followed Poisson distribution, so it is a Poisson process. For controlling air material tires inventory needs new tires supplement at a certain period, or refresh used tires. Set the period is M days, we should consider the statistical character of process X_M (k) = X_1 (k) + X_1 (k+1)+ …… + X_1 (k + M -1). X_1 (k) , X_1 (k+1) , …… , X_1 (k + M -1) is independent of each other, followed the same distribution, and has limited mathematical expectation and variance. According to central limit theorem, when M tends to infinity (actually, as long as M is enough large) X_M (k) obeys the normal distribution. It is that X_M (k) is followed normal random process.

It should be noted that the different fleets, different aircrafts have different X_1 (k). As different airlines with different route, taking off and landing frequency of flights are quite different every day from twice a day to dozen a day, and different aircrafts may have a huge difference in tire wear, therefore, the tire's loss properties statistical of different fleet are different.

After the acquisition of air material inventory and maintenance data from a number of airlines, it uses Statistical Product and Service Solutions (SPSS), MATLAB and other software for data statistical processing. A case of airline "A" is analyzed. We use the tire loss data of a fleet which includes ten same aircrafts from March 1, 2008 to November 1, 2008. After data analysis, there are tables as follows, Table 6 is about the data, and Table 7 is about the results of fitting analysis with normal process, even process, Poisson process, and exponential process.

Analysis below shows:

1. From Table 7, tires loss process is a random process and has a very high fitting degree with Poisson process.
2. As can be seen from Table 7, with the increase in computing cycles, the fitting degree with the normal process is increasing.
3. From the autocorrelation analysis, we learn that when the delay is 0, the correlation coefficient is 1, the relevant degree is less than 0.2 under the rest delay.

We can get the conclusion from below analysis as follows:

1. Taking the date serial number as the independent variable, tires loss time-series can be handled as a Poisson process.

2. Tire loss data correlation is weak between different days. Thus from an engineering point of view, the loss of tire number of different dates are independent.
3. With the increase of computing cycles, random distribution tends to normal distribution. Application of engineering control theory to solve the problem of optimal inventory seems necessary.

<table>
<tr><th>Date</th><th>Quantity</th><th>3 Days</th><th>7 Days</th><th>10 Days</th><th>20Days</th><th rowspan="30">……</th></tr>
<tr><td>3.1</td><td>1</td><td rowspan="3">2</td><td rowspan="7">2</td><td rowspan="10">3</td><td rowspan="29">……</td></tr>
<tr><td>3.2</td><td>1</td></tr>
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<tr><td>3.28</td><td>0</td><td rowspan="2">0</td></tr>
<tr><td>3.29</td><td>0</td><td>4</td></tr>
</table>

Table 6. The fleet tires loss situation (2008.3.1—2008.11.1)

Excessive tire inventory will increase storage costs, administrative costs, regular test costs and renovation costs, etc. On the other hand, the lack of tire inventories will cause difficulty in timely maintenance and affect the flight delays, and cause economic and social loss, thus, the optimal inventory levels need to be determined.

Period	Normal Process Fitting Degree	Uniform Process Fitting Degree	Poisson Process Fitting Degree	Index Process Fitting Degree
1 Day	0.000	0.000	0.981	0.000
3 Days	0.001	0.000	1.000	0.000
7 Days	0.351	0.000	0.999	0.001
10 Days	0.862	0.147	1.000	0.027
20 Days	0.781	0.180	0.930	0.011

Table 7. Fitting degree of tires loss data compared to different stochastic process

Figure 7 to Figure 10 shows the correlation analysis result of data

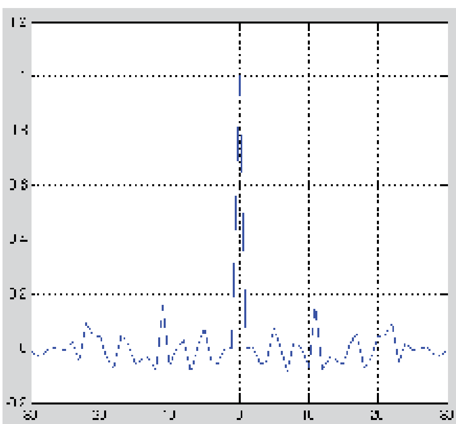

Fig. 7. Auto-correlation at period of 1 day

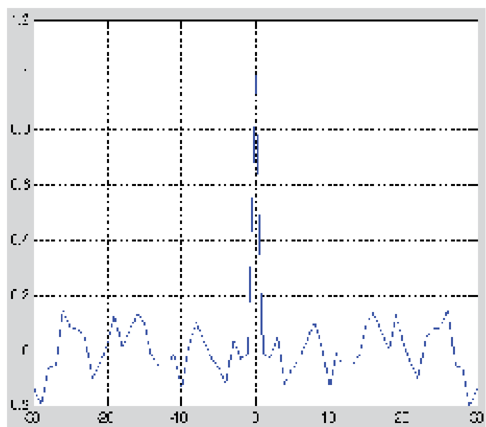

Fig. 8. Auto-correlation at period of 3 days

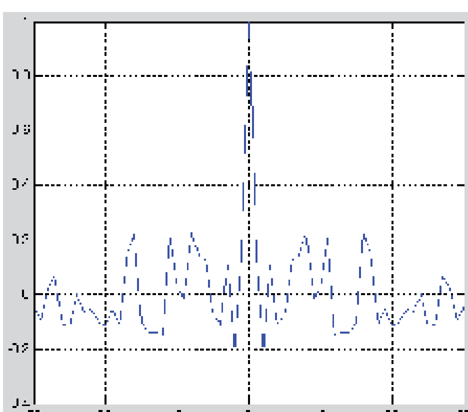

Fig. 9. Auto-correlation at period of 7 days

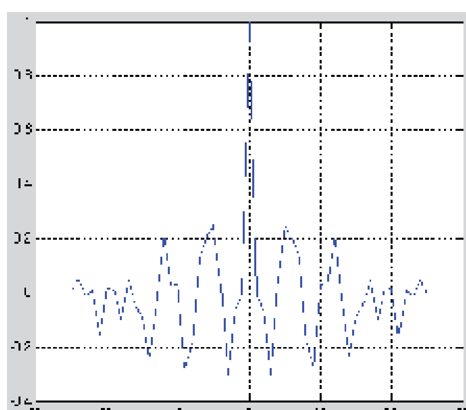

Fig. 10. Auto-correlation at period of 10 days

Considering the long period of tire repair, we take tire inventory as a normal distribution process. Table 8 is the assumptions and parameters of the optimal inventory analysis.

Symbol	Descriptions of volume and parameter
N_0	Average inventory
σ	Stock volume variance
G_1	Inventory costs（100￥/ a tire）
G_2	The loss of delay for the lack of tires（10000￥/ a tire）
k	Number of tires
F	Total cost

Table 8. Analysis of assumptions and parameters of the optimal inventory

Because the event of tires shortage is a small probability event, it sets inventory costs for N_0G_1. For convenience of calculating, it is considered that the number of lack tires is no more than 5, and corresponding loss of the lack of tires is as follows:

$$G_2\sum_{k=1}^{5}k\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{(-k-N_0)^2}{2\sigma^2}}=G_2\sum_{k=1}^{5}\frac{k}{\sqrt{2\pi}\sigma}e^{-\frac{(k+N_0)^2}{2\sigma^2}} \tag{2}$$

Then total cost is:

$$F=N_0G_1+G_2\sum_{k=1}^{5}\frac{k}{\sqrt{2\pi}\sigma}e^{-\frac{(k+N_0)^2}{2\sigma^2}} \tag{3}$$

As can be seen from the equation, when the average inventory increases, the first increase, the second reduction, when the average inventory reduction, the first decrease, while the second increase. When stocks Mean Square Error (MSE) is constant, it can calculate the optimal value of the average stock. Table 9 gives the MSE of different stocks and optimal average inventory.

σ	1	2	3	4	5	6	7	8	9
N_0	2-3	4-5	6-7	9-10	11-12	13-14	14-15	16-17	18-19

Table 9. Optimal average inventory for the MSE of different stocks

Analysis above shows:

(1) Obviously, with the increase of the variance of inventory, optimal average inventory is straight up and inventory cost increases rapidly; (2) For different aircraft types, parameters has large difference, and inventory cost is not the same, so optimal inventory levels will be relatively large different; (3) It can be seen from qualitative analysis of the theory, when the period calculated increases, average inventory corresponding increases, then the MSE of stocks also increases, nonlinear relationship between the two, but not independent. Therefore, it uses the method of searching to solve the optimal value. Through theoretical

analysis and experimental data analysis, it shows that the process of tire loss can be seen as independent Poisson process in engineering. When the period calculated (in fact, tire repair period) is large, it is considered that this process is independent normal random process. In addition, through the optimal analysis and calculation of optimal average inventory for the MSE of different stocks, it can be seen that if it uses the method of reducing the MSE of stock to control inventory, it can reduce the total cost.

4. Prospects and challenges

In recent years, based on widely using of the maintenance theory of on-condition, condition monitoring, etc., it proposes maintenance concepts, such as digital maintenance, proactive maintenance and so on, which supported by strong monitoring and diagnosis techniques to improve the efficiency of maintenance greatly, so there must be strong decision support system to construct modern aviation maintenance system.

MDSS can provide effective decision support for aviation maintenance. It also improves maintenance efficiency and controls maintenance costs. However, the aviation MDSS still needs further research on the following topics:

1. Because modern aircraft has many systems and complex structure, many flight parameters need to monitor. How to build efficient database and research criteria for judging the effectiveness of real-time data should conduct further research.
2. Because real-time flight status data downloaded relate to cost problems, how to establish the fault information download criteria should conduct further research.
3. The system has a property of hybrid system, and there are many ways for DEDS and CVDS modeling, but theory and method of modeling the hybrid system is still needed to be improved, so how to organic combine CVDS system with DEDS system and modeling the hybrid system should conduct further research.
4. MDSS is closely related with the airline operating environment, as there are obvious differences between airlines, how to select appropriate parameters, and how to overcome the bad applicability should conduct further research.

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Evaluating the Power Consumption in Carbonate Rock Sawing Process by Using FDAHP and TOPSIS Techniques

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1. Introduction

The prediction of rock sawability is important in the cost estimation and the planning of the stone plants. An accurate estimation of rock sawability helps to make the planning of the rock sawing projects more efficient. Rock sawability depends on non-controlled parameters related to rock characteristics and controlled parameters related to properties of cutting tools and equipment. In the same working conditions, the sawing process and its results are strongly affected by mineralogical and mechanical properties of rock.
Up to now, many studies have been done on the relations between sawability and rock characteristics in stone processing. Norling (1971) correlated sawability with petrographic properties and concluded that grain size was more relevant to sawability than the quartz content. Burgess (1978) proposed a regression model for sawability, which was based on mineralogical composition, hardness, grain size and abrasion resistance. Vaya and Vikram (1983) found a fairly good correlation between the Brinell hardness test and diamond sawing rates. However, the variables involved were so many that they believed no mathematical solution would be possible. They also considered the Specific Energy (SE) concept, in conjunction with mineralogy, to give a better understanding of the sawing responses of various rock types. Ertingshausen (1985) investigated the power requirements during cutting of Colombo Red granite in up-cutting and down-cutting modes. He found out that the required power was less for the up- cutting mode when the cutting depth was below 20–25 mm. For deeper cuts, however, the power consumption was less for the down-cutting mode. Wright and Cassapi (1985) tried to correlate the petrographic analysis and physical properties with sawing results. The research indicated cutting forces to have the closest correlation. Birle et al. (1986) presented similar work in 1986, but again considered only blade life as the criterion on which a ranking system should be based. Hausberger (1989) concluded that an actual sawing test was the most reliable method for determining the machinability of a rock type. He observed that the higher proportion of minerals with well defined cleavage planes helps the cutting to be easier. Jennings and Wright (1989) gave an overall assessment of the major factors which affect saw blade performance. They found out that hard materials usually require a smaller size diamond than do softer stones because the load per particle is not sufficiently high and greater clearance is required for swarf.

Conversely, if large diamond grits are used on hard materials, the penetration of the diamond is limited, and normally either excessive grit pull-out will occur or large wear flats will appear on the diamond particles. Unver (1996) developed empirical equations for the estimation of specific wear and cutting force in the sawing of granites. He used mean quartz grain size, NCB cone indenter hardness number, and mean plagioclase grain size in his equations. Clausen et al. (1996) carried out a study on the acoustic emission during single diamond scratching of granite and suggested that acoustic emission could be used in sawability classification of natural stones. They also concluded that the cutting process is affected by the properties and frequency of minerals, grain size and degree of interlocking. Tonshoff and Asche (1997) discussed the macroscopic and microscopic methods of investigating saw blade segment wear. Luo (1997) investigated the worn surfaces of diamond segments in circular saws for the sawing of hard and relatively soft granites. He found out that for the sawing of hard granite, the worn particles were mainly of the macro-fractured crystal and/or pull-out hole type. Ceylanoglu and Gorgulu (1997) correlated specific cutting energy and slab production with rock properties and found good correlations between them. Webb and Jackson (1998) showed that a good correlation could be obtained between saw blade wear performance and the ratio of normal to tangential cutting forces during the cutting of granite. Xu (1999) investigated the friction characteristics of the sawing process of granites with diamond segmented saw blade. The results of the experimental studies indicated that most of the sawing energy is expended by friction of sliding between diamonds and granites. Xipeng et al. (2001) found that about 30 percent of the sawing energy might be due to the interaction of the swarf with the applied fluid and bond matrix. Most of the energy for sawing and grinding is attributed to ductile ploughing. Brook (2002) developed a new index test, called Brook hardness, which has been specifically developed for sliding diamond indenters. The consumed energy is predictable from this new index test. Konstanty (2002) presented a theoretical model of natural stone sawing by means of diamond-impregnated tools. In the model, the chip formation and removal process are quantified with the intention of assisting both the toolmaker and the stonemason in optimising the tool composition and sawing process parameters, respectively.

Li et al. (2002) proposed a new machining method applicable to granite materials to achieve improved cost effectiveness. They emphasized the importance of the tribological interactions that occur at the interface between the diamond tool surface and the workpiece. Accordingly, they proposed that the energy expended by friction and mechanical load on the diamond crystal should be balanced to optimize the saw blade performance. Xu et al. (2003) conducted an experimental study on the sawing of two kinds of granites with a diamond segmented saw blade. The results of their study indicated that the wear of diamond grits could also be related to the high temperatures generated at individual cutting points, and the pop-out of diamonds from the matrix could be attributed to the heat conducted to saw blade segments. Ilio and Togna (2003) proposed a theoretical model for the interpretation of saw blade wear process. The model is based on the experimentally determined matrix characteristics and grain characteristics. The model indicates that a suitable matrix material must not only provide the necessary grain support in the segment, but it should also wear at an appropriate rate in order to maintain constant efficiency in cutting. Eyuboglu et al. (2003) investigated the relationship between blade wear and the sawability of andesitic rocks. In their study, a multiple linear regression analysis was carried out to derive a prediction equation of the blade wear rate. They showed that the wear rate of andesite could be predicted from the statistical model by using a number of stone properties. The model indicated the Shore scleroscope hardness as the most important rock property affecting wear rate. Xu et al. (2003) carried out an experimental study to investigate the characteristics of the force ratio in the sawing of granites with a diamond segmented blade. In the experiments, in order to determine the tangential and the normal force components, horizontal and vertical force components and the consumed power were measured. It was found out that the force components and their ratios did not differ much for different granites, in spite of the big differences in sawing difficulty. Gunaydin et al. (2004) investigated the correlations between sawability and different brittleness using regression analysis. They concluded that sawability of carbonate rocks can be predicted from the rock brittleness, which is half the product of compressive strength and tensile strength. Ersoy et al. (2004, 2005) experimentally studied the performance and wear characteristics of circular diamond saws in cutting different types of rocks. They derived a statistical predictive model for the saw blade wear where specific cutting energy, silica content, bending strength, and Schmidt rebound hardness were the input parameters of the model. An experimental study was carried out by Xipeng and Yiging (2005) to evaluate the sawing performance of Ti–Cr coated diamonds. The sawing performances of the specimens were evaluated in terms of their wear performances during the sawing of granite. It was concluded that the wear performance of the specimens with coated diamonds were improved, as compared with uncoated diamonds. Delgado et al. (2005) experimentally studied the relationship between the sawability of granite and its micro-hardness. In their study, sawing rate was chosen as the sawability criterion, and the micro-hardness of granite was calculated from mineral Vickers micro-hardness. Experimental results indicated that the use of Vickers hardness microindentor could provide more precise information in sawability studies. Mikaeil et al. (2008a and 2008b) developed a new statistical model to predicting the production rate of carbonate rocks based on uniaxial compressive strength and equal quartz content. Additional, they investigated the sawability of some important Iranian stone. Yousefi et al. (2010) studied the factors affecting on the sawability of the ornamental stone.

Especially, among the previous studies some researchers have developed a number of classification systems for ranking the sawability of rocks. Wei et al. (2003) evaluated and classified the sawability of granites by means of the fuzzy ranking system. In their study, wear performance of the blade and the cutting force were used as the sawability criteria. They concluded that with the fuzzy ranking system, by using only the tested petrographic and mechanical properties, a convenient selection of a suitable saw blade could be made for a new granite type. Similarly, Tutmez et al. (2007) developed a new fuzzy classification of carbonate rocks based on rock characteristics such as uniaxial compressive strength, tensile strength, Schmidt hammer value, point load strength, impact strength, Los Angeles abrasion loss and P-wave velocity. By this fuzzy approach, marbles used by factories were ranked three linguistic qualitative categories: excellent, good and poor. Kahraman et al. (2007) developed a quality classification of building stones from P-wave velocity and its application to stone cutting with gang saws. They concluded that the quality classification and estimation of slab production efficiency of the building stones can be made by ultrasonic measurements.

The performance of any stone factory is affected by the complex interaction of numerous factors. These factors that affect the production cost can be classified as energy, labour, water, diamond saw and polishing pads, filling material and packing. Among the above factors, energy is one of the most important factors. In this chapter, it was aimed to develop a new hierarchy model for evaluating and ranking the power consumption of carbonate rock in sawing process. By this model, carbonate rocks were ranked with the respect to its power consumption. This model can be used for cost analysis and project planning as a decision making index. To make a right decision on power consumption of carbonate rock, all known criteria related to the problem should be analyzed. Although an increasing in the number of related criteria makes the problem more complicated and more difficult to reach a solution, this may also increase the correctness of the decision made because of those criteria. Due to the arising complexity in the decision process, many conventional methods are able to consider limited criteria and may be generally deficient. Therefore, it is clearly seen that assessing all of the known criteria connected to the power consumption by combining the decision making process is extremely significant.

The major aim of this chapter is to compare the many different factors in the power consumption of the carbonate rock. The comparison has been performed with the combination of the Analytic Hierarchy Process (AHP) and Fuzzy Delphi method and also the use of TOPSIS method. The analysis is one of the multi-criteria techniques that provide useful support in the choice among several alternatives with different objectives and criteria. FDAHP method has been used in determining the weights of the criteria by decision makers and then ranking the power consumption of the rocks has been determined by TOPSIS method. The study was supported by results that were obtained from a questionnaire carried out to know the opinions of the experts in this subject.

This chapter is organized as follows; in the second section, a brief review is done on concept of the fuzzy sets and fuzzy numbers. In the third section FDAHP method is illustrated. This section is included the methodology of FDAHP method. Fourth section also surveys TOPSIS method. In the fifth section, after explanation of effective parameters on power consumption, the FDAHP method is applied for determination of the weights of the criteria given by experts. Then the ranking the power consumption of carbonate rocks is carried out by TOPSIS method. Eventually, in sixth and seventh sections, results of the application are reviewed. These sections discuses and concludes the paper. According to the authors' knowledge, ranking the power consumption using the FDAHP-TOPSIS is a unique research.

2. Fuzzy sets and fuzzy numbers

To deal with vagueness of human thought, Zadeh (1965) first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. With different daily decision making problems of diverse intensity, the results can be misleading if the fuzziness of human decision making is not taken into account (Tsaur et al., 2002) Fuzzy sets theory providing a more widely frame than classic sets theory, has been contributing to capability of reflecting real world (Ertugrul & Tus, 2007).

Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling: uncertain systems in industry, nature and humanity; and facilitators for common-sense reasoning in decision making in the absence of complete and precise information. Their role is significant when applied to complex phenomena not easily described by traditional mathematical methods, especially when the goal is to find a good approximate solution (Bojadziev & Bojadziev, 1998). Fuzzy set theory is a better means for modeling imprecision arising from mental phenomena which are neither random nor stochastic. Human beings are heavily involved in the process of decision analysis. A rational approach toward decision making should take into account human subjectivity, rather than employing only objective probability measures. This attitude, towards imprecision of human behavior led to study of a new decision analysis filed fuzzy decision making (Lai & Hwang, 1996). A tilde '~' will be placed above a symbol if the symbol represents a fuzzy set. A triangular fuzzy number (TFN), $\tilde{M}$ is shown in Fig. 1. A TFN is denoted simply as $(l|m,m|u)$ or (l,m,u). The parameters l, m and u, respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event.

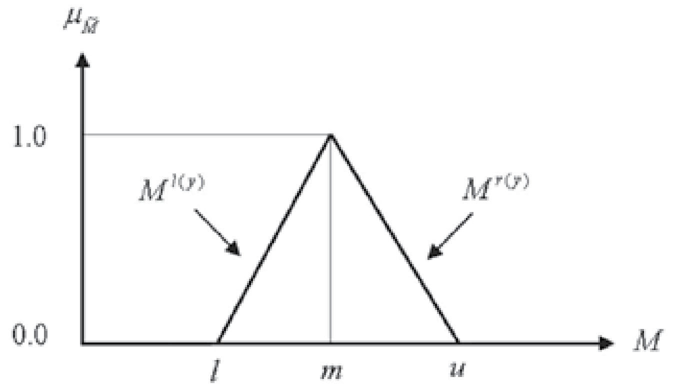

Fig. 1. A triangular fuzzy number, $\tilde{M}$

Each TFN has linear representations on its left and right side such that its membership function can be defined as

$$\mu(x|\ \tilde{M}) = \begin{cases} 0, & x < l, \\ (x-l)/(m-l), & l \le x \le m, \\ (u-x)/(u-m), & m \le x \le u, \\ 0, & x > u. \end{cases} \tag{1}$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

$$\tilde{M} = (M^{l(y)}, M^{r(y)}) = (l + (m-l)y, u + (m-u)y), \qquad y \in [0,1], \tag{2}$$

Where $l(y)$ and $r(y)$ denote the left side representation and the right side representation of a fuzzy number, respectively. Many ranking methods for fuzzy numbers have been developed in the literature. These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation. The algebraic operations with fuzzy numbers have been explained by Kahraman (2001) and Kahraman et al. (2002).

3. Fuzzy Delphi Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is an approach that is suitable for dealing with complex systems related to making a choice from among several alternatives and which provides a comparison of the considered options, firstly proposed by Saaty (1980). The AHP is based on the subdivision of the problem in a hierarchical form. In fact, the AHP helps organize the rational analysis of the problem by dividing it into its single parts; the analysis then supplies an aid to the decision makers who, making several pair-wise comparisons, can appreciate the influence of the considered elements in the hierarchical structure; the AHP can also give a preference list of the considered alternative solutions (Bentivegna et al., 1994; Roscelli, 1990; Saaty, 1980; Saaty & Vargas, 1990).

The AHP is a tool that can be used for analyzing different kinds of social, political, economic and technological problems, and it uses both qualitative and quantitative variables. The fundamental principle of the analysis is the possibility of connecting information, based on knowledge, to make decisions or previsions; the knowledge can be taken from experience or derived from the application of other tools. Among the different contexts in which the AHP can be applied, mention can be made of the creation of a list of priorities, the choice of the best policy, the optimal allocation of resources, the prevision of results and temporal dependencies, the assessment of risks and planning (Saaty & Vargas, 1990). Although the AHP is to capture the expert's knowledge, the traditional AHP still cannot really reflect the human thinking style (Kahraman et al., 2003).

The traditional AHP method is problematic in that it uses an exact value to express the decision maker's opinion in a comparison of alternatives (Wang & Chen, 2007). And AHP method is often criticized due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pair-wise comparison process (Deng, 1999). To overcome all these shortcomings, FDAHP was developed for solving the hierarchical problems. Decision makers usually find that it is more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to explicit his/her preference to explicit about the fuzzy nature of the comparison process.

Delphi method is a technique for structuring an effective group communication process by providing feedback of contributions of information and assessment of group judgments to enable individuals to re-evaluate their judgments. Since its development in the 1960s at Rand Corporation, Delphi method has been widely used in various fields (Liu and Chen, 2007a, Liu and Chen, 2007b, Hoseinie et al. 2009, Cheng and Tang, 2009, Cheng et al. 2009). On the other hand, Delphi Method use crisp number and mean to become the evaluation criteria, these shortcomings might distort the experts' opinion. In order to deal with the fuzziness of human participants' judgments in traditional Delphi method, Ishikawa et al. (Ishikawa et al. 1993) posited fuzzy set theory proposed by Zadeh (Zadeh, 1965) into the Delphi method to improve time-consuming problems such as the convergence of experts' options presented by Hwang and Lin (Hwang and Lin, 1987). The FDM is a methodology in which subjective data of experts are transformed into quasi-objective data using the statistical analysis and fuzzy operations. The main advantages of FDM (Kaufmann and Gupta, 1988) are that it can reduce the numbers of surveys to save time and cost and it also includes the individual attributes of all experts. This paper proposes the use of FDAHP for determining the weights of the main criteria.

3.1 Methodology of FDAHP

Calculate the relative fuzzy weights of the decision elements using the following three steps based on the FDM and aggregate the relative fuzzy weights to obtain scores for the decision alternation.

(1) Compute the triangular fuzzy numbers (TFNs) ãij as defined in Eq. (3). In this work, the TFNs (shown as Fig. 2) that represent the pessimistic, moderate and optimistic estimate are used to represent the opinions of experts for each activity time.

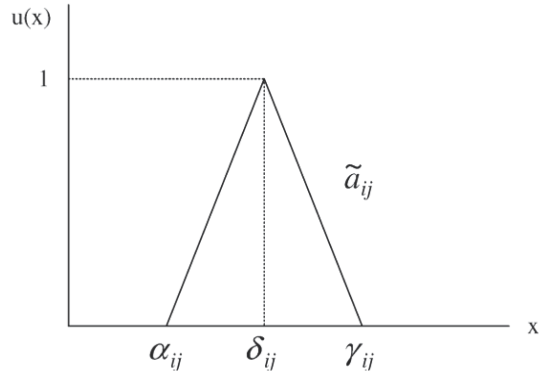

Fig. 2. The membership function of the Fuzzy Delphi Method.

$$\tilde{a}_{ij} = (\alpha_{ij}, \delta_{ij}, \gamma_{ij}) \tag{3}$$

$$\alpha_{ij} = Min(\beta_{ijk}), k = 1, \ldots, n \tag{4}$$

$$\delta_{ij} = (\prod_{k=1}^{n} \beta_{ijk})^{1/n}, k = 1, \ldots, n \tag{5}$$

$$\gamma_{ij} = Max(\beta_{ijk}), k = 1, \ldots, n \tag{6}$$

Where, $\alpha_{ij} \le \delta_{ij} \le \gamma_{ij}$, $\alpha_{ij}, \delta_{ij}, \gamma_{ij} \in [1/9, 1] \cup [1, 9]$ and $\alpha_{ij}, \delta_{ij}, \gamma_{ij}$ are obtained from Eq. (4) to Eq. (6). α_{ij} indicates the lower bound and γ_{ij} indicates the upper bound. β_{ijk} indicates the relative intensity of importance of expert k between activities i and j. n is the number of experts in consisting of a group.

(2) Following outlined above, we obtained a fuzzy positive reciprocal matrix $\tilde{A}$

$$\tilde{A} = [\tilde{a}_{ij}], \tilde{a}_{ij} \times \tilde{a}_{ji} \approx 1, \forall i, j = 1, 2, \ldots, n$$

Or

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (\alpha_{12}, \delta_{12}, \gamma_{12}) & (\alpha_{13}, \delta_{13}, \gamma_{13}) \\ (1/\gamma_{12}, 1/\delta_{12}, 1/\alpha_{12}) & (1,1,1) & (\alpha_{23}, \delta_{23}, \gamma_{23}) \\ (1/\gamma_{13}, 1/\delta_{13}, 1/\alpha_{13}) & (1/\gamma_{23}, 1/\delta_{23}, 1/\alpha_{23}) & (1,1,1) \end{bmatrix} \tag{7}$$

(3) Calculate the relative fuzzy weights of the evaluation factors.

$$\tilde{Z}_i = [\tilde{a}_{ij} \otimes \ldots \otimes \tilde{a}_{in}]^{1/n}, \tilde{W}_i = \tilde{Z}_i \otimes (\tilde{Z}_i \oplus \ldots \oplus \tilde{Z}_n)^{-1} \quad (8)$$

Where $\tilde{a}_1 \otimes \tilde{a}_2 \cong (\alpha_1 \times \alpha_2, \delta_1 \times \delta_2, \gamma_1 \times \gamma_2)$; the symbol $\otimes$ here denotes the multiplication of fuzzy numbers and the symbol $\oplus$ here denotes the addition of fuzzy numbers. $\tilde{W}_i$ is a row vector in consist of a fuzzy weight of the ith factor. $\tilde{W}_i = (\omega_1, \omega_2, \ldots, \omega_n)$ i=1, 2,…n, and W_i is a fuzzy weight of the ith factor.

4. TOPSIS method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is one of the useful MADM techniques to manage real-world problems (Yoon & Hwang, 1985). TOPSIS method was firstly proposed by Hwang & Yoon (1981). According to this technique, the best alternative would be the one that is nearest to the positive ideal solution and farthest from the negative ideal solution (Benitez, et al., 2007). The positive ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang & Elhag, 2006). In short, the positive ideal solution is composed of all best values attainable of criteria, whereas the negative ideal solution consists of all worst values attainable of criteria (Wang, 2008). In this paper TOPSIS method is used for determining the final ranking of the sawability of rocks. TOPSIS method is performed in the following steps:

Step 1. Decision matrix is normalized via Eq. (9):

$$r_{ij} = \frac{w_{ij}}{\sqrt{\sum_{i=1}^{J} w_{ij}^2}} \quad j = 1,2,3,\ldots,J \quad i = 1,2,3,\ldots,n \quad (9)$$

Step 2. Weighted normalized decision matrix is formed:

$$v_{ij} = w_i \times r_{ij}, \quad j = 1,2,3,\ldots,J \quad i = 1,2,3,\ldots,n \quad (10)$$

Step 3. Positive ideal solution (PIS) and negative ideal solution (NIS) are determined:

$$A^* = \left\{ v_1^*, v_2^*, \ldots, v_i^*, \ldots, v_n^* \right\} \text{ Maximum Values} \quad (11)$$

$$A^- = \left\{ v_1^-, v_2^-, \ldots, v_i^-, \ldots, v_n^- \right\} \text{ Minimum Values} \quad (12)$$

Step 4. The distance of each alternative from PIS and NIS are calculated:

$$d_j^* = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_j^* \right)^2} \quad (13)$$

$$d_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_j^- \right)^2} \quad (14)$$

Step 5. The closeness coefficient of each alternative is calculated:

$$CC_j = \frac{d_j^-}{d_j^* + d_j^-} \tag{15}$$

Step 6. By comparing CCj values, the ranking of alternatives are determined.

5. Application of FDAHP-TOPSIS method to multi-criteria comparison of sawability

The purpose of this paper was to ranking the power consumption of rock in sawing process, with the help of effective factors. Firstly, a comprehensive questionnaire including main criteria of effective factor is designed to understand and quantify the affecting factors in the process. Then, five decision makers from different areas evaluated the importance of these factors with the help of the mentioned questionnaire. FDAHP is utilized for determining the weights of main criteria and finally, TOPSIS approach is employed for ranking. By this way, the ranking of carbonate sawability according to their overall efficiency is obtained. Carbonate rock sawability depends on non-controlled parameters related to rock characteristics and controlled parameters related to properties of cutting tools and equipment. In the same working conditions, the sawing process and its results are strongly affected by mineralogical and mechanical properties of rock. The mineralogical and mechanical properties of rock which related to rock sawability are shown in Fig. 3.

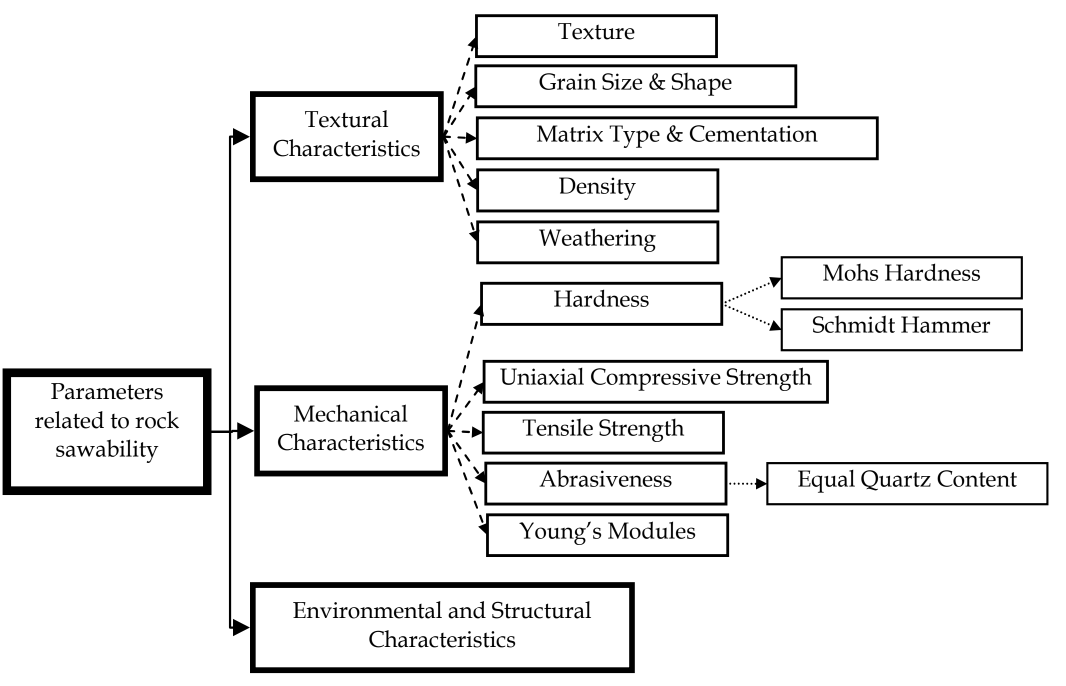

Fig. 3. Important characteristics influencing the rock sawability

5.1 Determination of criteria's weights

Because different groups have varying objectives and expectations, they judge on rock sawability from different perspectives. So, affecting criteria have different level of significance for different users. For this reason, five decision makers are selected from different areas and these decision makers evaluate the criteria. FDAHP is proposed to take the decision makers subjective judgments into consideration and to reduce the uncertainty and vagueness in the decision process.

Decision makers from different backgrounds may define different weight vectors. They usually cause not only the imprecise evaluation but also serious persecution during decision process. For this reason, we proposed a group decision based on FDAHP to improve pair-wise comparison. Firstly each decision maker (Di), individually carry out pair-wise comparison by using Saaty's (1980) 1–9 scale (Table 2).

Comparison index	score
Extremely Preferred	9
Very strongly Preferred	7
Strongly Preferred	5
Moderately Preferred	3
Equal	1
Intermediate values between the two adjacent judgments	2,4,6,8

Table 2. Pair-wise comparison scale (Saaty, 1980)

One of these pair-wise comparisons is shown here as example:

$$D_1 = \begin{array}{c} \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \\ c_7 \\ c_8 \\ c_9 \\ c_{10} \\ c_{11} \\ c_{12} \end{array} \begin{array}{c} \begin{array}{cccccccccccc} c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 & c_{10} & c_{11} & c_{12} \end{array} \\ \begin{bmatrix} 1 & 3 & 5 & 1 & 1 & 1 & 5 & 5 & 3 & 1/3 & 1 & 3 \\ 1/3 & 1 & 3 & 1/3 & 1/3 & 1/3 & 3 & 3 & 1 & 1/5 & 1/3 & 1 \\ 1/5 & 1/3 & 1 & 1/5 & 1/5 & 1/5 & 1 & 1 & 1/3 & 1/9 & 1/5 & 1/3 \\ 1 & 3 & 5 & 1 & 1 & 1 & 5 & 5 & 3 & 1/3 & 1 & 3 \\ 1 & 3 & 5 & 1 & 1 & 1 & 5 & 5 & 3 & 1/3 & 1 & 3 \\ 1 & 3 & 5 & 1 & 1 & 1 & 5 & 5 & 3 & 1/3 & 1 & 3 \\ 1/5 & 1/3 & 1 & 1/5 & 1/5 & 1/5 & 1 & 1 & 1/3 & 1/9 & 1/5 & 1/3 \\ 1/5 & 1/3 & 1 & 1/5 & 1/5 & 1/5 & 1 & 1 & 1/3 & 1/9 & 1/5 & 1/3 \\ 1/3 & 1 & 3 & 1/3 & 1/3 & 1/3 & 3 & 3 & 1 & 1/5 & 1/3 & 1 \\ 3 & 7 & 9 & 3 & 3 & 3 & 9 & 9 & 5 & 1 & 3 & 5 \\ 1 & 3 & 5 & 1 & 1 & 1 & 5 & 5 & 3 & 1/3 & 1 & 3 \\ 1/3 & 1 & 3 & 1/3 & 1/3 & 1/3 & 3 & 3 & 1 & 1/5 & 1/3 & 1 \end{bmatrix} \end{array}$$

The weighting factors for each criterion were presented in the following steps:

1. Compute the triangular fuzzy numbers (TFNs)

$$\tilde{a}_{ij} = (\alpha_{ij}, \delta_{ij}, \gamma_{ij})$$

According Eq. (4)- Eq. (6)

$$\alpha_{ij} = Min(\beta_{ijk}), k = 1,...,n$$

2. Fuzzy pair-wise comparison matrix $\tilde{A}$

By this way, decision makers' pair-wise comparison values are transformed into triangular fuzzy numbers as in Table 3.

	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_1	(1, 1, 1)	(0.7, 1, 1.4)	(0.7, 1.2, 2.3)	(0.6, 0.7, 1)	(0.6, 0.7, 1)	(0.6, 0.8, 1)	(0.7, 1.5, 2.3)	(1, 1.4, 2.3)	(0.7, 1.2, 2.3)	(0.6, 0.7, 0.8)	(0.7, 0.9, 1)	(0.7, 0.9, 1.4)
C_2	(0.7, 1, 1.4)	(1, 1, 1)	(0.7, 1.2, 1.7)	(0.7, 0.7, 0.8)	(0.6, 0.7, 1)	(0.7, 0.8, 1)	(1, 1.5, 1.7)	(1, 1.4, 1.7)	(0.7, 1.2, 2.3)	(0.6, 0.7, 1)	(0.7, 0.9, 1.4)	(0.7, 0.9, 1.4)
C_3	(0.4, 08, 1.4)	(0.6 0.8, 1.4)	(1, 1, 1)	(0.4, 0.6, 1)	(0.3, 0.6, 0.8)	(0.4, 0.6, 1)	(1, 1.2, 2.3)	(1, 1.1, 1.4)	(0.6, 1, 1.7)	(0.3, 0.5, 1)	(0.4, 0.7, 1.4)	(0.4, 0.8, 1)
C_4	(1, 1.4, 1.8)	(1.3, 1.4, 1.4)	(1, 1.7, 2.3)	(1, 1, 1)	(0.8, 1, 1.3)	(1, 1.1, 1.3)	(1.3, 2, 2.3)	(1.4, 1.9, 2.3)	(1, 1.7, 3)	(0.8, 0.9, 1.3)	(1, 1.2, 1.8)	(1, 1.3, 1.8)
C_5	(1, 1.4, 1.8)	(1, 1.4, 1.8)	(1.3, 1.8, 3)	(0.8, 1.1, 1.3)	(1, 1, 1)	(0.8, 1.1, 1.3)	(1.3, 2.1, 3)	(1.4, 2.1, 3)	(1.3, 1.7, 3)	(0.8, 1, 1.3)	(1, 1.2, 1.8)	(1.3, 1.3, 1.4)
C_6	(1, 1.3, 1.8)	(1, 1.3, 1.4)	(1, 1.6, 2.3)	(0.8, 1, 1)	(0.8, 0.9, 1.3)	(1, 1, 1)	(1, 1.9, 2.3)	(1.4, 1.8, 2.3)	(1, 1.6, 3)	(0.8, 0.9, 1)	(1, 1.1, 1.4)	(0.4, 0.6, 1)
C_7	(0.4, 0.7, 1.4)	(0.6, 0.7, 1)	(0.4, 0.8, 1)	(0.4, 0.5, 0.8)	(0.3, 0.5, 0.8)	(0.4, 0.5, 1)	(1, 1, 1)	(0.6, 1, 1.4)	(0.4, 0.8, 1.7)	(0.3, 0.5, 1)	(0.4, 0.6, 1.4)	(0.4, 0.6, 1)
C_8	(0.4, 0.7, 1)	(0.6, 0.7, 1)	(0.7, 0.9, 1)	(0.4, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.4, 0.6, 0.7)	(0.7, 1, 1.7)	(1, 1, 1)	(0.6, 0.9, 1.7)	(0.3, 0.5, 0.7)	(0.4, 0.6, 1)	(0.4, 0.7, 1)
C_9	(0.4, 0.8, 1.4)	(0.4, 0.8, 1.4)	(0.6, 1, 1.7)	(0.3, 0.6, 0.8)	(0.3, 0.6, 0.8)	(0.3, 0.6, 1)	(0.6, 1.2, 2.3)	(0.6, 1.1, 1.7)	(1, 1, 1)	(0.3, 0.5, 1)	(0.4, 0.7, 1.4)	(0.4, 0.8, 1)
C_{10}	(1.3, 1.5, 1.8)	(1, 1.5, 1.8)	(1, 1.8, 3)	(0.8, 1.1, 1. 3)	(0.8, 1.1, 1.3)	(1, 1.2, 1.3)	(1, 2.2, 3)	(1.4, 2.1, 3)	(1, 1.8, 3)	(1, 1, 1)	(1.3, 1.3, 1.4)	(1, 1.4, 1.8)
C_{11}	(1, 1.1, 1.4)	(0.7, 1.1, 1.4)	(0.7, 1.4, 2.3)	(0.6, 0.9 1)	(0.6, 0.8, 1)	(0.7, 0.9, 1)	(0.7, 1.7, 2.3)	(1, 1.6, 2.3)	(0.7, 1.4, 2.3)	(0.7, 0.8, 0.8)	(1, 1, 1)	(0.7, 1.1, 1.4)
C_{12}	(0.7, 1.1, 1.4)	(0.7, 1.1, 1.4)	(1, 1.3, 2.3)	(0.6, 0.8, 1)	(0.7, 0.8, 0.8)	(0.6, 0.8, 1)	(1, 1.6, 2.3)	(1, 1.5, 2.3)	(1, 1.3, 2.3)	(0.6, 0.7, 1)	(0.7, 0.9, 1.4)	(1, 1, 1)

Table 3. Fuzzy pair-wise comparison matrix

3. Calculate the relative fuzzy weights of the evaluation factors.

$$\tilde{Z}_1 = \left[\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes ...\tilde{a}_{112}\right]^{1/12} = [0.6948, 0.968, 1.3738]$$

$$\tilde{Z}_2 = \left[\tilde{a}_{21} \otimes \tilde{a}_{22} \otimes ...\tilde{a}_{212}\right]^{1/12} = [0.7451, 0.968, 1.2989]$$

$$\tilde{Z}_3 = \left[\tilde{a}_{31} \otimes \tilde{a}_{32} \otimes ...\tilde{a}_{312}\right]^{1/12} = [0.5373, 0.7861, 1.2268]$$

$$\tilde{Z}_4 = \left[\tilde{a}_{41} \otimes \tilde{a}_{42} \otimes ...\tilde{a}_{412}\right]^{1/12} = [1.0284, 1.3098, 1.7181]$$

$$\tilde{Z}_5 = \left[\tilde{a}_{51} \otimes \tilde{a}_{52} \otimes ...\tilde{a}_{512}\right]^{1/12} = [1.0502, 1.3773, 1.8295]$$

$$\tilde{Z}_6 = \left[\tilde{a}_{61} \otimes \tilde{a}_{62} \otimes ...\tilde{a}_{612}\right]^{1/12} = [0.9, 1.1823, 1.5363]$$

$$\tilde{Z}_7 = \left[\tilde{a}_{71} \otimes \tilde{a}_{72} \otimes ...\tilde{a}_{712}\right]^{1/12} = [0.4665, 0.6661, 1.0885]$$

$$\tilde{Z}_8 = \left[\tilde{a}_{81} \otimes \tilde{a}_{82} \otimes ...\tilde{a}_{812}\right]^{1/12} = [0.508, 0.6897, 0.9733]$$

$$\tilde{Z}_9 = \left[\tilde{a}_{91} \otimes \tilde{a}_{92} \otimes ...\tilde{a}_{912}\right]^{1/12} = [0.4601, 0.7858, 1.2189]$$

$$\tilde{Z}_{10} = \left[\tilde{a}_{101} \otimes \tilde{a}_{102} \otimes ...\tilde{a}_{1012}\right]^{1/12} = [1.0284, 1.4483, 1.8295]$$

$$\tilde{Z}_{11} = \left[\tilde{a}_{111} \otimes \tilde{a}_{112} \otimes ...\tilde{a}_{1112}\right]^{1/12} = [0.7451, 1.1074, 1.4128]$$

$$\tilde{Z}_{12} = \left[\tilde{a}_{121} \otimes \tilde{a}_{122} \otimes ...\tilde{a}_{1212}\right]^{1/12} = [0.7717, 1.0353, 1.4128]$$

$$\sum \tilde{Z}_i = [8.9356, 12.327, 16.919]$$

$$\tilde{W}_1 = \tilde{Z}_1 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0411, 0.0785, 0.1537]$$

$$\tilde{W}_2 = \tilde{Z}_2 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.044, 0.0785, 0.1454]$$

$$\tilde{W}_3 = \tilde{Z}_3 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0318, 0.064, 0.1373]$$

$$\tilde{W}_4 = \tilde{Z}_4 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0608, 0.1063, 0.1923]$$

$$\tilde{W}_5 = \tilde{Z}_5 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0621, 0.1117, 0.2047]$$

$$\tilde{W}_6 = \tilde{Z}_6 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0532, 0.0959, 0.1719]$$

$$\tilde{W}_7 = \tilde{Z}_7 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0276, 0.054, 0.1218]$$

$$\tilde{W}_8 = \tilde{Z}_8 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.03, 0.056, 0.1089]$$

$$\tilde{W}_9 = \tilde{Z}_9 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0272, 0.0637, 0.1364]$$

$$\tilde{W}_{10} = \tilde{Z}_{10} \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0608, 0.1175, 0.2047]$$

$$\tilde{W}_{11} = \tilde{Z}_{11} \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.044, 0.0898, 0.1581]$$

$$\tilde{W}_{12} = \tilde{Z}_{12} \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0456, 0.084, 0.1581]$$

The final weights of each parameter are calculated as follow:

$W_1 = (\prod_{i=1}^{3} \omega_j)^{1/3} = 0.07928$, W_2=0.0796, W_3=0.0655, W_4=0.1076, W_5=0.1125, W_6=0.0958, W_7=0.05675, W_8=0.0569, W_9=0.0619, W_{10}=0.1136, W_{11}=0.0857, W_{12}=0.0847. Mentioned priority weights have indicated for each criterion in table 4.

Criteria	Global weights
Uniaxial Compressive Strength	0.1136
Hardness	0.1125
Equal Quartz Content	0.1076
Abrasiveness	0.0958
Tensile Strength	0.0857
Young's Modules	0.0847
Grain Size & Shape	0.0796
Texture	0.0793
Matrix Type & Cementation	0.0655
Schmidt Hammer Rebound	0.0619
Density	0.0569
Weathering	0.0568

Table 4. Priority weights for criteria

5.2 Ranking the sawability of carbonate rock

In attempting to present a ranking system for assessing rock sawability, using all mentioned parameters is difficult from a practical point of view. In this ranking system three following rules have been considered: (a) the number of parameters used should be small, (b) equivalent parameters should be avoided, and (c) parameters should be considered within certain groups. Considering these rules, the parameters which have been chosen for assessing the rock sawability are listed as follows:

a. Uniaxial Compressive Strength (UCS)
b. Schmiazek F-abrasivity factor (SF-a)
c. Mohs Hardness (MH)
d. Young's Modulus (YM)

5.3 Uniaxial Compressive Strength (UCS)

Uniaxial compressive strength is one of the most important engineering properties of rocks. Rock material strength is used as an important parameter in many rock mass classification systems. Using this parameter in classification is necessary because strength of rock material constitutes the strength limit of rock mass (Bieniawski, 1989). Factors that influence the UCS of rocks are the constitutive minerals and their spatial positions, weathering or alteration rate, micro-cracks and internal fractures, density and porosity (Hoseinie et al. 2009). Therefore, uniaxial compressive strength test can be considered as representative of rock strength, density, weathering, texture and matrix type. Thus, the summation of the weights of five parameters (texture, weathering, density, matrix type and UCS) is considered as weight of UCS. In total, the weight of UCS is about 0.372.

5.4 Schmiazek F-abrasivity factor (SF-a)

Abrasiveness influences the tool wear and sawing rate seriously. Abrasiveness is mainly affected by various factors such as mineral composition, the hardness of mineral constituents and grain characteristics such as size, shape and angularity (Ersoy and Waller, 1995). Schimazek's F-abrasiveness factor is depend on mineralogical and mechanical properties and has good ability for evaluation of rock abrasivity. Therefore, this index has been selected for using in ranking system. F-abrasivity factor is defined as

$$F = \frac{EQC \times Gs \times BTS}{100} \tag{16}$$

Where F is the Schimazek's wear factor (N/mm), EQC is the equivalent quartz content percentage, Gs is the median grain size (mm), and BTS is the in direct Brazilian tensile strength. Regarding the rock parameters which are used in questionnaires, summation of the weights of abrasiveness, grain size, tensile strength and equivalent quartz content is considered as weight of Schimazek's F-abrasiveness factor. In total the weight of this factor is 0.3687.

5.5 Mohs Hardness (MH)

Hardness can be interpreted as the rock' s resistance to penetration. The factors that affect rock hardness are the hardness of the constitutive minerals, cohesion forces, homogeneity, and the water content of rock (Hoseinie et al. 2009). Thus, hardness is a good index of all above given parameters of rock material. Considering the importance of hardness in rock sawing, hardness, after Schmiazek F-abrasivity factor, is considered the most relevant property of rock material. Regarding the questionnaires, summation of the weights of Mohs hardness and Schmidt hammer rebound value was considered as total weight of mean Mohs hardness. In total the weight of this factor is 0.1745.

5.6 Young's Modulus (YM)

According to rock behaviour during the fracture process, especially in sawing, the way that rocks reach the failure point has a great influence on sawability. The best scale for rock elasticity is Young's modulus. Based on ISRM suggested methods (ISRM, 1981), the tangent Young's modulus at a stress level equal to 50% of the ultimate uniaxial compressive strength is used in this ranking system. Regarding the questionnaires, the weight of this factor is about 0.0847 in total. According to FDAHP results the final weights of major parameters are shown in fig. 4.

5.7 Laboratory tests

For laboratory tests, some rock blocks were collected from the studied factories. An attempt was made to collect rock samples that were big enough to obtain all of the test specimens of each rock type from the same piece. Each block sample was inspected for macroscopic defects so that it would provide test specimens free from fractures, partings or alteration zones. Then, test samples were prepared from these block samples and standard tests have been completed to measure the above-mentioned parameters following the suggested procedures by the ISRM standards (ISRM, 1981). The results of laboratory studies are listed in table 5 and used in next stage.

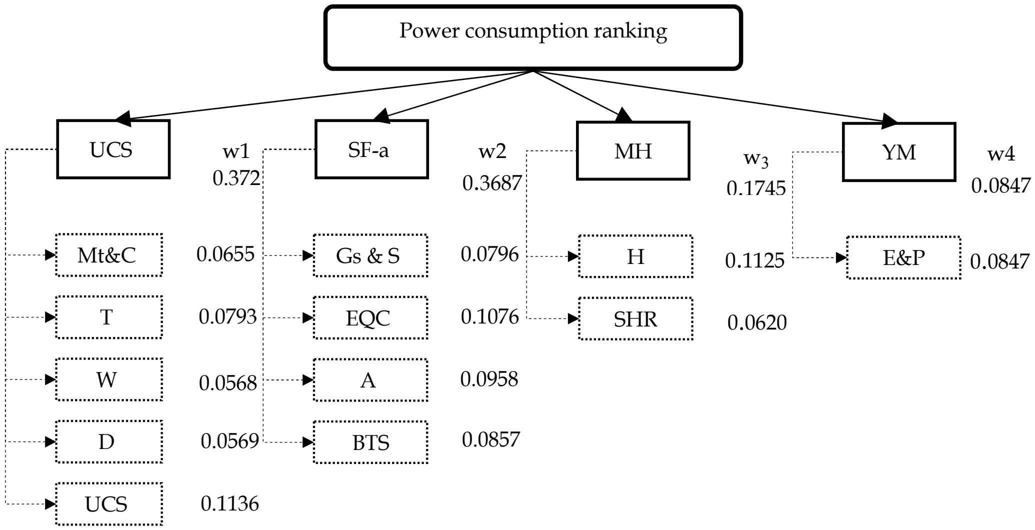

Fig. 4. The final weights of major parameters in power consumption ranking system

Rock sample		UCS	BTS	EQC	Gs	SF-a	YM	MH
		MPa	MPa	%	mm	N/mm	GPa	n
1	MHAR(Marble)	71.5	6.8	3.6	0.55	0.135	32.5	3.5
2	MANA(Marble)	74.5	7.1	3.4	0.45	0.109	33.6	3.2
3	TGH(Travertine)	53	4.3	2.8	1.01	0.122	20.7	2.9
4	THAJ(Travertine)	61.5	5.6	2.6	0.85	0.124	21	2.9
5	TDAR(Travertine)	63	5.4	2.7	0.87	0.127	23.5	2.95
6	MSAL(Marble)	68	6.3	3.2	0.52	0.105	31.6	3.1
7	MHAF(Marble)	74.5	7.2	4	0.6	0.173	35.5	3.6

Table 5. The result of laboratory studies

After determining the weights of the criteria with FDAHP method and laboratory studies, ranking the sawability of carbonate rocks is performed by TOPSIS method. Firstly, the amount of each criterion is filled in decision matrix for each criterion.

Decision matrix is obtained with respect to important rock properties (Table. 6). Decision matrix is normalized via Eq. (9) (Table. 7). Then, weighted normalized matrix is formed by multiplying each value with their weights (Table. 8). Positive and negative ideal solutions are determined by taking the maximum and minimum values for each criterion:

$$A^{*} = \{0.1547, 0.1863, 0.0393, 0.0748\}$$

$$A^{-} = \{0.1101, 0.1130, 0.0229, 0.0602\}$$

Then the distance of each method from PIS (positive ideal solution) and NIS (negative ideal solution) with respect to each criterion are calculated with the help of Eqs. (13) and (14). Then closeness coefficient of each rock is calculated by using Eq. (15) and the ranking of the rocks are determined according to these values.

	UCS	SF-a	YM	MH
	C1:	C2:	C3:	C4:
1	71.5	0.135	32.5	3.5
2	74.5	0.109	33.6	3.2
3	53	0.122	20.7	2.9
4	61.5	0.124	21	2.9
5	63	0.127	23.5	2.95
6	73	0.105	31.6	3.1
7	74.5	0.173	35.5	3.6

Table 6. Decision matrix

	UCS	SF-a	YM	MH
	C1:	C2:	C3:	C4:
1	0.3991	0.3937	0.4243	0.4166
2	0.4158	0.3176	0.4387	0.3809
3	0.2958	0.3556	0.2703	0.3452
4	0.3432	0.3619	0.2742	0.3452
5	0.3516	0.3709	0.3068	0.3511
6	0.4074	0.3065	0.4126	0.3690
7	0.4158	0.5052	0.4635	0.4285

Table 7. Normalized decision matrix

	UCS	SF-a	YM	MH
	C1:	C2:	C3:	C4:
1	0.1485	0.1452	0.0360	0.0727
2	0.1547	0.1171	0.0372	0.0665
3	0.1101	0.1311	0.0229	0.0602
4	0.1277	0.1334	0.0232	0.0602
5	0.1308	0.1368	0.0260	0.0613
6	0.1516	0.1130	0.0350	0.0644
7	0.1547	0.1863	0.0393	0.0748

Table 8. Weighted normalized matrix

The power consumption ranking of carbonate rocks are also shown in Table 9 in the descending order of priority.

Rank	Carbonate rock	dj*	dj-	CCj
1	MHAF(Marble)	0	0.0886	1
2	MHAR(Marble)	0.0418	0.0532	0.5602
3	MANA(Marble)	0.0697	0.0475	0.4050
4	MSAL(Marble)	0.0742	0.0434	0.3693
5	TDAR(Travertine)	0.0582	0.0317	0.3528
6	THAJ(Travertine)	0.0632	0.0270	0.2992
7	TGH(Travertine)	0.0743	0.0181	0.1958

Table 9. Rankings of the sawability of carbonate rocks according to CCj values

6. Discussion and validation of the new ranking

A new hierarchical model is developed here to evaluate and ranking the sawability (power consumption) of carbonate rock with using of effective criteria and considering of decision makers' judgments. The proposed approach is based on the combination of Fuzzy Delphi and Analytic Hierarchy Process (FDAHP) methods. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is also used in this study. FDAHP was used for determining the weights of the criteria according to decision makers then rankings of carbonate rocks were determined by TOPSIS. The proposed method was applied for Iranian ornamental stone to evaluation the power consumption in rock sawing process. The sawability ranking results of tested carbonate rocks are shown in section 5.

For validation of applied ranking system, experimental procedure was carried out. For this purpose, a fully-instrumented laboratory cutting rig was used. The rig was based on a commercially available machine and was capable of simulating realistic cutting conditions. It consists of three major sub-systems, a cutting unit, instrumentation and a personal computer. Sawing tests were performed on a small side-cutting machine, with a maximum spindle motor power of 7.5 kW. Cutting parameters such as feed rate, depth of cut, and peripheral speed control in the monitoring system. The variation of ampere was measured with a digital ampere-meter. The circular diamond saw blade used in the present tests had a diameter of 410 mm and a steel core of thickness 2.7 mm, 28 pieces of diamond impregnated segments (size 40×10×3 mm) were brazed to the periphery of circular steel core with a standard narrow radial slot. The grit sizes of the diamond were approximately 30/40 US mesh at 25 and 30 concentrations. This blade is applied for travertine, limestone and marble types of the stones, which are non-abrasive and medium hard. During the sawing trials, water was used as the flushing and cooling medium and the peripheral speed and depth of cut were maintained at constant 1770 rpm and 35 mm. Each rock was sawn at particular feed rate (200, 300 and 400 cm/min). During the sawing trials, the ampere and power consumption were monitored and calculated. The monitored ampere and calculated power consumption are listed in Table 10. According to Tables 9 and 10, the first rock in ranking (MHAF) has a maximum value of power consumption among other rock samples. It means that the new developed ranking is correct.

	Rock sample	Test 1		Test 2		Test 3	
		Fr=200 (cm/min)		Fr=300 (cm/min)		Fr=400 (cm/min)	
		I(A)	P(W)	I(A)	P(W)	I(A)	P(W)
1	MHAF(Marble)	12	2280	17.5	4370	28.6	8588
2	MHAR(Marble)	11.5	2090	16.4	3952	22	6080
3	MSAL(Marble)	11.5	2090	15.7	3686	20.2	5396
4	MANA(Marble)	11.2	1976	16.5	3990	22.2	6156
5	THAJ(Travertine)	11.2	1976	15.4	3572	19	4940
6	TDAR(Travertine)	10.6	1748	15.6	3648	17.2	4256
7	TGH(Travertine)	9.5	1330	12	2280	18	4560

Table 10. Ampere and calculated power consumption in sawing trials

The calculated power consumption of each carbonate rock in Figure 5 shows that the new ranking method for carbonate rock is reasonable and acceptable for evaluating them.

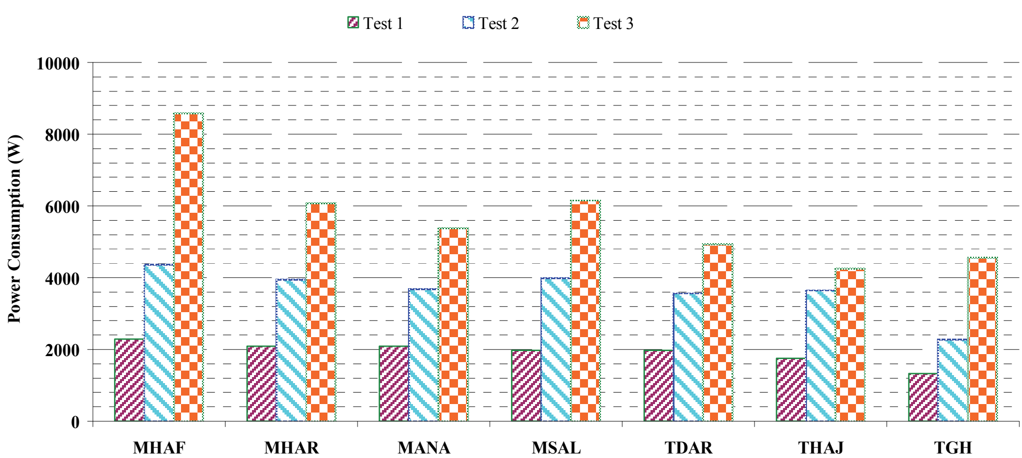

Fig. 5. The power consumption of carbonate rocks in sawing trials

7. Conclusion

In this chapter, a decision support system was developed for ranking the power consumption of carbonate rocks. This system designed to eliminate the difficulties in taking into consideration many decision criteria simultaneously in the rock sawing process and to guide the decision makers for ranking the power consumption of carbonate rocks. In this study, FDAHP and TOPSIS methods was used to determine the power consumption degree of the carbonate rocks. FDAHP is utilized for determining the weights of the criteria and TOPSIS method is used for determining the ranking of the power consumption of carbonate rocks. During this research a fully-instrumented laboratory sawing rig at different feed rate for two groups of carbonate rocks were carried out. The power consumptions were used to verify the result of applied approach for ranking them by sawability criteria. The experimental results confirm the new ranking results precisely.

This new ranking method may be used for evaluating the power consumption of carbonate rocks at any stone factory with different carbonate rock. Some factors such as uniaxial compressive strength, Schmiazek F-abrasivity, mohs hardness and young's modulus must be obtained for the best power consumption ranking.

8. Acknowledgment

The authors would like to say thank to educational workshop centre of Sharif University of Technology and central laboratory of Shahrood University of Technology for providing the facilities in order to perform an original research.

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22

A Supporting Decisions Platform for the Design and Optimization of a Storage Industrial System

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1. Introduction

In a recent survey the consulting company AT Kearney (ELA/AT Kearney survey 2004) states that there are more than 900,000 warehouse facilities worldwide from retail to service parts distribution centers, including state-of-art, professionally managed warehouses, as well as company stockrooms and self-store facilities. Warehouses frequently involve large expenses such as investments for land and facility equipments (storage and handling activities), costs connected to labour intensive activities and to information systems. Lambert et al. (1998) identify the following missions:

- Achieve transportation economies (e.g. combine shipment, full-container load).
- Achieve production economies (e.g. make-to-stock production policy).
- Take advantage of quantity purchase discounts and forward buys.
- Maintain a source of supply.
- Support the firm's customer service policies.
- Meet changing market conditions and again uncertainties (e.g. seasonality, demand fluctuations, competition).
- Overcome the time and space differences that exist between producers and customers.
- Accomplish least total cost logistics commensurate with a desired level of customer service.
- Support the just-in-time programs of suppliers and customers.
- Provide customers with a mix of products instead of a single product on each order (i.e. consolidation).
- Provide temporary storage of material to be disposed or recycled (i.e. reverse logistics).
- Provide a buffer location for trans-shipments (i.e. direct delivery, cross-docking).

Bartholdi and Hackman (2003) conversely recognize three main uses:

- *Better matching the supply with customer demands*

Nowadays there is a move to smaller lot-sizes, point-of-use delivery, high level of order and product customization, and cycle time reductions. In distribution logistics, in order to serve customers, companies tend to accept late orders while providing rapid and timely delivery within tight time windows. Consequently the time available for order picking becomes shorter.

- *Consolidating products*

The reason to consolidate products is to better fill the carrier to capacity and to amortize fixed costs due to transportation. These costs are extremely high when the transportation mode is ship, plane or train. As a consequence a distributor may consolidate shipments from vendors into larger shipments for downstream customers by an intermediate warehouse.

- *Providing Value-added processing*

Pricing, labelling and light assembly are simple examples of value added processing. In particular the assembly process is due for a manufacturing company adopting the postponement policy. According to this policy products are configured as close to customers as possible.

As a result warehousing systems are necessary and play a significant role in the companies' logistics success.

2. Classification and notation

A classification of warehouse design and operation planning problems is illustrated in Figure 1 (Gu et al., 2007).

A more detailed description of each problem category previously identified is given in Table 1. This paper will focus mostly on both warehouse design issues and the operation planning problems.

Table 1 reports a large number of problems whose literature presents many studies, models and supporting decision methods and tools. A limited number of studies present integrated approaches to face simultaneously a few of these problems which are significantly correlated. The performance of the generic operation usually depends on design decisions (see Table 1). As a consequence the authors of this chapter decides to develop, test and apply an original DSS based on an integrated approach to best design and manage a warehousing system. It takes inspiration from literature models and algorithms developed during last two decades.

Main operations and functional areas within a general warehousing system are: receiving, transfer and put away, order picking/selection, accumulation/sorting, cross-docking, and shipping.

Fig. 2. Typical warehouse operations (Inspired by: Tompkins et al., 2003) show the flows of product and identifies the typical storage areas and relative logistic movements.

In particular, the *receiving activity* includes the unloading of products from the transport carrier, updating the inventory record, inspection to find if there is any quantity or quality inconsistency. The *transfer* and *put away* involves the transfer of incoming products to storage locations. It may also include repackaging (e.g. full pallets to cases, standardized containers), and physical movements (from the receiving docks to different functional areas, between these areas, from these areas to the shipping docks). The *order picking/selection* involves the process of obtaining a right amount of the right products for a set of customer orders. It is the major activity in most warehouses. The *accumulation/sorting* of picked orders into individual (customer) orders is a necessary activity if the orders have been picked in batches. The *cross-docking* activity is performed when the received products are transferred directly to the shipping docks (short stays or services may be required but no order picking is needed). The storage function is the physical containment of products while they are awaiting customer demands. The form of storage will depend on the size, quantity of the products stored, and the handling characteristic of products or their product carriers (Tompkins et al., 2003).

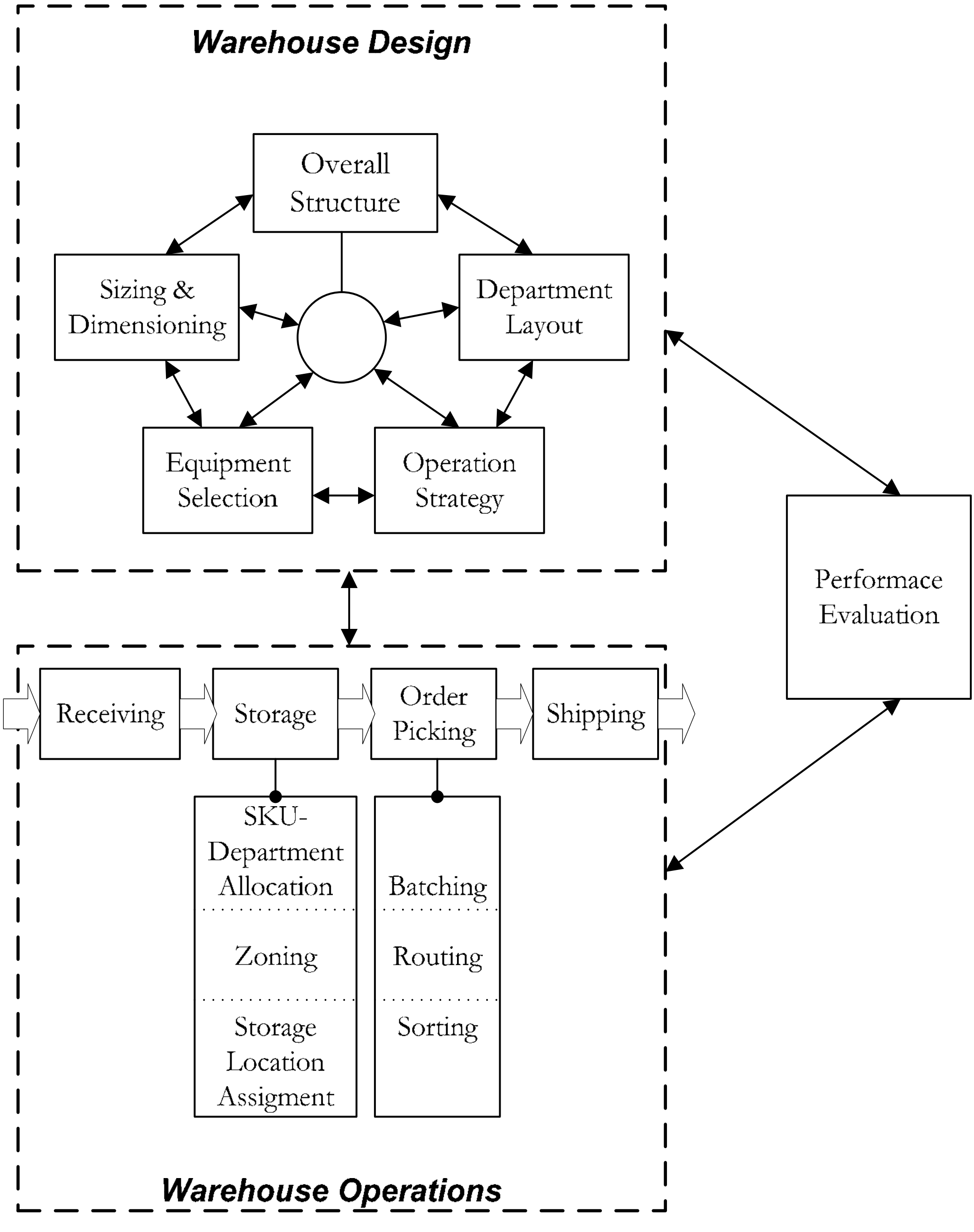

Fig. 1. Framework for warehouse design and operation problems, (Gu et al., 2007).

2.1 Order picking systems

Order picking (*OP)* can be defined as the retrieval of items from their warehouse locations in order to satisfy demands from internal or external customers (Petersen, 1999). In order picking systems (OPSs) incoming items are received and stored in (large-volume) unit pallet loads while customers order small volumes (less than unit loads) of different products as simply shown in Figure 3. Typically, hundreds of customer orders, each made of many requests (orderlines), have to be processed in a distribution warehousing system per day.

Design and operation problems			Decisions
Warehouse design	Overall structure		• Material flow
			• Department identification
			• Relative location of departments
	Sizing and dimensioning		• Size of the warehouse
			• Size and dimension of departments
	Department layout		• Pallet block-stacking pattern (for pallet storage)
			• Aisle orientation
			• Number, length, and width of aisles
			• Door locations
	Equipment selection		• Level of automation
			• Storage equipment selection
			• Material handling equipment selection (order picking, sorting)
	Operation strategy		• Storage strategy selection (e.g., random vs. dedicated)
			• Order picking method selection
Warehouse operation	Receiving and shipping		• Truck-dock assignment
			• Order-truck assignment
			• Truck dispatch schedule
	Storage	SKU-department assignment	• Assignment of items to different warehouse departments
			• Space allocation
		Zoning	• Assignment of SKUs to zones
			• Assignment of pickers to zones
		Storage location assignment	• Storage location assignment
			• Specification of storage classes (for class-based storage)
	Order picking	Batching	• Batch size
			• Order-batch assignment
		Routing and sequencing	• Routing and sequencing of order picking tours
			• Dwell point selection (for AS/RS)
		Sorting	• Order-lane assignment

Table 1. Description of warehouse design (Gu et al. 2007)

Even thought there have been various attempts to automate the picking process, automatic systems are rarely found in practice. Order picking, like many other material handling activities, still is a repetitive and labour-intensive activity. Order picking systems, which involve human operators can be generally organized in two ways, namely as a *part-to-picker* system in which the requested products are delivered automatically to a person at an input/output (I/O) point, or as a *picker-to-parts* system in which the order picker travels to storage locations in order to bring together the required products. Figure 4 gives a comprehensive classification of OPSs (De Koster 2004).

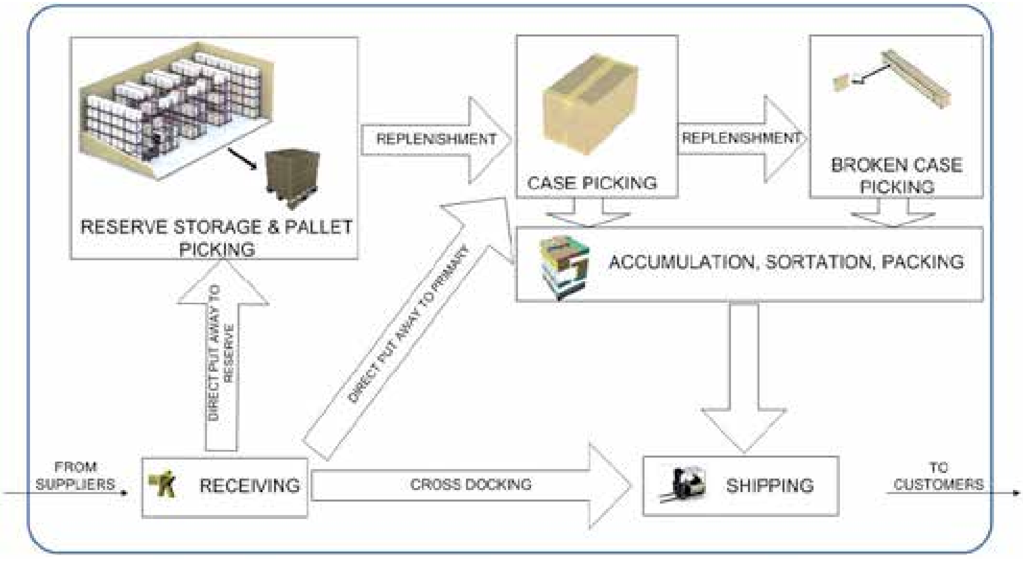

Fig. 2. Typical warehouse operations (Inspired by: Tompkins et al., 2003)

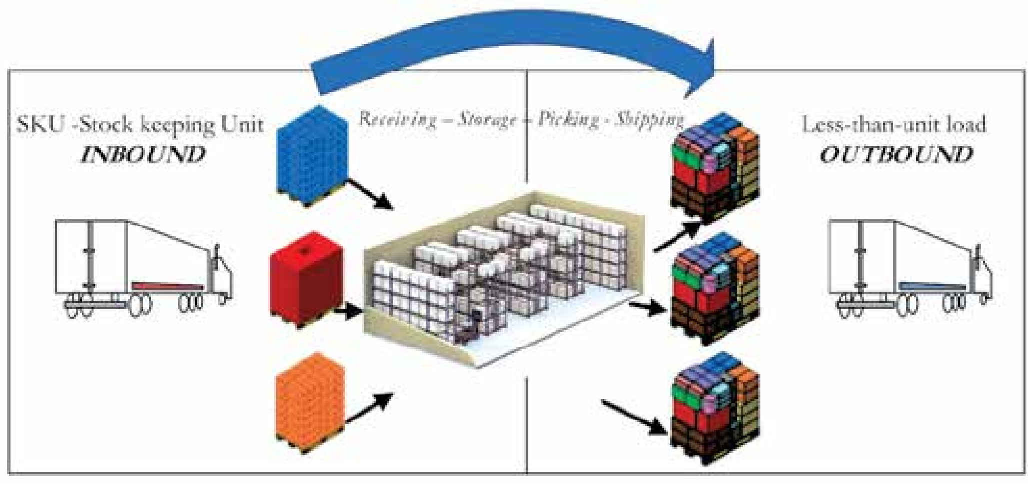

Fig. 3. From stock keeping units (skus) to customer orders

It can be distinguished two types of picker-to-parts systems: *low-level* systems and *high-level* systems. In low-level OPSs the picker picks requested items from storage racks or bins. Due to the labour intensity, low level systems often are called manual OPSs. Some other order picking systems have high storage racks; order pickers travel to the pick locations on board of a stacker or order-pick truck, or a crane. The crane mechanically stops in front of the correct pick location and waits for the order picker to execute the pick. This type of system is called high-level or *man-aboard system*. Parts-to-picker systems include *automated storage and retrieval systems* (AS/RS), using mostly aisle-bound cranes that retrieve one or more unit loads (e.g. of bins: mini-load system, or pallets) and carry the loads to a pick station (i.e. I/O point). At this station the order picker picks the right quantity requested by the customer order, after which the residual stock quantity is stored again. This type of system is also called *unit-load OPS*. The automated crane can work under different functional modes: single, dual and multiple *command cycles*. The *single-command* cycle means that either a load is moved from the I/O point to a rack location or from a rack location to the I/O point. In the *dual-command* mode, first a load is moved from the I/O point to the rack location and next another load is retrieved from the rack. In multiple command cycles, the S/R machines have more than one shuttle and can pick up several loads in one cycle, at the I/O point or retrieve them from rack locations.

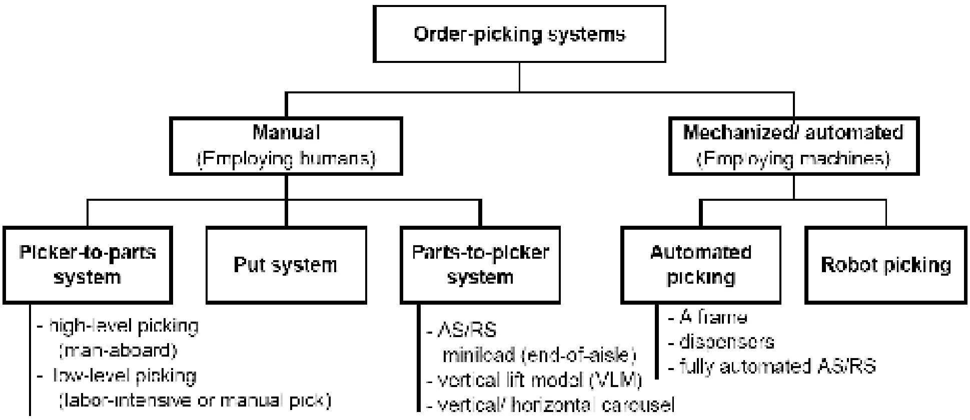

Fig. 4. Classification of order-picking systems (based on De Koster 2004)

Manual-pick picker-to-parts systems are the most common (De Koster, 2004). The basic variants include picking by article (*batch picking*) or pick by order (*discrete picking*). In the case of picking by article, multiple customer orders (the batch) are picked at the same time by an order picker. Many in-between variants exist, such as picking multiple orders followed by immediate sorting (on the pick cart) by the order picker (sortwhile-pick), or the sorting takes place after the pick process has finished (pick-and-sort).

Another basic variant is *zoning*, which means that a logical storage area (this might be a pallet storage area, but also the entire warehouse) is split in multiple parts, each with different order pickers. Depending on the picking strategy, zoning may be further classified into two types: *progressive zoning* and *synchronized zoning*. Under the progressive (or sequential) zoning strategy, each batch (possibly of one order) is processed only in one zone at a time; at any particular point in time each zone processes a batch that is dissimilar from the others. Hence, the batch is finished only after it sequentially visits all the zones containing its line items. Under the synchronized zoning strategy, all zone pickers can work on the same batch at the same time.

3. Conceptual framework and DSS for warehousing systems

Figure 5 illustrates a conceptual framework for the design, control and optimization of an industrial storage system. This framework is the result of the integration of different models and supporting decision methods & tools by the adoption of a systematic multi-step approach. The proposed approach involves several decisions which rarely are faced simultaneously by the decision maker. As a consequence he/she has to accept local optima and sub optimizations.

Main decisions deal with the determination of (1) the *system type*, e.g. automatic or manual warehousing system, parts-to-picker or picker-to-parts, unit-load or less than unit-load, forward-reserve or forward only, etc.; (2) the best *storage capacity* of the system in terms of number of pallet locations for each sku; (3) the *structure of the system*, i.e. the layout and configuration of the system in terms of racks, bins, aisles, etc.; (4) the *allocation of product* volumes to the storage area in agreement with the whole capacity defined by (1) and in presence/absence of a reserve area; (5) the *assignment of products* to the storage area; (6) the *evaluation of the performance* of the adopted system configuration by the simulation of vehicles' routes.

A brief and not exhaustive classification of storage systems types has been introduced in previously illustrated Figure 4 (as proposed by De Koster 2004). The generic form of the proposed DSS is made of active tables for data entry, reports, graphs and tables of results, etc. A "Quick report" section reports all necessary information for the user: for example it is possible to show the sequence of picking in an order according to a given picking list and to collect a set of performance indices. Next subsections illustrate main data entry forms and decision steps for the design of a storage system.

This chapter adopts the following terms many times: fast-pick, reserve, bulk, sku, etc.. *Which is the difference between the fast-pick area and the reserve one?* The *fast-pick area* is a site inside the warehouse where the most popular skus are stored in rather small amounts so that a large part of daily picking operations can be carried out in a relatively small area with fast searching process and short travelled routes. The items most frequently requested by customers are grouped in this storage area, which is often located in an easily accessible area so that the time of picking and handling is minimized. The location of the items in the fast pick area is better than any other in the warehouse and related operations, e.g. stocking, travelling, searching, picking, and restocking, are faster.

3.1 Storage capacity evaluation

The proposed DSS adopts two alternative approaches for the so-called *stock capacity evaluation* (step 2): *historical inventory* (2/HI) based approach and *demand profile* (2/DP) based approach. 2/HI identifies a storage capacity of a warehousing system in agreement with a set of historical, e.g. monthly, stock levels and a specified *risk of stockout*, as a measure of probability a generic stockout occurs in a period of time, such a year. The generic value of inventory level usually refers to the global storage quantity (volume) level of products including both the level for picking and the level for reserve: companies rarely collect historical data on their storage quantities and very rarely they distinguish the storage levels in fast pick area from corresponding levels in bulk area.

The proposed platform supports the determination of the storage level constructing a non parametric *class based frequency analysis* and/or a non parametric continuous *frequency based analysis*. These are non parametric statistical analyses because they do not identify statistical distributions, e.g. Normal, Lognormal, Weibull, etc., as a result of best fitting available data (Manzini et. al 2010). These analyses are the basis for estimating percentiles of historical variation of inventory, i.e. the expected *risk of stockout* adopting a specific level of storage capacity and assuming future movements of products into/out of the system similar to the historical ones.

The so-called class based analysis of historical storage quantities generates a histogram of frequency values of storage levels collected in the adopted historical period of time by the preliminary definition of a number of histogram classes of values. The histogram of cumulative values identifies the probability of "stockin", i.e. the probability of the complementary event of the stockout (the probability that stockout would not occur).

The *continuous frequency based* analysis generates a similar set of graphs without the preliminary definition of a number of classes of values (historical measures).

The so called DP approach identifies the best level of storage capacity by the analysis of historical demand profiles. Given a period of time, e.g. one year, and a set of values of demand quantities for each product within this period, DP quantifies the expected demand during an assumed subperiod of time *t*, called *time supply* (e.g. 3 weeks). As a consequence this approach assumes to store an *equal time supply* of each sku. This is a frequently adopted strategy in industrial applications and is widely discussed by Bartholdy and Hackman (2003): the equal time strategy - EQT. By this strategy the storage system should supply the expected demand orders for the period of time *t* without stockouts. Obviously this depends on the adopted *fulfilment system*, which relates with *inventory management decisions* significantly correlated to the storage/warehousing decisions object of this chapter.

The output of a storage capacity evaluation is the storage volume of products in the fast pick area (adopting a forward-reserve configuration system) and the whole storage capacity (including the bulk area when forward-reserve configuration is adopted). In presence of fast picking, it usually refers to the lowest level of storage: the so-called 0 level.

This capacity is usually expressed in terms of cubic meter, litres, number of pallets, cases, carton, pieces of products, etc.

Figure 6 presents the form of the proposed DSS for data entry and evaluation of historical storage levels given an admissible risk of stockout. This figure also shows a curve "risk of stockout" as a result of the statistical analysis of historical observations: this is the *stockout probability plot*. Obviously given a greater storage capacity this risk decreases.

3.2 Structure of the system: layout & configuration

This section deals with the determination of the layout and configuration of the storage system as the result of warehouse type (see previous discussion and classification) selection including the existence/absence of the forward-reserve strategy, picking at low/high levels, etc.; pallet/unit load dimensions; racks and shelves dimensions; adopted vehicles for material handling. It is important to underline that the layout of the storage area significantly depends on the width of the aisles which have to host different kinds of vehicles:

- vehicles for the *pallet-loading/put-away* process, which usually involves unit loads;
- vehicles for *restocking* (generally unit loads) in presence of a forward-reserve system;
- vehicles for *picking* (unit loads and less than unit loads) at low/high levels.

Figure 7 and 8 present the forms for data entry of *unit load parameters* and *warehouse setting* respectively. All vehicles are characterized in terms of *routing strategies*, distinguishing *traversal* from *return* (Manzini et al. 2006). It is possible to distinguish the vehicle parameters for put-away, restocking and picking. The *shape factor* of a storage system is the ratio between the frontal length and longitudinal length of system layout: this value can be optimized in presence of pallet-loading of unit loads, given the location of the I/O depot area and adopting a shared, i.e. randomized, storage allocation of products. In any different hypotheses, e.g. in presence of less than unit load picking activities, there is not an optimal value of this ratio and the user can arbitrary choose it.

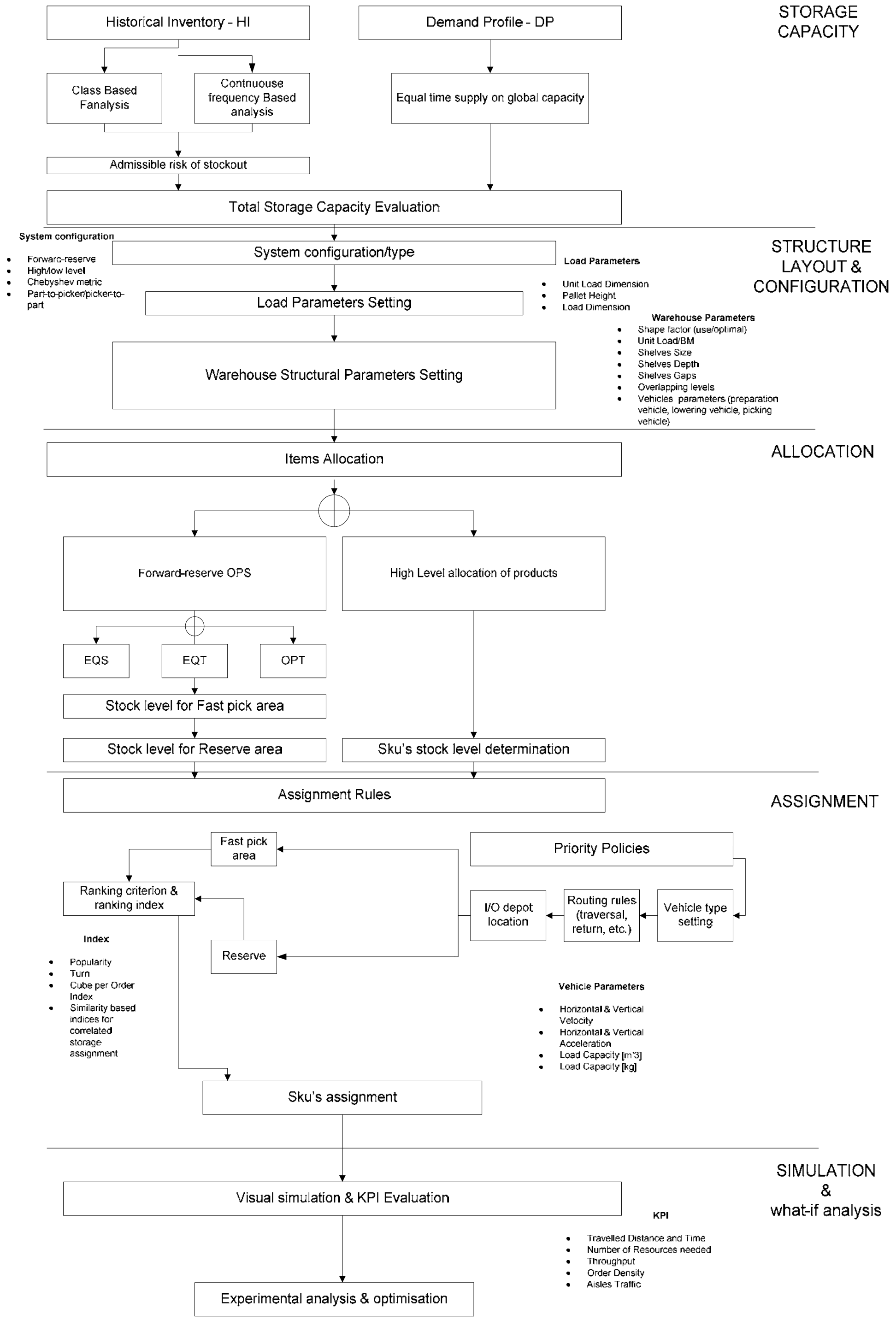

Fig. 5. Conceptual framework

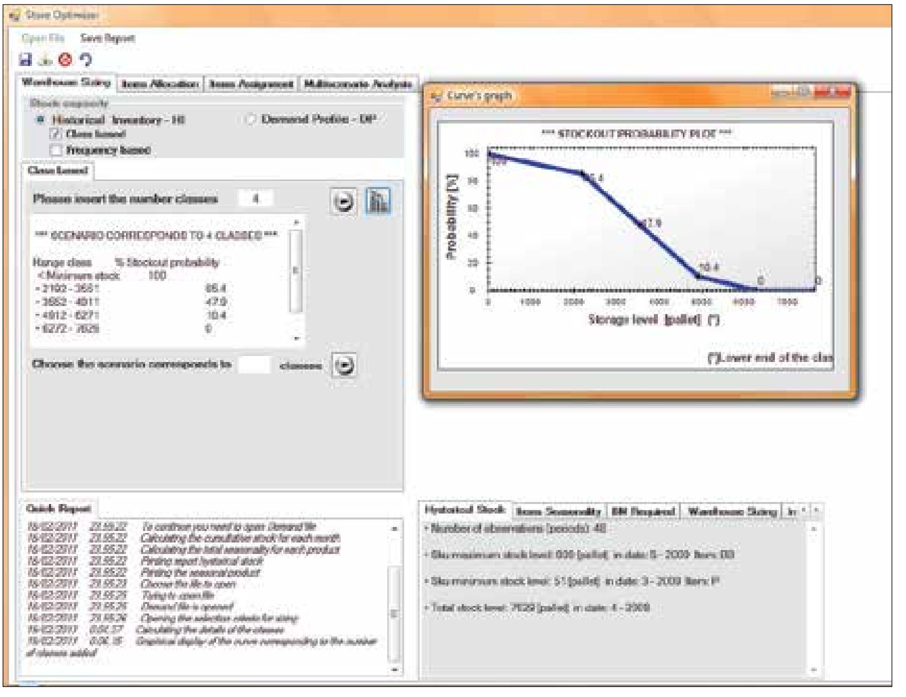

Fig. 6. Historical storage levels analysis and capacity evaluation.

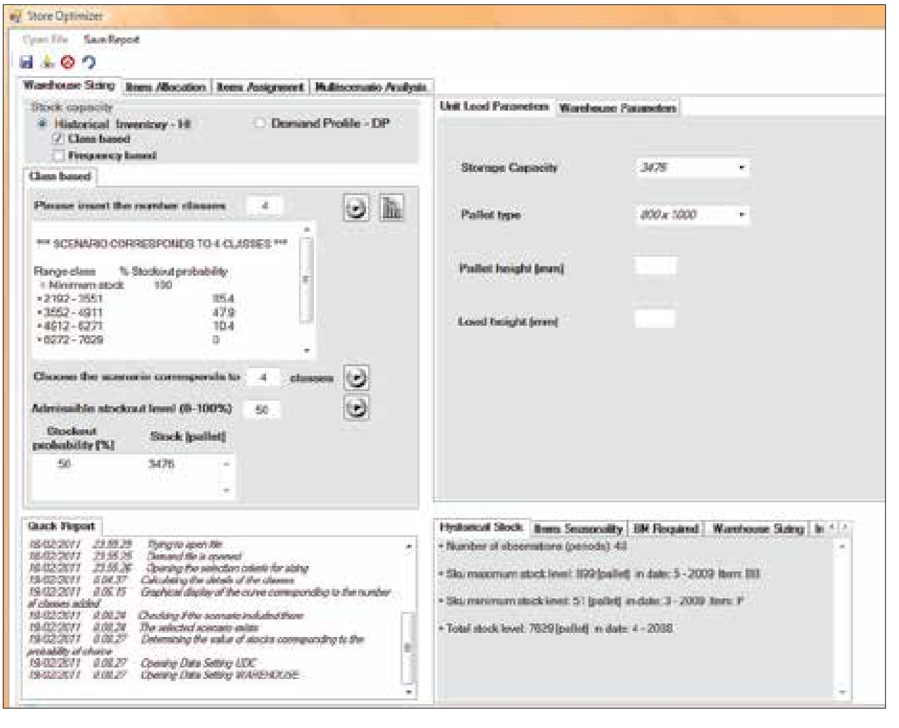

Fig. 7. Data entry, unit load parameters.

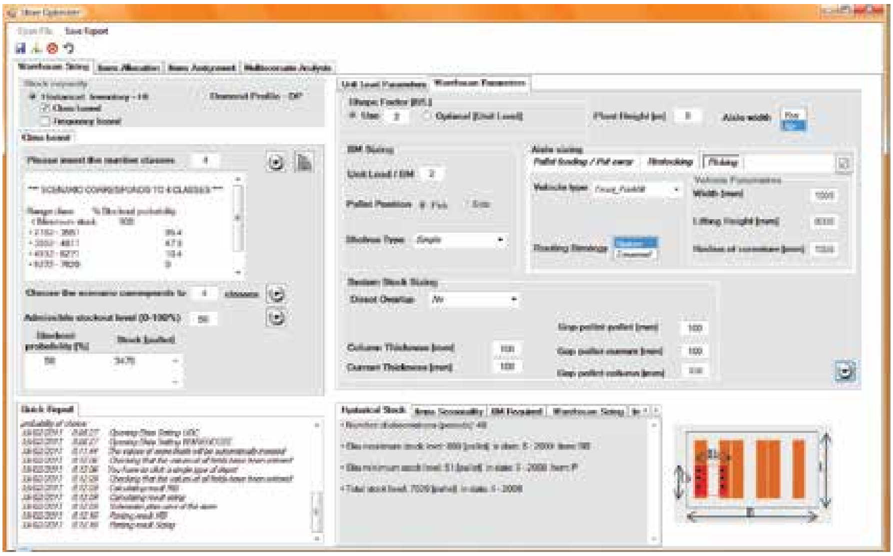

Fig. 8. Data entry, warehouse parameters.

Many other parameters are not described in this brief illustration of the proposed DSS. Figure 9 shows an exemplifying set of reports collecting the results as output of layout & configuration design. They are grouped in different sections: historical stock, BM required, warehouse sizing, etc. A few exemplifying results are: number of historical observations, storage volume available, number of levels, number of bays, number of aisles, etc.

Fig. 9. Warehouse sizing reports

3.3 Items allocation

This sections deal with the application of the so called *allocation strategy*, i.e. the determination of the fraction of storage volume for each sku that is a product (also called item). In particular the manager is interested in the following critical question: *which is the best amount of space to assign to any skus?* This question refers to the fast pick area in presence of a forward-reserve storage system and adopting a *dedicated storage*, which adopts *fixed storage locations* for the generic sku.

Bartholdi and Hackman (2003) discuss this issue in order to reduce the number of restocks in a fast pick (forward) and bulk storage (reserve) picking system. The fast pick area cannot contain the right volume of each item required to satisfy the total customer demand in a

specific supply period of time e.g. a month or a year. Consequently, it is necessary to ensure replenishment of picked goods from a bulk storage area, known as *reserve area*.
Therefore, consideration has to be given to an appropriate choice between the space allocated for an item in the fast pick area and its restock frequency (Bartholdi and Hackman, 2003). They discuss three different allocation strategies for calculating the volume to be assigned to each sku assuming it incompressible, continuously divisible fluid. The models proposed for determining the sku level of stock are based on the following notation:

- let f_i be the rate of material flow through the warehouse for the sku_i;
- let the physical volume of available storage be normalized to one. v_i represents the fraction of space allocated to sku_i so that:

$$\sum_i v_i = 1 \tag{1}$$

Three different levels of stock for sku_i are defined as follows:

i. *Equal Space Strategy* (EQS). This strategy identifies the same amount of space for each sku. The fraction of storage volume to be dedicated to the sku_i under EQS is:

$$EQS_i = \frac{1}{n} \tag{2}$$

ii. *Equal Time Strategy* (EQT). In this strategy each sku i is replenished an equal number of times according to the demand quantities during the period of time considered. Let K be the common number of restocks during a planning period so that:

$$\frac{f_i}{v_i} = K \tag{3}$$

From equations (1) and (3):

$$K = \sum_i f_i \tag{4}$$

The fraction of storage volume to be dedicated to the sku_i under EQT is:

$$EQT_i = \frac{f_i}{K} = \frac{f_i}{\sum_i f_i} \tag{5}$$

iii. *Optimal Strategy* (OPT). Bartholdi and Hackman (2003) demonstrate that this strategy minimizes the number of restocks from the reserve area. The fraction of available space devoted to sku_i is:

$$OPT_i = \frac{\sqrt{f_i}}{\sum_i \sqrt{f_i}} \tag{6}$$

A critical issue supported by the what-if multi-scenario analysis, which can be effectively conducted by the proposed DSS, is the best determination of the fraction of storage volume for the generic sku as the result of the minimization of pickers travelling time and distance in a forward – reserve picker to part order picking system.
Equations (2), (5), and (6) are fractions of fast pick volume to be assigned to the generic item i. As a consequence it is necessary to preliminary know the level of storage to be assigned to the fast pick area in order to properly defined each dedicated storage size. A company usually traces and knows the historical picking orders with a high level of detail (date of order, pickers, picked skus and quantities, visited locations, pickers id, restocking movements, etc.) thanks to traceability tools and devices (barcode, RFID, etc.), but it rarely

has "photographs" of the storage systems, i.e. historical values of storage levels. In presence of forward-reserve systems and a few (or many) photographs of storage levels, the generic inventory level, made available by the warehouse management system, does not distinguish the contribution due to fast pick area and that stored in bulk area as discussed in section 3.1. The proposed DSS supports the user to define the whole level of storage for fast picking, the level of storage for bulk area and those to be assigned to each sku in both areas.

Items allocations affect system performance in all main activities previously discussed: pallet-loading (L), restocking/replenishment (R) and picking (P). This is one of the main significant contributions of the proposed DSS to knowledge and warehousing system optimization. The following questions are still open: *Which is the effect of storage allocation to travel time and distances due to L, R and P activities? Given a level of storage assigned to the fast pick area, is the OPT the best allocation storage for travel distance and time minimization?*

We know that the OPT rule, equation (6), supports the reduction of the number of restocks (R) but the logistic cost of material handling is also due to (I) and (P) activities. The multi-scenarios what-if analysis supported by the proposed DSS helps the user to find the most profitable problem setting which significantly varies for different applications.

Figure 10 presents exemplifying results of the item allocation for an industrial application. This is a low level forward-reserve OPS: for each sku the number of products in fast pick and reserve areas is determined.

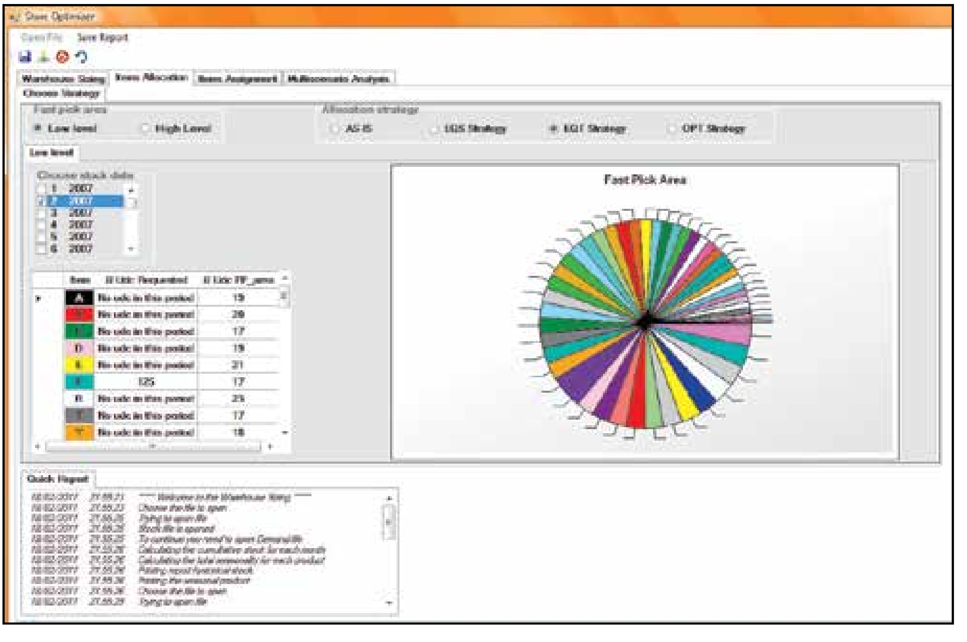

Fig. 10. Allocation of products, fast-pick area.

3.4 Skus assignment

The *storage assignment problem* deals with the assignment of products to storage locations in order to identify which is the best location for the generic product (Cahn, 1948). Decisions on storage assignment affect both time and costs due to I, R and P activities. The assignment problem has been formalized by Frazelle and Sharp (1989) and classified as a Non – Polynomial (NP) hard problem.

A list of typical indices adopted to rank the skus for the assignment of storage locations follows:

- *Popularity (P).* This is defined as the number of times an item belongs to an order in a given set of picking orders which refer to a period of time *T*:

$$P_{i,T} = \sum_{\substack{order\ j \\ in\ period\ T}} x_{ij} \tag{7}$$

where

$$x_{ij} = \begin{cases} 1\ if\ item\ i\ occures\ in\ order\ j \\ 0\ Otherwise \end{cases}$$

(x_{ij}) product-order incidence matrix.

- *Cube per Order Index (COI)* can be defined as the ratio of volume storage to inventory for the generic sku to the average number of occurrences of sku in the order picking list for a given period of time (Haskett, 1963). Given an sku *i*, COI is defined as the ratio of the volume of the stocks to the value of its popularity in the period of interest *T*. Formally:

$$COI_{i,T} = \frac{v_{i,T}}{\sum_{\substack{order\ j \\ in\ period\ T}} x_{ij}} \tag{8}$$

where

$v_{i,T}$ average storage level of sku *i* in time period *T*.

- *Order Closing Index (OC).* Order Completion (OC) assignment is based on the OC principle introduced by Bartholdi and Hackman (2003). Bindi (2010) introduced the Order Completion rule based on an index called *OC index* that evaluates the probability of a generic item being part of the completion of an order, composed of multiple orderlines of different products (items). The OC index is the sum of the fractions of orders the generic item performs. For a generic sku and a time period *T*, OC is defined as follows:

$$OC_{i,T} = \sum_j f_{ij,T} \tag{9}$$

where

$$f_{ij,T} \underset{\substack{order\ j\ in \\ period\ T}}{=} \frac{x_{ij}}{\sum_{z=1}^{m(j)} x_{ij}} \tag{10}$$

$m(j)$ number of orderlines for picking order *j*.

According to the previous hypotheses the OC index for a certain item can assume the following special values:

- *Minimum value* = 1/ Total Number of Items, when the item belongs to all the customer orders.
- *Maximum value* = number of orders, when the item belongs to all customers orders and there are no other items.

- *Turn Index (T)*. Given an sku *i*, it is defined as the ratio of the picked volume during a specific period of time *T* to the average stock stored in *T*. The index can be written as:

$$T_{i,T} \underset{\substack{order\ j\ in \\ period\ T}}{=} \frac{\sum_j p_{ij}}{v_{i,T}} \tag{11}$$

where

p_{ij} picked volume of product *i* in the order *j*. The unit of measurement is the same as $v_{i,T}$.

The literature presents several storage assignment policies that can be classified in one of the following main categories (Van der Berg and Zijm 1999, Manzini et al. 2006 and 2007):

- *Randomized Storage*
  This policy provides for skus randomly assigned to the first available space in the warehouse. The random storage policy is widely adopted in the warehousing industry because it is easy to use, often requires less space than other storage methods, and uses all the picking aisles intensively.
- *Dedicated Storage*
  This policy reserves specific locations for each sku within the warehouse. It requires more space in the pick area for storage but allows the pickers to memorize fixed locations of skus producing time labour saving. The choice of dedicated location to assign a generic item follows one of the following rules:
  - *class based storage rule*. This rule defines several classes as groups of skus located in storage areas more or less favorable to satisfying particular criteria. Frazelle (2002) punctually states the two most frequently used criteria used to assign a class of products to storage locations are popularity and the cube per order index (COI) as defined by Haskett (1963).
  - *ranked index based rules*. They are based on the ascending or descending values of one of the previously introduced indices e.g. P, COI, OC, or T defined for each sku. The P-based assignment rule considers a list of items sorted by decreasing value of popularity and assigns the highest of them to the nearest location from the depot area (I/O point) i.e. the most favourable location. The COI-based assignment rule considers a list of items sorted by increasing value of COI and assigns the lowest of them to the most favourable location. The OC-based assignment rule arranges items in a similar way to the P-based rule: it considers a list of items sorted by decreasing value of OC index and assigns the highest of them to the most favourable locations. The Turn-based assignment rule assigns items in the same way as for the previous OC rule but uses Turn index instead of OC.
  - *correlated storage policy*. This policy locates items with a high degree of correlation close to each other, which is usually based on the frequency of being in different picking orders. The allocation of products within a storage area can be based on different types of correlation existing between products. Once the correlation has been calculated for all pairs of products, the couples with the highest value of correlation are stored together. For example, customers may usually order a certain item together with another. These products might reasonably have high correlation and it may be useful to locate them close together within the system to reduce the

travelling distance and time during the picking activity. In order to group products, the statistical correlation between them should be known or at least be predictable, as described by Frazelle and Sharp (1989), and by Brynzér and Johansson (1996).

The proposed tool assigns the location to the generic sku by the Cartesian product, as the direct product of two different sets. The first set $(RANK_{sku})_i$ is made of the list of skus ordered in agreement with the application of a *ranking criterion* (see Figure 10), e.g. the popularity measure based rule or a similarity based & clustering rule (Bindi et al. 2009). The second set is made of available locations ordered in agreement with a priority criterion of locations assignment, e.g. the shortest time to visit the location from the I/O depot area. As a consequence most critical sku are assigned to the nearest available locations. Obviously the generic sku can be assigned to multiple locations in presence of more than one load stored in the system.

This assignment procedure refers to the products quantities subject to picking, e.g. located in the so called fast picking area: this is the so called *low level OPS*. In *high level* systems all locations at different levels can be assignable in agreement with the adopted ranking procedure. Both types of warehouses are supported by the proposed DSS. Figure 10 shows the form for setting the assignment of products within the system.

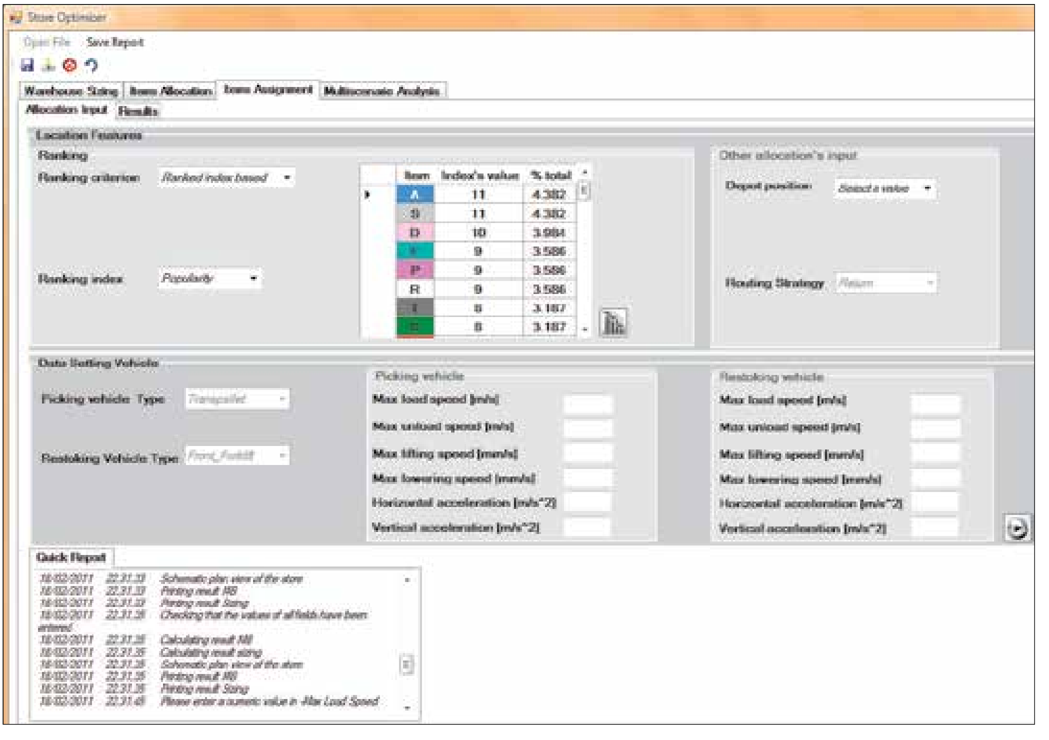

Fig. 10. Storage assignment setting, *ranking criterion* and *ranking index*.

Correlated storage assignment rules are supported by the DSS in agreement with the systematic procedure proposed and applied by Bindi et al. (2009 and 2010). Figure 11 exemplifies the result of the assignment of products within the fast pick area by the use of different colours, one for each sku. Similarly the result of the assignment of products to the higher levels can be shown as illustrated in Figure 12.

3.5 Performance evaluation

This section deals with the evaluation and analysis of the performance of the systems in terms of monetary and not monetary costs. Examples of the second set of costs: meters and hours spent in travelling by the pickers in a period of time, e.g. one day, a year, etc.; number of vehicles and pickers; percentage level of use for each logistic resource.

Given a system layout, an allocation of skus to fast pick area, the assignment of products, and the performance of adopted vehicles, it is possible to simulate the routes travelled by pickers and restockers to satisfy (L), (R) and (P) activities.

The analysis can be conducted comparing different operating scenarios as the result of different settings (system layout & configuration, storage allocation, storage assignment, etc.) as previously illustrated, and it is supported by a visual animation and a set of graphs and summary tables as illustrated in Figure 13. The adopted parameters of the what-if setting are: routing strategy, ranking index, allocation strategy, and the depot location.

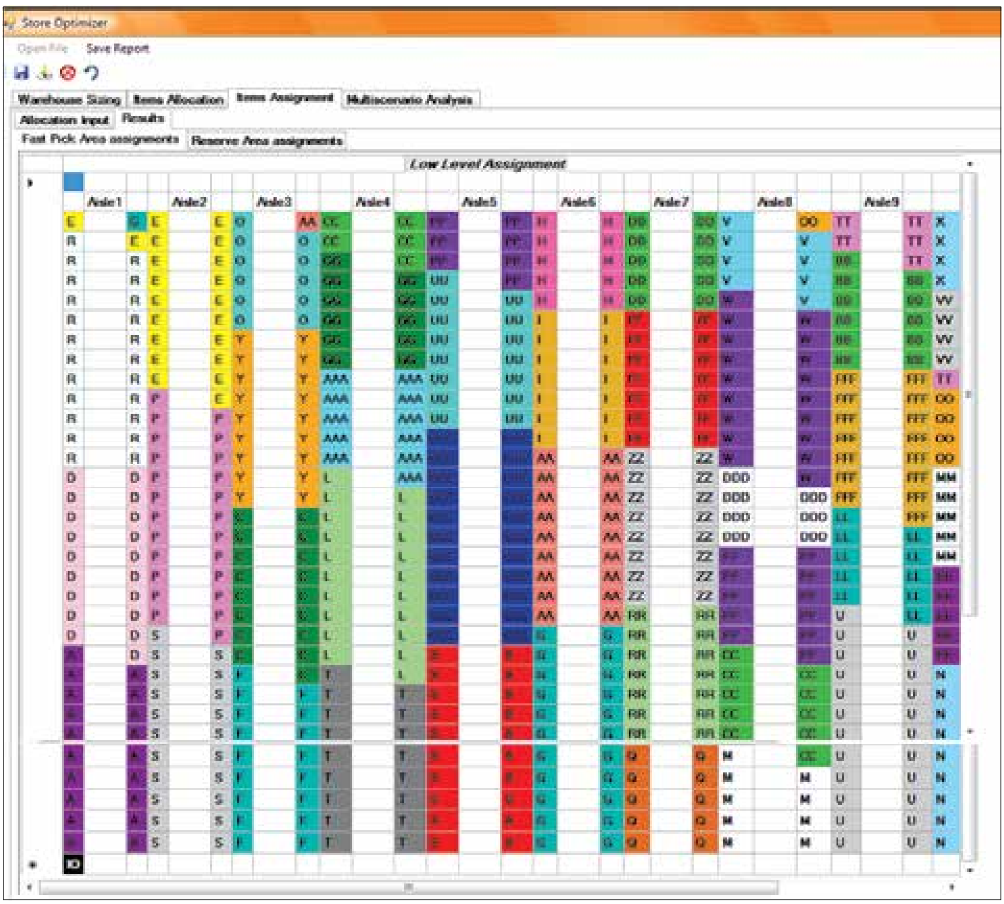

Fig. 11. Storage assignment results, fast-pick area.

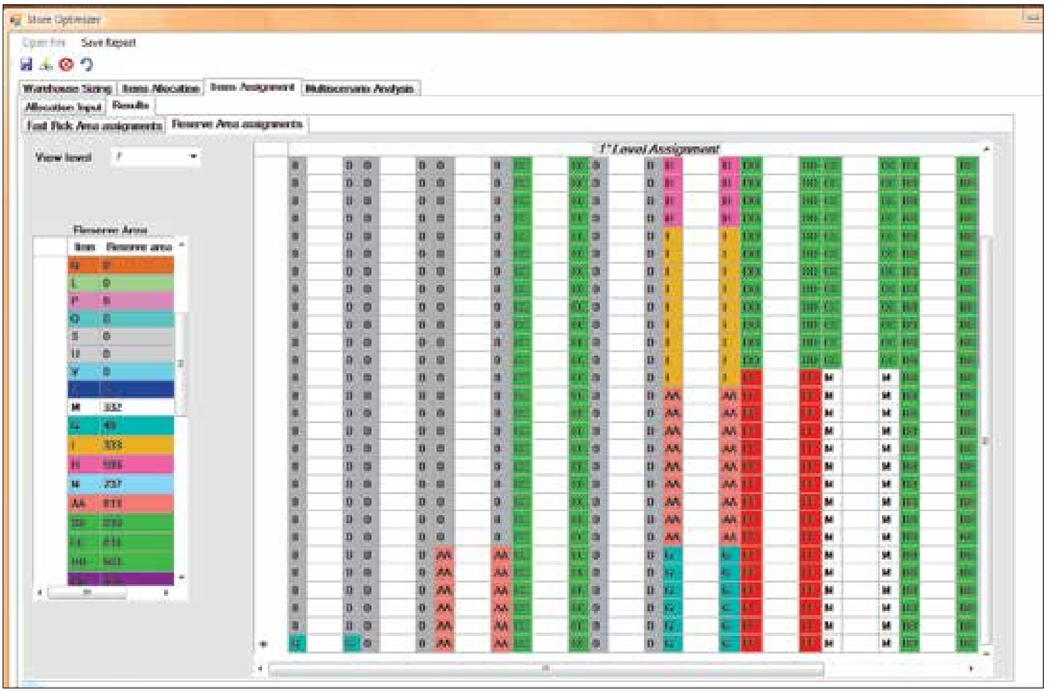

Fig. 12. Storage assignment results, reserve area.

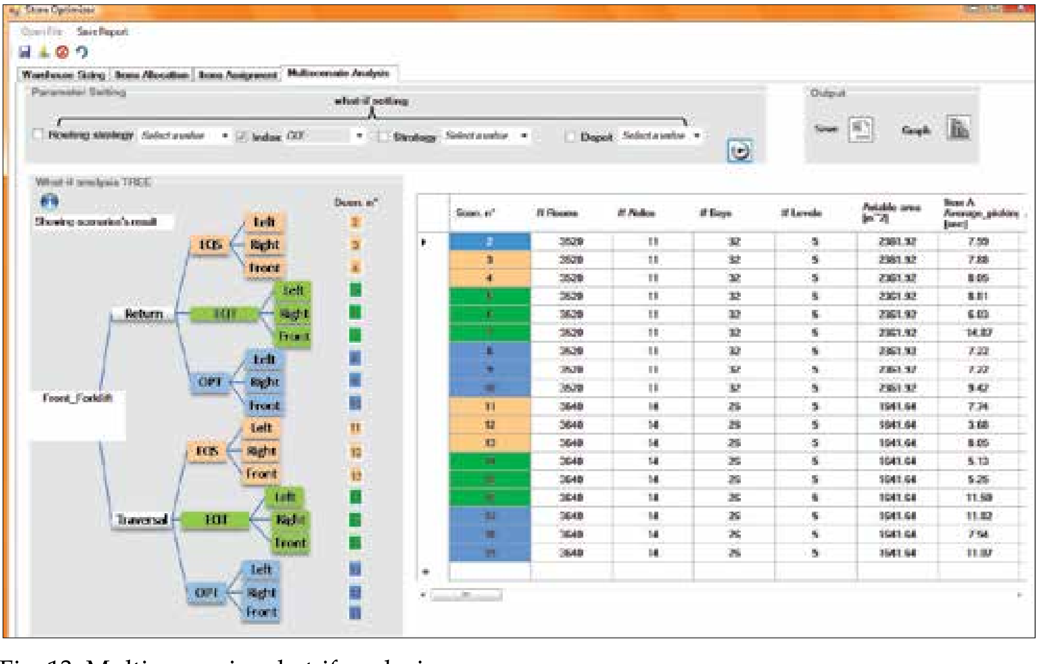

Fig. 13. Multi-scenario what-if analysis.

Figure 14 shows the form for the visual simulation of the picking orders in forward-reserve OPS. This simulation also quantifies the costs due to restocking. Similarly it is possible to simulate the behaviour of the system including *pallet loading* (L) activities, and/or in presence of AS/RS (adopting *Chebyshev* metric), and/or in presence of correlated storage assignment.

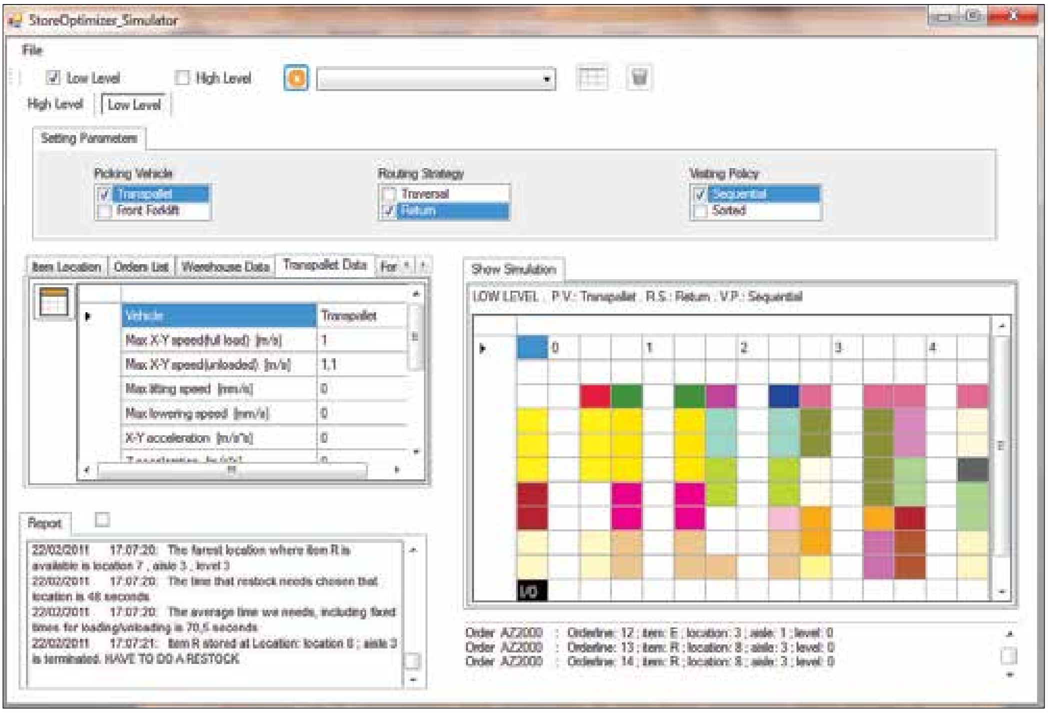

Fig. 14. Visual animation and simulation run.

4. Case study

The proposed DSS has been applied to a low level picker to part OPS for spare parts of heavy equipment and complex machinery in a popular manufacturing company operating worldwide. The total number of items stored and handled is 185,000 but this is continuously growing due to new business acquisitions and above all to engineering changes to address new requirements for pollution control and reduction.

The subject of the analysis is the picking activities concerning medium-sized parts weighing less than 50 pounds per piece. These parts are stored in light racks corresponding to about 89,000 square feet of stocking area. This area contains more than 3,000 different items.

The horizon time for the analysis embraces the order profile data during four historical months. The number of order picking lines is 37,000 that correspond to 6,760 different customer orders. The picking list presents an average of 86 orders fulfilled per day with the average depth varying around 6 items per order.

The result of the design of the order picking system is a 58,400 square foot picking area (350 feet x 170 feet). Table 2 demonstrates that OPT strategy significantly reduces the number of

restocks for the historical period of analysis in agreement with Bartholdi and Hackman (2010). The reduction is about 55% compared to EQS, and about of 62% compared to EQT, thus confirming the effectiveness of OPT strategy.
Table 3 reports the values of traveled distances and aisles crossed in retrieving operations i.e. excluding restocking for different assignment rules and allocation strategies. Table 3 demonstrates that COI and P assignment rules reduce picking activities and cost the most.
In particular, the best performance is obtained by adopting the COI assignment rule and the EQS allocation strategy, quite different from the OPT strategy which minimizes the number of restocks (see Table 2).

	EQS	EQT	OPT
Total Restocks	3,650	4,269	**1,635**
% Reduction	55.2%	61.7%	

Table 2. Restocks with different allocation strategies

	Allocation strategies					
	EQS		*EQT*		*OPT*	
Assignment rules	Traveled distance	Aisles crossed	Traveled distance	Aisles crossed	Traveled distance	Aisles crossed
COI	**6,314,459**	**33,579**	6,025,585	33,659	6,706,537	34,482
OC	6,536,697	33,922	8,047,296	36,210	7,241,533	35,424
P	6,379,887	33,713	7,254,318	35,270	6,869,774	34,655
T	8,015,507	35,766	8,155,378	36,191	8,717,042	36,497

Table 3. What-if analysis results. Traveled distance [feet] and aisle crossed [visits] during a picking period of 4 months

Figure shows where the most frequently visited skus are located in the fast pick area: the size of circles is proportional to the popularity value respectively according to the return and the traversal strategies.

5. Conclusions and further research

This chapter presents an original DSS for the design, management and optimization of a warehousing system. The large amount of decisions is usually faced separately as demonstrated by the literature proposing sub-optimal models and supporting decision methods. The proposed DSS is the result of the integration of different decisions, models and tools by the adoption of a systematic and interactive procedure. It supports the design of the system configuration, the allocation of skus, and their assignment to storage location, the vehicle routing and sequencing within the system. The evaluation of the performance is supported by the dynamic construction of vehicle routes to satisfy material handling needs collected in a period of time, named observation period.
Further research is expected on the following topics of interest:

- 3D computer aided design - CAD of the mechanical structure of the system as a result of the best system configuration

- System validation and analysis of vehicle congestions by the execution of a dynamic and visual evaluation of system performance. A similar analysis can be conducted by the adoption of visual interactive simulation commercial tool, e.g. AutoMod ™ simulation software. The development of ad hoc tools for a similar analysis conducted on warehousing systems is achieved.

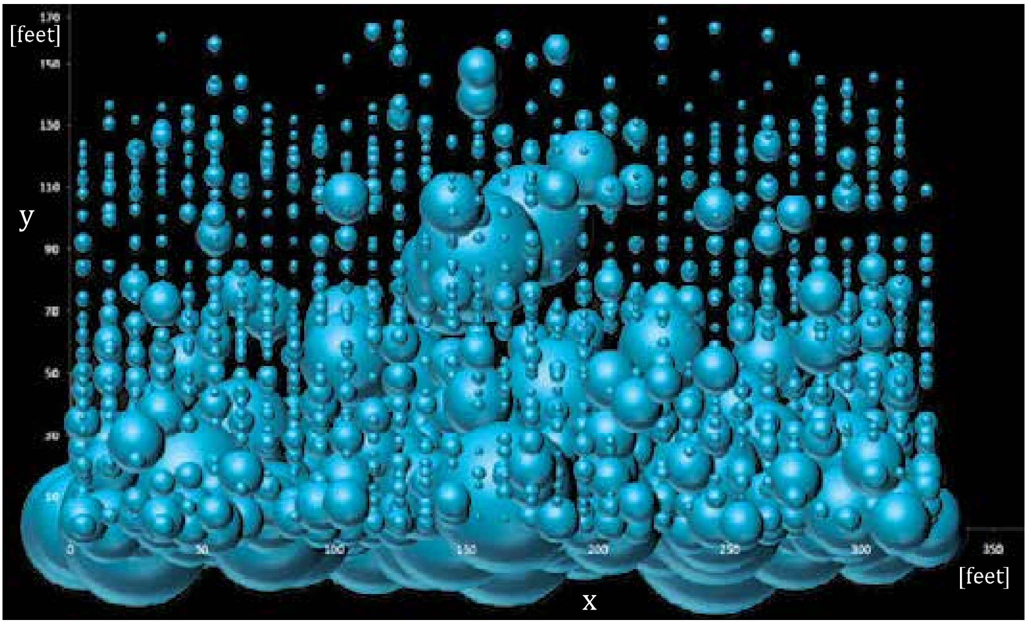

Fig. 15. Storage assignment in return strategy with I/O located at (x,y)=(170,0)

6. Acknowledgment

The authors would like to thank Prof. John J. Bartholdi of the Georgia Institute of Technology who gave us several useful suggestions to improve the research.

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23

Challenges in Climate-Driven Decision Support Systems in Forestry

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1. Introduction

The history of Decision Support Systems in forestry is quite long as well as the list of created systems and reviews summarizing their merits and flaws. It is generally recognized that a modern decision support system (DSS) should address simultaneously as many economical and ecological issues as possible without becoming overly complex and still remain understandable for users (Reynolds et al., 2008). The ongoing global change including the climate change sets new boundary conditions for decision makers in the forestry sector. The changing growth conditions (Albert & Schmidt, 2010) and expected increasing number of weather extremes like storms force forest owners to make decisions on how to replace the damaged stands and/or how to mitigate the damages. This decision making process requires adequate information on the future climate as well as on complex climate-forest interactions which could be provided by an appropriate climate-driven decision support tool. Both the damage factors and the forest management (e.g. harvesting) result in changes of the structure of forest stands. The structural changes result in immediate changes of albedo and roughness of land surface as well as of microclimatological conditions within the stand and on the soil surface. The consequences are manifold. The changed stand density and leaf area index trigger energy and water balance changes which in turn increase or decrease the vulnerability of the remaining stand to abiotic and biotic damage factors like droughts or insect attacks. A change of the microclimatic conditions might strengthen the forest against drought, but at the same time reduce its resistance to windthrow. The sign and extent of vulnerability changes depend on complex interactions of the effective climatic agents, above- and belowground forest structure, and soil. There are many DSS that are capable of assessing one or several risk factors; however there are few that are able to assess the additional increase or decrease of risks triggered by modification of forest structure resulting from previous damage or forest management activities. Disregarding these effects will inevitably lead user to either under- or overestimation of the potential damages. The question arises whether these additional risks are significant enough to be considered in a DSS.

In this chapter we present a new DSS developed according to the above mentioned requirements and capable to provide decision support taking into account economical and ecological considerations under the conditions of changing climate - the Decision Support

System – Forest and Climate Change. We then use the modules of that system to investigate the contribution of additional forest damage risks caused by structure changes into the general vulnerability of forest stand under changing climate.

2. DSS WuK

The Decision Support System – Forest and Climate Change (DSS-WuK) was developed to assist forest managers in Germany selecting an appropriate tree species under changing climate, considering future risks (Jansen et al., 2008, Thiele et al., 2009). It operates with a daily time step and combines traditional statistical approaches with process-based models.

2.1 Input

The system is driven by SRES-climate scenarios and hindcast data modelled by coupled ocean - atmospheric general circulation model ECHAM5-MPIOM developed by the Max-Planck-Institute for Meteorology (Roeckner et al. 2006). Additional input data are a digital elevation model (Jarvis et al., 2008) and its derivatives: aspect and slope, soil data from the national forest soil map (Wald-BÜK, Richter et al., 2007) at a resolution of 1:1 Mio. and atmospheric nitrogen deposition estimated using a modified version of the extrapolation model MAKEDEP (Alveteg et al., 1998, Ahrends et al., 2010a) with data from Gauger et al. (2008). The user of the DSS provides additional input on stand characteristics (tree species, age, yield class) on the forest of interest.

2.2 Model structure

Besides the climate-dependent forest growth the system estimates also biotic (insect attacks) as well as abiotic risks (wind damage and drought mortality). At present the system is able to evaluate the site sensitive growth and risks for the five most important tree species in German forestry (*Norway spruce*, *Scots pine*, *European beech*, *Sessile oak*, *Douglas fir*) of any age and state growing on any of the 124 soils typical for Germany. Thus, the economic outcome estimated by the DSS-WuK is based on complex interactions of many factors, e.g. climate, soils, tree species, stand characteristics and relief. The results are averaged and summed up over climatological periods of 30 years as defined by the World Meteorological Organisation. The period of 1971-2000 was chosen as the “present state” and replaced the old standard reference period of 1961-1990. To characterize the future development of forests the system provides information aggregated for the three periods: 2011-2040, 2041-2070 and 2071-2100.

The system is web-based and freely accessible. To tackle the usual requirements of transparency, focus on target audience, and usability we involved the potential end users into the development process during all phases. As a result the system took a two-stage form:

- The first stage presents pre-processed data covering entire Germany. The report includes growth and yield data, the various risks, and an economic evaluation. The user can choose a tree species, soil conditions at the spatial resolution of the employed regional climate model (e.g. 0.2°x0.2° of CLM, Datastream 3). The report of the first stage is, therefore, based on rather coarse input data and enables the user to decide whether a more detailed analysis (second stage) is needed. The obvious advantage of a system based on pre-processed data is the very short response time. The disadvantages, however, are the coarse spatial resolution and the fixed stand characteristics for the different tree species, since the first stage does not include stand growth. To avoid the underestimation of risks the stands are chosen roughly at their rotation age, as these stands have the highest vulnerability to wind and insect damage.

- If a user is interested in a detailed description of changes in growth and yield data or the various risks, she/he can obtain a more sophisticated analysis by starting the second stage of the system. In this part of the DSS-WuK the on-demand simulations for a user-defined stand with downscaled climate data (1 km resolution) are carried out. Because of the relatively long response time, the system sends a report as a pdf file via email. In the second stage, the stand does not have a static structure any more but grows climate-dependent using an individual-tree growth model. The stand characteristics are updated every 10 years and submitted to the risk modules which carry out their calculations with a new structure with a daily time step (Fig. 1). The effect of growing stands on the risks is evaluated, meaning the stand characteristics determine the effect of damage factors, i.e. extreme weather events. The risks in the system are defined as a percentage of area loss of a fully stocked stand.

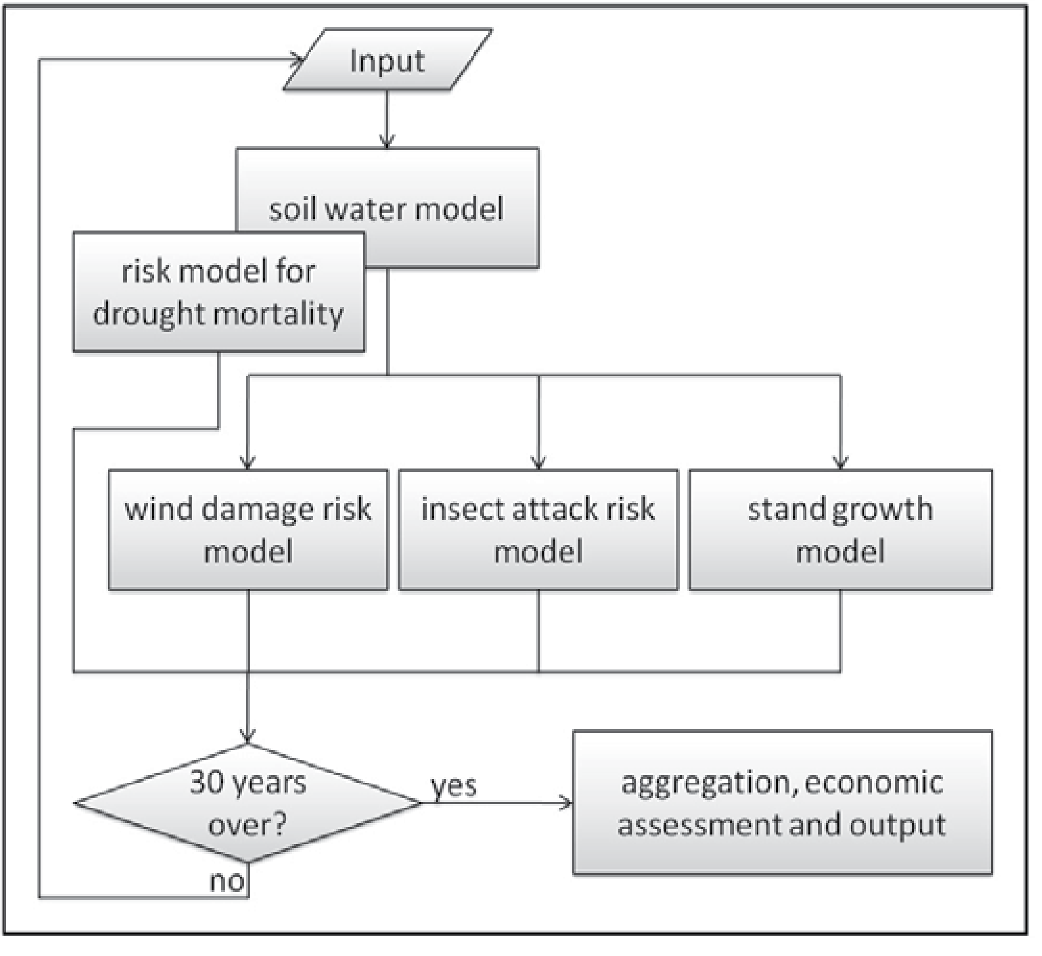


Fig. 1. A simplified flow chart of the core model process in DSS-WuK.

Both stages use the same core model (Fig. 1) and all calculations are carried out with daily resolution. All models get an update of their input data after each 10 year period. The risk model for drought mortality is coupled to the soil water model. The soil water itself, is influenced inter alia by the current stand characteristics. The soil water and climate conditions influence the output of the wind damage and insect attack risk models as well as the stand growth model. In the next iteration, the soil water model gets the stand characteristics actualized by the stand growth model. The results are finally aggregated to 30 year climatological periods mentioned above.
However, working at a level of forest stand the model is not able to consider the effect of the risks on stand growth, structure and microclimate, yet (Fig. 1). The estimated damage risks are not taken into account in calculations of stand growth and are executed (conceptually) in parallel. The system, thus, ignores the fact that a tree, which was, for example, thrown by wind, cannot be damaged by insects or drought later on. Overcoming this weakness is one of the challenges in forest decision support systems development. In the following, we will present the importance of this point by performing numerical experiments with a reduced-complexity, directly-interacting part of the simulation system DSS-WuK.

3. Setup of the experiment: risk assessment and damage factors interactions under current and future climate

The main purpose of the article is to demonstrate the interaction of factors influencing the forest vulnerability to abiotic risks and the feedback of forest damage to forest vulnerability under real and projected future climatic conditions. Results for a real forest stand under present climate are presented first, in order to show how the 30-years aggregated risk probabilities are formed. A detailed analysis of risk probabilities and interaction of different factors leading to or inhibiting the forest damage was performed on example of the real spruce stand research forest site "Otterbach", Solling, Central Germany. The meteorological data measured at the station of German Weather Service nearest to the forest stand with more than 30-years series of meteorological measurements were used as the basis for the investigation. The numerical experiments and analysis were carried out for generated idealized boreal forest stands under the conditions of climate scenarios C20 (reference) and SRES A1B.
To demonstrate the abilities of the DSS tool to evaluate the dynamics of abiotic risks and their variability for various climatic conditions the idealized forest stands growing in maritime and continental boreal zones of Finland and Russia, respectively, were generated. The hypothesis that similar forest damage can trigger different feedbacks in different climatic zones and under different development of climate conditions will be evaluated. The mechanism how the forest structure changes caused by forest damage or forest management activities are practically taken into account in coupled modules of DSS-WuK is described below.

3.1 Feedbacks of forest structure changes

Generally any changes in forest structure influence a forest ecosystem in many ways and perform a feedback to forest microclimate and stand vulnerability. In ecosystem and Soil-Vegetation-Atmosphere-Transfer process-based models the interaction of factors and the feedbacks can be summarized as shown in Fig. 2. The damage or thinning event reduces stand density and, thus, the Leaf Area Index (LAI) which is one of the most important parameters in forest ecosystem models. The decrease of leaf area leads immediately to the decreasing of rain and light interception and, therefore, to the enhanced supply of light and water under the forest canopy. This in turn results in increased evaporation from soil surface under the canopy, but decrease of transpiration due to reduced LAI. Thus, the interplay of all these factors may lead to the increase or decrease of soil moisture depending on particular site conditions: latitude, meteorological conditions, soil type, tree species, initial LAI, extent of damage/management etc. These changed conditions may increase or decrease forest vulnerability and the probability of various consequent damages. If, for example, the resulting effect of windthrow would be an increase of soil moisture in a stand it would, on the one hand lead to the stand destabilisation against next storm, but at the same time – reduce the probability of drought stress (Ahrends et al., 2009).

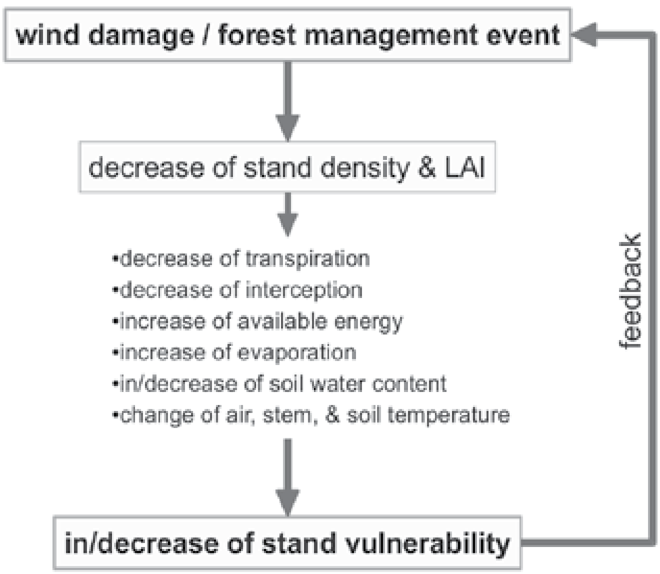


Fig. 2. Impacts of changing forest structure on stand vulnerability resulting from triggered interaction of ecosystem processes.

Therefore, to quantify the contribution of additional damage caused by forest structure changes the experiments with each of the chosen forest sites were carried out twice as shown in Fig. 3:

- with static structure, i.e. the climate caused structure damages were registered and summed up for the 30-years climatic periods, but the actual structure of modelled stands remained unchanged.
- with dynamic structure, i.e. the part of stand was removed according to the damage degree and the calculations proceed with the changed structure until the next damage event and so on for the rest of particular 30-years period.

3.2 Site description, tree species, and soil conditions

3.2.1 Otterbach, Solling

A 85-year-old pure spruce stand in Otterbach, located in the central part of Germany about 60 km North-West of Göttingen in the Solling highland, at 51.77° N and 09.45° E and about

300 m above sea level, was selected to study the possible effects of windthrow events on forest vulnerability to following windthrow damage risk – windthrow feedback. The characteristics of the investigated spruce stand are given in Table 1.

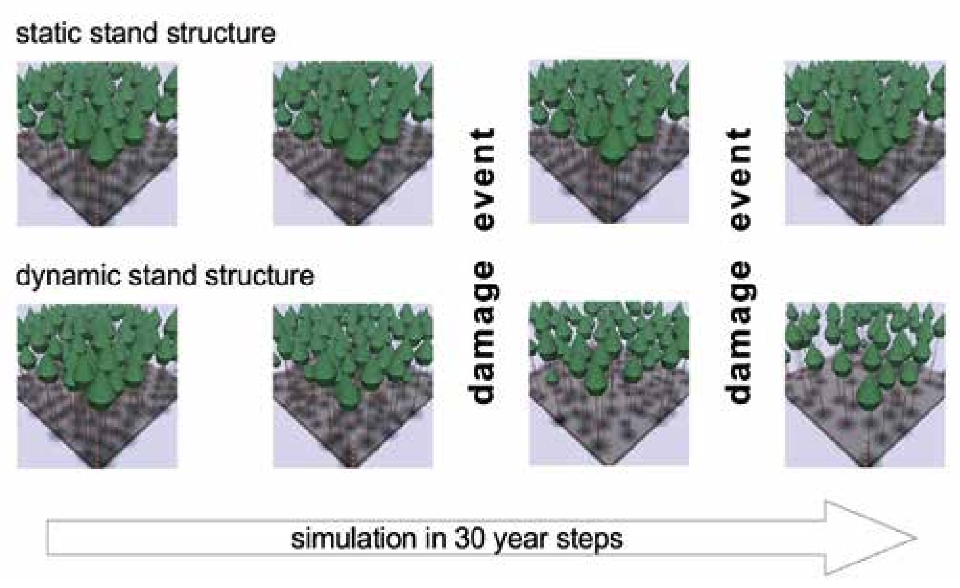


Fig. 3. The scheme of calculations with damage-independent structure (upper panel) and with forest structure updated (LAI and stand density reduced) after each damage event during 30-years period (lower panel).

Parameter	Unit	Value	Source
age	years	85	Olchev et al., 2009
tree density	trees ha^{-1}	350	Olchev et al., 2009
average tree height	m	34.0	Olchev et al., 2009
diameter at breast height, dbh	cm	36.0	Olchev et al., 2009
max. leaf conductance	cm s^{-1}	0.53	Federer et al., 2003
max. leaf area index	$m^2\ m^{-2}$	4.6	Olchev et al., 2009
relative winter LAI	-	0.8	Hammel & Kennel, 2001
Fine root length	m m^{-2}	3100	Federer et al., 2003
Critical leaf water potential	MPa	-2.0	Czajkowski et al., 2009
Albedo	-	0.14	Federer et al., 2003
Albedo with snow	-	0.14	Federer et al., 2003

Table 1. Structural characteristics and model parameters of the forest in Otterbach (central Germany).

To describe the soil water budget a characteristic soil profile for this stand was selected (Fröhlich, 2009). According to FAO (1990) the soil type is a Dystric Cambisol derived from Triassic sandstone covered by loess. The soil hydraulic parameters are given in Tab. 2. According to Fröhlich (2009) free drainage is accepted at the lower boundary condition at 2 m depth.

Depth	Stone	Ψ_u	θ_u	θ_s	b	K_u	f_i
	[%]	kPa	-	-	-	mm day^{-1}	-
+5-0 (FF)	0	-6.3	0.384	0.848	5.23	2.3	0.92
0-5	2	-6.3	0.615	0.621	6.4	4.98	0.92
5-15	3	-6.3	0.615	0.621	6.4	4.98	0.92
15-20	3	-6.3	0.508	0.517	6.12	4.98	0.92
20-40	3	-6.3	0.508	0.517	6.12	4.4	0.92
40-60	30	-6.3	0.472	0.482	8.7	4.4	0.92
60-70	30	-6.3	0.472	0.482	8.7	1.76	0.92
70-95	30	-6.3	0.371	0.377	26.5	1.76	0.97
95-200	30	-6.3	0.371	0.377	26.5	1.28	0.97

Table 2. Soil hydraulic at saturation (subscript 's') and at the upper limit of available water (subscript 'u'). Note that ψ is matrix potential, K is hydraulic conductivity, θ is volumetric water fraction, b is the pore-size distribution parameter, f_i is the Clapp-Hornberger inflection point, K_u is the hydraulic conductivity at the upper limit of available water and FF is the forest floor. The stone content was taken from Feisthauer (2010).

The climate conditions at the research site "Otterbach" in Solling was characterized by means of long-term measurements at the meteorological station "Silberborn" (51.76°N, 9.56°E, 440 m a.s.l.) of German weather Service located near "Otterbach" site. The measurements time series cover the period from 1976 to 2008. To account for 140 m altitude difference between "Otterbach" site and "Silberborn" station the station's temperature was corrected using constant gradient of 0.0065°C m^{-1}.

3.2.2 Finland and Russia

The changes of forest risks in 21st century in dependence on changing climate were projected for two idealized forest stands located in two variations of boreal climate zone: a maritime one (Finland) and a continental one (Central Russia). The location for Finnish site was approximated at the centre of ECHAM5 grid cell (62.48°N, 28.125°E) and the location of Russian site – at 53.16°N, 91.875°E. To separate the effects of climate and damage feedbacks from the effects of other factors – soils, topography, vegetation composition etc. both Finnish and Russian stands were modelled identically: monocultural, mean tree height of 16 m, mean diameter at breast height (dbh) of 20 cm, and a stand density of 860 trees ha^{-1}. The Podzol soil type was assumed as typical for boreal zone according to FAO (2003): Map of World Soil Resources. The soil characteristics are given in FAO (2003) and therefore do not need to be repeated.

3.3 Modelling methods

The climate, wind and drought damage modules of DSS-WuK were used to investigate the contribution of additional structure-caused risks to the vulnerability of forest stands. The forest structure dynamics leads to both short- (days, months) and long-term (years, climatic periods) changes. To investigate the dependence of forest risk factors and of additional damage on short- and long-term climate variations we used the SRES climate scenario A1B (IPCC, 2000) modelled by a coupled ECHAM5-MPIOM general circulation model for AR4 of IPCC as climatological input.

3.3.1 Leaf area index

For modelling the leaf area index dynamics the LAI model by Ahrends et al. (2010b), applied previously at the Solling site (Sogachev et al., 2010, Panferov et al., 2009, 2010, Ahrends et al., 2009) is used. The model was calibrated to the maximum LAI value given by Olchev et al. (2009). After a windthrow event the damaged trees are 'removed' from the stand; accordingly the stand density and leaf area index, decrease. The calculations with other modules continued from the time point of damage with the new values of structural characteristics. The changes in structure result in a modified stand's water balance, which might enhance or inhibit the next windthrow event, thus creating positive or negative feedback.

3.3.2 Soil water

To simulate the water balance the 1D-SVAT model BROOK90 (version 4.4e) is used (Federer, 1995; Federer et al., 2003). It is a detailed, process-oriented model which can be used to investigate the potential effects of changes in leaf area index. For each soil horizon the parameters of the water retention curve and the hydraulic conductivity Brooks & Corey (1966) function were fitted through the van Genuchten parameter (van Genuchten, 1980) given by Fröhlich (2009) for Otterbach site and by Hammel & Kennel (2001) for the forest floor. The parameter of the water retention curve for Finland and Russia were deduced from soil texture classes (Clapp & Hornberger, 1978). The architecture of root systems is mainly influenced by the parent material, soil type, bulk density, chemical soil conditions, and depth of ground water, tree species and age. However, in each particular situation the information on rooting depth and the root distribution within the soil profile is a main source of uncertainty. For estimation of the effective rooting depth the rules from Czajkowski et al. (2009) are applied. The relative root density is modelled as a function of soil depth (Ahrends et al., 2010b).

3.3.3 Wind load

The model of atmospheric boundary-layer SCADIS (SCAlar, DIStribution, Sogachev et al., 2002) was used to calculate the wind load on trees. The model implements a two-equation closure approach. The model constants were modified by Sogachev and Panferov (2006) to enhance the applicability of approach for description of air flow over heterogeneous landscape coved by forest vegetation. The modification was shown to perform well for different vegetation canopies. In present study the model was driven by measured meteorological parameters as well as by climate model data. Other input parameters are forest structure: height, stand density, Leaf Area Density and aerodynamic drag coefficient Cd. Model equations and details about numerical schemes and boundary conditions can be found in Sogachev et al. (2002). It should be noted however, that the model is capable to describes separately the mean and gust loads on trees which allows more exact evaluation of possible wind damage cause and of high risk areas within the stand (Panferov and Sogachev, 2008).

The estimation of critical loads leading to overturning or breakage of trees is described in details in Panferov et al. (2009, 2010). Here we would like to show the modification of critical loads caused by changes soil moisture, LAI and rooting depth, which in turn were triggered by changes in forest structure.

It was assumed that the critical values of wind load derived from tree pulling experiments were obtained under some "normal" conditions characterising certain soil moisture and temperature, rooting depth and applied on a standard leaf area typical for a given tree species. The variations of these characteristics increase or decrease critical wind load threshold.

Influence of rooting depth (RD) is taken into account as the linear factor describing the ratio of actual tree anchorage (RD_{act}) to "reference" value (RD_{ref}) for given tree species, age and state $f_{RD}= RD_{act}/(RD_{ref})$. As an indicator of soil moisture provided by soil water module the Relative Extractable Water (REW) (Granier et al., 2007) was adapted. The effect of soil moisture on windthrow is expressed as a linear function of REW deviations relatively to its reference value: REW_{ref} = 0.6 REWt,s, for the certain combination of tree species (subscript "t") and soil type (subscript "s"). The critical wind load (CWL) for actual soil moisture and forest structure is, therefore, derived from its reference value: $CWL_{act}= CWL_{ref}/REW_{act}* f_{RD}$. The system distinguishes between wet, dry (REW_{ref} < 0.6 REWt,s) and frozen (Tsoil < 0°C) conditions. Under dry and frozen conditions the probability of overturning is assumed zero and only a damage caused by stem breakage is possible.

Thus, when the actual wind load calculated from climate and wind modules exceeds the CWL (either for overturning or for stem breakage) modified by outcome of soil and LAI modules, the next wind damage event occurs. The stand density and LAI are reduced, which in turn leads to changes in stand microclimate, soil water regime and tree anchorage as described above, and consequently to further modification of CWL. The new CWL can be either higher or lower then the one before the damage event, so the stand vulnerability is either increased or decreased. Simultaneously the risk of drought stress is changed as well.

4. Results

4.1 Reference period, Otterbach

4.1.1 Climate and water budget components

As mentioned above the system was run at first for the real spruce stand at research site "Otterbach" under real climate measured during the period from 1976 to 2008.

Fig. 4 demonstrates the time courses of air temperature and maximal wind speed at the research site. A slight trend towards higher temperatures can be observed in the 32-year series. The warming trend generally results in a destabilization of forest stands in terms of wind damage as the number of days with frozen soil decreases in winter - e.g. the anchorage is reduced during the period of winter storms (Peltola et al., 1999). The wind curve shows several years with very strong storm events: 1983, 1990, 1993, and 1994. The Fig. 5 shows the course of precipitation sums and of the major water balance components calculated by the soil water module of the system. Except for 1994 the storm years were not accompanied by unusually high annual precipitation sums.

4.1.2 Windthrow

The calculations of wind damage with unchanged structure, i.e. without feedback clearly shows that despite the importance of soil, relief and vegetation factors the driving force defining the temporal pattern of damage is the wind (Fig. 6). The extensive windthrow events coincide with the strong windstorm years listed above, with the largest event in 1993 – the year with the strongest storm. The effect of other factors, however, is clearly visible in the non-linear relationship between storm strength and damage amount. For instance the damage in 1990 is lower than in 1994 and 1995, although the storm was stronger. The possible reason could be deduced from Fig. 5 where it is shown that 1990 was also drier than both 1994 and 1995. The drier soil provided better anchorage for trees.

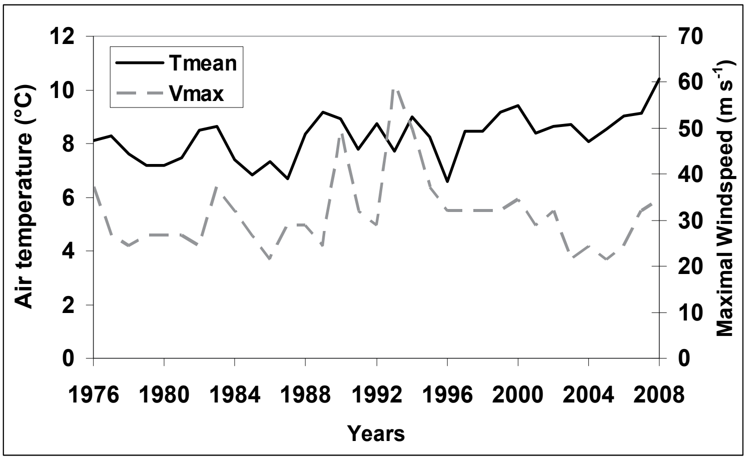


Fig. 4. Mean annual air temperature and maximal windspeed measured at the meteorological station of German Weather Service near research station "Otterbach" for the simulation period from 1976 to 2007.

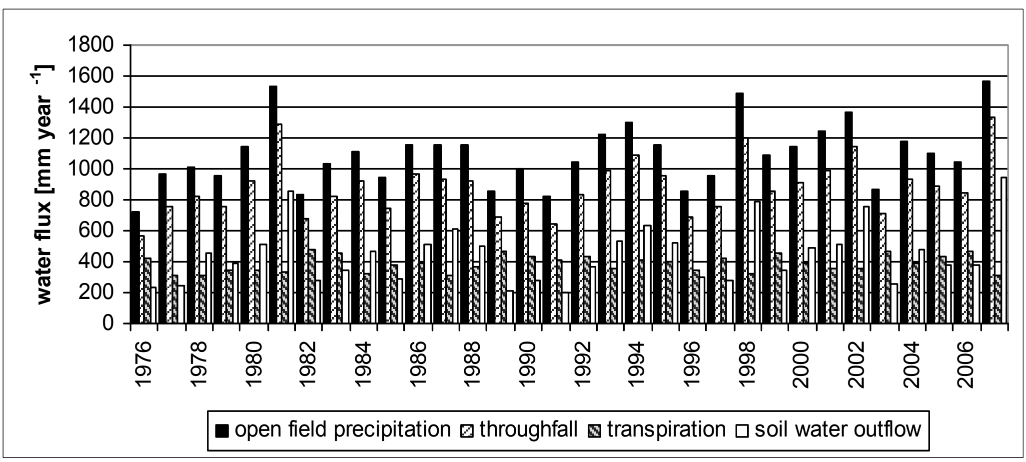
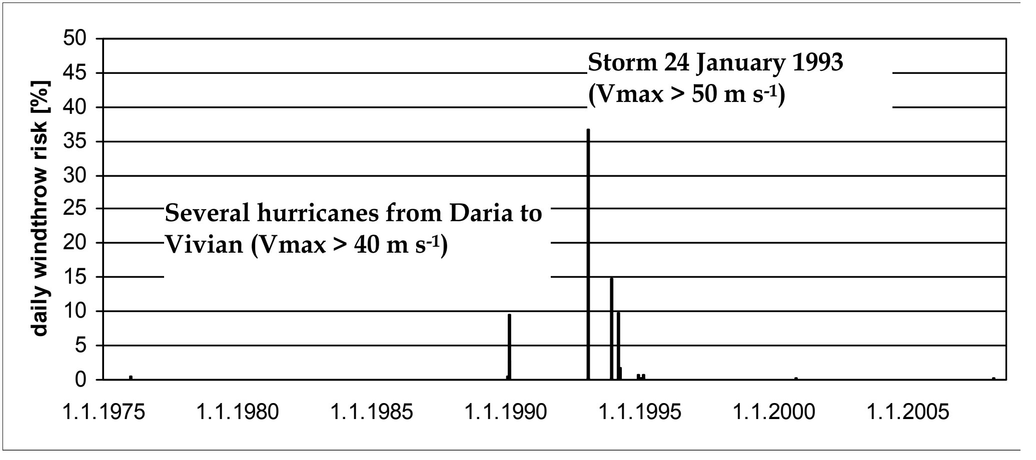


Fig. 5. The main water budget components for the simulation period from 1976 to 2007.

This effect could be observed even better when the feedbacks of the windthrow damage are taken into account (Fig. 6, lower panel). The reduction of stand density and LAI resulting from first strong storm in 1990 leads to considerable destabilization of stand and increase of its vulnerability, so that the strongest storm in 1993 produced even higher damage. This, in its turn results in more than 5% damage increase during following storms in 1994-1995. Thus, the decreasing resilience of stands and decreasing of CWL produce a cascade of wind damage events at the end of the period. Though each event in itself is not very extensive, the constantly decreasing CWL sum up the small damages to the significant annual sums. The constant small windthrows are also observed in reality at the Otterbach research site. This cascade is not observed in modeling results when the feedbacks are not considered (Fig. 6, upper panel).



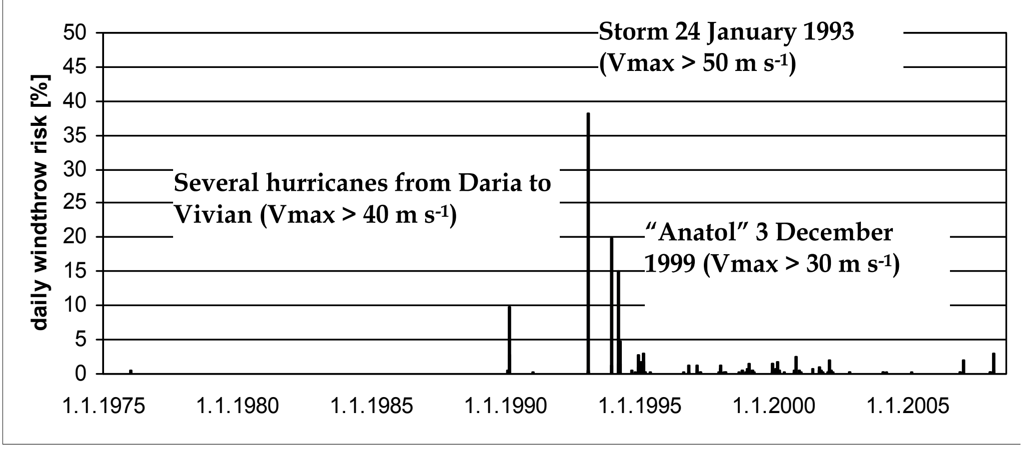


Fig. 6. Daily windthrow risk without (upper panel) and with feedback (lower panel) for the simulation period.

4.1.3 Interaction of risk factors

To analyse the causes and consequences of these additional risks caused by damaged forest structure, the strong storm and forest damage event of 25.01.1993 is considered here in details (Fig. 7).

The upper panel shows the stand LAI reduced after storm from 3.7 to 2.4 $m^2\ m^{-2}$. The reduced LAI resulted in slightly decreased transpiration during following summer comparing to the simulation without feedback (Fig. 7, middle panel). Another effect of decreased LAI is the higher soil water content in "feedback simulation" which is the combined result of lower transpiration and higher throughfall (lower interception due to fewer trees).

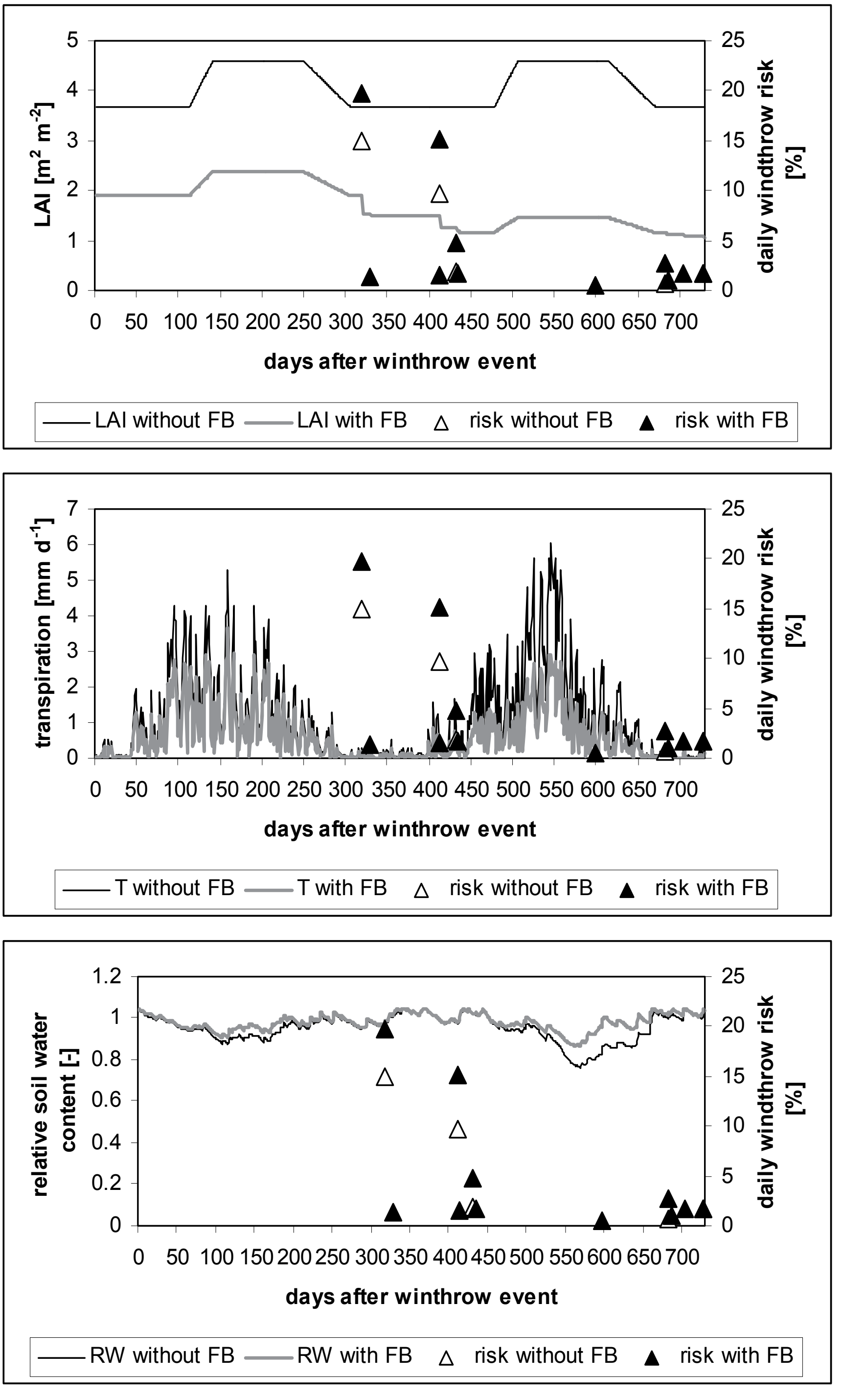


Fig. 7. Effect of static and dynamic (with feedback) forest structure on water budget components after strong wind storm at 25.01.1993.

However, towards the next winter (1994) the temperature limited transpiration and increased precipitation result in highest soil water content both for feedback (reduced LAI) and without feedback (normal LAI) calculations. Therefore, the 5% higher damage produced by the next storm (1994) in calculation with feedback is caused only to very small degree by reduced anchorage in soil, but mainly due to destabilisation of forest resulted from reduced stand density. Another consequence of this destabilisation is the occurrence of several small windthrows in the feedback calculations, which are definitely the product of reduced CWL and therefore not observed in calculation without feedback. The latter one registers only the damage of two main storms in 1994.

The strong events in 1994 caused further decrease of LAI in the feedback version which lead to even stronger difference in transpiration in summer 1995 (Fig. 7, middle panel, days 450-650) and, therefore, significantly higher soil moisture (Fig. 7, lower panel, days 450-650). Combined with reduced stand density the total effect was such a strong reduction of CWL that it led to the untypical windthrow event in late summer around the day 600 from initial windthrow event in 1993. The damage risks from feedback are twice higher then without feed under the presented soil and climate conditions.

4.2 Climate projection SRES A1B and damage risks in Finland and Russia

4.2.1 Projected climate

The experiment was limited to the two variations of boreal climate: the more continental one in Russia and the maritime one in southern Finland. The Norway spruce and Scots pine stands were chosen as typical for boreal zone. According to the same criteria a podzol was taken as soil type for the experiment. The calculations were carried out for a period of 120 years (1981 – 2100) with daily time step.

The analysis of the projected climate data shows a considerable increase of both summer and winter temperatures for boreal climate zone (Fig. 8). The precipitation in Finland increases noticeably during the 21st century, while the increase is due to higher summer and winter precipitation. In Russia the projected increase of precipitation is very weak, whereas only the winter precipitation shows the consistent rise (Fig. 9).

Both in Finland and in Russia the maximal windspeed shows similar pattern during 21st century: strong increase from present conditions to the period 2011-2040 and almost constant values (or even slight decrease) towards 2100 (Fig. 10). For both sites the winter winds are stronger then in summer, while in Finland the difference is more pronounced. The period 2041-2070 has the highest number of strong storms (not shown here) and period 2071-2100 with second highest number.

4.2.2 Wind damage and feedbacks

All trends of climate variables projected by ECHAM5-MPIOM as SRES A1B scenario indicate an increase of vulnerability of maritime and continental boreal forests. The increased temperature leads to reduced number of days with frozen soil, decreasing the anchorage of trees during autumn and spring storms. Higher precipitation result in higher soil moisture also leading to reduced tree anchorage. Stronger winds and higher number of storms on the other hand increase the wind load on forest. However, it is expected that pine trees will be less vulnerable to the wind damage than spruce.

If simulations are performed with the given setup the system indeed projects higher windthrow risks for boreal forests during 21st century. Figure 11 shows the windthrow risks in 21st century for Finland and Russia aggregated over 30-year periods. The upper panel demonstrates the nonlinearity of damage dependence on combination of influencing climatic factors. The projected damage risks are generally higher for Finland due to higher windspeed and precipitation. The differences in temporal patterns of Russian and Finnish

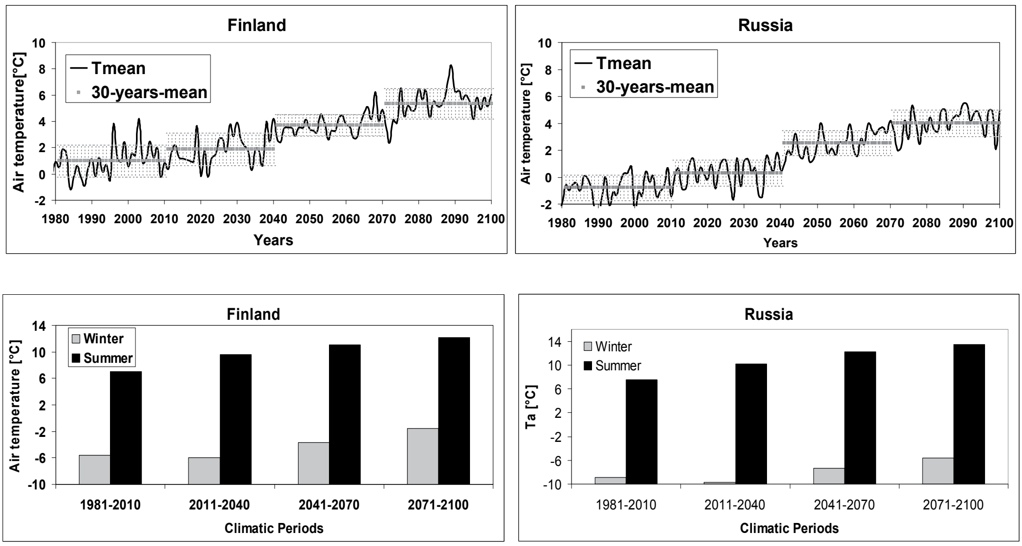


Fig. 8. Changes of mean annual air temperature (upper panels) and mean seasonal temperatures for 30-years climatic periods (lower panel) in 21st century in Russia and Finland according to SRES A1B (ECHAM5-MPIOM).

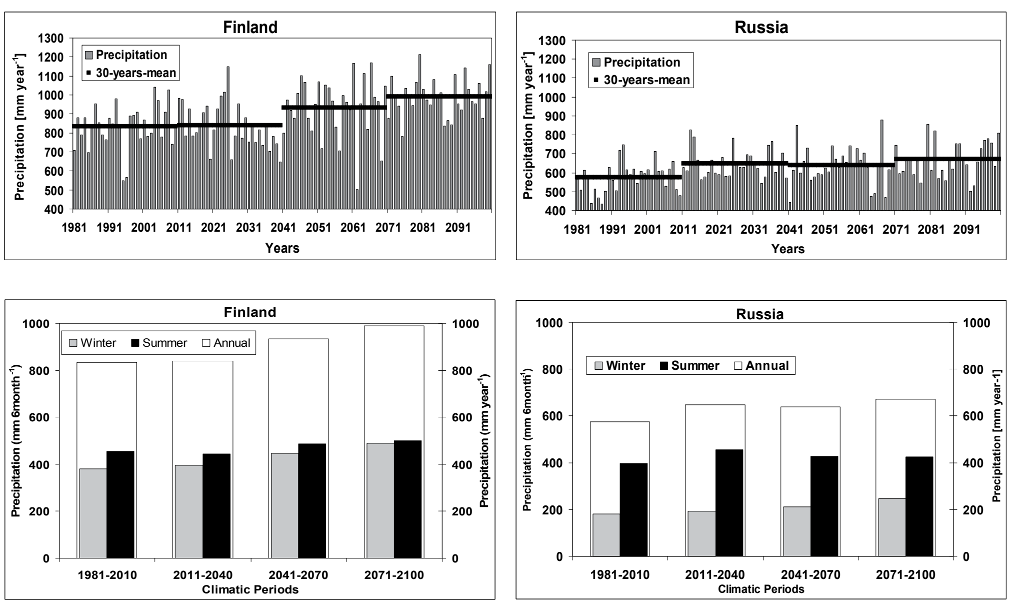
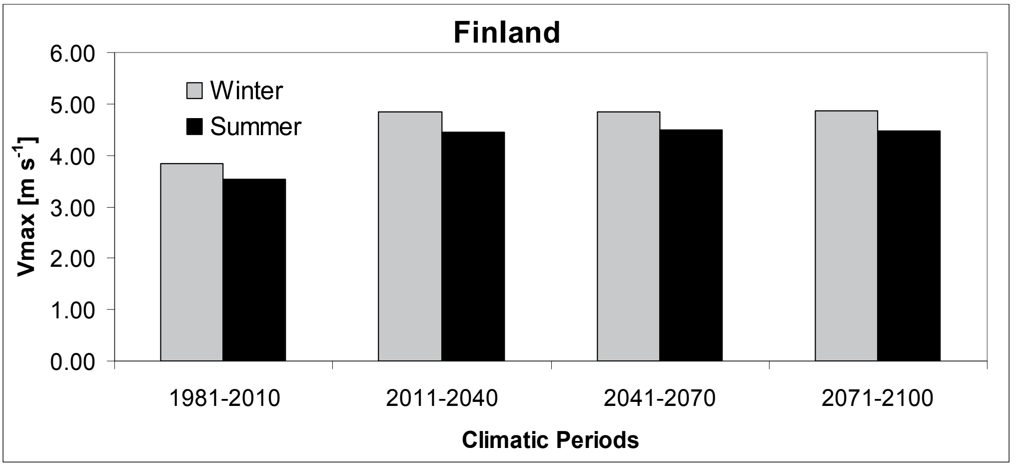


Fig. 9. Changes of annual precipitation sum (upper panels) and mean seasonal precipitation sums for 30-years climatic periods (lower panel) in 21st century in Russia and Finland according to SRES A1B (ECHAM5-MPIOM).



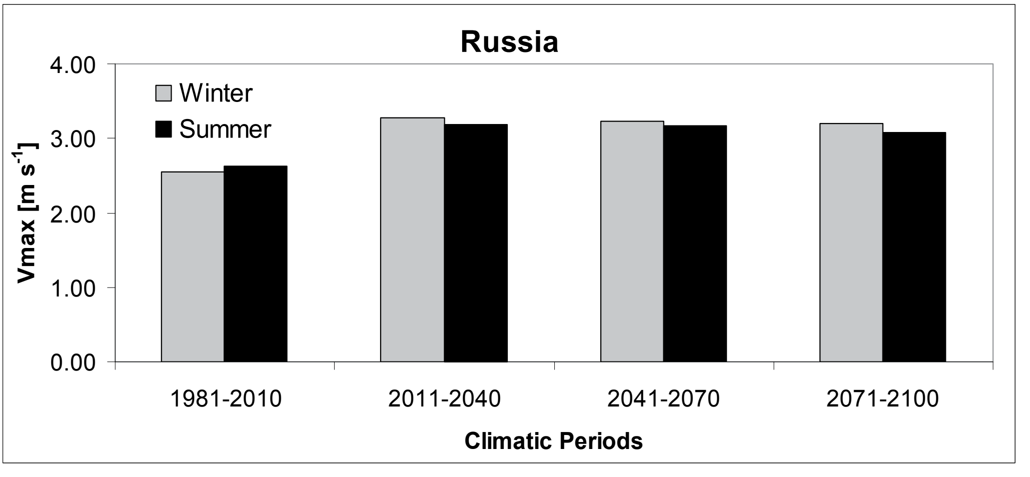


Fig. 10. Changes of seasonal-averaged daily maximal windspeed (Vmax) for 30-years climatic periods (lower panel) in 21st century in Russia and Finland according to SRES A1B.

sites are not easily explained. In Russia the maximum of windthrow falls on the period of 2011-2040 where the maximal increase of mean windspeed is observed. The maximal increase of windspeed in Finland is also observed in 2011-2040, however the maximal damage risk is projected for 2041-2070. The main reason is the higher number of extreme storms events during 2041-2070 though the mean Vmax is almost as high as in 2011-2040. Additionally the joint effect of increased precipitation and temperature which are considerably higher than in 2011-2040 contributes to the difference. The following decrease of wind damage toward 2100 in Finland is caused by reduction of windstorms comparing to previous period. Although the storms number during the period 2071-2100 is similar to the reference period the slightly higher mean Vmax and considerably higher temperature and precipitation result in twice higher damage during 2071-2100 comparing to P0. The analysed dynamics of wind damage demonstrates that to capture such joint effects of several climatic parameters the system has to use coupled process-based approach.

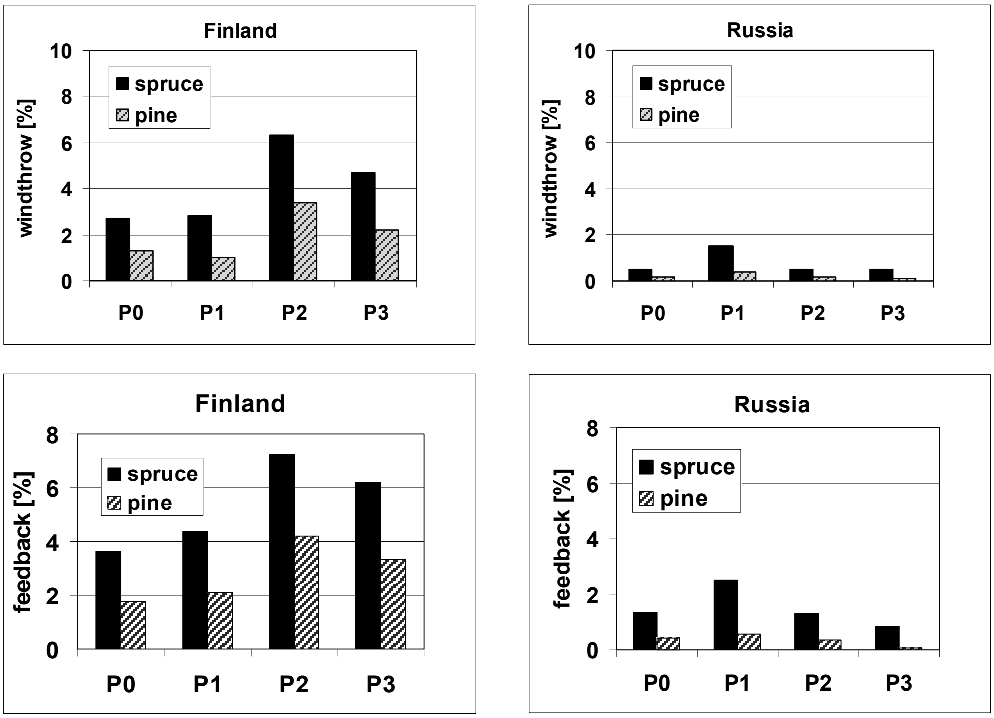


Fig. 11. Changes of windthrow risks and feedback contribution to wind damage aggregated for 30-years climatic periods (upper panel) in 21st century in Russia and Finland according to SRES A1B. Periods P0: 1981-2010, P1: 2011-2040, P2: 2041-2070, P3: 2071-2100.

The lower panel of figure 10 shows the contribution of feedbacks to initial damage, i.e. the additional damage produced in model when the vegetation damaged by initial windthrow event is "removed" from the modelled stand as described in previous sections. Comparing the upper and lower panels as well as Finnish site to the Russian one, one can see again the non-linear dependences of damage risks on combinations of effecting factors. Generally the magnitude of feedbacks is proportional to the magnitude of initial damage. Therefore the feedback contribution in Finland is higher than in Russia. However, the complexity of influencing agents might produce a complex response which would be higher or lower than considering only one factor. For instance the damages in P0: 1981-2010, P1: 2011-2040 (Finland) are almost of the same magnitude – for pine even lower in 2011-2040 - however due to the higher windspeed in 2011-2040 the same or lower initial damage produces more extensive consequences. The same is true for Russian site when compare the periods P2: 2041-2070 and P3: 2071-2100. Generally the contribution of feedbacks to initial damage in modelled stands is almost negligible comparing to real conditions presented in section 4.1. The main reason is the coarse resolution of Global Circulation Model (ECHAM5-MPIOM) which is not really suitable for evaluation of wind damage event at stand level. Due to wide area averaging it underestimates considerably the small-scale variations of windspeed caused by local surface heterogeneities and therefore – wind gustiness and Vmax. In present study it was implemented for purely demonstration purposes. For any practical use of DSS with climate projections, the downscaled scenarios should be implemented.

5. Conclusions

The additional damage caused by forest structural changes resulting from previous damage or forest management activities might contribute considerably to the projected forest risks and it is advisable to take it into account in a decision support process. It is emphasized that the degree of contribution as well as a sign of feedback in each particular case will strongly depend on the local or regional combination of climatic and soil conditions with tree species, age and structure. The DSS-user should be aware that one kind of damage might strengthen (windthrow -> windthrow) or weaken (windthrow -> drought) the contribution of other damage factors. Although, the projected total amount of damaged forest might even remain the same the losses would be redistributed between damage factors, which are the extremely important information for the forest owner looking for a decision support. Therefore, the adequate evaluation of projected risks in forestry requires the coupled modelling capable to consider the combined effect of risk factors.

The DSS-user should be also aware that although the system is quite advanced it has certain limitations. We would like to list the main limitations here. In present form is applicable in Germany only as the empirical functions are derived there. The systems works with monospecies stands only. The user should also take into account that the climate projections are not forecasts and the skill of estimation of future risks is limited by uncertainties of climate scenarios.

6. Acknowledgment

The development of DSS-WuK was supported by the German Ministry for Education and Research (Program *klimazwei)* we gratefully acknowledge this support.

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