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Supplier Selection in E-Procurement Using Fuzzy Analytic Hierarchy Process

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Supplier Selection in E-Procurement Using Fuzzy Analytic Hierarchy Process

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Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
In partial fulfillment of the requirements for the degree of

Master of Science
in
Systems Science

Department of Systems Science
School of Management
University of Ottawa

Thesis Supervisor: Professor Morad Benyoucef, PhD

Your file Votre référence
ISBN: 0-494-11229-8
Our file Notre référence
ISBN: 0-494-11229-8

Table of Contents

LIST OF FIGURES IV
LIST OF TABLES VI
ABSTRACT VII
ACKNOWLEDGMENTS VIII
CHAPTER 1: INTRODUCTION 1
1.1 Motivation of the Research 2
1.2 Research Objectives 3
1.3 Thesis Organization 3
CHAPTER 2: E-PROCUREMENT 5
2.1 Background 5
2.1.1 E-Procurement Framework 5
2.1.2 E-Procurement Application Types 6
2.1.2.1 E-Procurement Software 6
2.1.2.2 Internet Market Exchanges 8
2.1.2.3 Internet Purchasing Consortia 8
2.1.2.4 Internet Business-to-Business (B2B) Auctions 9
2.1.2.5 Conclusion 10
2.1.3 Technology Support for E-procurement 10
2.1.3.1 Electronic Data Interchange 10
2.1.3.2 Internet Technologies and XML 11
2.2 Standardization 12
2.2.1 Quality Related Standardization 14
2.2.1.1 ISO 9000 Series and ISO 14000 Certifications 14
2.2.2 Ethical Standardization 14
2.2.2.1 EG9001 - Ethical Governance 9001 14
2.2.2.2 SA8000 Social Accountability 8000 14
2.2.2.3 Other Standardization Efforts 14
2.2.3 Integration Related Standardization Issues 15
2.2.4 Data Security Related Standardization Issues 15
2.2.4.1 Data Handling Protocol 3003(DHP3003) 15

2.2.4.2 SSL (Secure Socket Layers) and Other Efforts 15

CHAPTER 3: REVİEW AND CLASSİFİCATİON OF THE LİTERATURE 16

3.1 Understanding Buyer-Supplier Relationships 16
3.1.1 Value Creation in Buyer–Supplier Relationships (Walter et al., 2001) 16
3.1.2 Making the Most out of Supplier Relationships (Gadde and Snehota, 2000) 16
3.1.3 Organizing and Managing Supplier Relationships in Information Technology Procurement (Heckman, 1999) 18
3.1.4 Conclusion 18
3.2 Strategic Sourcing 19
3.2.1 A Methodology for Strategic Sourcing (Talluri S., Narasimhan R., 2002) 19
3.2.2 Continuous Strategic Sourcing (Freytag P.V., Kirk L., 2003) 20
3.2.3 Conclusion 21
3.3 Migrating to E-Procurement 21
3.3.1 Moving Procurement Systems to the Internet: The Adoption and Use of e-Procurement Technology Models (Davila et al., 2003) 21
3.3.2 Migrating Procurement onto the Internet (Yen et al., 2002) 23
3.3.3 B2B Procurement and Marketplace Transformation (Segev and Gebauer, 2001) 25
3.3.4 Characterization of the Security Implications of Alternative E-procurement Topologies (Ponce and Duran, 2003) 26
3.3.5 Conclusion 26
3.4 Fuzzy Concepts in Buyer-Supplier Relationships 26
3.4.1 Conclusion 28
3.5 Supplier Selection 28
3.5.1 Classification Efforts on Supplier Selection Literature 28
3.5.1.1 (Weber et al., 1991)'s Survey on Supplier Selection Methods (1966 – 1990) 28
3.5.1.2 (Boer et al., 2001)'s Classification of Supplier Selection Methods (1967- 2000) 29
3.5.2 Criteria Issues 31
3.5.3 Model Issues 32
3.5.3.1 Case Study Based Approaches 32
3.5.3.2 E-Tool Based Approaches 37
3.5.3 Conclusion 39

CHAPTER 4: METHODOLOGY 40
4.1 AHP Modeling 40
4.2 Fuzzy Sets Theory 43
4.2.1 Fuzzy Numbers and Arithmetic 43
4.3 Integrated Fuzzy AHP Modeling 45
4.4 Linear Programming Method for Fuzzy AHP 46
CHAPTER 5: DESIGN AND IMPLEMENTATION 50
5.1 Web-Based Supplier Selection System 50
CHAPTER 6: APPLICATION 57
6.1 Introduction 57
6.2 Healthcare Procurement 57
6.2.1 Supplier Selection Criteria in Healthcare Procurement 57
6.2.2 Healthcare e-Procurement 59
6.3 The Procurement Process of a Local Hospital 60
6.4 The Case Study 61
6.4.1 Procurement of a Routine Product 62
6.4.1.1 Data Collection 62
6.4.1.2 Results 63
6.4.2 Procurement of an Operational Product (Minor Capital) 65
6.4.2.1 Data Collection 66
6.4.2.2 Results 67
6.4.3 Procurement of a Capital Product 69
6.4.3.1 Data Collection 69
6.4.3.2 Results 73
6.4.4 Final Discussion 79
6.5 Conclusion 81
CONCLUSIONS 83
FUTURE WORK 84
PUBLICATIONS RESULTED FROM THIS WORK 85
REFERENCES 86
APPENDIX 91

List of Figures

Figure 1: Number of Suppliers vs. Relationship Level for E-procurement Application Types 6
Figure 2: Buyer Supplier Relationships with E-Procurement Software 7
Figure 3: Buyer Supplier Relationships with Internet Purchasing Consortia 9
Figure 4: Buyer Supplier Relationships with Internet Market Exchange 8
Figure 5: Buyer Supplier Relationships with Internet B2B Auctions 9
Figure 6: EDI Communication Architecture (Weber, 2001) 11
Figure 7: XML-based Frameworks for B2B Interactions (Weber, 2001) 12
Figure 8: Cost-Benefit Graph for Supplier Relationships. 17
Figure 9: Companies using e-procurement technology 2000-2001 22
Figure 11: Evolution of IT in Supplier Relationships (Segev and Gebauer, 2001) 25
Figure 12: Terms of the Linguistic Variable "PERFORMANCE" for Supplier 27
Figure 13: Supplier Selection Process Framework. Classification of Papers 30
Figure 14: AHP Structure of a Firm's Selection Criteria (Kahraman et al., 2003) 36
Figure 15: Analytical Hierarchy Process Design 41
Figure 16: Triangular Fuzzy Number and Crisp Number 43
Figure 17: Decision Support System Environment 50
Figure 18: Supplier Selection System 51
Figure 19: Suppliers and Criteria Selection for Comparison 52
Figure 20: MySql Database Relationship Diagram 53
Figure 21: Database Table for Supplier Rates 53
Figure 22: Formation of Triangular Fuzzy Numbers using Supplier Rates 54
Figure 23: Supplier Scores Based on Criteria as Fuzzy Numbers 54
Figure 24: Linguistic Variables and their Membership Functions 55
Figure 25: Pair-wise Comparisons for Criteria 55
Figure 26: Rankings of the Criteria 64
Figure 27: Overall Rankings of Routine Product Suppliers 64
Figure 28: Rankings based on Supplier Relationships along Alpha-Cuts 65
Figure 29: Rankings of the Criteria 67
Figure 30: Overall Rankings of Sterilization Containers Suppliers 68
Figure 31: Rankings based on Clinical Acceptability along Alpha-Cuts 68
Figure 32: Rankings of all the Criteria for a Capital Product 74

Figure 33: Change in the Consistency Index along Alpha-Cut levels 75
Figure 34: Overall Rankings of the Suppliers 76
Figure 35: Rankings of the Suppliers Based on Criterion: Price 76
Figure 36: Overall Rankings for the Sensitivity Analysis 78

List of Tables

Table 1: Relative Importance of Decision Criteria (Bharadwaj, 2004) 32
Table 2: Measures of Scales for Alternatives in AHP Design (Weber, 1993) 42
Table 3: Ratings for Routine Products Suppliers 63
Table 4: Linguistic Comparison of Criteria 63
Table 5: Ratings for Sterilization Containers Suppliers 66
Table 6: Linguistic Comparison of Criteria 66
Table 7: Criteria Weight Assessments and Supplier Ratings 70
Table 8: Supplier Ratings per Criterion 71
Table 9: Pair-wise Comparison of the Criteria using Fuzzy Linguistic Variables 72
Table 10: Assessed and Calculated Weights for the Evaluation Criteria 73
Table 11: Criteria Weights after Removing Price Related Criteria 77
Table 12: Supplier Weights 78

Abstract

In today's competitive business world, it is extremely important for decision makers to have access to decision support tools in order to make quick, right and accurate decisions. One of these decision making areas is supplier selection in e-procurement. Supplier selection is a multi-criteria decision making process that deals with the optimization of conflicting objectives such as quality, cost, and delivery time. If it is not supported by a system, this would be a complex and time consuming process.

In spite of the fact that the term "supplier selection" is commonly used in the literature, and many methods and models have been designed to help decision makers, few efforts have been dedicated to develop a system based on any of these methods.

In this thesis, we propose a web based supplier selection decision support system based on the analytic hierarchy process (AHP) method which has been commonly used for multi-criteria decision making problems. Inasmuch as we believe that fuzzy concepts and usage of empirical data extend the capability of any modeling approach, integrating them into our model will lead to a more powerful system. To validate our choice of the Fuzzy AHP model and also to validate the conceptual design of our supplier selection decision support system, we conducted a case study in a local hospital. We opted for a hospital case study because the nature of the procured goods calls for different procurement (as well as e-procurement) processes.

Acknowledgments

I would like to thank Professor Morad Benyoucef, my thesis supervisor, for his guidance, help, comments and revisions in improving this thesis. Without his instruction and guidance, this thesis could not be accomplished. I would also thank Professors Wojtek Michalowski, David Wright and Bijan Raahemi for their valuable comments. Thanks also go to Yves Jobin of University of Ottawa Material Management Department and Adriana Milito of CHEO Material Management who provided data, time and comments and helped us in validating the results.

Lastly, to Hasibe and Sara: Thank you for your patience, support and love…

"Çaba bizden başarı Allah'tandır"

Chapter 1: Introduction

In the early 2000s, business and governmental organizations began to realize that electronic procurement (e-procurement) can significantly improve their efficiency and reduce their costs. E-procurement is defined as the process of acquiring goods and services through electronic means, and more specifically using the Internet.

According to Kameshwaran and Narahari, “upgrading to e-procurement from traditional procurement helps organizations reduce operational costs, shorten the order fulfillment cycle time, lower inventory levels, and create collaborative partnerships” (Kameshwaran S. and Narahari Y., 2003).

Supplier selection in e-procurement (and in traditional procurement as well) is set to answer the question: “which suppliers to buy from and what quantity to buy from each supplier?” Most techniques used to select the right supplier consider a number of criteria. Based on these criteria, new and existing suppliers are evaluated then ranked. The decision is based on the rankings. Two situations arise. First, a single supplier can fulfill all the requirements of the buying organization. Consequently, managers only need to decide on the best supplier, and automatically order all their goods/services from that supplier. This situation is called “single sourcing”. In the second situation, which is usually the real life case most of the time, more than one supplier is necessary to fulfill the requirements of the buying organization. This is called “multiple sourcing” and in this case managers are faced with a more complex task: “which suppliers to select, and how much to order from each one?” Depending on the procurement strategy of the buying organization, both single sourcing and multiple sourcing can be employed. Each strategy has its advantages and disadvantages. In this thesis, we consider an approach to single sourcing supplier selection with the possibility that it can be extended to a multiple sourcing situation.

1.1 Motivation of the Research

In fuzzy Analytic Hierarchy Process (AHP) literature, a scale with fuzzy numbers is used instead of a traditional crisp numbered scale. The fuzzy scale has pre-determined fuzzy numbers to capture vagueness in the decision maker's mind. Within a supplier selection problem, based on AHP modeling, the decision maker needs to compare each supplier against the other suppliers as well as each criterion against the other criteria using a given scale. However, having a decision maker perform pair-wise comparisons of suppliers is not always successful because he/she may not be certain about his/her comparisons and/or incomplete information or knowledge might lead him/her to make the wrong decision (Mikhailov, 2003). In this case, even fuzziness cannot reflect the real situation. We believe that empirical data is always useful for decision making. We therefore intend to use it to generate pair-wise comparisons of suppliers. Empirical data is brought into the system either from back-end systems or from a third party (offering the data through a web service for instance). It is the decision maker's choice to accept the data "as is" or modify it. This approach gives us an opportunity to reflect real comparisons of the criteria and rates.

Also, if we look at the applications of different supplier selection models in the literature, most are case based with a pre-determined number of suppliers and with criteria that are collected through questionnaires. A lack of flexibility results from the fact that adding or removing a supplier or criterion requires repeating the whole process. There are some academic (Web-Hipre[1]) and commercial (ExpertChoice[2]) tools using traditional AHP as opposed to fuzzy AHP, but they are not specifically designed for e-procurement. Moreover, these tools lack the ability to capture vagueness in the decision maker's mind. They use crisp numbers with the static scale proposed by (Saaty, 1980).

Thus it is essential to propose and establish a support system for multi criteria supplier selection, which combines the power of web based systems, fuzzy concepts and empirical data, to improve efficiency of supplier selection process.

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[1] http://www.hipre.hut.fi
[2] http://www.expertchoice.com

1.2 Research Objectives

The objectives of this research are as follows:

a) Gain an understanding of supplier relationships, the effects of e-procurement on supplier relationships, and how supplier relationships evolve in an e-business environment. Also, find out and define the most important measures and criteria of the supplier selection process. Performing an extensive review of the literature will give us an opportunity to define commonly used measures and criteria. Additionally, review supplier selection models in the literature that have been used to evaluate, rank and select suppliers and perform a detailed review of traditional AHP and Fuzzy AHP models.

b) Design, implement and deploy a web-based decision support system for supplier selection based on a fuzzy AHP model.

c) Validate the model and the system with a healthcare case study; discuss the advantages and disadvantages of the model and the system.

d) Perform an assessment of the impact of supplier relationships as well as decision criteria on the supplier selection process in healthcare procurement.

1.3 Thesis Organization

The remainder of this thesis is organized as follows:
In section II, a detailed discussion of e-procurement technologies and trends is provided. The first part of this section summarizes the framework of e-procurement, discusses the application types of e-procurement and illustrates the effects of these application types on supplier relationships. It also explains the evolution of information technology in supplier relationships and discussed the main frameworks and architectures being employed. The

second part is a brief overview of the current efforts on standardization related to supplier relationships.

The literature review, a summary of recent research papers related to supplier relationships and e-procurement, is presented in the first part of section III. The papers are classified into six main parts, according to the topics they are dealing with. In the second part of section three we review supplier selection literature and discuss the different approaches and their models from the perspective of buyer-supplier relationships. We also briefly address some basic concepts and discuss traditional and new methods used in the evaluation and selection of suppliers.

AHP and Fuzzy AHP models are introduced in section IV. Formulation of fuzzy AHP using the fuzzy linear programming method is also shown. Method to generate fuzzy ratings is also explained. Advantages and disadvantages of models are discussed.

Section V introduces our supplier selection system, its architecture, environment and database design.

The model is validated with a hospital case study in section VI. Results and analysis as well as comparison of methods are provided in this section as well.

The thesis ends with a summary and conclusion given in section VII.

Chapter 2: E-Procurement

2.1 Background

The changing nature of the marketplace along with the increasing power of Internet technologies has lead to an increased demand for cost control, quality, and innovation. In today's competitive marketplace, companies have to consider re-engineering their processes and getting rid of traditional understanding of management in order to minimize their cost, build a strong foundation, and survive. Instead of traditional relationships, companies have to build "true business partnerships" that can lead to agreements that provide equal risk sharing (Ross David F., 2003).

E-procurement is the outcome of all these efforts particularly aiming to improve supply process to gain efficiency and save money (IDC, 2003). E-procurement technology is defined as any technology designed to facilitate the acquisition of goods by a governmental or a commercial organization over the Internet. Upgrading to e-procurement from traditional procurement helps organizations to reduce operational costs, to shorten the order fulfillment cycle time, to lower inventory levels, and to create collaborative partnerships (Kameshwaran S. and Narahari Y., 2003).

2.1.1 E-Procurement Framework

Different understandings of e-procurement and particular solutions for specific businesses have resulted in four main types of e-procurement applications: E-procurement software solutions; Internet market exchanges; Internet purchasing consortia; and Internet B2B auctions, as mentioned by (Davila et al., 2003). All these applications need a common technological support. Companies consider their place in the market and decide what kind of application they should implement. This is a rather critical decision since implementing the wrong type of application costs huge amounts of money and leads to bad reputation. In this part, we will first introduce commonly used e-procurement applications and after that describe the technology used to support e-procurement applications.

2.1.2 E-Procurement Application Types

The application selection process is very important for companies and it depends on companies' policies defining what degree of relationship they would like to have with their buyers or suppliers. In this part, we will analyze the issue from the perspective of buyers and try to show how each of these application types affect buyer and supplier relationships. In the literature, most researchers argue that using electronic means in procurement processes will improve buyer supplier relationships. But this is not the case all the time. Relationship levels heavily depend on the type of application. Figure 1 shows the level of relationship and the number of suppliers for different application types.

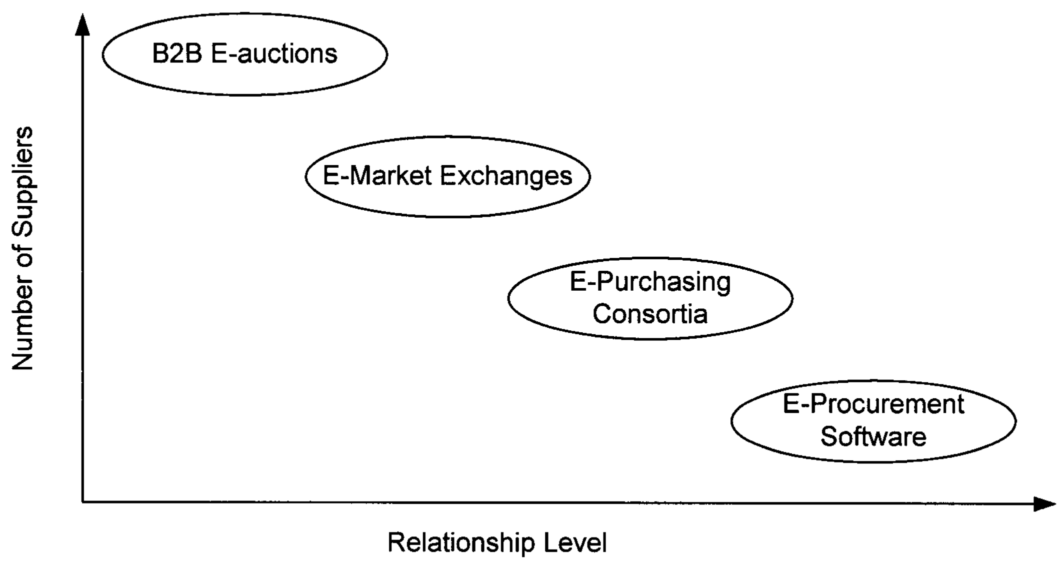

Figure 1: Number of Suppliers vs. Buyer and Supplier Relationship Level for E-procurement Application Types

2.1.2.1 E-Procurement Software

E-Procurement software solutions are known as electronic Supplier Relationship Management (e-SRM) solutions. They are basically designed to satisfy most of the needs of buyers who would like to deal with their suppliers by using electronic means. These software solutions are mostly created by giant enterprise software solution providers. Some of these solution providers are given below.

1. SAP [3]
2. SAS[4]
3. Epicor[5]
4. Manugistics[6]
5. PeopleSoft[7]
6. Synise[8]

E-procurement software solutions (see Figure 2) come with embedded features which are ready to be customized for specific needs. These features might also have some similarity with the other types of e-procurement applications. Most e-SRM solutions, for instance, have an embedded electronic auction (e-auction) feature.

Buyers who invest on e-SRM solutions want to have strong relationships with their suppliers, thus they don't deal with a large number of suppliers. By modifying the software for their needs and establishing secure connections through the use of e-SRM, they create a closed circuit, in which buyers and suppliers can exchange critical information that may lead them to build collaborative partnerships.

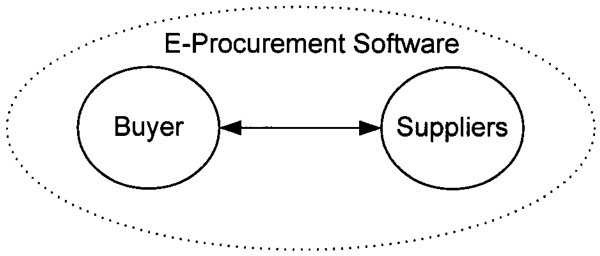

Figure 2: Buyer Supplier Relationships with E-Procurement Software

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3 http://www.sap.com/solutions/srm/index.asp
4 http://www.sas.com/solutions/srm/index.html
5 http://www.epicor.com/www/Solutions/srm.htm
6 http://www.manugistics.com/solutions/srm.asp
7 http://www.peoplesoft.com/corp/en/products/ent/srm/index.jsp
8 http://www.synise.com/solution_srm_overview.asp

2.1.2.2 Internet Market Exchanges

Internet market exchanges are another type of e-procurement applications. In every Internet market exchange there is a virtual host which brings together buyers and suppliers who meet certain conditions and requirements. Since there is no direct relationship between buyers or suppliers and host, the host may lower the requirements and allow more buyers and suppliers into the exchange place. Having more suppliers and buying from them using a third party may affect the relationship between buyer and supplier in a negative way. Usually, no strong relationships emerge from Internet market exchanges. But in some conditions, after knowing each other well enough, buyers and suppliers might move their relationships to the e-procurement software level to be able to create long-term collaborative partnerships. In Figure 4, the host is illustrated with a dotted circle, which means that neither buyers nor suppliers have an active relationship with the host.

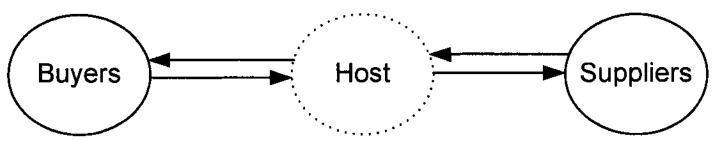

Figure 4: Buyer Supplier Relationships with Internet Market Exchange

2.1.2.3 Internet Purchasing Consortia

An Internet purchasing consortium (see Figure 3) can be seen as a much organized but small type of Internet market exchange. In Internet purchasing consortia, buyers and suppliers know each other very well and do not communicate through a third party. Entering into consortia is more restricted than Internet market exchanges and is supported by regulations which are created by both parties. Some examples can be seen in local businesses and municipalities. There are strong relationships among buyers and suppliers but there are no information exchange mechanisms which prevent buyers and suppliers from going into the collaborative partnerships.

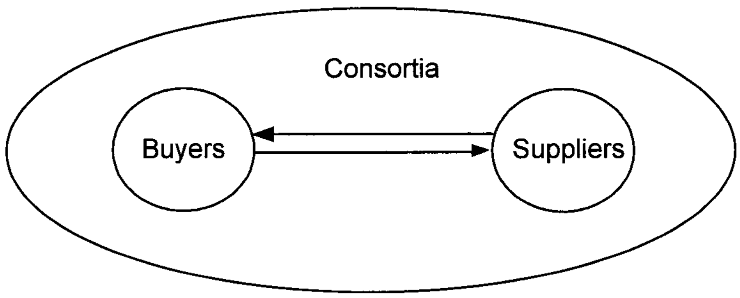

Figure 3: Buyer Supplier Relationships with Internet Purchasing Consortia

2.1.2.4 Internet Business-to-Business (B2B) Auctions

Internet B2B auctions (see Figure 5) are similar to Business-to-Customer (B2C) auctions but they mostly use reverse auctions rather than English or Dutch auctions which are common in B2C settings. Reverse auctions are designed in a way that the buyer invites suppliers for bidding and the supplier who submits the lowest bid wins. In this case the auction stands as a barrier around the buyer and keeps it from having strong relationships with its suppliers. Because auctions are competition tools, Internet B2B auctions mostly end up with "win-lose" rather than "win-win" situations. That will lead to "competitive relationships" between buyers and suppliers instead of "collaborative relationships". From the perspective of buyer and supplier relationships, B2B auctions are the worst type of e-procurement applications. However, these tools can be used for procuring maintenance, repair and operating (MRO) goods since procuring these goods does not necessarily need collaborative partnerships.

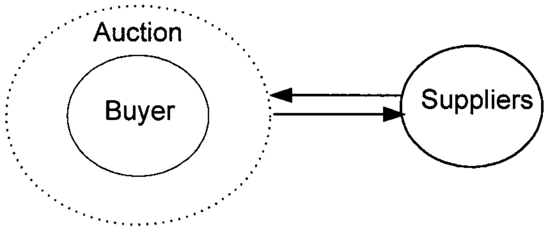

Figure 5: Buyer Supplier Relationships with Internet B2B Auctions

2.1.2.5 Conclusion

Buyer companies have to define their needs and make plans for moving their procurement process to the electronic environment. It is important to have collaborative partnerships with suppliers but it doesn't have to be a default case for all situations. The best way for companies to proceed is by following a flexible approach in which they can classify their procurement processes and adopt a different type of e-procurement application for each process.

2.1.3 Technology Support for E-procurement

(Shore, 2003) claims that the evolution of information technologies (IT) in buyer and supplier relationships goes through four stages. In the first stage, hard copy forms take place everywhere but IT and telecommunications play minor roles. In the second stage, Electronic Data Interchange (EDI) manages the electronic exchange of most of the business transactions. In the third stage, inter-enterprise systems integrate and coordinate the operations using a centralized database. The final stage is characterized by extensive information flows, strategic alliances and decision support systems.

2.1.3.1 Electronic Data Interchange

Electronic Data Interchange (EDI) was first introduced in the 1970s and has been commonly used since the 1980s to automate routine transactions between established trading partners, especially for the trade of direct goods and services. To enable the exchange of messages, the information technology used on both sides must be compatible (Weber, 2001). EDI uses Value Added Networks (VANs) in order to handle message delivery among business partners. (See Figure 6)

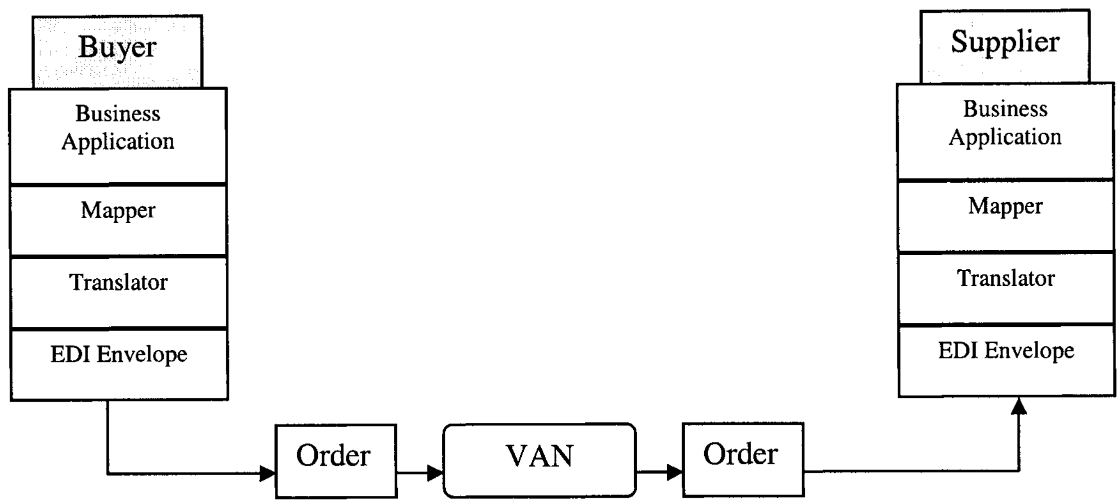

Figure 6: EDI Communication Architecture (Weber, 2001)

Since EDI is based on expensive networks, it is too costly for small and even medium-size businesses. Such businesses were eliminated from being partners with larger enterprises due to the mandatory usage of EDI (Weber, 2001). Despite the fact that information technology has brought new and better solutions, EDI is still being used in larger enterprises.

2.1.3.2 Internet Technologies and XML

From the early 1990s, Internet related technologies have been used to support the procurement of goods and services. The emergence of Internet related technologies can be portrayed as the migration (Liao et al., 2003) of procurement onto the Internet. This migration would not only result in collaborative cost reduction initiatives but also help improve partnerships between buyers and suppliers.

Today, there is a variety of different electronic methods supporting B2B interactions and companies interact with each other using a variety of standards and protocols from EDI to the eXtensible Markup Language (XML). Since these methodologies have evolved over time, companies deployed the ones that are best suited to their particular business needs.

One of the most important enabling components is XML, which is a superset of the Hyper Text Markup Language (HTML). XML, viewed as the data language for electronic commerce, is a product of a World Wide Web Consortium (W3C[9]) standards effort.

XML is not a data language; rather, it is a standard for defining data languages for specific purposes. So far, XML has been the foundation for B2B transactions. The ultimate goal of XML is to pick up where EDI leaves off to enable standardized data sharing between buyers and suppliers via the Internet (See Figure 7).

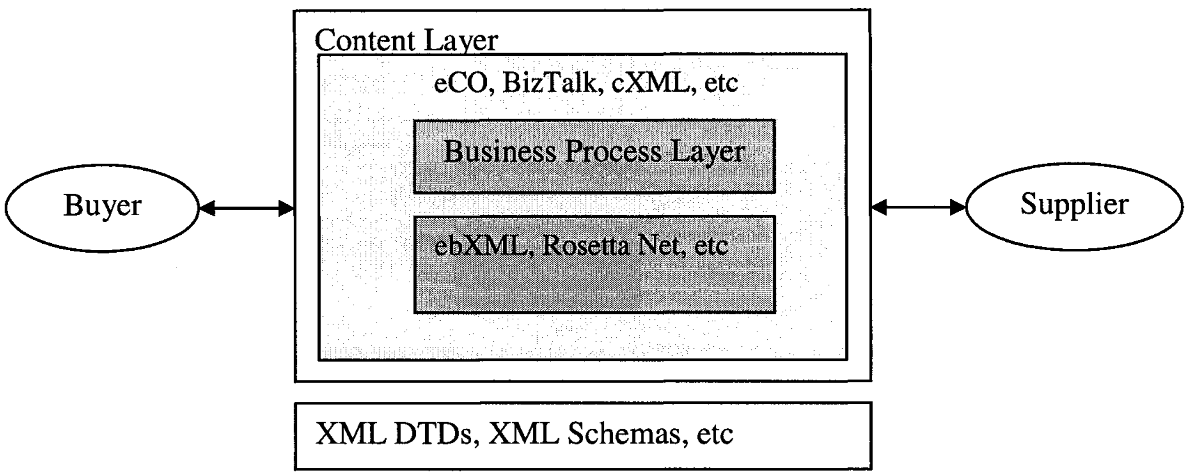

Figure 7: XML-based Frameworks for B2B Interactions (Weber, 2001)

Over the long term, open standards based on XML technology are expected to lower procurement processing costs, reduce the price of materials, accelerate order placement, and improve the overall visibility and tracking of orders (Sun, 2002).

2.2 Standardization

Until recently, buyer companies which had been using traditional procurement techniques had no intention of buying from a company before recognizing it as a potential supplier. The process of getting on a suppliers list was long and hard for potential suppliers, and it

[9] http://www.w3.org/XML/Core

included face-to-face meetings, sample requests, etc. Also, some companies had ethical and security concerns which prevented them from buying from foreign suppliers. Now, using Internet technologies, buyers have a chance to procure, and suppliers have a chance to sell from and to any part of the world. To make this process simple and fast, there has been a huge standardization effort taking place.

Think about joining an e-auction site and buying a part that you need in a short period, from one of the far-east countries. How will the quality be? Are they going to send you the wrong part? How will the packaging be? Are you going to get the part safely? These are all quality related standardization issues and we expect to see international quality standards applied in this situation.

But there are still other issues. Are they giving acceptable wages to their workers? Do they have child workers? You might not want to be part of an ethical violation just because you are getting a high quality part for less. This is an issue of ethical standards.

You got the part and you are satisfied with it and want to do more business with this company. Will you be able to establish an integrated communication framework without spending a lot of money? Integration standards can help you answer this question.

Also, you might want to get a part that calls for a specific design. Can you trust that your supplier would not sell your design to your competitors? Or is there a chance that your design can be stolen due to lack of security from the supplier's side?

Standardization efforts can be used as a remedy for these problems and they are summarized below.

2.2.1 Quality Related Standardization

2.2.1.1 ISO 9000 Series and ISO 14000 Certifications[10]

ISO stands for "International Standardization Organization". ISO 9000 and ISO 14000 are part of the ISO standards family. The former is an international reference for quality requirements for B2B relationships; the latter deals primarily with environmental issues to minimize environmental damage. ISO 9000 includes basic requirements for calibration and tests, scheduling, labeling, shipping, packaging and handling procedures.

2.2.2 Ethical Standardization

2.2.2.1 EG9001 - Ethical Governance 9001[11]

This standard consists of twelve commandments based on principles defined in the Universal Declaration of Human Rights. It regulates a wide range of human rights such as health, safety and welfare of the public, and goes as far as preventing aggressive electronic marketing (e-marketing) campaigns.

2.2.2.2 SA8000 Social Accountability 8000[12]

This standard consists of the best combination of common labour laws around the world. It assures companies do not have child labour, forced labour, discrimination, and illegal disciplinary procedures. It also regulates health and safety, unionization, working hours and compensation issues.

2.2.2.3 Other Standardization Efforts

The Ethical Trading Initiative (ETI)[13] is a buyers' organization in the UK. These buyers refuse to buy from suppliers unless they adopt ETI's code of practice and comply with minimum labour standards.

The Fair Labour Association (FLA)[14] is a US based non-profit organization that enforces the fact that suppliers have fair labour standards in their production facilities.

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[10] http://www.iso.org
[11] http://www.icharter.org/standards/eg9001/
[12] http://www.cepaa.org/SA8000/SA8000.htm
[13] http://www.ethicaltrade.org/Z/abteti/index.shtml

The Worldwide Responsible Apparel Production Certification Program (WRAP)[15] defines itself as "an independent non-profit corporation dedicated to the promotion and certification of lawful, humane and ethical manufacturing throughout the world".

2.2.3 Integration Related Standardization Issues

Integration of buyers' and suppliers' e-procurement applications is very important in order to have active collaboration between buyers and suppliers. There are many EDI, XML or EDI based XML standards being used. Commerce XML (cXML)[16], Electronic Business XML (ebXML)[17] and RosettaNet[18] are the most commonly used standards enabling easy integration.

2.2.4 Data Security Related Standardization Issues

2.2.4.1 Data Handling Protocol 3003(DHP3003)[19]

This standard regulates the data collection and destruction procedures within companies. It also insures that shared information will not be used against the owner of the information.

2.2.4.2 SSL (Secure Socket Layers) and Other Efforts

In today's B2B world, companies either continue to use EDI-based, old but secure communications, or common 128-bit encrypted Hypertext Transfer Protocol over SSL (HTTPS). There are also other XML-based standards and solutions such as XML Signature, Digital Certificates, SAML, XACML, etc.

A research paper on e-procurement security issues is presented and summarized in Subsection 3.4.4.

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[14] http://www.fairlabor.org/index.html

[15] http://www.wrapapparel.org/

[16] http://www.cxml.org

[17] http://www.ebxml.org

[18] http://www.rosettanet.org

[19] http://www.icharter.org/standards/dhp3003/index.html

Chapter 3: Review and Classification of the Literature

3.1 Understanding Buyer-Supplier Relationships

3.1.1 Value Creation in Buyer–Supplier Relationships (Walter et al., 2001)

(Walter et al., 2001) argue that buyers and suppliers engage in relationships towards gaining a "value" which they expect to have as an outcome of the relationships. The paper describes the concept of value as a variety of benefits that not only buyers but also suppliers acquire. The authors looked at the issue of value creation from the suppliers' perspective and conducted an empirical study for the sake of defining key elements of value creation. Suppliers have to attract buyers by creating values for them while trying to find ways for creating their own value, which could also emerge automatically from the relationships.

Based on the literature given in the paper, buyer and supplier relationships can be modeled through functions which can be divided into two parts: direct and indirect functions. Direct functions create value for the supplier and their results do not effect the supplier's other relationships. Three important direct functions are: profit, volume, and safeguard. In contrast, indirect functions effect the supplier's other relationships. Market function is one of them and it is created through getting referrals from existing buyers. These referrals help the supplier acquire new buyers. In this case, getting a small financial benefit is less important than having a good referral. The scout function is the second indirect function mentioned in the paper. Having a buyer with a wide variety of market contacts acting as a scout for the supplier helps the supplier stay informed about market developments and changes. Finally, the access function lets suppliers use the experience of buyers in terms of how to deal with official authorities, banks and other associations.

3.1.2 Making the Most out of Supplier Relationships (Gadde and Snehota, 2000)

(Walter et al., 2001) discussed the benefits of relationships from the suppliers' perspective. In contrast, this paper (Gadde and Snehota , 2000) looked at the benefits perceived by buyers from cooperation with suppliers. The authors argue that collaboration with suppliers is reasonable as long as the benefits derived from the relationship are greater than the collaboration costs. It is obvious that while creating a relationship that needs high involvement, the buyer is faced with some costs. What buyers and suppliers might easily see in the short term is only a small percentage of the iceberg representing the costs, but in the long term, these relationships bring cost benefits and revenue benefits for both of them. Figure 8 illustrates the situation.

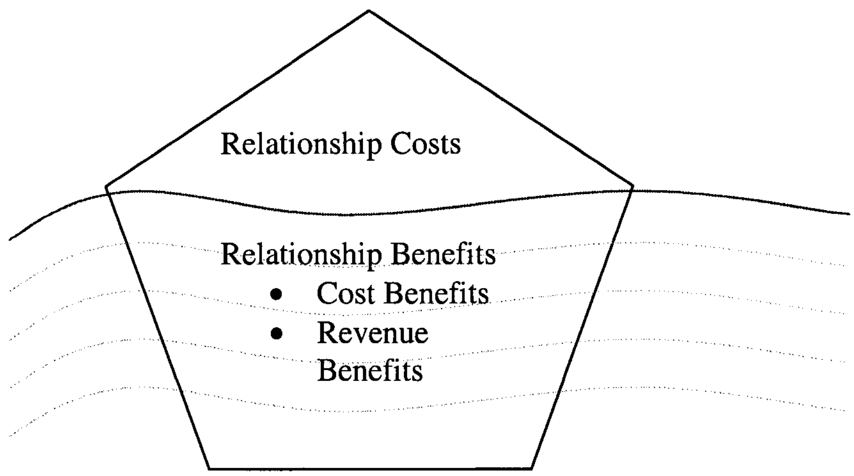


Figure 8: Cost-Benefit Graph for Supplier Relationships.

The paper emphasizes the importance and difficulty of establishing supplier relationships. Determining a pool of selected suppliers, as well as deciding on the level of relationship, is a major task for the buyer.

The authors argue that thinking of outsourcing non-critical activities, establishing collaborative partnerships with suppliers, looking at the quality of suppliers, and decreasing the number of suppliers is becoming popular among today's buyers. But there should be a framework of supply strategy that buyers follow. The paper aims to develop such framework.

3.1.3 Organizing and Managing Supplier Relationships in Information Technology Procurement (Heckman, 1999)

(Heckman, 1999) studied supplier relationships, and addressed three specific research questions that will lead researchers to understand how the relationship between IT suppliers and customers should be organized and managed. These questions are:

1. Is there any attempt from IT buyers to formalize the process of managing relationships with IT suppliers?
2. Are IT buyers and IT suppliers voluntarily engaged in collaboration? (Discretionary collaborative behavior)
3. Are formalization and discretionary collaboration related to perceived effectiveness influencing supplier behavior?

Heckman conducted a survey on 518 large North American companies. Empirical results indicate that more than two-thirds of the companies have relatively informally defined supplier relationship management processes. They have neither staff to manage supplier relationships nor documentation to help in sorting out suppliers. The results showed the clear situation of 1998. In recent years, having understood the importance of creating partnerships in order to survive, companies have started investing on supplier relationship management systems. According to Goldman Investment Research (1999) B2B e-commerce is expected to grow from $114 billion in 1999 to $1.5 trillion in 2004. Since the number of SRM solution providers has been increasing in the market along with the increased capabilities of the solutions, we believe that if a new survey was conducted, it would certainly give favorable results.

3.1.4 Conclusion

Research on supplier relationships is mainly based on empirical work. Questionnaires, surveys and interviews are the main elements in such research initiatives. It is not easy to design good questionnaires which make company officials confident that the information they provide in the survey will not be used to hurt the company or to lessen its competitive advantage. That's why the response rate to these questionnaires is low. Results from a small amount of filled out questionnaires might not truly reflect the situation in the market either. Finally, researchers have realized the importance and difficulty of establishing supplier relationships. They have focused on how the relationship between buyers and suppliers should be organized and managed and to that end a number of them tried to develop a framework for supply strategy.

3.2 Strategic Sourcing

Strategic sourcing is a multi-dimensional decision making process, which covers all aspects of the pre-contractual stages of procurement (Sun, 2002). Deciding whether to produce or to outsource is the first important stage of the outsourcing process. If a company decides to outsource instead of produce, the second stage comes into consideration. The company relies on suppliers for all its manufacturing needs. At this stage a company should have the ability and methodology to select appropriate suppliers and "effectively collaborate" with them to come up with "win-win" relationships.

Based on these two stages, there are two main interpretations of strategic sourcing in the literature. Some researchers (Talluri S., Narasimhan R., 2002), (Slaight T.H., 1999) simply think that strategic sourcing is a methodology for supplier selection. Having a strategic list of "potential suppliers" makes this sourcing activity "strategic". In contrast, other researchers (Freytag P.V., Kirk L., 2003), (Tayles M., Drury C., 2001) claim that it is a decision-making activity that helps the company decide whether to produce the goods or to perform outsourcing.

3.2.1 A Methodology for Strategic Sourcing (Talluri S., Narasimhan R., 2002)

(Talluri S., Narasimhan R., 2002) suggest a framework for supplier selection that will lead to a long-term partnership between the buyer and the supplier. The authors argue that companies should not select a supplier just based on operational factors, which do not have a big impact on their futures. Strategic factors such as "quality management practices", "cost reduction capabilities" and "collaboration potentiality" are also important and should be considered in the selection process according to the authors.

The paper argues that operational factors are useful and critical at the stage of supplier selection along with strategic factors, but strategic factors, rather than the operational ones are important and necessary for building long-term partnerships between buyers and suppliers, thus these factors make the sourcing activity "strategic".

Here, the supplier selection process is not simply a mathematical optimization problem that would be solved if a model could be constructed. Many other attributes and factors are part of the problem making it hard to model.

A model should help buyers in their decisions. The authors suggest a data envelopment analysis (DEA) model that uses nonparametric statistical tests to evaluate suppliers. Fifteen models from the literature are listed in the paper, but the authors claim that the presented model is superior to the others not only because it uses both strategic and operational factors, but also because it utilizes statistical models to find out the differences between suppliers.

3.2.2 Continuous Strategic Sourcing (Freytag P.V., Kirk L., 2003)

This paper (Freytag P.V., Kirk L., 2003) focuses on strategic sourcing as well, but in contrast to the previous paper, it argues that the term "strategic sourcing" has a meaning of "whether or not to perform outsourcing". The authors conducted a research with the aim of developing decision-making tools that can help a company make fast and accurate decisions in the outsourcing process.

The authors followed an "action research" approach to get empirical data instead of simply following traditional approaches such as questionnaires and interviews. It means they actually participated in the observations and were part of the process. They claim that the questionnaires or interviews might tell an "official story" of what is going on and might not reflect the real situation. Detailed information regarding the "action research" approach can be found in the referenced paper.

A dialogue based self assessment tool was developed that maps out the buyer's present activities and helps in deciding what activities should be kept internally in the company and what activities should be considered for outsourcing. To do that, the purchasing function was divided into activities and each activity was given a point as a result of an assessment. The paper claims that the framework is helpful for directing buyers to the appropriate way of sourcing.

3.2.3 Conclusion

In this section examples from the two different approaches on "strategic sourcing" have been presented. While the second approach claims that "strategic sourcing" is a way of selecting long-term partnerships, the first approach is a question of deciding whether to produce or to outsource. Actually, outsourcing requires strong relationships between buyers and suppliers since suppliers need to satisfy all buyers' requirements. Also, the outsourcing process requires knowledge and involves data traffic. In this way we can reach a conclusion that without having a long-term partnership it is not useful or recommended for a buyer to outsource (in other words, the buyer should not be thinking of outsourcing from the supplier if there is no close relationship).

3.3 Migrating to E-Procurement

3.3.1 Moving Procurement Systems to the Internet: The Adoption and Use of e-Procurement Technology Models (Davila et al., 2003)

According to this paper, the expected rapid growth rate of e-procurement predicted by market analysts has not taken place as desired. Analysts have thought that the B2C Internet boom would also accelerate the e-procurement investments but it didn't take too long for organizations to see that the implementation of e-procurement solutions was actually harder than predicted. Thus, companies that are already faced with many problems while implementing Enterprise Resource Planning (ERP) or Supply Chain Management (SCM) solutions are acting more carefully by following a "wait and see" policy.

(Davila et al., 2003) conducted a survey to understand the benefits and the risks of moving procurement solutions to the Internet and mapped out the current state of e-procurement technologies. The survey was based on data available from financial institutions, which includes data from a wide variety of industries and organizations, including universities, non-profit organizations, and several large and small private-sector companies.

Survey results testify that e-procurement based solutions are still in their infancy and each solution provider vies to create a main solution structure that satisfies the needs of today's business world and has a flexibility to be upgraded for future needs. The paper claims that this development follows exactly the technology S-curve showing a slow growth for the infancy and maturity stages but a fast one in between.

Four main types of e-procurement based solutions are discussed in the paper. These are e-procurement software; Internet market exchanges, Internet B2B auctions and finally Internet purchasing consortia (see Section 2.1). Results show that each type has found acceptors from a particular kind of organizations. For example, 43 per cent of organizations that started using e-procurement software are Fortune 500 companies (Figure 9). On the other hand, non-profit organizations mostly (61 per cent) use market exchanges and purchasing consortia.

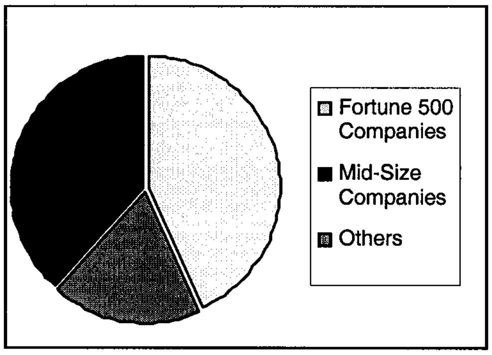


Figure 9: Companies using e-procurement technology 2000-2001

According to the survey results, companies have different e-procurement technology adoption strategies. Just small percentages of the companies (4 per cent) are not involved in any experimentation and are just waiting to see the maturity of e-procurement technology. They neither want to take a risk nor spend time on it. Almost 27 per cent of the companies have a policy that supports moving fast into e-procurement while 3 per cent of them vow for rapid movement in order to be a leader of their field. But the majority (70 per cent) does not follow either way. Instead, they monitor the developments carefully, invest selectively by committing minor resources, and prepare themselves for the maturity of e-procurement technology to be able to heavily invest in it at the right time.

Overall, according to the authors, moving procurement to the Internet has not been very successful. Although some benefits emerge from using e-procurement solutions, the current situation is rather disappointing.

3.3.2 Migrating Procurement onto the Internet (Yen et al., 2002)

(Yen et al., 2002) as well analyzed migrating procurement to the Internet but from a supplier's perspective. The paper starts with the identification of a 4-phase migration model that is a composition of an 11-step procedure that helps the traditional procurement process of the supplier to be moved easily to the Internet.

The proposed migration model starts from the first phase, which aims to digitize data and upgrade its supported services. Actually many companies in today's business world have almost passed this phase except some services in which they are still using paper-based processes.

The problem starts at the second phase: building communication infrastructures with other companies. Indeed, technical, security and financial requirements such as EDI or XML based communication framework constructions, firewall needs, and communication costs peak in this phase.

In the third phase the company has to make a decision on selecting the type of e-procurement based solution which can be e-procurement software, Internet market exchanges, Internet B2B auctions or Internet purchasing consortia, depending on the type and field of the company. The paper suggests implementing web sites and search-engines, which are believed to be capable of performing the job of Internet market exchanges.

The last phase is the integration of the company with third parties such as credit card companies or logistics providers. This is an important part of the infrastructure of the migration process since it regulates the payment and transportation issues.

The eleven-step procedure gives further explanation of the main four steps, although it seems that some important points are missing. Since the paper looks at the issue from the supplier's perspective, there is no information on the migration of the traditional supplier selection process to the electronic one. Moreover, the authors do not consider the issue of integration with existing partners. If the partners are not ready to migrate their processes to the Internet, there will be huge integration related problems that will cause loss of time and money. Finally, the authors mention changes in each step of the procurement process. Figure 10 (Yen et al., 2002) summarizes these changes.

Process Steps	Traditional Procurement	E-procurement
Information Gathering	Catalogs, magazines	e-catalogs, websites
Sourcing	Paper catalog	e-catalog, website
Quotation	Fax, phone	electronic means
Sample Request	Postal mail	postal mail
Negotiation	Fax, phone	electronic means
Order Placement	Paper contract	electronic means
Transaction	Banks, third parties	secure e-payments

Figure 10: Changes in Procurement Process Steps (Yen et al., 2002).

3.3.3 B2B Procurement and Marketplace Transformation (Segev and Gebauer, 2001)

Similar to (Davila et al., 2003) and (Yen et al., 2002), (Segev and Gebauer, 2001) inquired about B2B procurement and proposed several ideas on how the purchasing function of companies has been transformed from operational to strategic with the evolvement of supporting technology. Figure 11 below summarizes this transformation (Segev and Gebauer, 2001). The term "strategic" in the paper is used to refer to the procurement of capital equipment and services rather than maintenance, repair and operational supplies.

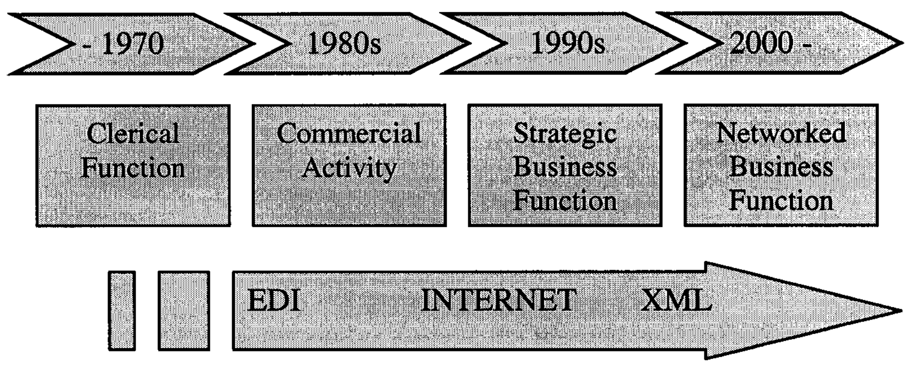


Figure 11: Evolution of IT in Supplier Relationships (Segev and Gebauer, 2001)

This paper focuses mainly on the effects of this transformation and aims to find out whether there is a strong positive linear correlation between this transformation and the level of buyer and supplier relationships. The more transformation strategic procurement brings the stronger buyer and supplier relationships are, according to the paper.

An increasing number of e-procurement solutions emerged in the market as a result of this transformation. The paper uses the term "Desktop Purchasing Systems" to represent these e-procurement software solutions and claims that the categories of desktop purchasing applications can give us a clue that shows the direction of the transformation.

The authors also looked at the issue of outsourcing from the perspective of this transformation. In recent years many companies have chosen to contract parts of their operations with the help of new technologies, which are playing a major role in the outsourcing process by regulating the integration issues.

3.3.4 Characterization of the Security Implications of Alternative E-procurement Topologies (Ponce and Duran, 2003)

According to (Ponce and Duran, 2003), knowledge is one of the most important assets that any company has and it can be easily lost or stolen while using electronic means. Security is a very important issue, and B2B procurers have to be satisfied that there will be no harm but more benefits through using e-procurement.

This paper provides alternative e-procurement topologies for buyers who want to use e-procurement for their strategic needs but mostly use it for their non-production materials because of the security problems they might face. Obviously, security is not the only issue for deciding on different e-procurement solutions, but it is certainly one of the most strategic.

3.3.5 Conclusion

Either from the supplier's perspective or from the buyer's perspective, moving procurement to the Internet is beneficial. There is a continuous but slow movement from procurement to e-procurement but e-procurement technology and related technologies are still in their infancy, which explains why some of the applications have not been successful. By the time the security and integration problems are solved and widely accepted standards are in place, moving from procurement to e-procurement will be accelerated.

3.4 Fuzzy Concepts in Buyer-Supplier Relationships

Fuzzy concepts deal with objects that are a matter of degree, with all the possible grades of truth between yes and no. It originates from the inability of classical logic to capture the ill-defined language and common sense reasoning used by people every day. Fuzzy logic uses linguistic variables with their membership functions (Bojadziev G. and M., 1999). Linguistic variables such as "risk", "benefit", "honesty" play an important role in financial and management systems. Figure 12 shows the terms of the linguistic variable "performance" for suppliers. Linguistic variables combined with "if-then" rules can be used for approximate decision making. For example, a buyer can select suppliers based on linguistic rules such as “If the performance of a supplier is high and the price of the supplier's products is moderate, then the probability of order action is high". Fuzzy logic combines all these propositions using fuzzy set operations yielding a composed graph. By de-fuzzifying the combination of composed graphs, the expected value can be found. Detailed information related to fuzzy concepts can be found in the literature.

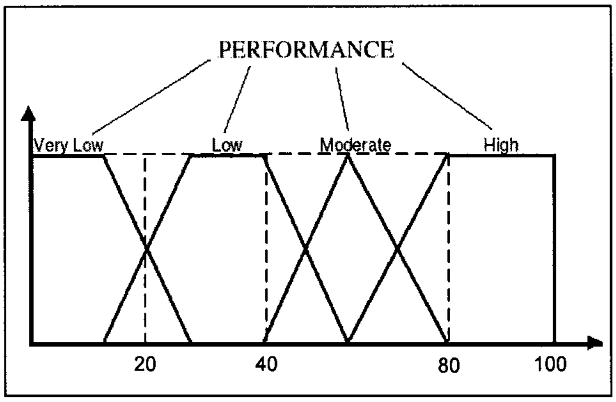


Figure 12: Terms of the Linguistic Variable "PERFORMANCE" for Supplier

For the sake of understanding why we use triangular or trapezoidal memberships rather than crisp ones, let’s consider this case. In Figure 12, we rate each supplier’s performance between 0 and 100. If we were to use crisp membership values, what would we do with a supplier which has a rating of 79? It is very close to “high” but we have to see it as “moderate”. It seems better to represent “high” performance as a linguistic fuzzy set instead of representing it as a crisp one. Values of these fuzzy sets are defined by using empirical results, experience, etc.

Negotiation normally does not take place in web based B2C relationships. Auction and marketplace based online B2C services are common on the web and none of them requires or allows negotiation. We can see that most of the negotiations take place in B2B relationships. With the migration of procurement to the Internet, traditional face-to-face negotiations have to leave their place to electronic negotiations conducted either directly by buyers and suppliers or through the mediation of software agents (Kowalczyk, 2002).

As an example of the application of fuzzy concepts in e-commerce, particularly in buyer-supplier relationships, (Kowalczyk, 2002) presents a prototype of Fuzzy e-Negotiation Agents (FeNAs) for autonomous multi-issue negotiation. He used fuzzy reasoning in offer evaluation and counter-offer generation. "The agents negotiate over multiple issues through the exchange of offers on the basis of the information available and negotiation strategies used by each party in order to reach a consensus that satisfies their private (hidden) preferences, constraints and objectives" (Kowalczyk, 2002). This information can go into fuzzy linguistic variables describing the level of satisfaction of an agent with different potential solutions. The objective of an agent is to maximize the satisfaction level of its fuzzy constraints that is also acceptable by other agents.

3.4.1 Conclusion

Fuzzy concept has an ability of dealing with vague objectives and extending the capability of any modeling approach. Only recently, some efforts have been made to apply fuzzy concepts in business, finance and management. We believe that fuzzy concept, integrated with other methodologies is a good potential research domain within the topic of supplier relationships.

3.5 Supplier Selection

3.5.1 Classification Efforts on Supplier Selection Literature

3.5.1.1 (Weber et al., 1991)'s Survey on Supplier Selection Methods (1966 – 1990)

The first survey and review of supplier selection methods in the literature was conducted by (Weber et al., 1991). This paper is based on an extensive search in the academic literature. It classifies and reviews 74 articles published in the area of supplier selection between 1966 and 1990.

According to the paper, 33 out of 74 articles were published in the "Journal of Purchasing and Materials Management". The authors found it surprising that only few papers had been published in Operational Research or Management Science based journals.

Review of quantitative approaches for supplier selection in the paper is grouped into three main categories and their sub-categories:

1) Linear weighting models
2) Mathematical programming models
3) Statistical and/or probabilistic models

Linear weighting models are the simplest from the modeling perspective. Each criterion is assigned a weight and the supplier's performance for each criterion is multiplied by this weight. The sum of these multiplications gives the total performance of that supplier. Most of the reviewed papers had used this type of model.

Mathematical models such as linear programming, integer programming, mixed integer programming, goal programming were not very popular and had been used in just ten of the seventy-four papers.

Statistical approaches could not find a place in most of the research papers. In only three papers statistical models, including cluster analysis, had been used.

3.5.1.2 (Boer et al., 2001)'s Classification of Supplier Selection Methods (1967- 2000)

(Boer et al., 2001) also analyzed the literature from the perspective of supplier selection methodologies and proposed an extension to the research done by (Weber et al., 1991). The authors categorized the methodologies based on a framework developed by (De Boer, 1998) in his PhD thesis. In the framework, the supplier selection process was divided into four phases. The first phase deals with defining the objective of supplier selection. What will be the outcome of the supplier selection process? Why we want to select suppliers? Once the objective is clarified, depending upon the objective, criteria are defined in the second phase and pre-selection of potential suppliers is done in the third phase. In the last phase, final selection is performed. The authors argue that the supplier selection process heavily depends on the type of goods and services to be procured. The selection process for a low valued routine item will be different from that of a strategic item.

Figure 13 shows a classification of the literature based on the framework.

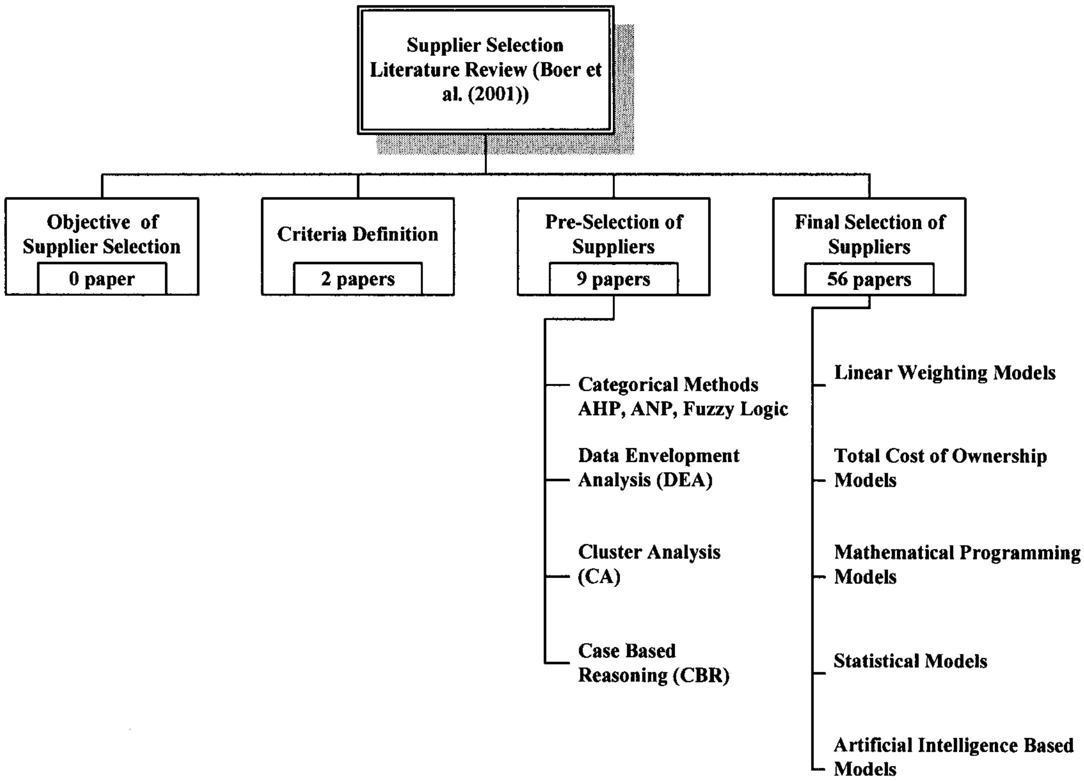


Figure 13: Supplier Selection Process Framework. Classification of Papers

(Boer et al., 2001) performed an excellent review that outlines all research efforts being done in supplier selection literature including PhD dissertations. In the paper, there are some points that should be discussed. For the first phase of the framework, the paper could not identify any research on problem definition of supplier selection. Perhaps it is because, in most of the papers, authors concentrate on pre-selection or final selection of the suppliers and discuss the "need for selecting suppliers" in their introduction part.

Moreover the authors made immovable the methods supporting the pre-selection and final selection of the suppliers. Fuzzy logic is classified as a categorical method for pre-selection process. Actually fuzzy logic can be integrated with many other methods and can take place in both pre-selection and final selection phases. In addition, Cluster Analysis is a statistical model and should be placed under statistical models.

Overall, the framework reflects the situation of supplier selection research very well but lacks the ability to be expanded if it is subjected to the introduction of new models or integration of models.

3.5.2 Criteria Issues

(Dickson, 1966), one of the earliest researchers to study criteria issues in supplier selection, conducted a survey and suggested 23 different criteria to be considered in order to perform an appropriate supplier performance evaluation. Although different buyers can rank these criteria differently, the author proposed a score for each criterion based on its importance. The three highest scores went to "quality", "delivery" and "performance history", while the three lowest scores went to "amount of past business", "training aids" and "reciprocal arrangements".

Not only did (Weber et al., 1991) perform a survey on supplier selection methods, but they also surveyed the criteria being used. Most of the papers discussed some of Dickson's first 7 most important criteria excluding the third and fourth one which are "performance history" and "warranties and claim policies", respectively. (Weber et al., 1991) argues that this does not show conflict between the research papers and Dickson's study and does not point out the uselessness of these two criteria. Rather, these two criteria might be considered as sub-elements of other criteria, thus they had not been mentioned in most of the research papers.

Also the lists of the criteria by year of publication of the articles show a possible trend. Several criteria such as "warranties" and "claim process", "labour relation records" had received little attention while some of them including "net price", "delivery" and "quality" had received huge amount of attention.

The recent paper (Bharadwaj, 2004) investigates decision criteria used for supplier selection in the procurement of electronic components. To determine the "key buying criteria" the author deployed a cross-sectional survey. On a seven-point scale, the ratings are outlined in Table 1.

Criterion	**Mean Rating (/ 7)**	**Normalized Mean Rating**	**Standard Deviation**
Quality	6.51	0.29	0.77
Delivery	5.88	0.26	1.07
Price	5.63	0.25	1.12
Service	4.64	0.20	1.45

Table 1: Relative Importance of Decision Criteria (Bharadwaj, 2004)

3.5.3 Model Issues

Researchers have used many different models for supplier selection and some of them are applied to e-procurement systems. Below, we classify supplier selection literature based on the approach taken: case study based and electronic tool (e-tool) based.

3.5.3.1 Case Study Based Approaches

(Ghodsypour and O'Brien, 1998) presented an integrated approach of AHP and linear programming (LP) to solve the supplier selection problem and the order quantity optimization problem. The implementation aims to come up with the best suppliers with optimum number of order quantities. The study first settles the criteria to evaluate suppliers. AHP is used to figure out the weights of the factors, then a LP model is developed to select the vendors and to allocate the orders among them.

(Masella and Rangone, 2000) used the AHP approach for supplier selection. They argued that the type of relationship between buyer and supplier plays a critical role in the supplier selection process. To support this idea they introduced four different Supplier Selection Systems (SSS) based on the type of relationship. The buyer might have either long-term or short-term relationship with its suppliers so that there are two classes of SSS defined from the perspective of relationship time according to the paper. Also from the content perspective, buyer and suppliers relationship are categorized into two classes of SSS which are logistic and strategic. Logistic relationship cares about operational criteria such as quality, service support and delivery time while strategic relationship attach importance to know-how involvement, joint design of new products, etc. All four types of relationships are summarized below:

1. short-term logistic relationship
2. long-term logistic relationship
3. short-term strategic relationship
4. long-term strategic relationship

The authors suggested using AHP for supplier selection not only because it has an ability to deal with both qualitative and quantitative measures but also because of its effectiveness on supplier selection problems. Classifying suppliers based on relationship type prevents buyer from adding irrelevant measures into the AHP model. It is very important to have appropriate criteria in AHP model to get correct evaluation thus the classification opens a way to do that.

Data Envelopment Analysis (DEA) was defined by (Liu et al., 2000) as "a mathematical programming procedure for evaluating the relative efficiencies of multiple decision making units that involve multiple inputs (criteria) and multiple outputs (objective)". DEA is a powerful management science tool and has been successfully used in different types of decision making problems. The main idea behind DEA in supplier selection is comparing each supplier with the suppliers that meet all buyers' requirements. If there is no such supplier, an artificial supplier should be created and put in the model in order to perform comparisons.

In (Liu et al., 2000)'s study, the DEA model was applied to a large agricultural equipment manufacturer. The company procures 8000 parts to be used in its assembly lines from as many as 400 suppliers. Inasmuch as there are too many suppliers, the company faces partnership problems as well as problems with order processing, quality, delivery, etc. To solve the problem with the DEA model, first of all, the authors shared 8000 parts among 18 commodity groups since each commodity group has similar suppliers. Each supplier in any commodity group can be replaced by any other supplier in the same group. If a supplier has a unique importance it should be eliminated from the evaluation process because it is impossible to eliminate or replace it. Price, delivery and distance factors are used as inputs in the model while the number of supplied parts and the percentage of defective parts are used as outputs. Different models are created for all commodity groups and solved using LINGO[20] optimization software which is particularly designed for solving mathematical optimization problems. Based on the satisfactory results, recommendations have been made for the elimination of inefficient suppliers.

(Bhutta and Huq, 2002) examined the Total Cost of Ownership (TCO) and AHP approaches and discussed their advantages and disadvantages when they were applied to supplier selection. As defined by (Ellram, 1994) TCO deals with monetary factors and criteria which are associated with the procurement of each good from each supplier and determines the total cost originated from these factors. Suppliers' performances are determined by this total cost. There is a debate going on among researchers as stated in (Bhutta and Huq, 2002) on the issue of how non-monetary criteria such as quality, delivery, etc. would be added into the model.

The AHP procedure can be summarized as follows:

[20] http://www.lindo.com/cgi/frameset.cgi?leftlingo.html;lingof.html

1. Identify the measures and the alternatives that exist
2. Generate the pair-wise comparison matrix
3. Create the weights of the measures
4. Normalize weights to get the consistency among measures
5. Calculate the overall ratings of suppliers. This calculation can be performed using Saaty's eigen-weight procedure outlined in (Saaty, 1980) or any other optimization method.

The authors compared the approaches not only by presenting other researchers' opinions but also by giving an example. Results show that both approaches might be useful to evaluate suppliers but AHP has an advantage because many criteria can be added into the model including qualitative data and quantitative data. The only problem with AHP discussed in the paper is, since AHP is a matrix based pair-wise comparison approach, adding and eliminating any criterion would cause repeating the process.

Recently, artificial intelligence (AI) techniques were implemented in supplier selection systems. (Ding et al., 2003) combined simulation and optimization approaches using a genetic algorithm (GA). A GA uses a probabilistic approach rather than the deterministic approach used in mathematical programming methods. The authors proposed a discrete event simulation model using an integrated GA as a search mechanism for optimal supplier selection. Although the authors claim that their approach is better than the other selection methods, and simulation results look satisfactory, there is no base to support this claim since the performance of the model has not been tested against other models.

(Kahraman et al., 2003) also approached the multi-criterion supplier selection problem from the perspective of AHP. They claim that not only the cost but also the common set of criteria and measures affect the buyer's decision on supplier selection. To get the advantage of using imprecise knowledge rather than content themselves with precise knowledge, they integrated AHP with fuzzy logic and came up with a powerful evaluation method. Catching the imprecise data and using it for evaluation purposes enabled them to see most of the hidden points of measures and criteria.

As measures and criteria, they concentrated on qualitative types and divided them into four categories that are also divided into sub-categories. These categories are "supplier criteria", "product performance criteria", "service performance criteria" and "cost criteria". Some of these criteria may not be collected in certain situations such as limited time, difficulty of gathering data, etc. Information collected through comparison questionnaires on these categories and their sub-categories were used to build a fuzzy AHP methodology.

Since it is very hard to assign crisp evaluation scores for comparison of two measures, fuzzy linguistic variables were used in questionnaires. For example the importance of one attribute over another was requested using words such as "absolute", "very strong", "weak", etc.

The authors performed supplier selection in an aspirator production firm using a fuzzy AHP methodology. Comparison matrices were built based on the measures and criteria given above and data was acquired through questionnaires. Only qualitative data was used in the model. Figure 14 (Kahraman et al., 2003) shows the AHP structure of the firm's selection criteria.

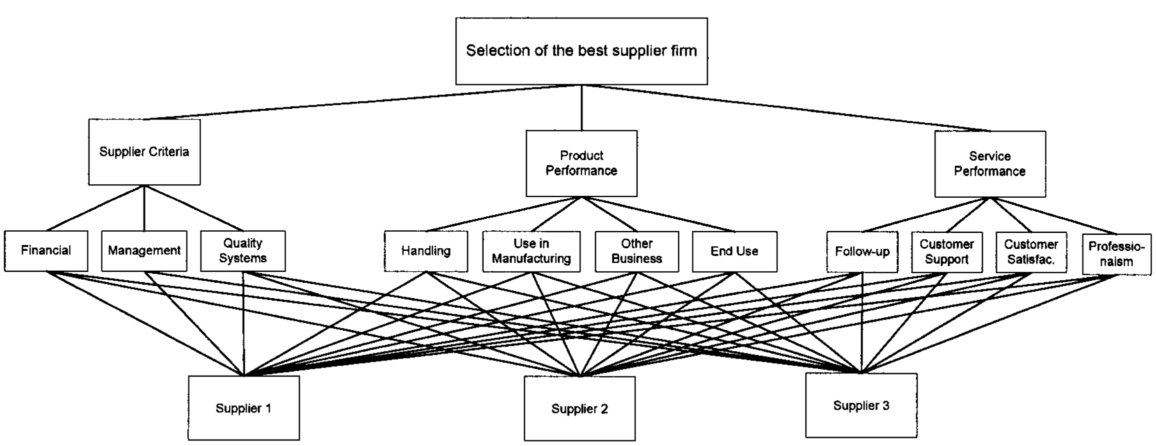


Figure 14: AHP Structure of a Firm's Selection Criteria (Kahraman et al., 2003)

Figure 14 shows a typical AHP shape. The objective, criteria, sub-criteria and alternatives are all connected to each other, which makes it easier for decision makers to perform pair-wise comparisons. Constructing such a figure is the first important step of the AHP process.

(Zaim et al., 2003) conducted a case study in TV production suppliers and used Fuzzy AHP in their decision making process. They used (Buckley, 1985)'s method to find the weights from full pair-wise comparison matrices. They evaluated the suppliers on some main criteria, performance assessment, human resources, quality system assessment, manufacturing, business criteria and information technology. All these main criteria also have some sub-criteria. They compared their results with results from traditional AHP method and concluded that fuzzy AHP was more effective.

Finally, (Wang et al., 2004) propose a supplier selection model using an integrated AHP and preemptive goal programming (PGP) methodology. AHP is used for selecting suppliers and PGP for determining optimal order quantities from selected suppliers. In their model, the authors used the supply chain operations reference model (SCOR) constructed by the Supply Chain Council (SCC)[21]. The SCOR model suggests using twelve performance criteria in four categories. These categories are "delivery reliability", "flexibility and responsiveness", "cost", and "assets". AHP results and the priority of alternatives are input into the PGP model, along with the capacity constraints. This determines the optimal order quantity from each supplier by minimizing the total value of purchase and maximizing the total cost of purchase.

3.5.3.2 E-Tool Based Approaches

If we do not count commercial electronic supplier relationship management (e-SRM) solutions, there is a limited number of tool based approaches to supplier selection in the literature. The first commercial tool was developed in a partnership between Dun & Bradstreet[22] and SAS[23], who tried to find out if they could decrease sourcing times by utilizing web-based technologies to execute supplier selection and allocation processes.

[21] http://www.supply-chain.org/
[22] http://www.dnb.com/us
[23] http://www.sas.com

Eventually, they created one of the components of SAS e-SRM solution, which is called "Supplier Portfolio Optimizer". Supplier Portfolio Optimizer uses a mixed-integer programming approach to solve the selection problem. The output of the optimization process is a portfolio of suppliers that satisfies all the conditions specified by the design parameters and maximizes leverage in future negotiations (Cohen M.D. et al., 2001).

(Choy et al., 2003) use artificial intelligence in the outsourcing functions of supplier relationship management to select appropriate suppliers from a pool of suppliers. The authors aimed to reduce the time cycle of the supplier selection phase in the outsourcing process by using a hybrid case based neural networks approach. The paper introduces two main modules in the intelligent decision making system. The first module is called "case based supplier selection module". Basically, case based reasoning (CBR) is a method which uses past experiences and applies them to finding solutions for new problems. This is not really different than what human beings normally do. This module helps the system select the suppliers based on criteria that consist of technical capability, quality assessment and organizational profile, and store them in a potential suppliers list. The paper outlines the three important steps of the CBR cycle. In the first step the user takes the request or enquiry and finds the most similar case from the past experience database. By looking at the solution for past cases, the user adapts a solution for the new problem in the second step. The third step is the step of verification. If the new solution satisfies the problem's requirements, it will be accepted as a verified solution and be added to the database for future usage.

Supplier benchmarking is performed by the second module, "neural networks (NN) based supplier benchmarking module" (NNSBM). NN is a paradigm of mimicking the operation of the human brain. NN is composed of one input, one output and one or more hidden layers and some nodes in every layer. These nodes act like neurons in the human brain. NN can be trained using historical or empirical data and can be used for forecasting, prediction or optimization.

In order to find the most suitable supplier, NNBSM gets the potential suppliers list from the CBR module and benchmarks them by comparing the performance scores using the NN approach.

The best thing with NN design is the easiness of adding or eliminating inputs. In contrast to linear programming models or generally speaking mathematical models it is easy to build and operate. Many inputs which are considered to have some impact on the outputs can be added into the model. The only important necessity with NN model is that it needs a large amount of historical or empirical data in order to get accurate results. As a case study, supplier selection process using the hybrid model was applied to Honeywell[24]. The results were compared with traditional ways of supplier selection and found very satisfactory.

3.5.3 Conclusion

There has been a great research effort dedicated to the supplier selection problem. Some researchers have tried to classify all these research efforts and published papers in this regard. Some papers concentrated on criteria issues in the supplier selection problem. Supplier selection criteria can be different for each case therefore it is very important to define right criteria in order to perform an appropriate supplier performance evaluation. Additionally, many supplier selection models have been developed and different methodologies and models have been presented in research papers. It is really hard and sometimes subjective to decide which methodology or model is better than the other. However, by looking at the results, it can be seen that most of them are successful.

[24] http://www.honeywell.com

Chapter 4: Methodology

Supplier selection is a multi-criteria decision making process that deals with the optimization of conflicting objectives such as quality, cost, and delivery time. If it is not supported by a system, this would be a complex and time consuming process.

In spite of the fact that the term "supplier selection" is commonly used in the literature, and many methods and models have been designed to help decision makers, few efforts have been dedicated to develop a system based on any of these methods.

In this thesis, we propose a web based supplier selection decision support system based on the fuzzy analytic hierarchy process (AHP) method. As discussed in the literature [(Kahraman et al., 2003), (Zaim et al., 2003)], fuzzy AHP supplier selection models have been successfully applied for ranking and evaluating suppliers in a large variety of organizations. Given that, the supplier selection decision support system will be used to rank and evaluate suppliers of a local hospital. The ranking and evaluation will enable us to validate the design of the system and the underlying fuzzy AHP model.

Below, we provide detailed information about the AHP and Fuzzy AHP.

4.1 AHP Modeling

AHP was first introduced by Thomas Saaty in the 1970's and since then it has been used in many areas including finance, marketing, energy resource planning, sociology and architecture. It can be defined as a multi-criterion decision making approach which compares all defined measures in pairs and calculates their relative importance. Most of the time the AHP is used in the choice phase of decision making. Afterwards other techniques such as linear programming, queuing, multiple objective decision making are used to solve the problem. In fact the aim of AHP is to combine quantitative factors to evaluate all the objectives. (Saaty, 1994)

According to (Vargas, 1990), AHP is carried out in two phases which are hierarchic design and evaluation. Hierarchic design is not unique for any problem and can differ from other designs for a same problem. For a defined problem, hierarchic design can be constructed using experts' knowledge and empirical data. In any AHP design, there is an objective at the top, and criteria and alternatives are located under the criteria respectively (Figure 15). A design can be expanded by adding some sub-criteria between alternatives and criteria.

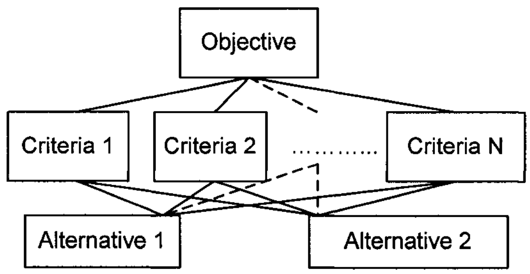


Figure 15: Analytical Hierarchy Process Design

The evaluation phase is divided into the four steps given below:

1. Generate pair-wise matrices
2. Generate the weights of the measures
3. Normalize weights to get the consistency among measures
4. Calculate the overall ratings of suppliers.

In the first step of the evaluation phase, the decision maker performs paired comparisons of alternatives according to criteria and generates a pair-wise comparison matrix. For example, given *Criteria 1* and two alternatives *Alternative 1* and *Alternative 2*, which alternative satisfies the requirements of *Criteria 1*? The numerical value assigned for comparison will be taken from Table 1 (Weber, 1993).

Value	Interpretation
1	Alternatives have equal importance
3	Alternative 1 is weakly more important than Alternative 2
5	Experience and judgment indicate that Alternative 1 is strongly more important than Alternative 2
7	Alternative 1 is very strongly more important than Alternative 2
9	Objective 1 is absolutely more important than Alternative 2
2,4,6,8	Intermediate values show the midway of any odd values.

Table 2: Measures of Scales for Alternatives in AHP Design (Weber, 1993)

Let "Alternative n" be A_n . The expected pair-wise comparison matrix will be (Saaty, 1990);

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ . \\ . \\ A_N \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & . & . & A_n \end{array} \\ \begin{pmatrix} w_1/w_1 & w_1/w2 & . & . & w_1/w_N \\ w2/w_1 & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ w_N/w_1 & . & . & . & w_N/w_N \end{pmatrix} \end{array}$$

Where;

w_i is the weight of alternative i

w_i/w_j is the pair - wise comparison value of alternatives i and j.

In normal conditions if A_1 is x times more preferred than A_2, then A_2 is 1/x times more preferred than A_1. But sometimes this is not the case. This is the problem of inconsistency. According to (Saaty, 1990), the solution of $A \otimes w = n \otimes w; w = (w_1, w_2, ..., w_n)$ called the principal right eigenvector of A. (Saaty,1980) proves that if pair-wise comparisons are consistent, this eigenvector represents the true weights of the alternatives for the largest eigenvalue of A. These weights are the weights of the criteria and weights of the suppliers in the supplier selection problem.

To make w unique and consistent, its entries will be normalized by dividing them by their sum. This is repeated for all columns to get the normalized matrix A (A_{norm}).

The last step is finding the overall score of an alternative. Each of the alternatives defined at first hand are evaluated according to the objectives and their overall scores are calculated. The best alternative is chosen. However, as mentioned before, this step may be replaced by other techniques like linear programming or goal programming.

4.2 Fuzzy Sets Theory

(Zadeh, 1965) first introduced the fuzzy sets theory, which aims to mimic humans ability of approximate reasoning. Decision makers are faced with many problems in their daily life and it is easy for them to give their opinions in a degree rather than an absolute value. Fuzzy sets theory performs very well in approximation and it can be used in mathematical operations.

4.2.1 Fuzzy Numbers and Arithmetic

a) Fuzzy Numbers

Let $\tilde{X}$ be a triangular fuzzy number and X be a crisp number.

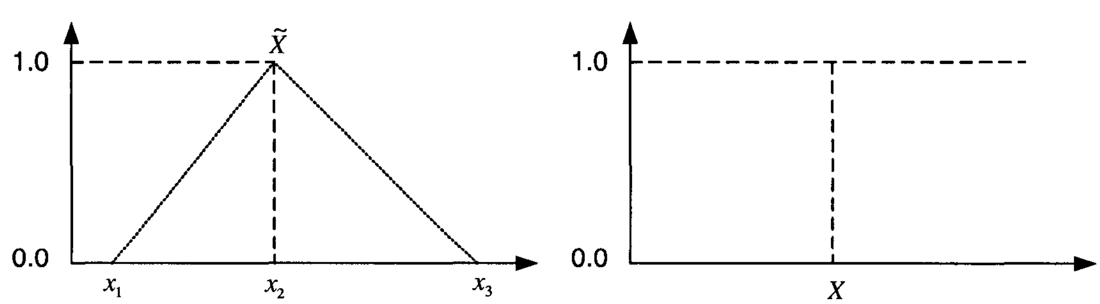


Figure 16: Triangular Fuzzy Number and Crisp Number

Triangular fuzzy number can be shown as $\tilde{X}\ (x_1, x_2, x_3)$. The numbers represent the smallest possible value, the most probable value and the largest possible value, respectively.

The membership function $(\mu_X(x))$ of $\tilde{X}$ can be defined as;

$$\mu_X(x) = \begin{Bmatrix} \dfrac{x - x_1}{x_2 - x_1} \, for \rightarrow x_1 \leq x \leq x_2 \\ \dfrac{x - x_3}{x_2 - x_3} \, for \rightarrow x_2 \leq x \leq x_3 \\ 0 \\ \end{Bmatrix}$$

Fuzzifying the crisp number of X gives us a chance for approximation.

b) Fuzzy Arithmetic

(Kahraman et al., 2003) outlined the basics of fuzzy arithmetic. Let $\tilde{\mathrm{P}}(\mathrm{a,b,c})$ and $\tilde{\mathrm{Q}}(\mathrm{d,e,f})$ be fuzzy numbers. (a, b, c, d, e, f) are all positive numbers.

Changing Sign:

- (a, b, c) = (-c, -b, -a)

Addition:

$\tilde{\mathrm{P}} + \tilde{\mathrm{Q}} = (\mathrm{a + d, b + e, c + f})$

Subtraction:

$\tilde{\mathrm{P}} - \tilde{\mathrm{Q}} = (\mathrm{a - f, b - e, c - d})$

Multiplication:

$\tilde{\mathrm{P}} \otimes \tilde{\mathrm{Q}} = (\mathrm{ad, be, cf})$

Division:

$\tilde{P} / \tilde{Q} = (a/f, b/e, c/d)$

4.3 Integrated Fuzzy AHP Modeling

Integrated fuzzy AHP modeling with trapezoidal fuzzy numbers was first introduced by (Buckley, 1985) as an extension to (Saaty, 1980)'s AHP. In fuzzy AHP modeling, fuzzy ratios rather than crisp ratios are used for pair-wise comparisons. Let us suppose that a buyer wants to compare suppliers based on some criteria. Assume that one of the criteria is service performance. If the buyer had to perform pair-wise comparisons using normal AHP in order to build a comparison matrix, then he/she would have to choose a score from 0 to 9 to show how one supplier compares to another in terms of service performance. Although the comparison scales provide flexibility for a decision maker to set scores, in some conditions this flexibility does not guarantee a satisfactory decision. A fuzzy approach, on the other hand, captures the uncertainty in the decision maker's mind.

In fuzzy AHP literature, there are several approaches for deriving priorities from fuzzy pair-wise comparison judgments or matrices. Table 2 below lists some of these approaches.

Publication	**Fuzzy AHP Method**	**Type of Fuzzy Number**
(Van Laarhoven and Pedrycz, 1983)	Fuzzy logarithmic least squares method	Triangular
(Buckley, 1985)	Fuzzy geometric mean method	Trapezoidal
(Cheng and Mon, 1994)	Interval arithmetic	Triangular
(Chang, 1996)	Synthetic extent analysis	Triangular
(Xu, 2000)	Fuzzy least-squares priority method	Triangular
(Mikhailov, 2003)	Fuzzy linear and non-linear programming method	Crisp or Triangular

Table 2: Fuzzy AHP Approaches in the Literature

4.4 Linear Programming Method for Fuzzy AHP

We selected Mikhailov's fuzzy linear programming method among the methods presented in Table 2. As outlined in (Mikhailov, 2003), current methods have some clear disadvantages. They require heavy computations, may result in unacceptable final fuzzy scores, and need additional fuzzy ranking procedures. Fuzzy preference programming methods do not require constructing fuzzy comparison matrices. Also, priorities can be derived from an incomplete set of fuzzy judgments. This means knowing the fuzzy comparison number $\tilde{a}_{ij}$ (importance of $\tilde{a}_i$ over $\tilde{a}_j$) is enough for solving the problem, and it does not require $\tilde{a}_{ji}$ or $\tilde{a}_{ij}^{-1}$.

Fuzzy Linear Programming is an optimization method that aims to maximize the consistency index and results in finding the weights as shown below.

$$
\boxed{
\begin{array}{l}
\textit{maximize } \lambda \\
\textit{Subject to} \\
d\lambda + w_i - u_{ij}(\alpha) w_j \le d \\
d\lambda - w_i + l_{ij}(\alpha) w_j \le d \\
\sum_{k=1}^{n} w_k = 1 \\
w_k \ge 0, k = 1,2,\dots n \\
i = 1,2,\dots,n \quad j = 2,3,\dots n \quad j > i \\
\textit{where} \\
\tilde{a}_{ij} \textit{ is a triangular fuzzy number} = (l_{ij}, m_{ij}, u_{ij}) \\
l_{ij}(\alpha) = \alpha(m_{ij} - l_{ij}) + l_{ij} \\
u_{ij}(\alpha) = \alpha(m_{ij} - u_{ij}) + u_{ij} \\
\alpha, \mathrm{d} = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1 \\
i = 1,2,\dots n \;\; \mathrm{j} = 1,2,\dots,\mathrm{n} \;\; \mathrm{j} > \mathrm{i}
\end{array}
}
$$

The value of λ is called consistency index and has a value greater than one if the interval judgments are consistent, otherwise there will be a degree of inconsistency depending on the value of λ between zero and one. d_i is a tolerance parameter and can be set to 1 if all comparisons are symmetric. In this thesis, we assume that all comparisons are symmetric and set d_i to 1. In the decision support system, however, this value can be changed. α represents the membership value of the variable and is called alpha-cut. w_k represents the weight of the kth element. The total weights sum up to 1.

As indicated in (Mikhailov, 2003) the tolerance parameters should be chosen large enough to ensure a feasible solution and a positive value of λ. It is proven that values of these parameters greater than or equal to 1 fulfill these requirements. If the fuzzy judgements are symmetrical, it is safe for all tolerance parameters to be set equal to 1, since usually the decision maker has no preferences about his pair-wise comparison judgements. It should be noted that equal values of all tolerance parameters do not affect the value of the maximising solution w^* . A simple algorithm for adjusting the tolerance parameters, which maximises the degree of membership when the fuzzy judgements are non-symmetrical, is provided in (Mikhailov, 2003).

Example:

Let us consider this numerical example in order to understand how the algorithm works. We have three criteria, Quality (Q), Price (P) and Service (S) and we would like to weigh the importance of each criterion. We ask a decision maker to perform pair-wise comparisons of these criteria. We are going to have 3 pair-wise comparisons for these criteria in total. Assume that the decision maker provided the information below.

$$\tilde{a}_{(Q/P)} = (2.5, 3.0, 3.5)$$
$$\tilde{a}_{(Q/S)} = (3.5, 4.0, 4.5)$$
$$\tilde{a}_{(P/S)} = (1.5, 2.0, 2.5)$$

Then putting this information into the algorithm, assuming d = 1 and alpha-cut = 1;

$\max imize\ \lambda$

Subject to

$d\lambda + w_Q - u_{QP}(1)w_P \leq d$

$d\lambda - w_Q + l_{QP}(1)w_P \leq d$

$d\lambda + w_Q - u_{QS}(1)w_S \leq d$

$d\lambda - w_Q + l_{QS}(1)w_S \leq d$

$d\lambda + w_P - u_{PS}(1)w_S \leq d$

$d\lambda - w_P + l_{PS}(1)w_S \leq d$

$w_Q + w_P + w_S = 1$

$w_Q, w_P, w_S \geq 0$

where

$\tilde{a}_{ij}$ is a triangular fuzzy number $= (l_{ij}, m_{ij}, u_{ij})$

$l_{QP}(\alpha) = \alpha(m_{QP} - l_{QP}) + l_{QP} = 1 \times (3.0 - 2.5) + 2.5 = 3.0$

$l_{QS}(\alpha) = \alpha(m_{QS} - l_{QS}) + l_{QS} = 1 \times (4.0 - 3.5) + 3.5 = 4.0$

$l_{PS}(\alpha) = \alpha(m_{PS} - l_{PS}) + l_{PS} = 1 \times (2.0 - 1.5) + 1.5 = 2.0$

$u_{QP}(\alpha) = \alpha(m_{QP} - u_{QP}) + u_{QP} = 1 \times (3.0 - 3.5) + 3.5 = 3.0$

$u_{QP}(\alpha) = \alpha(m_{QP} - u_{QP}) + u_{QP} = 1 \times (4.0 - 4.5) + 4.5 = 4.0$

$u_{QP}(\alpha) = \alpha(m_{QP} - u_{QP}) + u_{QP} = 1 \times (2.0 - 2.5) + 2.5 = 2.0$

α, d = 1 (for simplicity)

$i = 1, 2, \ldots n$ $\mathrm{j} = 1,2,\ldots,\mathrm{n}$ $\mathrm{j} > \mathrm{i}$

As can be seen from the example this is a simple linear programming problem. The weights which maximize the lambda are the weights of the criteria. From here the system builds an optimization problem and calculates the weight of each criterion.

The resulting weights are:

$$W_Q = 0.62,\ W_P = 0.22,\ W_S = 0.16$$

The system then calculates weights of each supplier against each criterion along alpha-cut levels. It provides flexibility and ease of use, and allows the user to make quick and accurate decisions and try different alternatives. Weights of the suppliers for each criterion can be found in the same way and overall priorities can be calculated through aggregation of the priorities. The system finds the results for alpha-cuts from 0.1 to 1 increasing by 0.1, does the aggregation of priorities and shows the results in a graphical form. Detailed information on this can be found in the Chapter 5. Also for more detail on the fuzzy linear and non-linear methods as well as aggregation of the priorities can be found in (Mikhailov, 2000) and (Mikhailov, 2003).

In Chapter 5, we designed our decision support system which organizes empirical data about suppliers and pair-wise comparisons of criteria as inputs of the algorithm given above. A linear maximization problem is then solved using an application program interface (API) which is a set of routines and protocols. Results are displayed as graphs using another API.

Chapter 5: Design and Implementation

5.1 Web-Based Supplier Selection System

The system is built in an environment (Figure 17) using Java Servlets Technology[25], MySql[26] database, Apache Tomcat[27] web server and some other open source support software. The system has four main components as shown in Figure 18. The first is a database component in which information about new and existing suppliers as well as criteria information is stored. The second is a data process component that allows decision makers to define criteria and select the suppliers to be ranked. Ratings for some of the criteria can also be acquired from a third party or from back end systems such as enterprise resource planning (ERP) systems. The third and fourth components are calculation and optimization engines. The third component uses AHP with options of fuzzy linear and non-linear programming modules. Drasys API[28] functions are used only for solving the linear programming problem. Supplier ranking and selection is performed by the third component, but in case the decision maker needs to determine the optimal quantity of goods to order from selected suppliers, he/she can use the fourth component but this part has not been implemented in this thesis. In this last situation, constraints such as the capacity of suppliers must be taken into account.

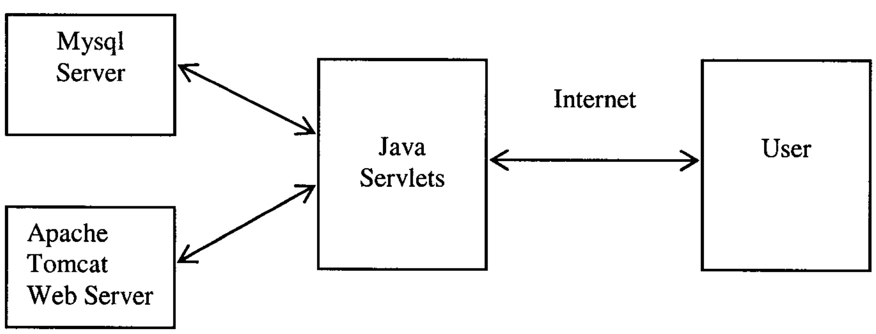


Figure 17: Decision Support System Environment

[25] http://java.sun.com/products/servlet/
[26] http://www.mysql.com/
[27] http://jakarta.apache.org/tomcat/
[28] http://opsresearch.com/OR-Objects/api/overview-summary.html

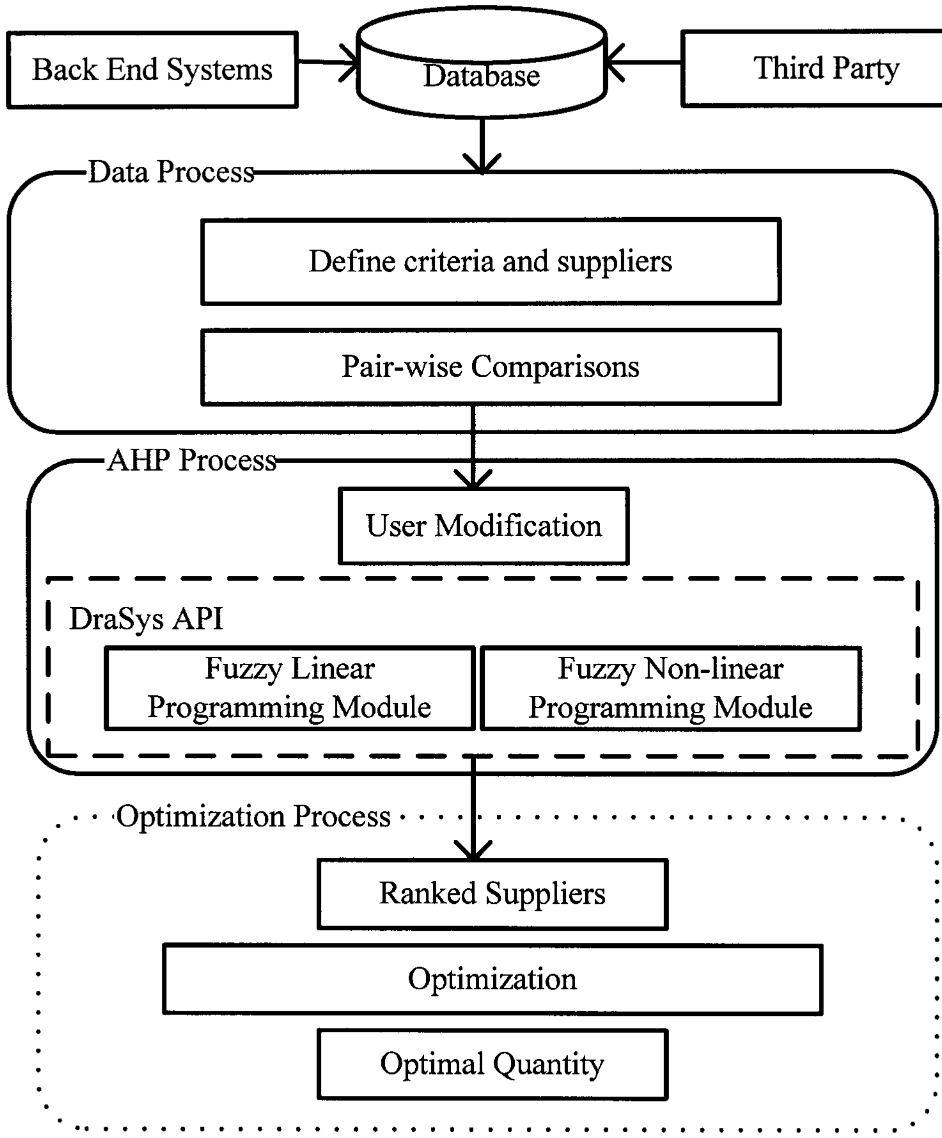


Figure 18: Supplier Selection System

The various steps of the methodology as well as some screenshots are provided below.

1. Step: Defining Suppliers and Comparison Criteria

Determining the number of suppliers which will be compared under certain criteria is the first step for supplier selection process using the system. The system displays all suppliers from a certain category (maintenance parts suppliers for instance) as well as a number of criteria including the most important ones mentioned in the literature such as quality, delivery, price and service (Figure 19). Some other criteria can also be added into the system depending on the user's needs and considerations.

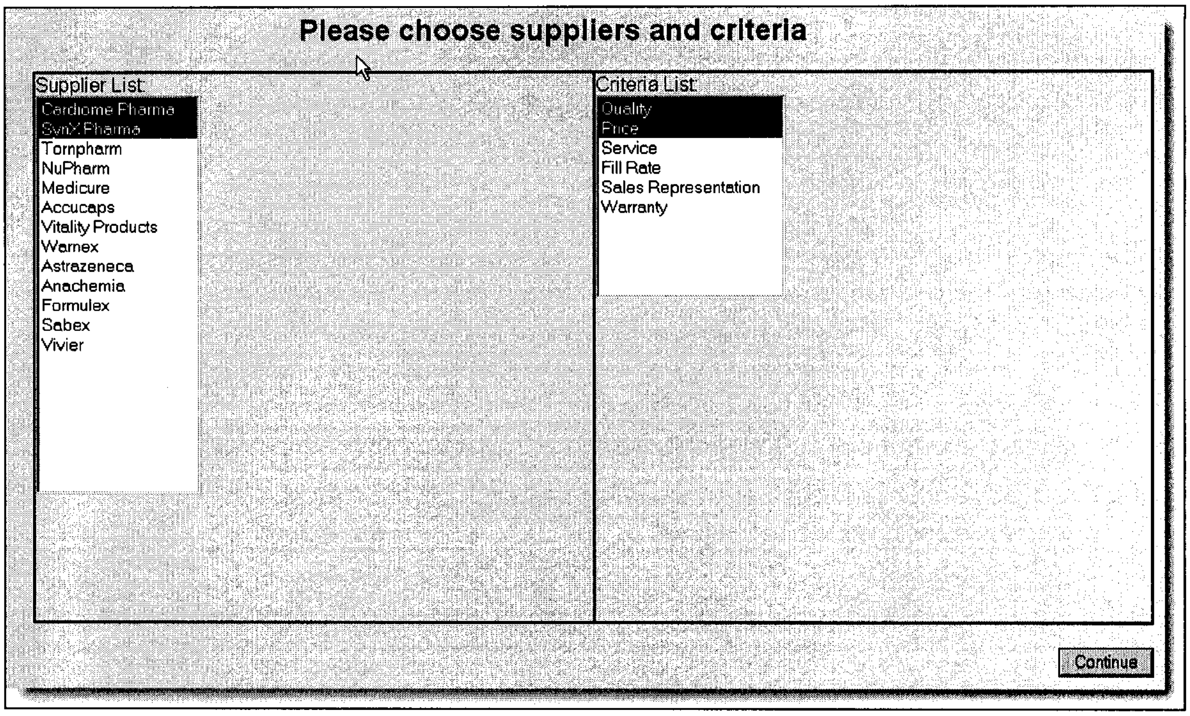


Figure 19: Suppliers and Criteria Selection for Comparison

2. Step: Review and/or Modification of Supplier Ratings

Our system requires that suppliers should be rated periodically or after every transaction based on a number of criteria. These ratings are stored in a relational database (Figure 20, 21). The scale used for these ratings is between zero and ten. By using mean ratings and standard deviations ($\pm \sigma$) the system produces triangular fuzzy numbers and gives the ratio of these fuzzy numbers as comparison values (Figure 22). When producing these numbers, in order to prevent from going outside the scale boundary, the upper value of the triangular fuzzy number is defined as $Min(10,(\bar{x}+\sigma))$ and the lower value is defined as $Max(0,(\bar{x}-\sigma))$. Decision makers have the option to change these numbers if they wish. Also if there is a new supplier to be added and there is no rating available for this supplier, the decision maker should fill out ratings for this supplier based on his/her own judgement. Figure 23 is a screenshot that shows supplier ratings.

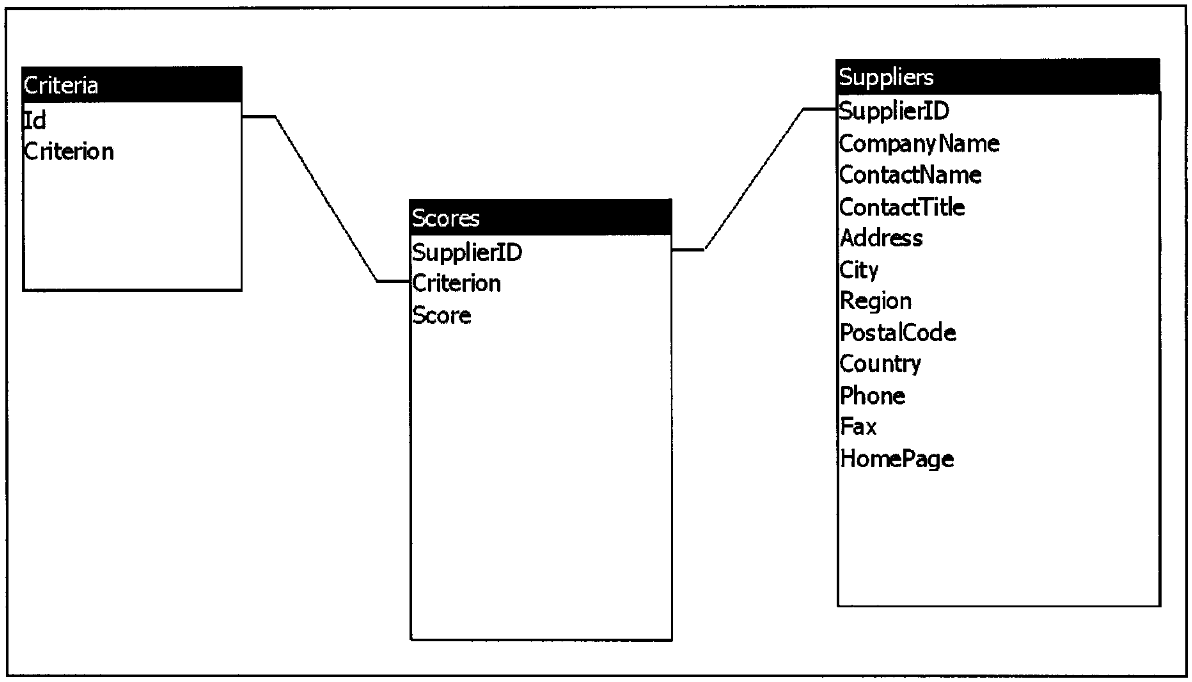
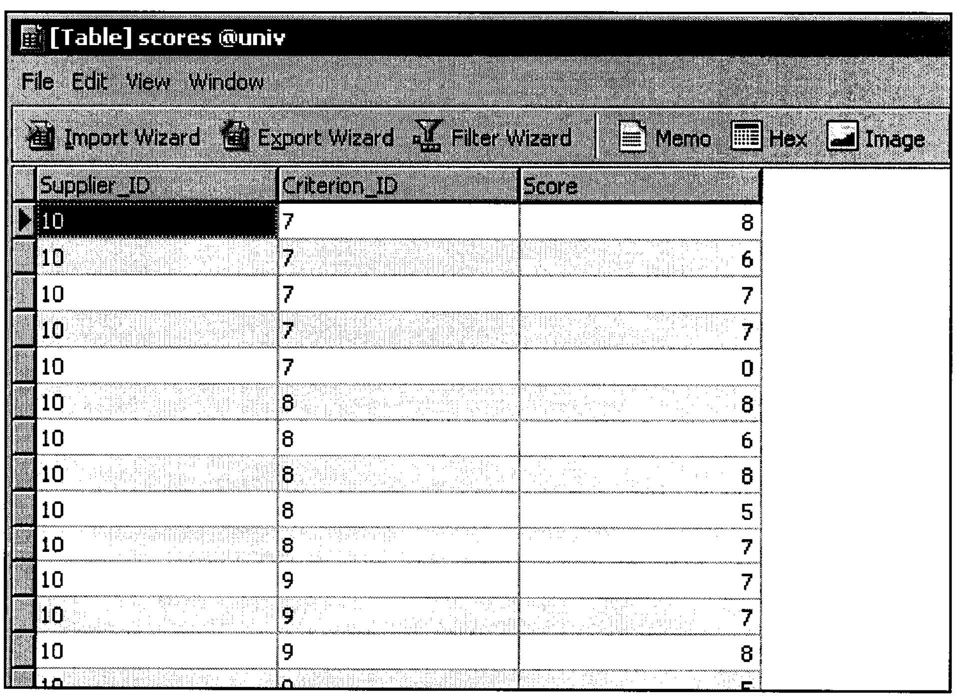


Figure 20: MySql Database Relationship Diagram



Supplier_ID	Criterion_ID	Score
10	7	8
10	7	6
10	7	7
10	7	7
10	7	0
10	8	8
10	8	6
10	8	8
10	8	5
10	8	7
10	9	7
10	9	7
10	9	8

Figure 21: Database Table for Supplier Rates

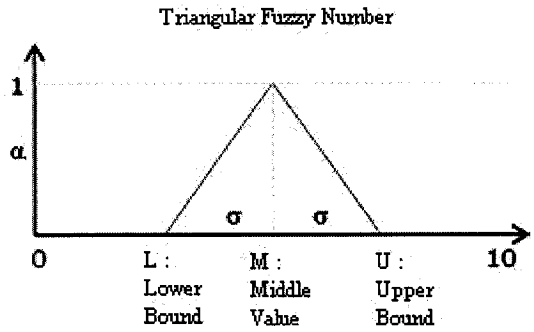


Figure 22: Formation of Triangular Fuzzy Numbers using Supplier Rates

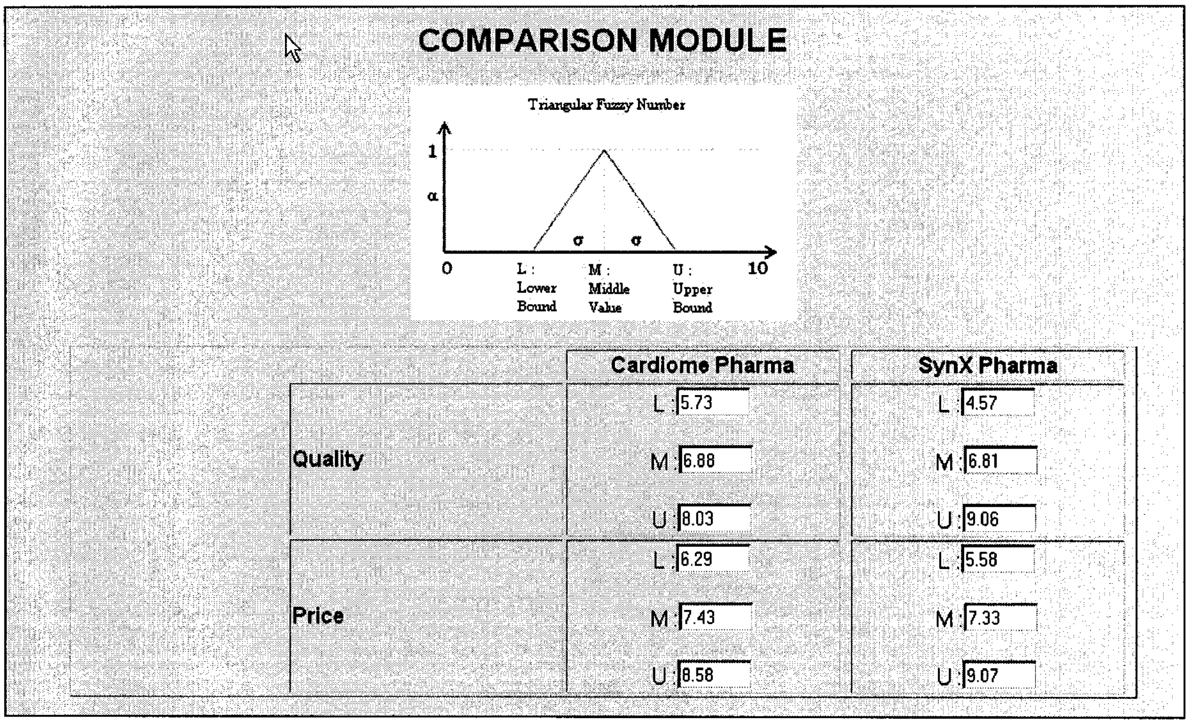
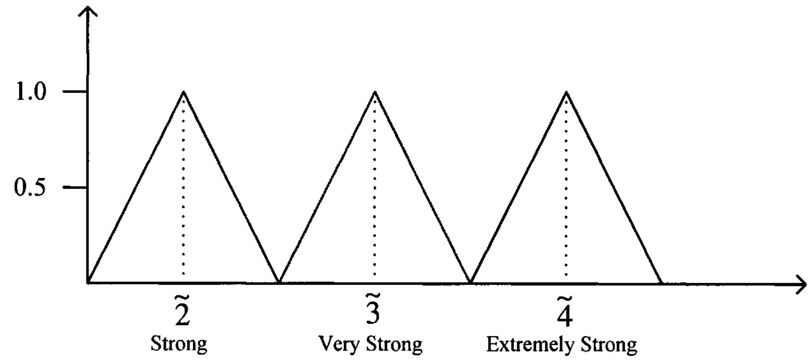


Figure 23: Supplier Scores Based on Criteria as Fuzzy Numbers

3. Step: Pair-Wise Comparison of Criteria

If supplier rates are accepted by the user either as is, or after modification, then the user performs pair-wise comparison of criteria using linguistic comparison variables (Figure 24, 25).



	Lower Value	Middle Value	Upper Value
Extremely Strong	7/2	4	9/2
Very Strong	5/2	3	7/2
Strong	3/2	2	5/2
Same	3/4	1	5/4
Weak	2/3	1/2	2/5
Very Weak	2/5	1/3	2/7
Extremely Weak	2/7	1/4	2/9

Figure 24: Linguistic Variables and their Membership Functions

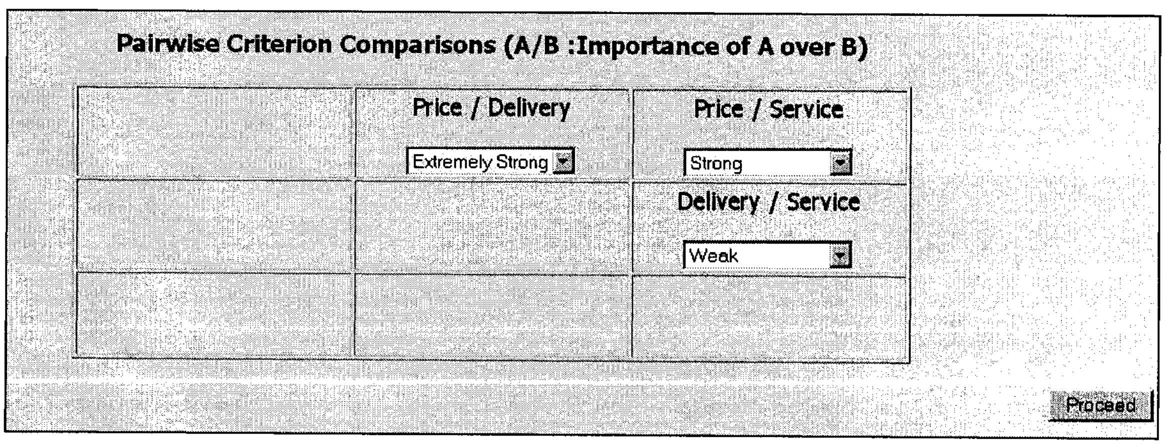


Figure 25: Pair-wise Comparisons for Criteria

Each linguistic variable has a family of fuzzy sets that represent its membership value. These sets are named as alpha-cuts.

From here the system builds an optimization problem and calculates the weight of each criterion using the fuzzy linear programming method for each alpha-cut level. The system then calculates weights of each supplier against each criterion along alpha-cut levels.

Overall ranking of each supplier is calculated by combining criteria weights with supplier weights for each criterion. Results are provided for each alpha-cut and displayed in graphs. Graphs are created using "Kava Chart"[29], a Java charting utility. Results and output graphics are provided with a case study.

Our system framework is designed for single and multiple sourcing as well as for fuzzy linear and non-linear optimization methods. However, in this thesis we only consider single sourcing and we only used fuzzy linear programming. But the system can easily be improved to enable the buyer to order an optimal quantity from each supplier under given constraints. The system provides flexibility and ease of use, and allows the user to make quick and accurate decisions and try different alternatives.

[29] http://www.ve.com/kavachart/index.html

Chapter 6: Application

6.1 Introduction

To validate our choice of the Fuzzy AHP model and also to validate the conceptual design of our supplier selection decision support system, we conducted a case study in a local hospital. We opted for a hospital case study because the nature of the procured goods calls for different procurement (as well as e-procurement) processes. The second section of this chapter discusses procurement in the healthcare sector, and then describes some efforts to introduce e-procurement. The third section looks at the procurement and e-procurement processes of the local hospital where the case study is conducted. The fourth section is dedicated to the actual case study. In this section, three different types of products are considered: routine, operational, and capital. Several supplier selection criteria are used in the ranking process. Whenever possible, we used empirical data, but in the absence of empirical data, decision makers were asked to use the support system to enter ratings.

6.2 Healthcare Procurement

Healthcare procurement is an interesting and unique process which has gone through significant changes along with technological developments over the past decade. Canadian healthcare procurement is public sector procurement which makes it even more interesting. The topic of healthcare procurement has attracted researchers, and several research papers are dedicated to it. Cost related issues, the importance of the price over other criteria, and buyer supplier relationships are among the most investigated topics in healthcare procurement.

6.2.1 Supplier Selection Criteria in Healthcare Procurement

Defining supplier selection criteria for different product types is very important in healthcare procurement as it is in other areas. (Lambert et al., 1997) observe that because of the huge increase in healthcare spending, efforts to reduce costs are focused on the procurement of health sector goods rather than delivery of healthcare to the patient. The authors state that procurement of goods is around 16 to 28 percent of a hospital's budget so that reduction in these costs would bring significant reduction to the whole budget. Since cost became an important issue, the authors inquired whether price is more important than the other key criteria such as quality, delivery and service and if that is the case, and whether low-priced suppliers are getting more sale contracts than the others.

Purchasing literature, in general, shows that for multiple sourcing environments, delivery, quality and price should be considered as important criteria while in single sourcing, reliability of the product and technical support are more important. The importance of these criteria also depends on whether we are dealing with a routine or strategic product (Lambert et al., 1997).

The authors examined various criteria used in the selection of suppliers of coagulation reagents which are used in hospital laboratories for various tests and diagnostics and considered as routinely used multiple sourcing items. Procurement happens in a strict environment that is regulated by federal specifications, brand substitution is high and there are only minor differences among competing products. Results show that "product reliability" is the most important criterion for healthcare procurement among a total of 79 criteria while "supplier sponsored technical seminars" is the last. High importance is also given to "supplier responsiveness" to product related problems. Delivery and service related criteria including "required lead time", "quality control information", and "ability to expedite emergency orders" are among the most important criteria as well. It is interesting to see that none of the 15 price related criteria are in the first 20. We can conclude from here that despite a big cost reducing efforts, price still is not as important as the other criteria for healthcare procurement.

Supporting (Lambert et al., 1997)'s conclusion, (Garfamy, 2003) argues that effective selection and evaluation of suppliers and collaboration with them in supply chain processes would bring improved performance as well as increased customer satisfaction to the buyer company. For supplier evaluation, the author initially considered six criteria, which are listed as cost, quality, cycle time, service, relationship and organization, and conducted a case study using a "cross-case synthesis" technique in two companies, one large sized public healthcare institution and the other medium sized private production company. Despite huge differences between the processes of these two firms, both results reveal that all the criteria except cost have an impact on performance and customer satisfaction. This indicates that in procurement processes that aim to improve performance and enhance customer satisfaction, price is not as important as the other criteria.

6.2.2 Healthcare e-Procurement

Findings of recent research reveal that usage of e-commerce technologies have added a positive value to healthcare procurement and resulted not only in cost savings and efficiency but also in improved buyer supplier relationships.

Recent news show hospitals and their suppliers have started improving their connectivity using e-commerce technologies because of great cost saving opportunity and improved efficiency. A US hospital utilized web based technology for its purchasing department which eventually reduced the costs and increased collaboration with suppliers. Collaboration with suppliers is an important issue in the healthcare industry, as important as the other industries, and IT helps create successful healthcare supply chains, by automating processes including contract management and facilitating collaboration as well as connectivity with suppliers (Solarek, 2004).

Supporting the idea, (White and Daniel, 2004) argue that e-marketplaces help buyers choose from a number of suppliers, compare their products and prices and help suppliers easily locate their buyers. Because of these benefits, the number of e-marketplaces is rapidly increasing within various sectors. Since competition in e-marketplaces is based on price, some buyers and suppliers who believe in collaboration refrain from joining such places. Taken this concern into consideration, the authors inquired about the impacts of e-marketplaces and IT on buyer-supplier relationships in the healthcare sector. Contrary to common belief, results show significant reduction in the number of suppliers and an improvement in buyer and supplier relationships. Also, both buyer and supplier companies reported an improvement in the process such as decreased number of errors, fast and efficient communication and rehabilitated payment procedure.

6.3 The Procurement Process of a Local Hospital

The stage of our case study is a local hospital. This hospital currently uses a combination of both traditional and electronic procurement. However, the term electronic procurement should be used with caution. The hospital's e-procurement is limited to Electronic Data Interchange (EDI) not the web based e-business version.

Traditional Method of Procurement

In a traditional procurement process, a properly authorized hard copy of a requisition is provided by the end-user to the purchasing department specifying the supplier, product description, product catalogue number, quantity, price, cost centre and special delivery instructions. Once all of the information is gathered, the purchasing department conducts price negotiations, determines the source of supply, verifies for quantities requested and arranges delivery schedules. Decisions are made with end users, finance and other departments as appropriate. Purchasing serves as the exclusive channel through which all requests regarding prices and products are handled except in the case where clinical or technical details are required, the using department may correspond directly with the suppliers. Buyer then assigns a purchase order and places the order via phone or fax.

e-Procurement

The hospital has a total of 405 suppliers, 14% of which have EDI capability. Buyer creates an electronic version of the requisition by transferring the specifications from the manual requisition provided by the end user. Orders are then submitted to the EDI capable suppliers electronically.

Classification of Procured Items

There are six types of products being procured by the hospital. In our case study we only consider three product types.

Routine: consumable product expensed to the operating budget

Service: non-tangible product, expensed to the operating budget

Minor Capital: equipment valued between $250- $2,499

Major Capital: equipment valued at $2500.00 and higher.

Direct: A product ordered by the end-user on an as need basis. Typically this is a slow moving product, which does not warrant keeping in-house as an inventory item.

Stock: high moving product kept in Stores (in-house)

Rating System Availability

As there are many sophisticated computer generated key performance indicators available via the hospital's GEAC[30] Smartstream software, Material Management currently rates vendors manually using a number of criteria. The hospital is currently working on activating the use of such indicators electronically.

6.4 The Case Study

For this case study we consider the procurement processes of routine products, operational products and major capital products.

For routine products or operational (minor capital) products, there normally is a primary supplier, and because of the importance of buyer supplier relationships, not many criteria are being considered. Order frequency for routine or operational products is very high; so that the supplier selection process would be very time consuming taking the previous reason into consideration. However, procurement of capital products is very complex and a number of criteria need to be considered.

[30] http://www.smartstream.geac.com/page/default_SMS

For the first two product types, routine and operational products, we couldn't find any empirical ratings, thus we asked decision makers to use the support system to enter ratings. The decision maker assigned crisp rating values so that triangular fuzzy numbers could not be created based on the decision maker's opinions. To handle this problem we assigned standard deviation of 1 to each rating and produced our fuzzy numbers. Since the assumed standard deviations are equal to each other and we have a limited number of suppliers and criteria, results are quite obvious. Nonetheless, the results validate the data, therefore we believe that for more complicated situations we would get correct results from the decision support system.

6.4.1 Procurement of a Routine Product

The hospital, like any other institution which provides accommodation, requires buying of routine products, such as soup, diapers, french fries, gloves, etc. For these types of high volume routine products, the buying frequency is very high. These types of products are procured from wholesale distributors not from manufacturers. There is a suggested manufacturer price so that profit margin is very low. Thus prices of distributors do not differ from each other too much. Procurement of these routine products, therefore, depends on some other criteria. Availability of the product is the most important criterion that the decision maker sees. Supplier Relationship is also an important criterion, since frequent interactions between buyer and supplier require special attention. The hospital wants to get awarded from ordering high volumes of a product at the end of the year, so that depending on sale amounts, supplier companies promise a share from the profit (called Value added Incentives). These three criteria are mostly used in procurement processes of routine products (See 6.4.1.1 and 6.4.2.1 for more details).

6.4.1.1 Data Collection

The hospital does not have empirical ratings for the suppliers who provide routine products. Therefore, we asked the decision maker to provide mean ratings for each supplier and each criterion combination as well as standard deviations. Table 3 shows these ratings. We also asked the decision maker to perform pair-wise comparisons of the criteria (see Table 4) that are considered in the procurement of routine products.

RATINGS PER CRITERION	Company A		Company B		Company C	
	Mean	StDev	Mean	StDev	Mean	StDev
Supplier Relationships	5	1	7	1	9	1
Availability	9	1	9	1	9	1
Value added Incentives	4	1	7	1	9	1

Table 3: Ratings for Routine Products Suppliers

Supplier Relationships	has	Weak	importance over	Availability
Supplier Relationships	has	Same	importance over	Value added Incentives
Availability	has	Extremely Strong	importance over	Value added Incentives

Table 4: Linguistic Comparison of Criteria

6.4.1.2 Results

Our results reflect the decision maker's thinking. Looking at Figure 26 we can see that almost 60% of the total weight is assigned to the Availability criterion. Availability is really important for routine products, as it was discussed before. 23% of the total weight is assigned to Supplier Relationships. Stronger supplier relationships in this case would result in higher availability rates since suppliers might have an opportunity to check stock levels of the buyer through web services and adjust their stock levels or production plans.

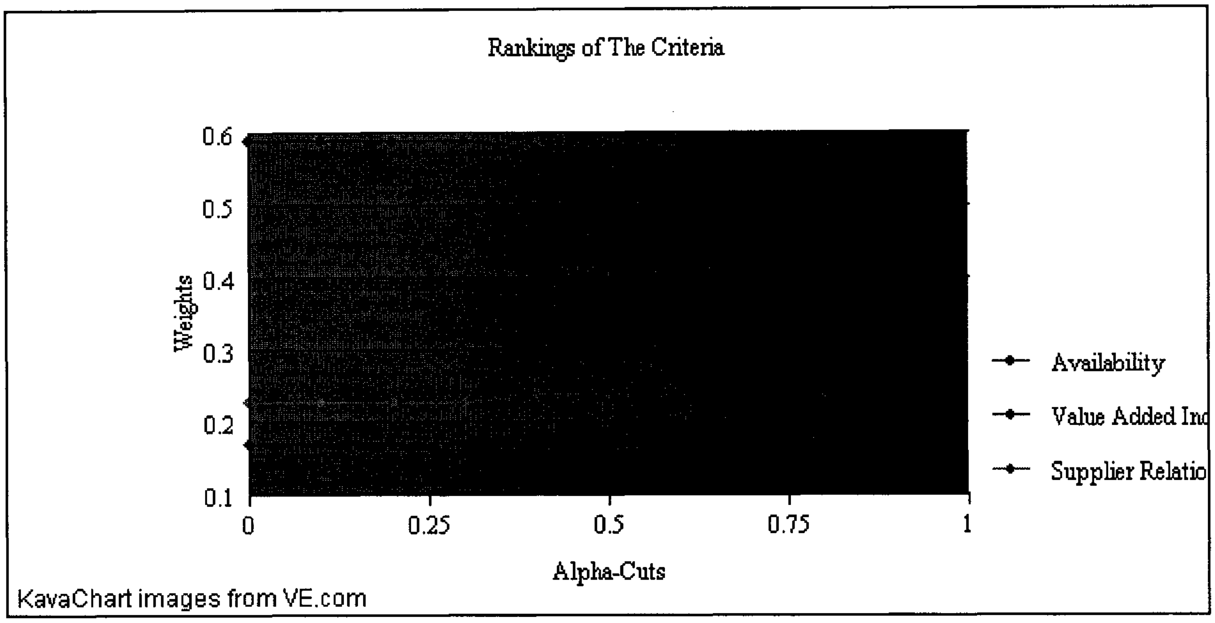


Figure 26: Rankings of the Criteria

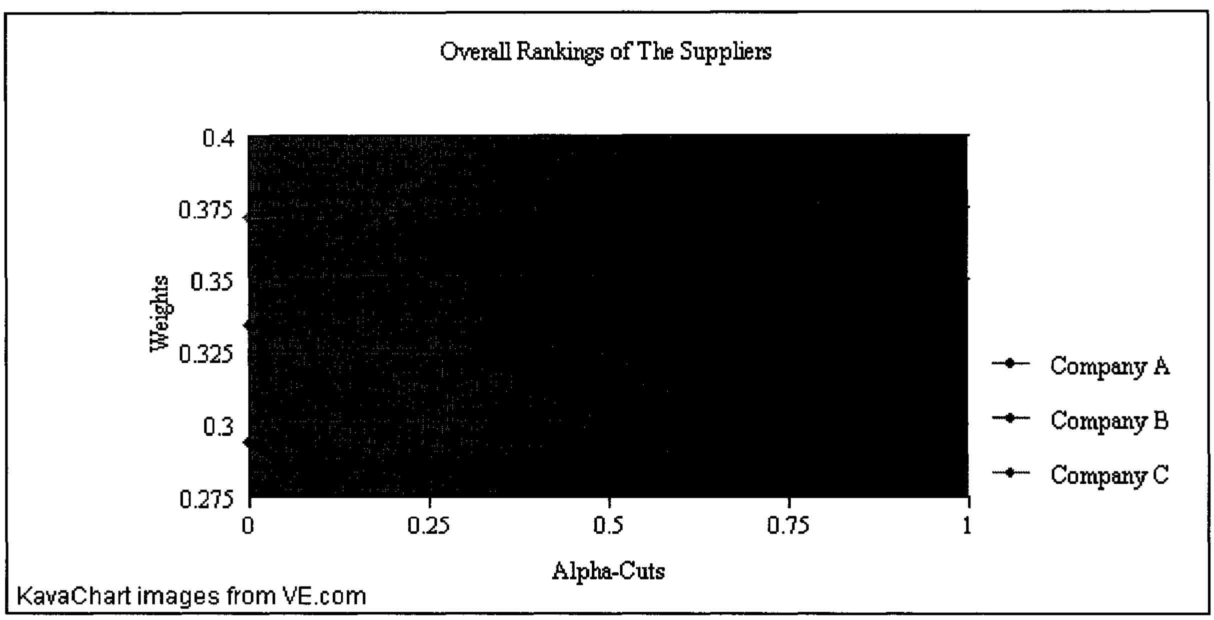


Figure 27: Overall Rankings of Routine Product Suppliers

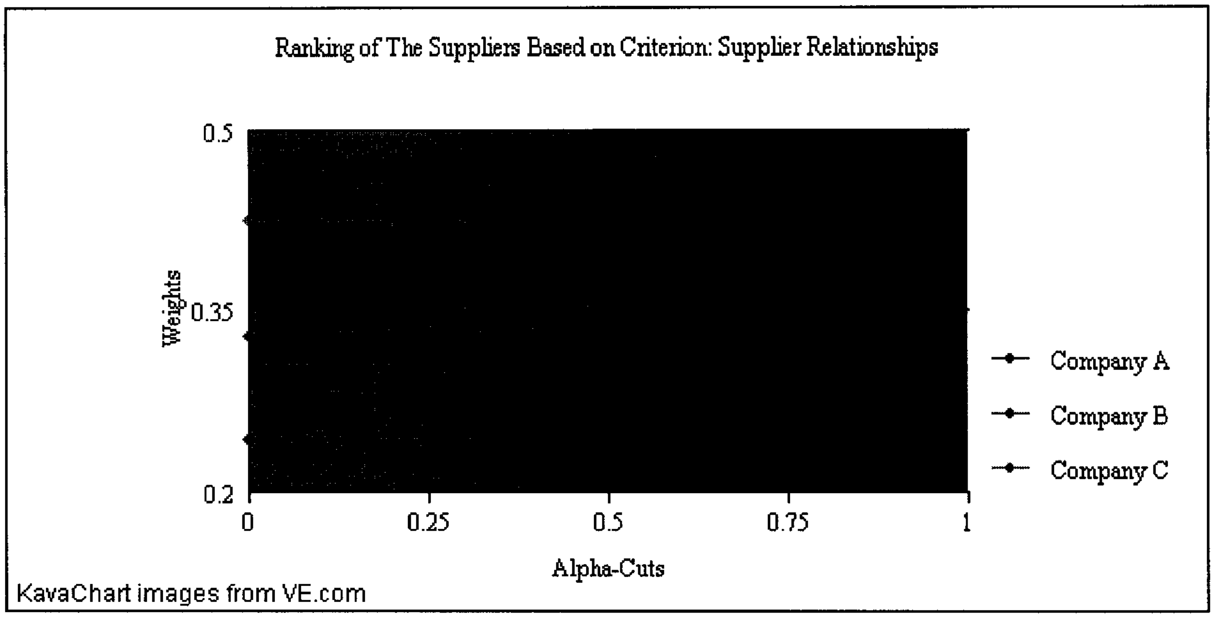


Figure 28: Rankings based on Supplier Relationships along Alpha-Cuts

Overall rankings of the suppliers show that the winner company for routine products is Company C (Figure 27). Rankings of the suppliers as well as overall weights assigned to the suppliers are reflective of the decision maker's thinking and they can be used to virtually illustrate the situation and conduct further analysis. Figures 28 shows ratings of the suppliers based on the Supplier Relationships criterion.

6.4.2 Procurement of an Operational Product (Minor Capital)

As a second type of product, we considered sterilization containers, which are operational products under the minor capital equipment category. Contrary to routine products, price plays an important role in this procurement process. But the most important criterion being considered is Clinical Acceptability. Supplier Relationships also play an important role. For this procurement process, four suppliers are selected to be ranked, and three criteria are considered for this ranking process: Clinical Acceptability, Price and Supplier Relationships. Price and Clinical Acceptability are conflicting objectives in this case and Supplier Relationship stands as an independent criterion whose importance might affect the selection process.

6.4.2.1 Data Collection

There are no empirical ratings for this procurement process, either. Therefore, we asked the decision maker to provide mean ratings for each supplier and each criterion combination. Table 5 provides these ratings.

We also asked the decision maker to perform pair-wise comparison of the criteria (See Table 6) that are considered in the procurement of operational products.

RATINGS PER CRITERION	**Company D**		**Company E**		**Company F**		**Company G**	
	Mean	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Clinical Acceptability	9	1	5	1	6	1	6	1
Price	9	1	8	1	7	1	5	1
Supplier Relationships	9	1	9	1	9	1	4	1

Table 5: Ratings for Sterilization Containers Suppliers

Clinical Acceptability	has	Very Strong	importance over	Price
Clinical Acceptability	has	Extremely Strong	importance over	Supplier Relationships
Price	has	Strong	importance over	Supplier Relationships

Table 6: Linguistic Comparison of Criteria

6.4.2.2 Results

For rankings of the criteria, we can see from the results (Figure 29) that "Clinical Acceptability" is the most important criteria with 62% of the total weight. Price is the second important criterion with 22% weight and Supplier Relationships, which has little less importance than price is the last one with 16% weight. Results fully confirm the decision maker's pair-wise comparisons of the criteria.

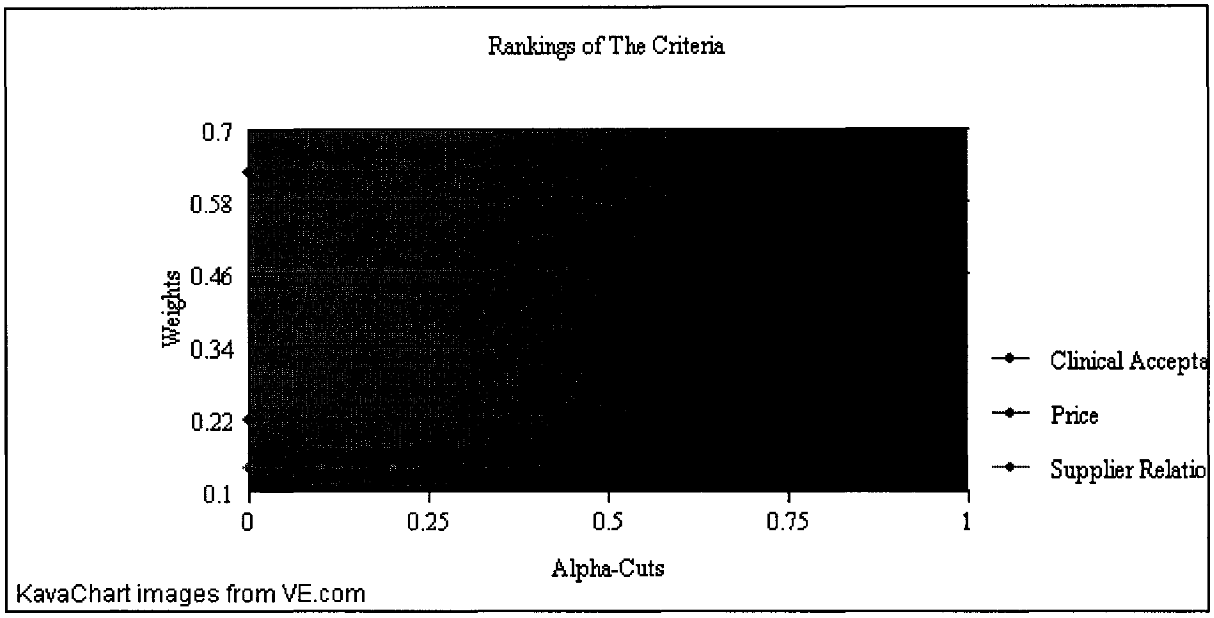


Figure 29: Rankings of the Criteria

Rankings of the suppliers (Figure 30) are also very reflective of the initial rankings of the suppliers. Overall, we can see that Company D is the winner and Company F follows. There is little difference between Company F and Company E, but Company G is the last in the rankings. Company D has a clear advantage from its Clinical Acceptability level. Results show that even with very high prices, rankings of the suppliers would not be different, and Company D would still keep its first place.

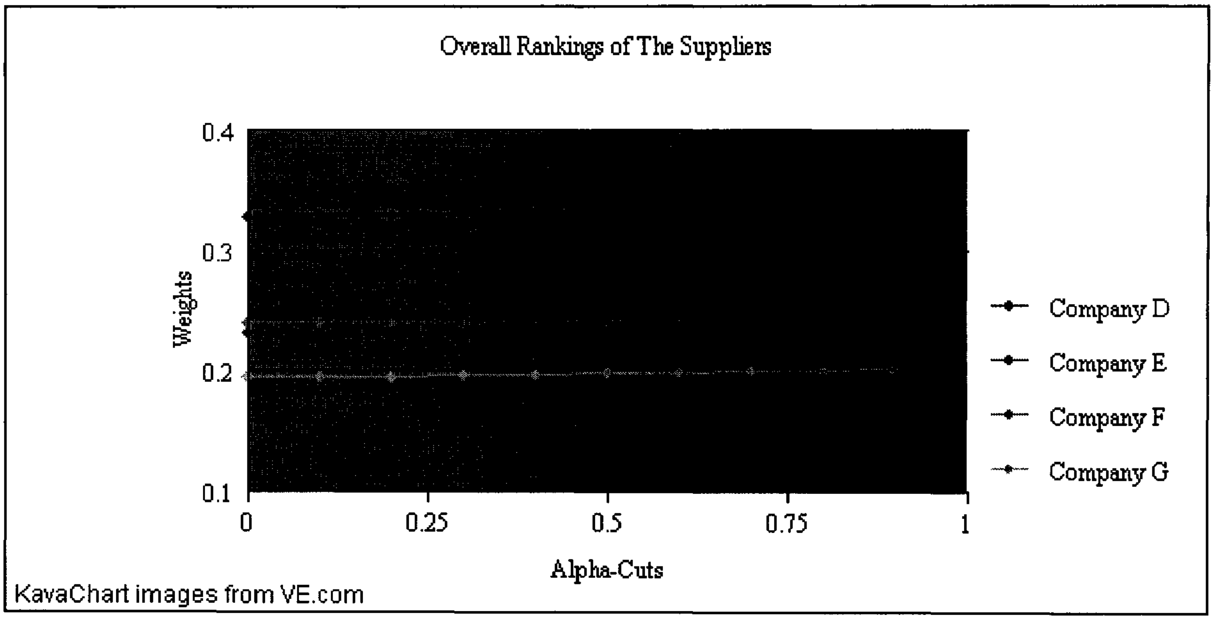


Figure 30: Overall Rankings of Sterilization Containers Suppliers

Looking at the supplier ratings per criteria, we can see differences in the rankings. Figure 31 shows that Company D has the most desired Clinical Acceptability level. Company F and Company G have almost the same level of Clinical Acceptability. Company D is close but has a lower weight. Despite Company E having the worst Clinical Acceptability level, it has ranked third overall, not last.

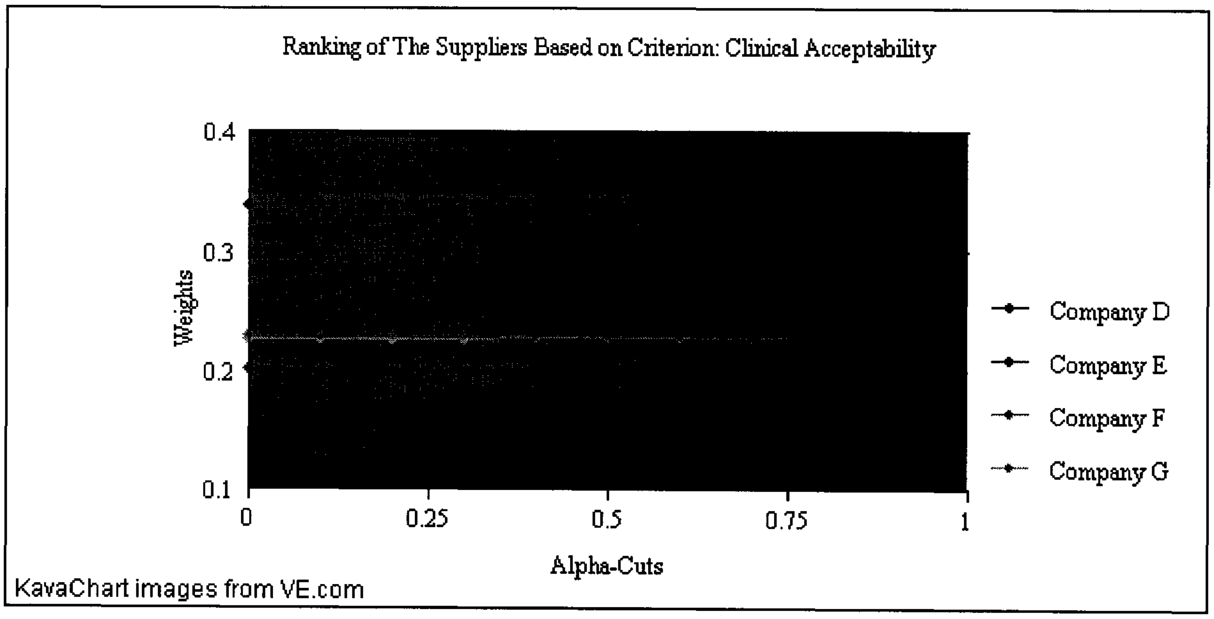


Figure 31: Rankings based on Clinical Acceptability along Alpha-Cuts

6.4.3 Procurement of a Capital Product

The last process we consider is procurement of a capital product. This process is the most interesting and complex one because of its nature. Many criteria are considered in the procurement of capital products so it is essential to have a decision support system. The right product with maximum benefits and minimum cost should be selected. There should be considerations such as "products which have more functions do not have to be the best; we only have to consider the functions that we need". Price related criteria are also important, so the decision maker should look at all price related criteria, not only the price tag. Payment term schedule, maintenance costs, etc. might have to be considered as well. From this perspective, we can see that this process is a good example of multi criteria decision making problems with conflicting objectives.

The decision maker considers three suppliers and nine criteria for this process. The criteria being considered are Price, Delivery Capabilities, Payment Term Schedule, Specifications and Upgrade Ability, Warranties and Service, References, Spectrums, Value Added or Partnership Initiatives, and Instrument Operating Cost. The decision maker did not consider Supplier Relationships as one of the criteria, but considered Warranties and Service instead.

6.4.3.1 Data Collection

Table 7 shows the original weight assessments for each criterion as well as the weighted average of the empirical ratings of two existing suppliers. For this process, we have access to empirical data as opposed to the other procured product types. However, we have a new supplier (Company J) which doesn't have any ratings available. Since we did not have any empirical ratings available for Company J, we asked the decision maker to use the system and enter ratings for this supplier. The decision maker did not assign any deviation for these ratings, thus we use crisp ratings rather than fuzzy ones for this supplier. Table 8 shows ratings per criterion as well as standard deviations of ratings. Table 9 shows pair-wise comparisons of the criteria considered in this procurement process.

We considered three different scenarios for this process. In the first scenario, we consider all the criteria and observe the differences between assigned weights of the criteria and weights from pair-wise comparisons. We also observe if we have same rankings of the suppliers. In the second scenario, we eliminate the two price related criteria and run the model again, to see if that would change the rankings of the suppliers and also to observe criteria weights. In the last scenario, we perform a sensitivity analysis on the price criterion.

Evaluation Criteria	Weight	Weighted Average of the Supplier Ratings	
		Company B	Company V
A – Price	25	20.8	15.8
B - Delivery Capabilities	10	6.4	7.2
C - Payment Term Schedule	5	3.5	3.4
D - Specifications and Upgrade Ability	15	10.8	10.8
E - Warranties and Service	10	8.2	4.8
F - References	5	3.2	2.1
G - Spectrums	15	8.4	6.6
H - Value Added or Partnership Initiatives	10	6.8	6.8
I - Instrument Operating Cost	5	3.7	2.9

Table 7: Criteria Weight Assessments and Supplier Ratings

RATINGS PER CRITERION	Company J		Company B		Company V	
	Mean	StDev	Mean	StDev	Mean	StDev
A – Price	8	0	8.3	1.16	6.32	2.07
B - Delivery Capabilities	4	0	6.4	2.42	7.2	2.14
C - Payment Term Schedule	5	0	7	1.9	6.8	1.94
D - Specifications and Upgrade Ability	6.67	0	7.2	0.98	7.2	1.17
E - Warranties and Service	7	0	8.19	1.17	4.8	0.75
F – References	1	0	8	1.26	5.2	2.14
G – Spectrums	6.67	0	5.6	2.87	4.4	2.73
H - Value Added or Partnership Initiatives	4	0	6.8	1.17	6.8	1.17
I - Instrument Operating Cost	8	0	7.4	1.62	5.8	1.17

Table 8: Supplier Ratings per Criterion

PAIRWISE COMPARISON OF CRITERIA	A	B	C	D	E	F	G	H	I
A – Price		Very Strong	Strong	Same	Extr. Strong	Very Strong	Extr. Strong	Strong	Extr. Strong
B - Delivery Capabilities			Same	Weak	Same	Strong	Strong	Weak	Very Strong
C - Payment Term Schedule				Weak	Same	Very Strong	Strong	Same	Very Strong
D - Specifications and Upgrade Ability					Very Strong	Extr. Strong	Same	Very Strong	Extr. Strong
E - Warranties and Service						Strong	Strong	Same	Strong
F - References							Same	Weak	Very Strong
G - Spectrums								Weak	Strong
H – Value Added or Partnership Initiatives									Very Strong
I - Instrument Operating Cost									

Table 9: Pair-wise Comparison of the Criteria using Fuzzy Linguistic Variables

6.4.3.2 Results

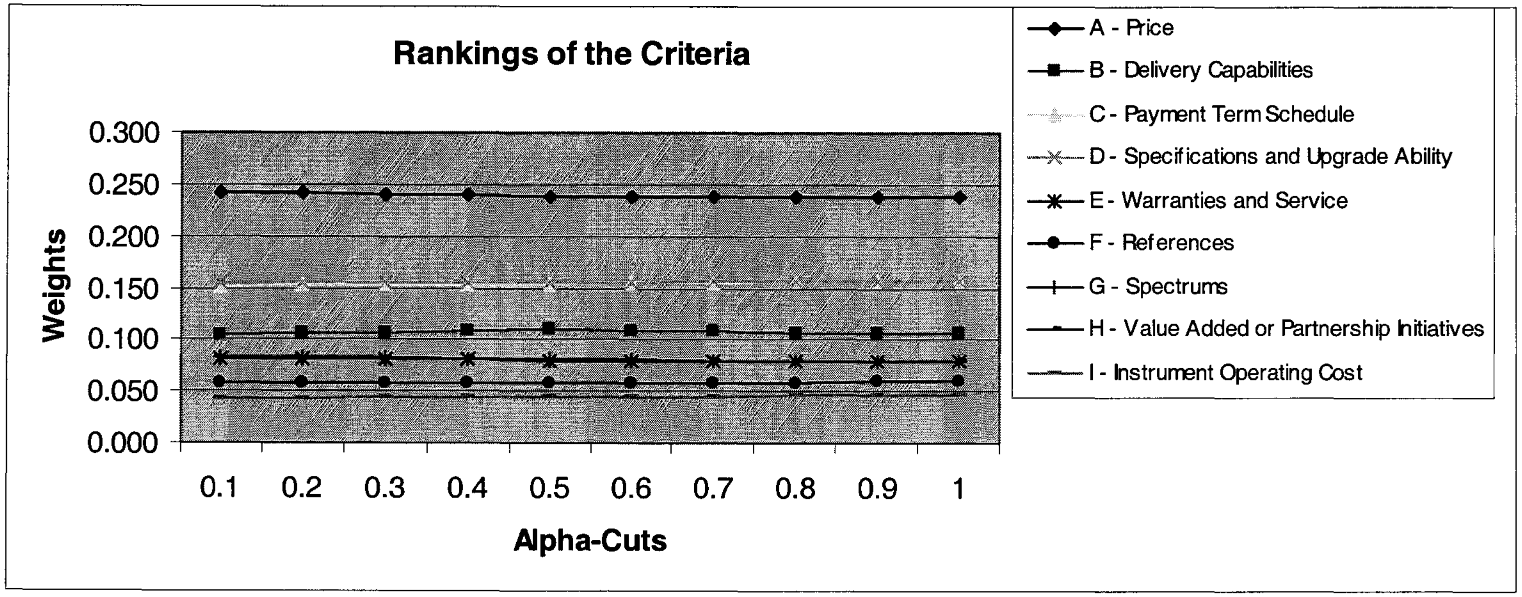
Considering All the Criteria

From the results (Figure 32, Table 10) we can see that the "Price" is the most important criteria for this capital product procurement process. After "Price", "Specifications and Upgrade Ability" takes the second place. "Payment Term Schedule" is third and "Delivery Capabilities" is fourth.

We also compared our results with the initial weights that are assigned by the decision maker. We can see that using fuzzy linguistic variables did change a few of the original ratings. These changes were found meaningful by the decision maker who anticipated these results before performing the pair-wise comparisons.

Evaluation Criteria	Assessed Weight	Calculated Weight
A - Price	25%	24%
B - Delivery Capabilities	10%	11%
C - Payment Term Schedule	5%	15%
D - Specifications and Upgrade Ability	15%	16%
E - Warranties and Service	10%	8%
F - References	5%	6%
G - Spectrums	15%	8%
H - Value Added or Partnership Initiatives	10%	8%
I - Instrument Operating Cost	5%	4%

Table 10: Assessed and Calculated Weights for the Evaluation Criteria



Alpha-Cuts	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Lambda	0.950	0.947	0.944	0.942	0.939	0.936	0.933	0.930	0.927	0.924
A – Price	0.242	0.241	0.241	0.240	0.238	0.238	0.238	0.238	0.237	0.237
B - Delivery Capabilities	0.104	0.106	0.107	0.108	0.110	0.109	0.108	0.107	0.106	0.106
C - Payment Term Schedule	0.152	0.152	0.152	0.153	0.154	0.155	0.155	0.156	0.157	0.157
D - Specifications and Upgrade Ability	0.154	0.154	0.154	0.154	0.155	0.155	0.156	0.157	0.157	0.157
E - Warranties and Service	0.081	0.081	0.081	0.080	0.080	0.079	0.079	0.079	0.079	0.079
F – References	0.058	0.058	0.058	0.058	0.058	0.059	0.059	0.059	0.059	0.059
G – Spectrums	0.083	0.083	0.082	0.082	0.081	0.080	0.080	0.080	0.079	0.079
H - Value Added or Partnership Initiatives	0.081	0.081	0.081	0.080	0.080	0.079	0.079	0.079	0.079	0.079
I - Instrument Operating Cost	0.043	0.043	0.044	0.044	0.045	0.045	0.045	0.045	0.046	0.046

Figure 32: Rankings of all the Criteria for a Capital Product

For pair-wise comparisons, we need to analyze the Consistency Index (Lambda) and see if there is any inconsistency among the decision maker's pair-wise comparisons. We would want Lambda to be greater than 1 for better consistency. The consistency index is close to one (Figure 33) and that shows us that the pair-wise comparisons are consistent and the results are meaningful.

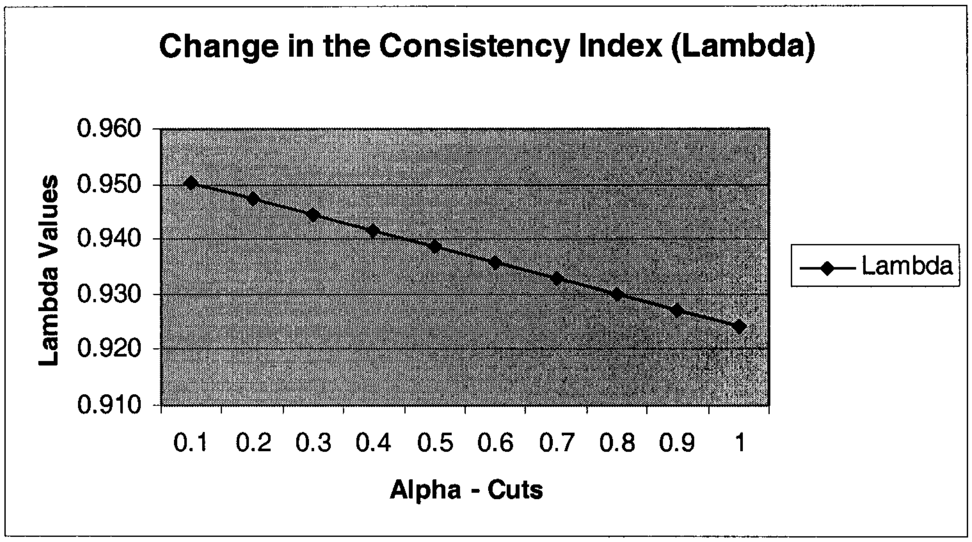


Figure 33: Change in the Consistency Index along Alpha-Cut levels

Based on the ratings of the suppliers for each criterion and linguistic comparisons of the criteria, system results (Figure 34) show that rankings of the suppliers from the best to the worst are Company B, Company V and Company J. These rankings are similar to the decision makers'. From Figure 35, we can see that Company B has the most competitive price and Company J follows it very closely. Despite the fact that it has the second place overall, Company V has the worst price offer. Because of this result, we consider eliminating all price related criteria in the second scenario and observe the winning supplier based on the other criteria.

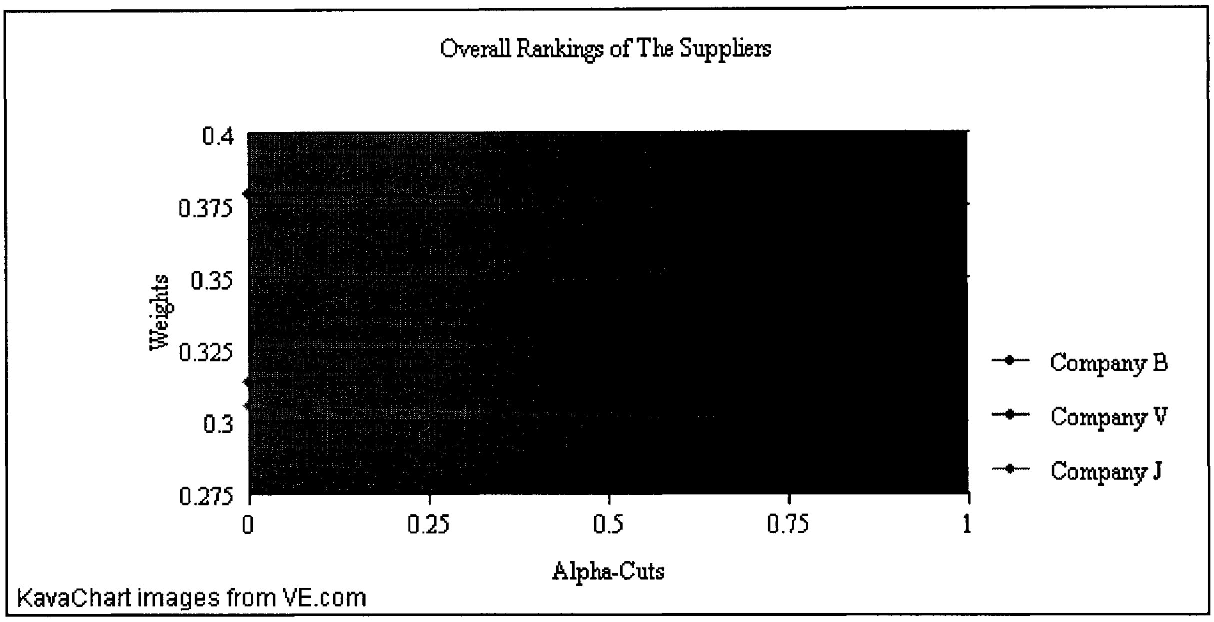


Figure 34: Overall Rankings of the Suppliers

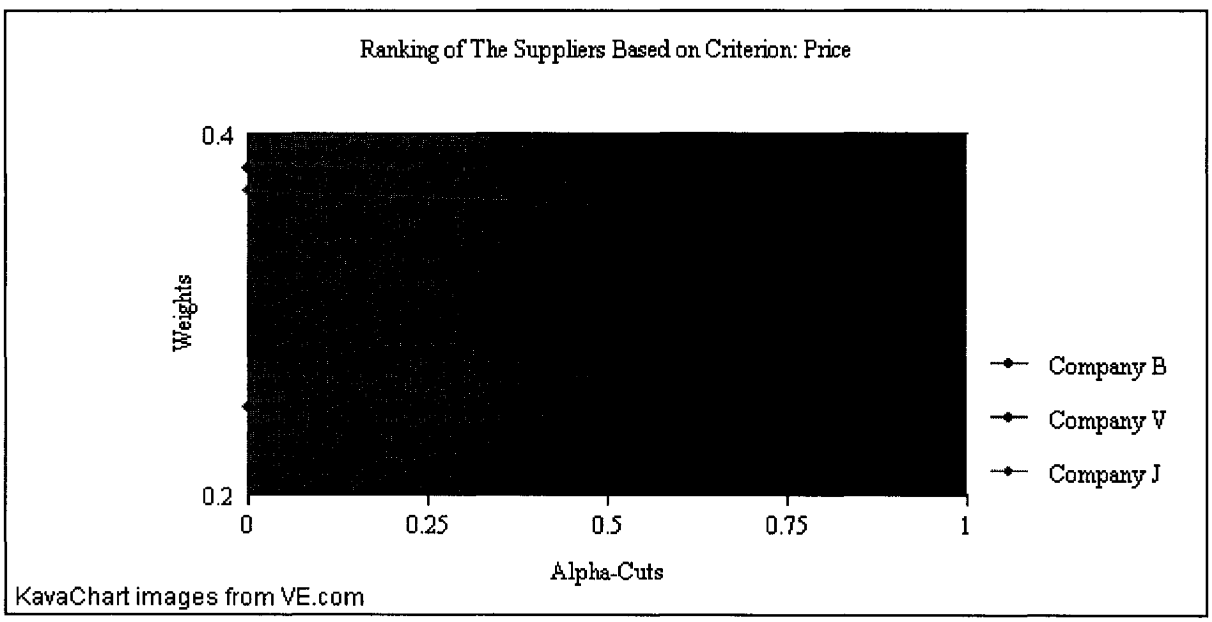


Figure 35: Rankings of the Suppliers Based on Criterion: Price

Eliminating the Price related criteria

Among the nine criteria we can see that there are two price related criteria: Price and Payment Term Schedule. We would like to find out after removing the two price related criteria, how the other seven criteria would weight. Results are provided below (See Table 11).

Criteria	Weights
D - Specifications and Upgrade Ability	25.5%
B - Delivery Capabilities	17.9%
G - Spectrums	13.5%
E - Warranties and Service	13.1%
H – Value Added or Partnership Initiatives	13.1%
F - References	9.6%
I - Instrument Operating Cost	7.2%

Table 11: Criteria Weights after Removing Price Related Criteria

Running the model without considering Price, and the "Payment Term Schedule", we observed that Company B is the winner. That shows that even not considering price or price related criteria, Company B has a clear advantage over other supplier companies.

Removing price related criteria from the supplier selection process might lead to a wrong decision since there might be huge differences in the prices of the suppliers and this removal might neutralize and conceal these differences. Therefore we need to conduct sensitivity analysis of the price to see how changes in the price ratings of the supplier affect rankings of the suppliers.

Sensitivity Analysis of Price Criterion

Leaving the other ratings constant, we need to answer the question "is there a chance for Company B to win if the other suppliers have a very competitive price?". To answer the question, we performed a sensitivity analysis on the price criterion. The results indicate that if Company J and Company V have very competitive prices, Company B still wins if its price rating is 6.5 or 65 %. If it has less than this rating, Company V wins (See Table 12, Figure 36).

Suppliers	Weights
Company B	34.7%
Company V	34.6%
Company J	30.7%

Table 12: Supplier Weights

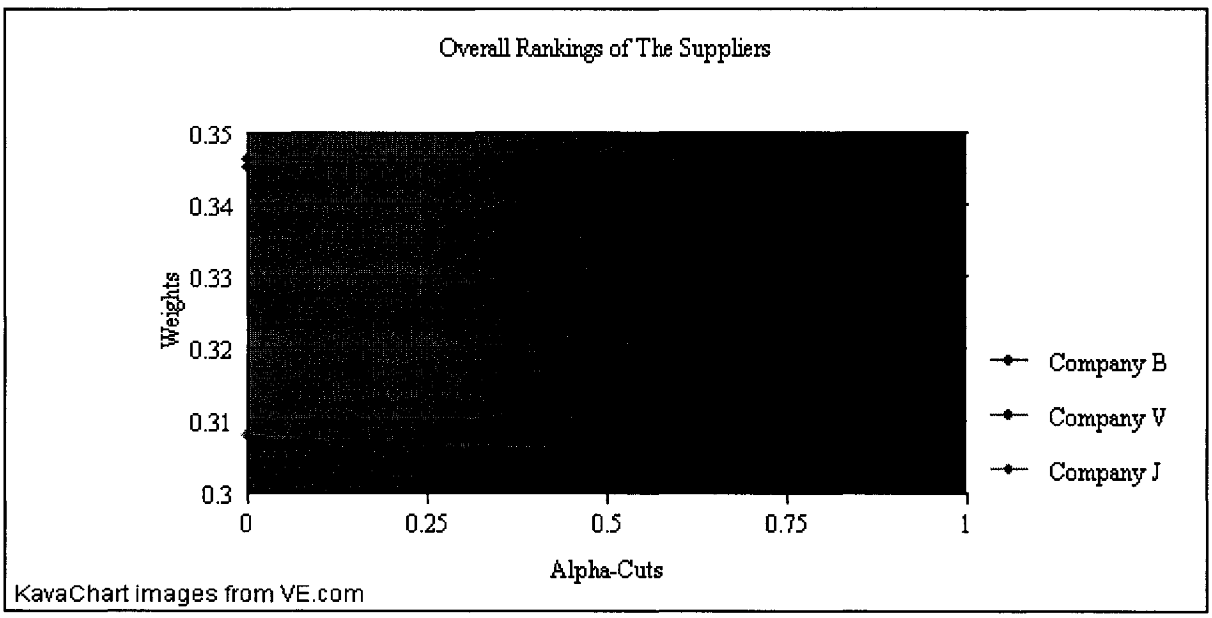


Figure 36: Overall Rankings for the Sensitivity Analysis

6.4.4 Final Discussion

Criteria Being Considered

Practically, for capital equipment purchasing processes, price is not very important, a belief that is also supported by the literature. But contrary to this belief, in their RFQ requests companies increase the weight of the price criterion to refrain their suppliers from increasing the price. If price is the second highest criterion, suppliers might make price higher than their normal asking values. Therefore, even if a buyer company doesn't believe that the price plays a big role in purchasing of capital products, they play aggressively on the price to keep it low.

Linguistic Pair-wise Comparison of Criteria

Discussions with the decision maker who used our system indicated that the decision maker finds the system a little bit complicated for simple purchasing processes and thinks that the system can only be best used with capital products, or very complex purchasing projects.

In a regular capital product purchasing process, stakeholders hold a meeting to decide on which criteria should be considered in purchasing of the product as well as the percentage weight of each criterion. One of the difficulties that the decision maker might face with the original assessment is lack of flexibility. For example if price is removed from the assessment, weights should be defined again since weights are determined in a scale. But with pair-wise comparisons in our model, there is no need to rescale the weights; only the pair-wise comparisons related to the price criterion need to be removed. The decision maker found linguistic variables helpful for smooth agreement among stakeholders, who do not directly decide on the weights of the criteria but decide on linguistic pair-wise comparisons between criteria.

Usage of Empirical Data

Since the system doesn't fully depend on pair-wise comparisons like traditional AHP, it is really important to see the feasibility of supplier data collection. Some commercial supplier rating systems, such as PeopleSoft's "Supplier Rating System"[31], are available but buyer companies should be aware of the fact that supplier rating is a continuous process and should be performed periodically, after every transaction, for instance.

However a dilemma emerges in this case because the decision maker needs to establish this kind of performance ratings database for high volume, routine products with high frequent order suppliers and normally, for this type of products, decision making is not a very complicated process. For capital products however, since the frequency of orders is low, it is hard to find empirical ratings.

The decision maker expressed his concerns over some other problems related to the usage of empirical data (supplier ratings) for the supplier ranking process. Rating after every transaction is industry dependent but there is still a need for a ratings database, since the buyer can measure, record, and validate past performance indicators of a certain supplier.

Ratings are important, but supplier relationships are also important, and that should be taken into consideration. The downside of using ratings for the ranking process is that you may have less room for change of position for your choice of suppliers. Also sometimes empirical data might not reflect the real situation and the supplier who had low ratings in the past might become a very good supplier and using bad empirical ratings from the past penalizes that supplier. The decision maker wants to store ratings for each supplier, especially key suppliers that touch the core of the business, but doesn't want to use the ratings as is in the supplier ranking process.

[31] http://www.peoplesoft.com/corp/en/products/epm/module/supplier_rating.jsp

As a conclusion, we think that an electronic supplier rating system is necessary for buyer companies and ratings of a supplier should be done after every transaction for capital equipment and at least every month for high volume products.

Graphical Display of Results

Ranking results are always open to arguments and disputes, and suppliers who lost the offer try to challenge the decision. Therefore graphical results are helpful for high level debriefing to suppliers and explaining to them weaknesses compared to the winner supplier.

Graphical displays are also useful to show how the weights are changing along alpha-cuts so that the decision maker would have an understanding of how rankings change from extreme values to expected values.

6.5 Conclusion

In this chapter, we have validated the application of fuzzy AHP methodology to the healthcare supplier selection process as well as the conceptual design of our web based decision support system. We have selected the healthcare industry because of the specificity of the industry and the nature of the procured goods. Research findings show that price is not an important criterion for healthcare procurement. To verify this claim while validating the methodology and the system, we conducted a case study considering three different product types: Routine, Operational and Capital. For each product type there are different criteria and each product type calls for a different process.

We are satisfied with the validation process, as we validated the design of a support system by letting decision makers use it, modify and/or enter ratings for suppliers and perform pair-wise comparisons. The decision makers found the system fast and easy to use, and found the results meaningful; however they found the system useful mostly for complex procurement processes such as capital products procurement. The decision makers found it beneficial to have a supplier ratings database for all product types, however usage of the system for routine products and operational products would be very time consuming and since these processes are simple in their nature, it is not recommended to use the system for these products.

The fuzzy AHP methodology has also been validated. All three product types in the case study involve conflicting objectives. Therefore, as a multi criteria decision making method with the ability to capture vagueness in a decision maker's thinking, fuzzy AHP is one of the best candidates for supplier selection in the healthcare industry.

We chose to validate our research in a healthcare environment, but results show that our supplier selection framework would be as beneficial in any industry that deals with complex procurement processes involving many suppliers and criteria.

Conclusions

In this thesis we studied e-procurement and its related technologies and trends. We classified e-procurement applications and illustrated the effects of these applications on supplier relationships.

We demonstrated that moving procurement to the Internet is beneficial to both buying and selling organizations. We noticed a continuous but slow movement from procurement to e-procurement. However, e-procurement technology and related technologies are still in their infancy, which explains why some of the applications have not been sufficiently successful. By the time the security and integration problems are solved and widely accepted standards are in place, moving from procurement to e-procurement will be accelerated.

Our research is focused on the supplier selection problem in e-procurement. We performed an extensive review of the literature which gave us the opportunity to define commonly used measures and criteria for the supplier selection task.

We also reviewed supplier selection models that have been used to evaluate, rank and select suppliers, and provided a review of general AHP and Fuzzy AHP models. Several fuzzy AHP models are applied to supplier selection and other areas as well. But many of these models are static, case-based, and problem oriented. Moreover, related criteria and objectives have to be well defined in advance, thus adding or removing a criterion would require questionnaires to be redesigned and calculations to be restarted. This shows the need for a decision support system in the supplier selection process based on the Fuzzy AHP methodology.

To our knowledge, all supplier selection solutions in the literature fully depend on the choices and comparisons made by the expert (also called the decision maker in this thesis). We propose that the expert be supported with empirical data. If no empirical data is available, a single expert can provide a range of ratings that can be used instead of empirical data. Another option is to have the services of expert assessors who assign ratings to suppliers based on past interactions with those suppliers. Pair-wise comparisons of criteria can be performed by one single expert or by different experts from different departments who would meet for that purpose.

Taking all of these observations into consideration, we built a web-based decision support system and validated the system and the underlying methodology using a case study that we conducted in a local hospital.

Our contribution to the literature is the design of the first AHP model that does not fully depend on an expert's pair-wise comparisons. The model combines empirical data with pair-wise comparisons. To the best of our knowledge, we have designed, implemented and deployed the first web-based Fuzzy AHP supplier selection system that uses a fuzzy linear programming method.

Future Work

The expansion of the research reported here may go in the following directions:

1. The system can be improved by letting decision makers use it and suggest way to make it more "user friendly". It can be extended and developed for multi supplier, multi criteria sourcing (see page 56), so that the system can support the "how much from each supplier question".

2. Results can be compared with the results of other models and tools. Fuzzy Data Envelopment Analysis would be an appropriate method to compare with Fuzzy AHP. Strengths and weaknesses of each method and/or tool can be compared and analyzed.

3. To justify the assumption that similar results can be obtained in other fields, more case studies can be conducted to insure that the system performs well with other data and organizations.

Publications Resulted from This Work

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Benyoucef M., Canbolat M. , "E-procurement Technologies and Trends", Working Paper, University of Ottawa, 2004

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Appendix

Summary of the procedures of the following codes is as follows;

Hosp. java: In this part, the system connects to the database and retrieves and displays lists of suppliers and criteria. A decision maker identifies a number of suppliers and determines the criteria to be considered in the selection process.

Hcompare.java: In this part, the system calculates ratings of the suppliers for each criterion and calculates the mean rating and the standard deviation of the ratings. Based on these mean values and standard deviations, it displays lower, middle and upper values of the ratings per criterion. The decision maker can modify these values if necessary. The system also displays a screen for the decision maker to perform pair-wise comparisons of the criteria selected.

Hopt.java: Finally, in this part, the system prepares the data for the optimization process. The optimization algorithm, which aims to maximize the consistency index and to find the weights of the suppliers for each criterion is coded. The linear programming problem in this optimization process is solved using Drasys API. Results are displayed as graphs using KavaChart API.

HOSP.JAVA

```
import javax.servlet.*;
import javax.servlet.http.*;
import java.io.*;
import java.sql.*;
import java.util.*;
import java.net.*;

public class hosp extends HttpServlet {
   private final String driverName = "com.mysql.jdbc.Driver";
   private final String connURL = "jdbc:mysql://localhost/hosp";
   private final String username = "root";
   private final String password = "123";
   private static final String CONTENT_TYPE = "text/html";



   public String getSuppliers()
   {
      Connection con = null;
      String html = "Supplier List:<br>\n";
      try {
         Class.forName(this.driverName).newInstance();
         con = DriverManager.getConnection(this.connURL, this.username,this.password);
         Statement statement = con.createStatement();
         ResultSet rs = statement.executeQuery("SELECT * from suppliers");

         html += "<SELECT NAME=suppliers MULTIPLE SIZE=20>";
         while (rs.next())  //FOUND RECORD!
         {
            String s = rs.getString("CompanyName");
            html += "<option value='" +s+ "'>" + s + "</option>";
         }
         html+= "</SELECT>";

         return(html);
      }
      catch (SQLException sqle) {
         return (html + "<br><br>" + sqle.toString() + "<br>SQL State: " +
sqle.getSQLState());
      }
      catch (ClassNotFoundException cnfe) {
         return (cnfe.toString());
      }
      catch (Exception e) {
         return (e.toString());
      }
      finally {
         try {
            if (con != null)
               con.close();  //try to close the db connection
         }
         catch (SQLException sqle) {
            return (sqle.toString());
         }
```

```
    }
  }

  public String getCriteria()

  {
    Connection con = null;
    String html = "Criteria List:<br>\n";
    try {
      Class.forName(this.driverName).newInstance();
      con = DriverManager.getConnection(this.connURL, this.username,
this.password);
      Statement statement = con.createStatement();
      ResultSet rs = statement.executeQuery("SELECT * from criteria");

      html += "<SELECT NAME=criteria MULTIPLE SIZE=10>";
      while (rs.next()) //FOUND RECORD!
      {
        String c = rs.getString("Criterion");
        html += "<option value='" +c+ "'>" + c + "</option>";
      }
      html+= "</SELECT>";

      return(html);
    }
    catch (SQLException sqle) {
      return (html + "<br><br>" + sqle.toString() + "<br>SQL State: " +
sqle.getSQLState());
    }
    catch (ClassNotFoundException cnfe) {
      return (cnfe.toString());
    }
    catch (Exception e) {
      return (e.toString());
    }
    finally {
      try {
        if (con != null)
          con.close();  //try to close the db connection
      }
      catch (SQLException sqle) {
        return (sqle.toString());
      }
    }
  }

  /**Initialize any global variables*/
  public void init(ServletConfig config) throws ServletException {
    super.init(config);
  }

  /**Process the HTTP Get request*/
  public void doGet(HttpServletRequest request, HttpServletResponse response)
  throws ServletException, IOException {
    response.setContentType(CONTENT_TYPE);
    PrintWriter out = response.getWriter();
```

```
    out.println("<html>");
    out.println("<head><title>Supplier List</title></head>");
    out.println("<p><h2 align=center>CHEO Material Management</h2>");
    out.println("<body bgcolor=white background=../images/PaperTexture.gif><h3 align=center>Please
Choose Suppliers and Criteria</h3>");
    //construct a page from the mySQL data
    out.println("<form action='../servlet/hcompare' method=POST>");
    out.println("<p><div align=right><table border=1 cellpadding=0 cellspacing=0 style=border-collapse:
collapse bordercolor=#111111 width=917 height=449><tr><td width=459 height=449 valign=top>");
    out.println(getSuppliers());
    out.println("<p><td width=458 height=449 valign=top>");
    out.println(getCriteria());
    out.println("</table></div>");
    out.println("<p align=right> <input name=\"value\" type=\"submit\" value=\"Continue\"></p>");
    out.println("</form>");
    out.println("</body></html>");

  }


  public void doPost(HttpServletRequest request, HttpServletResponse response)
  throws ServletException, IOException
  {

  }
    /** do any cleanup */
  public void destroy()
  {
  }
}
```

HCOMPARE.JAVA

```
import javax.servlet.*;
import javax.servlet.http.*;
import java.io.*;
import java.sql.*;
import java.util.*;
import java.net.*;

public class hcompare extends HttpServlet {


  public void init(ServletConfig config) throws ServletException {
    super.init(config);

  }

  public void destroy()
  {

  }

  protected void processRequest(HttpServletRequest request, HttpServletResponse response)
  throws ServletException, IOException {
```

```
response.setContentType("text/html");
PrintWriter out = response.getWriter();
//here we define the matrix to store scores for selected suppliers for a given criterion.
int maxcriteria = 20;
int maxsuppliers = 40;
double [][] average = new double [maxcriteria][maxsuppliers];
double [][] stdev = new double [maxcriteria][maxsuppliers];
double [][] lower = new double [maxcriteria][maxsuppliers];
double [][] upper = new double [maxcriteria][maxsuppliers];
double [] clower = new double [maxcriteria];
double [] caverage = new double [maxcriteria];
double [] cupper = new double [maxcriteria];
double [] cinterval = new double [maxcriteria];
double [][] cratio_lower = new double [maxcriteria][maxcriteria];
double [][] cratio_average = new double [maxcriteria][maxcriteria];
double [][] cratio_upper = new double [maxcriteria][maxcriteria];
String  selectedsuppliers[]=request.getParameterValues("suppliers");
String  selectedcriteria[]=request.getParameterValues("criteria");
out.println("<html>");
out.println("<head>");
out.println("</head>");
out.println("<body bgcolor=white background=../images/PaperTexture.gif>");
out.println("<h2 align=center>COMPARISON MODULE</h2>");
out.println("<p align=center><img src=../images/fuzzy.jpg></p>");
out.println("<FORM METHOD=POST ACTION='../servlet/hopt'>");
out.println("<table border=1 align=center>");
out.println("<TR><TH></TH>");
for (int i = 0;i<selectedsuppliers.length;i++)
{
  out.println("<TD><TH>"+selectedsuppliers[i]+"</TH></TD>");
}
out.println("</TR>");
for(int j = 0;j<selectedcriteria.length;j++)
    {
     out.println("<tr><td height=38 width=154>");
     out.println("<TH align=left width=200>"+selectedcriteria[j]+"</TH></TD>");

     for (int i = 0;i<selectedsuppliers.length;i++)
           {
            Connection con = null;
            try{
            Class.forName("org.gjt.mm.mysql.Driver");
            con = DriverManager.getConnection("jdbc:mysql://localhost/hosp", "root","123");
            Statement theStatement=con.createStatement();
            String sql = "SELECT Criterion_ID , Supplier_ID, Score, Avg(Score), STDDEV(Score)
from scores,suppliers,criteria ";
            sql += "WHERE scores.Criterion_ID = criteria.CriterionID ";
            sql += "and scores.Supplier_ID = suppliers.SupplierID ";
            sql += "and Criterion = '" + selectedcriteria[j] + "' ";
            sql += "and CompanyName = '" + selectedsuppliers[i] + "' "+ "GROUP BY Criterion_ID
and Supplier_ID";

            ResultSet theResult=theStatement.executeQuery(sql);
            while(theResult.next())
            {
            int getcriterionID = theResult.getInt("Criterion_ID");
```

```
int getsupplierID = theResult.getInt("Supplier_ID");
double score = theResult.getDouble("Score");
average[getcriterionID][getsupplierID] = theResult.getDouble("Avg(Score)");
stdev[getcriterionID][getsupplierID]= theResult.getDouble("STDDEV(Score)");
lower[getcriterionID][getsupplierID]= average[getcriterionID][getsupplierID]-
stdev[getcriterionID][getsupplierID];
upper[getcriterionID][getsupplierID]=
average[getcriterionID][getsupplierID]+stdev[getcriterionID][getsupplierID];
if (upper[getcriterionID][getsupplierID]>10)
{
  upper[getcriterionID][getsupplierID]=10;
}
if (lower[getcriterionID][getsupplierID]<0)
{
  lower[getcriterionID][getsupplierID]=0;
}
upper[getcriterionID][getsupplierID] = upper[getcriterionID][getsupplierID] > 0 ?
Math.floor(upper[getcriterionID][getsupplierID]* 100) / 100.0 :
Math.ceil(upper[getcriterionID][getsupplierID] * 100) / 100.0;
average[getcriterionID][getsupplierID] = average[getcriterionID][getsupplierID] > 0 ?
Math.floor(average[getcriterionID][getsupplierID]* 100) / 100.0 :
Math.ceil(average[getcriterionID][getsupplierID] * 100) / 100.0;
lower[getcriterionID][getsupplierID] = lower[getcriterionID][getsupplierID] > 0 ?
Math.floor(lower[getcriterionID][getsupplierID]* 100) / 100.0 :
Math.ceil(lower[getcriterionID][getsupplierID] * 100) / 100.0;
out.println("<td height=27 width=200>");
out.println("<p align=center>L :<input type=text
name=lower"+getcriterionID+"_"+getsupplierID+ " size=5 value="+
lower[getcriterionID][getsupplierID]+"></p>");
out.println("<p align=center>M :<input type=text
name=average"+getcriterionID+"_"+getsupplierID+ " size=5 value="+
average[getcriterionID][getsupplierID]+"></p>");
out.println("<p align=center>U :<input type=text
name=upper"+getcriterionID+"_"+getsupplierID+ " size=5 value="+
upper[getcriterionID][getsupplierID]+"></p><td>");
}
theResult.close();//Close the result set
theStatement.close();//Close statement
con.close(); //Close database Connection
}
catch(Exception e){
out.println(e.getMessage());//Print trapped error.
}
}

out.println("</tr>");
}
out.println("</table>");

// we build matrices for criterion values.
 for (int i = 0;i<selectedcriteria.length;i++)
  {
  Connection con = null;
  try{
  Class.forName("org.gjt.mm.mysql.Driver");
  con = DriverManager.getConnection("jdbc:mysql://localhost/hosp", "root","123");
```

```
        Statement theStatement=con.createStatement();
        String sql1 = "SELECT CriterionID, Value, Cinterval from criteria ";
        sql1 += "WHERE Criterion ='"+selectedcriteria[i]+"'";
        ResultSet theResult1=theStatement.executeQuery(sql1);
        while(theResult1.next())
        {
        int getcriterion_ID = theResult1.getInt("CriterionID");
        caverage[getcriterion_ID] = theResult1.getDouble("Value");
        cinterval[getcriterion_ID] = theResult1.getDouble("Cinterval");
        clower[getcriterion_ID] = caverage[getcriterion_ID]-cinterval[getcriterion_ID];
        cupper[getcriterion_ID] = caverage[getcriterion_ID]+cinterval[getcriterion_ID];
        if (cupper[getcriterion_ID]>10)
        {
          cupper[getcriterion_ID]=10;
        }
        if (clower[getcriterion_ID]<0)
        {
          clower[getcriterion_ID]=0;
        }


        }
        theResult1.close();//Close the result set
        theStatement.close();//Close statement
        con.close(); //Close database Connection
        }
        catch(Exception e){
        out.println(e.getMessage());//Print trapped error.
        }
       }

      //here we calculate comparison ratios for criteria

      out.println("<p><h3 align=center>Pairwise Criterion Comparisons</h3>");
      out.println("<p><table border=1 align=center>");
      out.println("<TR>");

      for(int m=0;m<=19;m++)
      {

        out.println("<TR>");

        for(int n=0;n<=19;n++)
          {
          if ((cupper[m] != 0) && (cupper[n] !=0))
              {

                if (n>m)
                {
                  //fuzzy arithmetic. division of two triangular fuzzy numbers
                cratio_lower[m][n] = clower[m]/cupper[n];
                cratio_lower[m][n] = cratio_lower[m][n] > 0 ? Math.floor(cratio_lower[m][n]* 100) / 100.0 :
Math.ceil(cratio_lower[m][n] * 100) / 100.0;
                cratio_average[m][n] = caverage[m]/caverage[n];
                cratio_average[m][n] = cratio_average[m][n] > 0 ? Math.floor(cratio_average[m][n]* 100) /
100.0 : Math.ceil(cratio_average[m][n] * 100) / 100.0;
```

```
                    cratio_upper[m][n] = cupper[m]/clower[n];
                    cratio_upper[m][n] = cratio_upper[m][n] > 0 ? Math.floor(cratio_upper[m][n]* 100) / 100.0 :
Math.ceil(cratio_upper[m][n] * 100) / 100.0;

                    }
                    if(cratio_lower[m][n]!=0)
                    {
                    out.println("<td height=27 width=200>");
                    out.println("<p align=center>Ratio of Criteria: "+m+"/"+n);
                    out.println("<p align=center>L :<input type=text name=cratio_lower"+m+"_"+n+" size=5
value="+ cratio_lower[m][n]+"></p>");
                    out.println("<p align=center>M :<input type=text name=cratio_average"+m+"_"+n+" size=5
value="+ cratio_average[m][n]+"></p>");
                        out.println("<p align=center>U :<input type=text name=cratio_upper"+m+"_"+n+"
size=5 value="+ cratio_upper[m][n]+"></p></td>");

                    }
                    else
                    {
                    out.println("<td height=27 width=200>");
                    out.println("<p align=center>L :<input type=text name=cratio_lower"+m+"_"+n+" size=5
disabled=true value="+ cratio_lower[m][n]+"></p>");
                    out.println("<p align=center>M :<input type=text name=cratio_average"+m+"_"+n+" size=5
disabled=true value="+ cratio_average[m][n]+"></p>");
                        out.println("<p align=center>U :<input type=text name=cratio_upper"+m+"_"+n+"
size=5 disabled=true value="+ cratio_upper[m][n]+"></p></td>");
                    }
                  }

            } out.println("</tr>");
        }   out.println("</table>");


      // finish comparison ratios for criteria


      out.println("<p align=right>Please fill out all empty values and click Proceed</p>");
      out.println("<p align=right> <input type=\"submit\" value=\"Proceed\"></p>");
      out.println("</form>");
      out.println("</body>");
      out.println("</html>");
      out.close();
    }



    protected void doGet(HttpServletRequest request, HttpServletResponse response)
    throws ServletException, IOException {
      processRequest(request, response);
    }

    protected void doPost(HttpServletRequest request, HttpServletResponse response)
    throws ServletException, IOException {
     processRequest(request, response);
}
}
```

HOPT.JAVA

```
import javax.servlet.*;
import javax.servlet.http.*;
import java.io.*;
import java.io.IOException;
import java.sql.*;
import java.util.*;
import java.net.*;
import drasys.or.mp.*;
import drasys.or.mp.lp.*;


public class hopt extends HttpServlet {

  public void init(ServletConfig config) throws ServletException {
    super.init(config);
    }

  public void destroy()
  {

  }

  protected void processRequest(HttpServletRequest request, HttpServletResponse response)
  throws ServletException, IOException {
    int maxcriteria = 20;
    int maxsuppliers = 40;
    int i=0;
    int j=0;
    int k=0;
    int x = 0;
    int ccount =0;
    int scount =0;
    double [] total = new double [maxcriteria];//to find the total ratings for each supplier
    double [] avg_total = new double [maxcriteria];
    int a=10; // a is representing alpha cuts
    double b; // b is alpha cuts represented by a.
    int [] selectedcriteria = new int[maxcriteria];
    int [] selectedsuppliers = new int[maxsuppliers];
    String [] suppliername = new String[maxsuppliers];
    String [] criterionname = new String[maxcriteria];
    double [][] lower = new double [maxcriteria][maxsuppliers];
    double [][] average = new double [maxcriteria][maxsuppliers];
    double [][] upper = new double [maxcriteria][maxsuppliers];
    double [][][] ratio_lower = new double [maxcriteria][maxsuppliers][maxsuppliers];
    double [][][] ratio_average = new double [maxcriteria][maxsuppliers][maxsuppliers];
    double [][][] ratio_upper = new double [maxcriteria][maxsuppliers][maxsuppliers];
    double [][][][] A = new double [a][maxcriteria][maxsuppliers][maxsuppliers]; //SUPPLIER
COMPARISONS
    double [][][][] B = new double [a][maxcriteria][maxsuppliers][maxsuppliers]; // SUPPLIER
COMPARISONS
    double [][][] CA = new double [a][maxcriteria][maxcriteria];
    double [][][] CB = new double [a][maxcriteria][maxcriteria];
    double [][] lambda = new double [maxcriteria][a]; //this lambda value shouldn't be less than 0.9
    double [] clambda = new double [a]; //this lambda value shouldn't be less than 0.9
```

```
    double [][][] W = new double [a][maxcriteria][maxsuppliers]; //weight of a supplier for a certain
criterion and alpha-cut.
    double [][] CW = new double [a][maxcriteria]; // criteria weights.
    double [][] SW = new double [a][maxsuppliers]; // supplier weights.
    double [][] cratio_lower = new double [maxcriteria][maxcriteria];
    double [][] cratio_average = new double [maxcriteria][maxcriteria];
    double [][] cratio_upper = new double [maxcriteria][maxcriteria];
    response.setContentType("text/html");
    PrintWriter out = response.getWriter();
    out.println ( "<html><head></head>" );
    out.println ( "<body bgcolor=white background=../images/PaperTexture.gif><center>");
    out.println("<h2 align=center>Ranking Results and Graphs</h2>");
    //out.println("<p align=center><img src=../images/lingu.JPG></p>");
    //out.println("<FORM METHOD=POST ACTION='../servlet/result'>");
    //out.println("<p align=center> <input name=\"value\" type=\"submit\" value=\"Get Rankings\"></p>");
    Enumeration enum = request.getParameterNames();
    while (enum.hasMoreElements())
    {
     String aToken = (String) enum.nextElement();
     if(aToken.startsWith("lower"))
     {
     if(aToken.substring(7,8)!="_")
     {
     i = Integer.parseInt(aToken.substring(5,6));
     j = Integer.parseInt(aToken.substring(7));
     lower[i][j] = Double.parseDouble(request.getParameter(aToken));
     //out.println ( "Lower["+i+"]["+j+"] :" + lower[i][j] + "<BR>" );
     }
     else
     {
     i = Integer.parseInt(aToken.substring(5,7));
     j = Integer.parseInt(aToken.substring(8));
     lower[i][j] = Double.parseDouble(request.getParameter(aToken));
     }
     }

     if(aToken.startsWith("average"))
     {
     if(aToken.substring(9,10)!="_")
     {
     i = Integer.parseInt(aToken.substring(7,8));
     j = Integer.parseInt(aToken.substring(9));
     average[i][j] = Double.parseDouble(request.getParameter(aToken));
     //out.println ( "Average["+i+"]["+j+"] :" + average[i][j] + "<BR>" );
     }
     else
     {
     i = Integer.parseInt(aToken.substring(7,9));
     j = Integer.parseInt(aToken.substring(10));
     average[i][j] = Double.parseDouble(request.getParameter(aToken));
     //out.println ( "Average["+i+"]["+j+"] :" + average[i][j] + "<BR>" );
     }
     }

     if(aToken.startsWith("upper"))
     {
```

```
if(aToken.substring(7,8)!="_")
{
i = Integer.parseInt(aToken.substring(5,6));
j = Integer.parseInt(aToken.substring(7));
upper[i][j] = Double.parseDouble(request.getParameter(aToken));
//out.println ( "Upper["+i+"]["+j+"] :" + upper[i][j] + "<BR>" );
}
else
{
i = Integer.parseInt(aToken.substring(5,7));
j = Integer.parseInt(aToken.substring(8));
upper[i][j] = Double.parseDouble(request.getParameter(aToken));
}
}

if(aToken.startsWith("cratio_lower"))
{
i = Integer.parseInt(aToken.substring(12,13));
j = Integer.parseInt(aToken.substring(14));
cratio_lower[i][j] = Double.parseDouble(request.getParameter(aToken));
//out.println ( "CratioLower["+i+"]["+j+"] :" + cratio_lower[i][j] + "<BR>" );
}
 if(aToken.startsWith("cratio_average"))
{
i = Integer.parseInt(aToken.substring(14,15));
j = Integer.parseInt(aToken.substring(16));
cratio_average[i][j] = Double.parseDouble(request.getParameter(aToken));
//out.println ( "CratioAverage["+i+"]["+j+"] :" + cratio_average[i][j] + "<BR>" );
}
 if(aToken.startsWith("cratio_upper"))
{
i = Integer.parseInt(aToken.substring(12,13));
j = Integer.parseInt(aToken.substring(14));
cratio_upper[i][j] = Double.parseDouble(request.getParameter(aToken));
//out.println ( "CratioUpper["+i+"]["+j+"] :" + cratio_upper[i][j] + "<BR>" );
}
}



for(int m=1;m<=19;m++)

{
  //out.println("<table border=1 align=center>");

  for(int n=1;n<=39;n++)
  {
    out.println("<tr>");
    for(int o=1;o<=39;o++)
    {

      if ((upper[m][n] != 0) && (upper[m][o] != 0))
         {
          if (o>n)
          {
          //fuzzy arithmetic. division of two triangular fuzzy numbers
```

```
                    ratio_lower[m][n][o] = lower[m][n]/upper[m][o];
                    ratio_lower[m][n][o] = ratio_lower[m][n][o] > 0 ? Math.floor(ratio_lower[m][n][o] * 100) /
100.0 : Math.ceil(ratio_lower[m][n][o] * 100) / 100.0;
                    ratio_average[m][n][o] = average[m][n]/average[m][o];
                    ratio_average[m][n][o] = ratio_average[m][n][o] > 0 ? Math.floor(ratio_average[m][n][o] *
100) / 100.0 : Math.ceil(ratio_average[m][n][o] * 100) / 100.0;
                    ratio_upper[m][n][o] = upper[m][n]/lower[m][o];
                    ratio_upper[m][n][o] = ratio_upper[m][n][o] > 0 ? Math.floor(ratio_upper[m][n][o] * 100) /
100.0 : Math.ceil(ratio_upper[m][n][o] * 100) / 100.0;

                    // generate A and B values for comparison values. These will be used as inputs
                    // to the optimization part.
                    b=0;
                    for(a=0;a<=9;a++)
                    {
                    A[a][m][n][o] = b*(ratio_average[m][n][o]-ratio_lower[m][n][o])+ratio_lower[m][n][o];
                    B[a][m][n][o] = b*(ratio_average[m][n][o]-ratio_upper[m][n][o])+ratio_upper[m][n][o];
                    b = b+0.1;
                    }
                    // print the result to a table. I don't need that, but for now it can stay.
                    //out.println("<td height=27 width=200>");
                    //out.println("<p align=center>L["+m+"]["+n+"]["+o+"] :<input type=text disabled=true
name=Lower_Ratio["+m+"]["+n+"]["+o+"] : size=5 value="+ratio_lower[m][n][o]+"></p>");
                    //out.println("<p align=center>M["+m+"]["+n+"]["+o+"] :<input type=text disabled=true
name=Average_Ratio["+m+"]["+n+"]["+o+"] : size=5 value="+ratio_average[m][n][o]+"></p>");
                    //out.println("<p align=center>U["+m+"]["+n+"]["+o+"] :<input type=text disabled=true
name=Upper_Ratio["+m+"]["+n+"]["+o+"] : size=5 value="+ratio_upper[m][n][o]+"></p></td>");

                     //take selected criterion IDs in a vector.
                    // ***********There is a problem here ****repeating last value. Added lines 172 and 173 to
correct it.

                    selectedcriteria[ccount]=m;
                    if (ccount<=0)
                    {
                       ccount = ccount+1;
                    }
                    else if(selectedcriteria[(ccount-1)]!=m)
                    {
                    ccount=ccount+1;
                    }

                    //take selected supplier IDs in a vector.
                    selectedsuppliers[scount]=n;
                    if (scount<=0)
                    {
                    scount = scount+1;
                    }
                    else if((selectedsuppliers[(scount-1)]!=n) && (selectedsuppliers[(scount-
1)]<selectedsuppliers[scount]))
                    {
                    scount=scount+1;
                    }

                    }
                    else
```

```
            {
            selectedsuppliers[scount] = o; //to be able to see the last supplier
            selectedcriteria[ccount] = 0; // to be able to get rid of repeating the last criterion.
            //out.println("<td height=27 width=200></td>");
            }

          }

      }//out.println("</tr>");
    }

    //out.println("</table><BR>");
  }


  // I just tested to see if I correctly get supplier and criterion IDs in two vectors.
  /*
  for(x =0;x<=selectedsuppliers.length;x++)
  {
    out.println("<p>"+"Selectedsupplier"+x+":"+selectedsuppliers[x]);
  }
  out.println("<BR>");
  */


  //OPTIMIZATION PART STARTS FOR COMPARISON OF SUPPLIERS BASED ON A
CRITERION.
  //Start optimization process now.
  int t,u,v; //u, v, t
  int f = 1;
  int y = 1; //y is used as a tolerance parameter.
  final byte LTE = Constraint.LESS;
  final byte EQU = Constraint.EQUAL;
  int n = scount+1;
  try
  {
  for(x=0;x<=selectedcriteria.length;x++)
  {
  if (selectedcriteria[x]!=0)
  {
  int criterion = selectedcriteria[x];
  //out.println("<h2>For Criteria"+criterion+"</h2>");
  for(a=0;a<=9;a++)
  {
  SizableProblemI prob = new Problem(n*(n-1)+1,n);
  prob.getMetadata().put("lp.isMaximize", "true");
  prob.newVariable("Lambda").setObjectiveCoefficient(1.0);
  for (t=0;t<=scount;t++)
  {
    prob.newVariable("W"+selectedsuppliers[t]).setObjectiveCoefficient(0);

  }


    for (v = 1;v <= n*(n-1);v++)
    {
```

```
      prob.newConstraint("constr"+v).setType(LTE).setRightHandSide(y);
    }
    prob.newConstraint("constr"+(n*(n-1)+1)).setType(EQU).setRightHandSide(1);
    // here, we are creating coefficients for lambda.
  for (u = 1; u <= n*(n-1); u++)
    {
      prob.setCoefficientAt("constr"+u,"Lambda",y);
    }


// here, we are creating coefficients for W's.

  int l = 1;

    for(int firsts=1;firsts<=39;firsts++)
    {
      for(int seconds=1;seconds<=39;seconds++)
      {

        if (ratio_upper[criterion][firsts][seconds] != 0)
            {
              if (seconds>firsts)
       {
         prob.setCoefficientAt("constr"+l, "W"+firsts, 1);
         prob.setCoefficientAt("constr"+l,"W"+seconds, (-B[a][criterion][firsts][seconds]));
         l = l + 1;
         prob.setCoefficientAt("constr"+l, "W"+firsts, -1.0);
         prob.setCoefficientAt("constr"+l, "W"+seconds, A[a][criterion][firsts][seconds]);
         l = l + 1;
         }
              }
    }
  }

/* here , we are creating coefficients for the last formula which is w1+w2+w3+....Wn = 1 */


    for (f=0; f <= (n-1); f++)
    {
    prob.setCoefficientAt("constr"+(n*(n-1)+1), "W"+selectedsuppliers[f], 1);
    }

/* API finds the solution below.*/
      LinearProgrammingI lp = new DenseSimplex(prob);
  double answer = lp.solve();
  lambda[selectedcriteria[x]][a]=lp.getSolution().elementAt(0);
  //out.println("<p>Lambda["+selectedcriteria[x]+"]["+a+"]="+lambda[selectedcriteria[x]][a]+"</p>");
  for (t=0;t<=scount;t++)
  {
    W[a][selectedcriteria[x]][selectedsuppliers[t]]= lp.getSolution().elementAt(t+1);

//out.println("<p>W["+a+"]["+selectedcriteria[x]+"]["+selectedsuppliers[t]+"]="+W[a][selectedcriteria[x]][se
lectedsuppliers[t]]);
  }

  }
```

```
  }
 }
}

 catch (Exception e)
 {
  e.printStackTrace();
 }
out.println("</form>");
// OPTIMIZATION PART ENDS


//OPTIMIZATION PART STARTS FOR COMPARISON OF CRITERIA
for(int m=0;m<=9;m++)
 {

   for(n=0;n<=9;n++)
      {
         if (n>m)
             {
               if(cratio_lower[m][n]!=0)
               {
                  b=0;
                  for(a=0;a<=9;a++)
                  {
                  CA[a][m][n] = b*(cratio_average[m][n]-cratio_lower[m][n])+cratio_lower[m][n];
                  CB[a][m][n] = b*(cratio_average[m][n]-cratio_upper[m][n])+cratio_upper[m][n];
                  b = b+0.1;
                  }
               }

             }
       }
}

 try
 {
 for(a=0;a<=9;a++)
 {
 n = ccount;
 SizableProblemI cprob = new Problem(n*(n-1)+1,n);
 cprob.getMetadata().put("lp.isMaximize", "true");
 cprob.newVariable("Lambda").setObjectiveCoefficient(1.0);
 for (t=0;t<ccount;t++)
 {
   cprob.newVariable("W"+selectedcriteria[t]).setObjectiveCoefficient(0);
 }


   for (v = 1;v <= n*(n-1);v++)
   {
     cprob.newConstraint("constr"+v).setType(LTE).setRightHandSide(y);
   }
   cprob.newConstraint("constr"+(n*(n-1)+1)).setType(EQU).setRightHandSide(1);
   // here, we are creating coefficients for lambda.
 for (u = 1; u <= n*(n-1); u++)
```

```
    {
      cprob.setCoefficientAt("constr"+u,"Lambda",y);
    }

  int l = 1;

  for(i=0;i<=9;i++)
  {

    for(j=0;j<=9;j++)
      {
        if (i<j)
            {
              if(cratio_lower[i][j]!=0)
              {

               cprob.setCoefficientAt("constr"+l, "W"+i, 1);
               cprob.setCoefficientAt("constr"+l,"W"+j, (-CB[a][i][j]));
               l = l + 1;
               cprob.setCoefficientAt("constr"+l, "W"+i, -1.0);
               cprob.setCoefficientAt("constr"+l, "W"+j, (CA[a][i][j]));
               l = l + 1;
              }
            }
      }
  }

/* here , we are creating coefficients for the last formula which is w1+w2+w3+....Wn = 1 */


  for (i=0; i < ccount; i++)
  {
  cprob.setCoefficientAt("constr"+(n*(n-1)+1), "W"+selectedcriteria[i], 1);
  }

 /* API finds the solution below.*/
     LinearProgrammingI lp = new DenseSimplex(cprob);
  clambda[a] = lp.solve();
  //out.println("<p>CLambda["+a+"]="+clambda[a]+"</p>");
  for (t=0;t<ccount;t++)
  {
    CW[a][selectedcriteria[t]]= lp.getSolution().elementAt(t+1);
    //out.println("<p>CW["+a+"]["+selectedcriteria[t]+"]="+CW[a][selectedcriteria[t]]);
  }

  }
  }

  catch (Exception e)
  {
   e.printStackTrace();
  }
 // CRITERIA OPTIMIZATION ENDS


 // RANKING PROCESS STARTS
```

```
for (a=0;a<=9;a++)
{
  for(i=0;i<=scount;i++)
  {
    double sum =0;
    for(j=0;j<ccount;j++)
    {
SW[a][selectedsuppliers[i]]=(CW[a][selectedcriteria[j]])*(W[a][selectedcriteria[j]][selectedsuppliers[i]]);
       sum = sum+SW[a][selectedsuppliers[i]];
    }
    SW[a][selectedsuppliers[i]]=sum;

  }


}

// Not necessary to print out
out.println("<table border=1><tr>");
for (i=0;i<=scount;i++)
{
  for(a=0;a<=9;a++)
  {
    total[i] = total[i] + SW[a][selectedsuppliers[i]];

  }
  avg_total[selectedsuppliers[i]]= total[i]/10;
  avg_total[selectedsuppliers[i]] = avg_total[selectedsuppliers[i]]> 0 ?
Math.floor(avg_total[selectedsuppliers[i]] * 1000) / 1000.0 : Math.ceil(avg_total[selectedsuppliers[i]] * 1000)
/ 1000.0;
  out.println("<tr><td>Supplier:"+selectedsuppliers[i]+"</td></tr>");
  out.println("<tr><td>"+avg_total[selectedsuppliers[i]]+"</td></tr>");
}
out.println("</tr></table>");

// RANKING PROCESS ENDS

// GRAPH PART STARTS



    //print overall ratings

    javachart.servlet.lineApp chart = new javachart.servlet.lineApp();
            StringBuffer sb1 = new StringBuffer();
    StringBuffer sb = new StringBuffer();

    b=0;
    for(a=0;a<=9;a++)
    {
      sb1.append("," + b);
      b=b+0.1;
    }
```

```
for(i=0;i<=scount;i++)
{
chart.setProperty("dataset"+i+"xValues", sb1.toString());
}


for(i=0;i<=scount;i++)
{
for(a=0;a<=9;a++)

{
        sb.append("," + Double.toString(SW[a][selectedsuppliers[i]]));

}
chart.setProperty("dataset"+i+"yValues", sb.toString());
//connect to the database to get supplier names
Connection con = null;
try{
Class.forName("org.gjt.mm.mysql.Driver");
con = DriverManager.getConnection("jdbc:mysql://localhost/hosp", "root","123");
Statement theStatement=con.createStatement();
String sql = "SELECT CompanyName from suppliers ";
sql += "WHERE SupplierID= "+selectedsuppliers[i];
ResultSet theResult=theStatement.executeQuery(sql);
while(theResult.next())
{
suppliername[i]=theResult.getString("CompanyName");
}

theResult.close();//Close the result set
theStatement.close();//Close statement
con.close(); //Close database Connection
}
catch(Exception e){
out.println(e.getMessage());//Print trapped error.
}

// connected and got supplier names

chart.setProperty("dataset"+i+"Name", suppliername[i]);
chart.setProperty("dataset"+i+"MarkerStyle", "1");
sb = new StringBuffer();
}
chart.setProperty("plotAreaColor", "gray");
chart.setProperty("backgroundColor", "white");
chart.setProperty("xAxisTitle","Alpha-Cuts");
chart.setProperty("yAxisTitle", "Weights");
chart.setProperty("writeDirectory", "C:\\Program Files\\Apache Software Foundation\\Tomcat
5.0\\webapps\\ROOT\\images\\");
        chart.setProperty("width", "600");
        chart.setProperty("height", "300");
chart.setProperty("titleString", "Overall Rankings of The Suppliers");
chart.setProperty("yAxisOptions", "rotateTitle, gridOn, tickOff, minTickOff, lineOn, labelOn");
chart.setProperty("legendOn", "yes");
chart.setProperty("iconWidth", "0.03");
chart.setProperty("legendHorizontal", "yes");
```

```
chart.setProperty("legendllX", "0.8");
chart.setProperty("legendllY", "0.2");

//generate our output here...
        try{

out.println("<p><img src=\"../images/" + chart.getFileName() + "\">"); //getting the file name
triggers image generation


}catch(Exception e){System.out.println("There is a problem, please try again");}

  //print criteria ratings


javachart.servlet.lineApp crchart = new javachart.servlet.lineApp();
        sb1 = new StringBuffer();
sb = new StringBuffer();

b=0;
for(a=0;a<=9;a++)
{
 sb1.append("," + b);
 b=b+0.1;
}
for(i=0;i<ccount;i++)
{
 crchart.setProperty("dataset"+i+"xValues", sb1.toString());
}


for(i=0;i<ccount;i++)
{
for(a=0;a<=9;a++)

{
   CW[a][selectedcriteria[i]] = CW[a][selectedcriteria[i]] > 0 ?
Math.floor(CW[a][selectedcriteria[i]]* 100) / 100.0 : Math.ceil(CW[a][selectedcriteria[i]] * 100) / 100.0;
   sb.append("," + Double.toString(CW[a][selectedcriteria[i]]));

}
crchart.setProperty("dataset"+i+"yValues", sb.toString());
//connect to the database to get supplier names
Connection con = null;
try{
Class.forName("org.gjt.mm.mysql.Driver");
con = DriverManager.getConnection("jdbc:mysql://localhost/hosp", "root","123");
Statement theStatement=con.createStatement();
String sql = "SELECT Criterion from criteria ";
sql += "WHERE CriterionID= "+selectedcriteria[i];
ResultSet theResult=theStatement.executeQuery(sql);
while(theResult.next())
{
criterionname[i]=theResult.getString("Criterion");
}
```

```
theResult.close();//Close the result set
theStatement.close();//Close statement
con.close(); //Close database Connection
}
catch(Exception e){
out.println(e.getMessage());//Print trapped error.
}

// connected and got criterion names
crchart.setProperty("dataset"+i+"Name", criterionname[i]);
crchart.setProperty("dataset"+i+"MarkerStyle", "1");
sb = new StringBuffer();
}
crchart.setProperty("plotAreaColor", "gray");
crchart.setProperty("plotAreaWidth", "400");
crchart.setProperty("backgroundColor", "white");
crchart.setProperty("xAxisTitle","Alpha-Cuts");
crchart.setProperty("yAxisTitle", "Weights");
crchart.setProperty("writeDirectory", "C:\\Program Files\\Apache Software Foundation\\Tomcat
5.0\\webapps\\ROOT\\images\\");
        crchart.setProperty("width", "600");
        crchart.setProperty("height", "300");
crchart.setProperty("titleString", "Rankings of The Criteria");
crchart.setProperty("yAxisOptions", "rotateTitle, gridOn, tickOff, minTickOff, lineOn, labelOn");
crchart.setProperty("legendOn", "yes");
crchart.setProperty("iconWidth", "0.03");
crchart.setProperty("legendHorizontal", "yes");
crchart.setProperty("legendllX", "0.8");
crchart.setProperty("legendllY", "0.2");

//generate our output here...
        try{

out.println("<p><img src=\"../images/" + crchart.getFileName() + "\">"); //getting the file name
triggers image generation


}catch(Exception e){out.println("There is a problem, please try again");}


//finish printing criteria ratings.


//print ratings for each criterion
for(j=0;j<ccount;j++)
{
javachart.servlet.lineApp cchart = new javachart.servlet.lineApp();
        sb1 = new StringBuffer();
sb = new StringBuffer();

b=0;
for(a=0;a<=9;a++)
{
 sb1.append("," + b);
 b=b+0.1;
}
```

```
for(i=0;i<=scount;i++)
{
 cchart.setProperty("dataset"+i+"xValues", sb1.toString());
}


for(i=0;i<=scount;i++)
{
 for(a=0;a<=9;a++)

{
        sb.append("," + Double.toString(W[a][selectedcriteria[j]][selectedsuppliers[i]]));

}
cchart.setProperty("dataset"+i+"yValues", sb.toString());
//connect to the database to get supplier names
Connection con = null;
try{
Class.forName("org.gjt.mm.mysql.Driver");
con = DriverManager.getConnection("jdbc:mysql://localhost/hosp", "root","123");
Statement theStatement=con.createStatement();
String sql = "SELECT Criterion from criteria ";
sql += "WHERE CriterionID= "+selectedcriteria[j];
ResultSet theResult=theStatement.executeQuery(sql);
while(theResult.next())
{
criterionname[j]=theResult.getString("Criterion");
}

theResult.close();//Close the result set
theStatement.close();//Close statement
con.close(); //Close database Connection
}
catch(Exception e){
out.println(e.getMessage());//Print trapped error.
}

// connected and got criterion names

cchart.setProperty("dataset"+i+"Name", suppliername[i]);
cchart.setProperty("dataset"+i+"MarkerStyle", "1");
sb = new StringBuffer();
}
cchart.setProperty("plotAreaColor", "gray");
cchart.setProperty("backgroundColor", "white");
cchart.setProperty("xAxisTitle","Alpha-Cuts");
cchart.setProperty("yAxisTitle", "Weights");
cchart.setProperty("writeDirectory", "C:\\Program Files\\Apache Software Foundation\\Tomcat
5.0\\webapps\\ROOT\\images\\");
        cchart.setProperty("width", "600");
        cchart.setProperty("height", "300");
cchart.setProperty("titleString", "Ranking of The Suppliers Based on Criterion: "+criterionname[j]);
cchart.setProperty("yAxisOptions", "rotateTitle, gridOn, tickOff, minTickOff, lineOn, labelOn");
cchart.setProperty("legendOn", "yes");
cchart.setProperty("iconWidth", "0.03");
cchart.setProperty("legendHorizontal", "yes");
```

```
        cchart.setProperty("legendllX", "0.8");
        cchart.setProperty("legendllY", "0.2");

        //generate our output here...
                try{

        out.println("<p><img src=\"../images/" + cchart.getFileName() + "\">"); //getting the file name
triggers image generation


        }catch(Exception e){out.println("There is a problem, please try again");}


        }
        //finish printing ratings for each criteria
    // GRAPH PART ENDS


    out.println ( "</center></body></html>" );
    out.close();
  }

  protected void doGet(HttpServletRequest request, HttpServletResponse response)
  throws ServletException, IOException {
     processRequest(request, response);
  }

  protected void doPost(HttpServletRequest request, HttpServletResponse response)
  throws ServletException, IOException {
     processRequest(request, response);
  }

 public String getServletInfo() {
     return "Short description";
  }

}
```