ANALYTICAL HIERARCHY PROCESS APPROACH FOR SELECTING ENTERPRISE RESOURCE PLANNING SOFTWARE PACKAGE IN OIL AND GAS EQUIPMENT MANUFACTURING FIRMS

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SEYED HAJIR LESANI

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Approval of the Graduate School of Natural and Applied Sciences, Atılım University.

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ABSTRACT

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In today's world, enterprises and firms, in order to be able to compete with their rivals, they have to use computer software applications mostly based on Information Technologies. Enterprise Resource Planning (ERP) is an integrated software package which combines all of software needs of a firm in order to connect different parts of the firm or organization to increase the output and is considered as an essential investment for firms. As there are many ERP system providers available in the world, selecting the most suitable software based on the requirements of firms is challenging. In order to select, both implementation aspects and software related aspects should be considered and they differ for every organization and consequently selecting one ERP system as the best is not possible. For choosing the most suitable ERP system for a firm, a Multiple Criteria Decision Making (MCDM) method can be used to have the optimal solution. In this thesis, Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy process (FAHP) are chosen as the MCDM methods and by using a questionnaire submitted to Information Systems departments and personnel involved in oil and gas equipment manufacturing firms in the United Arab Emirates, the data was gathered. In the end of this study it was found that two criterions of User friendliness and Finance were favored more among others. Finally,

a case study is presented to describe the processes and comparison of the methods of the decision making.

Keywords: Oil and gas equipment manufacturing firms, Enterprise resource planning (ERP), Multiple Criteria Decision Making (MCDM), Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (FAHP)

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ÖZ

PETROL VE GAZ EKİPMANLARI İMALAT FİRMALARINDA URUMSAL KAYNAK PLANLAMA YAZILIM PAKETİ SEÇMEK İÇİN ANALİTİK HİYERARŞİ SÜREÇ YAKLAŞIMI

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Günümüz dünyasında, işletmeler ve firmalar, birbirleri ile rekabet edebilmek için, çoğunlukla Bilgi Teknolojilerine dayalı bilgisayar yazılımlarından faydalanmak zorundadırlar. Kurumsal Kaynak Planlaması (ERP) firmalar için önemli bir yatırımdır. Bu yazılım paketi verimi artırma amacıyla firma veya kuruluşun farklı bölümleri arasında bağlantı sağlamak için firmanın tüm yazılım ihtiyaçlarını birleştiren entegre bir yazılım paketidir. Dünyada farklı ERP sistem sağlayıcıları olduğundan dolayı, firmalar açısından, kendi gereksinimlerine göre en iyi yazılımı seçmek zordur. En iyi sistemi seçmek için hem uygulama hem de yazılımla ilgili hususlar göz önünde bulundurulmalıdır ve bu hususlar her kuruluş için değişiklik gösterir. Dolayısıyla her firma için en iyi olan ERP sistemini seçmek mümkün değildir. Bir firma için en iyi ERP sisteminin seçiminde, en iyi sonucu elde etmek için Çok Ölçütlü Karar Verme (MCDM) yönetimi kullanılmalıdır. Bu tezde, MCDM yöntemleri olarak Analitik Hiyerarşi Süreci (AHP) ve Bulanık Analitik Hiyerarşi Süreci (FAHP) seçilmiştir ve veri toplamak için Birleşik Arap Emirlikleri'nde yer alan farklı petrol ve doğal gaz donanımı imalatçısı firmaların Bilgi Sistemleri bölümlerine ve bu alanda çalışan elemanlarına bir anket gönderilmiştir. Aynı zamanda, kendi ERP sistemlerini seçerken tercih ettikleri kriterleri tespit etmek için görüşmeler gerçekleştirilmiştir. Tezin sonucunda, kullanım kolaylığı ve maliyet

kriterlerinin diğerlerinden daha çok dikkate alındığı görülmüştür. Son olarak, söz edilen karar verme mekanizmaları karşılaştırılmış ve bu yöntemin işlemleri ve hesaplama adımlarını tanımlamak için bir vaka çalışması sunulmuştur.

Anahtar Kelimeler: petrol ve doğal gaz donanımı imalatçı firmalar, Kurumsal Kaynak Planlaması (ERP), Çok Kriterli Karar Verme (MCDM), Hiyerarşik Analitik Süreci (AHP), Bulanık Analitik Hiyerarşi Süreci (FAHP)

DEDICATION

I specially present this thesis to my Father, and my Mother. The spirit and passion on the accomplishment of this thesis is merely inspired from them.

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TABLE OF CONTENTS

ABSTRACT i

ÖZ iii

DEDICATION v

ACKNOWLEDGMENTS vi

TABLE OF CONTENTS vii

LIST OF TABLES x

LIST OF FIGURES xii

LIST OF ABBREVIATIONS xiii

CHAPTERS:

1 INTRODUCTION 1

2 LITERATURE REVIEW 4

3 ENTERPRISE RESOURCE PLANNING (ERP) 11

3.1 What is ERP? 11

3.2 History of ERP, how it began? 13

3.3 ERP Market share 17

3.4 Critical Success Factors (CSF) 17

4 MCDM 21

4.1 What is MCDM? 21

4.2 Overview of MCDM Methods 22

4.3 Analytical Hierarchy Process (AHP) 25

4.4 Fuzzy Analytical Hierarchy Process (FAHP) 25
4.5 Procedure of selecting ERP system 26
4.5.1 Review of selection methods 28
4.5.2 Criteria Selection 29
5 METHODOLOGY 35
5.1 Overview 35
5.2 Collecting the Data 35
5.3 Design of the Survey 36
6 ANALYSIS OF THE FINDINGS 37
6.1 Data obtained from the survey 37
6.2 Steps for analyzing data using AHP method 38
6.2.1 Analysis of the data obtained from the survey using AHP method 44
6.3 Steps for analyzing data using FAHP method 48
6.3.1 Aggregation of group decisions 49
6.3.2 Analysis of the data obtained from the survey using FAHP method 54
6.4 Case Study 61
6.4.1 Background information 61
6.4.2 Introduction of the two ERP providers used in this case study 61
6.4.3 Comparison data between two ERP providers using AHP 62
6.4.4 Comparison data between two ERP providers using FAHP 64
7 CONCLUSION, LIMITATIONS AND FURTHER STUDIES 67
REFERENCES 70
APPENDICES 79
A. Questionnaire 79
B. Calculations of Criteria 86
C. the Company of case study – OGASCO L.L.C Organization Chart 2014 90
D. Data of the survey completed by participants 91

8 Appendix II: Calculations of Criteria 94

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LIST OF TABLES

Table 3-1 Summarize of evolution of ERP through decades (sysoptima, 2005) 15
Table 3-2 Critical success factors of ERP implementation 19
Table 4-1 Important MCDM Methods (Thor et al., 2013) 22
Table 4-2 Selected Criteria and Sub-Criteria for ERP System providers 33
Table 4-3 Criteria presented in other studies 34
Table 6-1 Preference scale of two attributes (Saaty et al., 2000) 39
Table 6-2 Sample Matrix of PV calculation for Attributes A and B 40
Table 6-3 Calculation sample of alternatives Matrix of PV based on attribute A 40
Table 6-4 Calculation sample of alternatives Matrix of PV based on attribute B 41
Table 6-5 RCI of 1 to 10 (Saaty,et al., 2000) 42
Table 6-6 Attributes table example to calculate Consistency Ratio (CR) 42
Table 6-7 Geometric means of obtained comparison preferences of the criteria from the surveys 45
Table 6-8 Comparison pairwise matrix of main attributes 46
Table 6-9 Comparison pairwise matrix of Vendor Credential sub-criteria 46
Table 6-10 Comparison pairwise matrix of Finance sub-criteria 46
Table 6-11 Comparison pairwise matrix of Implementation sub criteria 46
Table 6-12 Calculated Relative weight of criteria and sub criteria after normalizing using AHP 47
Table 6-13 Fuzzy Fundamental Scale (Lee 2016) 50
Table 6-14 Geometric mean of fuzzy values for the compared criterions 54
Table 6-15 Triangular values for pairwise comparison of main criteria 55
Table 6-16 Triangular values for pairwise comparison of Sub-Criteria of Vendor Credential 57
Table 6-17 Triangular values for pairwise comparison of Sub-Criteria of Finance 58

Table 6-18 Triangular values for pairwise comparison of Sub-Criteria of Implementation 58
Table 6-19 Relative weights of criteria using FAHP 59
Table 6-20 Comparison of AHP and FAHP weights and rankings 60
Table 6-21 matrices of pairwise comparison between ERP 1 and ERP 2 63
Table 6-22 Comparison of relative weights of FAHP and AHP for each alternative based on 11 criterions 65

LIST OF FIGURES

Figure 3-1 with and without of ERP system in an organization 13
Figure 3-2 - ERP evolution 16
Figure 3-3 ERP world market share 2013 - Source: (Gartner, 2013) 17
Figure 4-1 The procedure of selecting an ERP system (Wei et al., 2005)..... 27
Figure 6-1 General form of AHP hierarchical structure (Saaty, and Vargas, 2000).. 38
Figure 6-2 scale of comparing two attributes of A and B 40
Figure 6-3 Decision making model of selecting ERP system for oil and gas firms using AHP 44
Figure 6-4 Triangular Fuzzy Number (Javanbarg et al., 2012) 48
Figure 6-5 The intersection between M1 and M2 (Chang 1996)..... 53
Figure 6-6 Comparison of the weights of Main Criteria..... 57
Figure 6-7 ERP 1 and ERP 2 provider selection using AHP 64
Figure 6-8 ERP 1 and ERP 2 provider selection using FAHP..... 66

LIST OF ABBREVIATIONS

ERP	-	Enterprise Resource Planning
AHP	-	Analytical Hierarchy Process
FAHP	-	Fuzzy Analytical Hierarchy Process
MCDM	-	Multiple Criteria Decision Making
VenC	-	Vendor credentials
Fin	-	Finance
Imp	-	Implementation
Mnt	-	Maintenance
RepVen	-	Reputation of vendor
MarS	-	Market Share
PrvDem	-	Demonstrations of previous Implementation
Fun	-	Functionality
SE	-	Software Expenses
CstU	-	Cost of upgrade and Maintenance with Consultation
CstI	-	Cost of Implementation
UF	-	User Friendliness
Custom	-	Customization
Comp	-	Compatibility
IS	-	Information System
TFN	-	Triangular Fuzzy Number
CI	-	Consistency Index

CR - Consistency Ratio

RCI - Random Consistency Index

CHAPTER 1

INTRODUCTION

This thesis focuses on selecting the most suitable ERP system, convenient for oil and gas industries using two MCDM methods.

Enterprise Resource Planning is packaged application software which during the past decades emerged significantly. The ERP definition which is used by several ERP studies is "integrated packaged software modules with purpose of integrating the entire functions and processes of a business in order to present a comprehensive view of the business from a single information and Information Technology (IT) architecture" *(Klaus, Rosemann, and Gable, 2000).*

Since today's business environments have become complicated, enterprises are going more after software packages in order to utilize them to achieve their goals more efficiently. Oil and gas industry is not an exception in this regard. ERP has an effective role in oil and gas Industry to handle complex Information System (IS) requirements.

In the first part of this thesis, ERP systems will be discussed. History of ERP will be reviewed and how it became an important topic of research in the past decades. Then MCDM and the sub branches of MCDM are introduced and the reason why AHP and Fuzzy AHP was chosen among all the methods of MCDM. In this process some explanations are brought about IT and what ERP is. The reason ERP is discussed here is the fact that unfortunately not many researches have been done specifically for ERP in oil and gas industry. The urge for these researches can be felt due to the complicated projects which necessitate the need of a good ERP system for the success of such projects. Also the most effective criteria are expected to be discovered among all other criteria in oil and gas firms.

Also some of important ERP systems in the market will be mentioned and in the end two ERP providers are going to be the examples of the survey to help us conclude which one is preferable using AHP method and the result was compared with Fuzzy AHP.

Multiple Criteria Decision Making (MCDM) is the process of selecting one alternative/ranking alternative from a set of alternatives considering different criteria (Thor, Ding, and Kamaruddin, 2013). The topic of MCDM will be explained because selecting an ERP software package requires a method of decision making. Some famous MCDM methods will be discussed and the impacts of ERP selections on enterprises will be reviewed as well.

In the next chapter, the literature review of ERP and MCDM is reviewed from 2000 until 2016. Then the methodology of selecting an ERP software package is elaborated using AHP and Fuzzy AHP. The reason of choosing AHP and Fuzzy AHP as the MCDM methods is justified and the criteria selection process is going to be explained as well.

There are two methods of data gathering applied for this thesis. One is through survey questionnaire and the other is by interviews with the personnel in-charge of the ERP implementation.

Afterwards, a case study of an oil and gas manufacturing company named OGASCO L.L.C is presented. This company is based in the UAE and wants to employ an ERP system in the company. The company background and how ERP system can be beneficial to their organization are explained. Two ERP providers are considered for ERP implementation and finally by utilizing AHP method, the optimum ERP provider is chosen and using fuzzy AHP the differences of answers are discussed.

This thesis addresses to the two following questions:

1- What are the key criteria for ERP selection in oil and gas equipment manufacturing industries that the firms in this field should more focus on?

2- How can we benefit using AHP and Fuzzy AHP methods to achieve selecting the most suitable ERP provider in oil and gas equipment manufacturing firms?

Currently various ERP software providers are available in the markets all over the world which they serve different needs of enterprises (Lui and Chan, 2008).

The purpose of this research is to identify a suitable decision making approach for oil and gas equipment manufacturing firms to select an ERP system based on their needs. Selecting the most suitable ERP system requires knowledge in different areas such as end users' readiness, project, change management, software functionality and etc.

ERP can affect the whole enterprise which means the users can have more experience of IT including the different ways of evaluation of IT. The old information system implementations were characterizing the departments separately and therefore their users were more homogenous.

After the design of ERP, the users are involved. The user's involvement includes the system which should be fitted to the organization. The users may have to learn two things at the same time one is the process of changes in the business and second the software capabilities.

CHAPTER 2

LITERATURE REVIEW

In this section the previous studies which were done in field of ERP implementation and MCDM methods which were used in this research are explained. The year range of this literature survey is from 2000 until 2016. According to Wei, Chien, and Wang (2005) there have been numerous studies of ERP selection methods introduced and applied such as ranking, MCDM, scoring, mathematical optimization and AHP method. Also no single or stable method or approach is available for selecting an ERP system (He and Li, 2009).

Analytic Hierarchy Process was first introduced by Saaty in the 1970s. Saaty (1987) introduced AHP as a method of measurement with ratio scales and illustrated it with examples.

Heabenicht, Scheubrein, and Scheubrein (2002) explained the process of decision making using multiple criteria focusing on the aspect of deterministic approach by considering problems of uncertainty and risk.

As there have been many successful and unsuccessful ERP implementation practices, Yusuf, Gunasekaran, and Abthorpe (2004) identify the failure reason as poor implementation process or management. They also did a case study of ERP implementation in Rolls-Royce Company to find the core issues of a sample large organization which avoid successful implementation while using SAP as the ERP software package. They concluded some of the problems encountered during the implementation as:

- Corresponding the process to the configuration of software

- Training the staff to adopt with the changes and work in an entirely new business environment
- Teaching the staff to get benefit of modern IT devices.
- Delay of arrival of equipment for the installation.
- Time consuming aspect of data migration as it needed old computer technology.

Wei et al. (2005) present a comprehensive ERP selection method using AHP by presenting a seven stages procedure of ERP system selection framework. They also explain how to used attributes and how to remove the unqualified ERP candidates. They divided the ERP system selection to two types of system factors and vendor factors and by a case study by forming a team and evaluating the systems, they explained how to select the most suitable criteria in the field.

Robert Jacobs and 'Ted' Weston (2007) explained the history of ERP, from where it started and the possible future steps. They also obtained information from one of the IBM employees who were working in mid-1980s as Industry consultant. Their study begins from 1960s and they discuss about technological aspects of ERP systems as well.

Capaldo, Iandoli, Rippa, Mercanti, and Troccoli (2008) discuss about the critical success factors (CSF) of ERP implementation in a telecommunication firm using AHP. They planned a survey based on AHP approach to identify the problems in this regard. Finally, they get to the conclusion that AHP is very convenient for identifying the importance of different variables in the successful implementation process.

As there are millions of dollars getting wasted by companies due to failure of selecting proper ERP system, Ghapanchi, Jafarzadeh, and Khakbaz (2008) used a Data Envelopment Analysis (DEA) approach, a mathematical programming technique for selecting an ERP system in a petroleum company.

Saaty (2008) explained the reliance of AHP on judgment of decision makers and how to measure inconsistency of the judgments and how to improve them.

Dezdar, and Ainin (2010) studied about the importance of quality of the ERP system and vendor support by using a questionnaire received from 384 participants. They

got the conclusion that both quality of the system and reliable vendor are having significant effect on the success of ERP implementation.

Romero, Menon, Banker, and Anderson (2010) studied about ERP's role in drilling field. According to their study, after IT infrastructure ERP was the second most spent category in US. As SAP R/3 was the highest used ERP software among companies in oil and gas industries between 1990 and 2005, they obtained their data from SAP software directly. They explained focusing in specific industry is better to obtain more accurate data. Finally, by comparing firms used SAP vs firms used ERP other than SAP and also firms used SAP vs firms didn't used any ERP systems, based on the data obtained by the survey they found the profitability, productivity and capacity performances are positive for the firms used SAP by 9%, 4% and 7%. The differences between using ERP other than SAP and no-ERP were not significant.

Erkan (2011) studied about the differences between ERP implementation procedures in Turkey and internationally. He explained the ERP focus point from 60s to 21st century. By this study using SAP as the ERP system of the case study, he concluded that there are differences between ERP implementation in Turkey and other countries in the world.

Rouyendegh, and Lesani (2014) studied about the Object-Oriented programming language selection utilizing Fuzzy AHP method.they explain that in order to have proper weight distribution and overcome the fuziness, FAHP is a suitable method to have more actual results.

Hidalgo, Albors, and Gómez (2011) studied about ERP selection in Metal transformation sector. They used AHP as the decision making approach for a firm in Spain using ERP success factors. They explain that ERP selection process is more important for small size companies as they have to focus on very specific characteristics.

Mishra and Mishra (2011) explained the lessons learned in ERP system implementation in oil and gas sector. They explained the ERP processes of transition, constraints and implementation. They discussed different methods of implementation and the effect of the cost for a successful implementation. From their study, they

concluded that not only a technology or software platform can change a company but how the company implements a technology is important in their success.

A comprehensive framework was presented by Rouyendegh and Erkan (2011) by using AHP method for selecting a suitable ERP system. They studied this method using organizations in Turkey. They considered the critical success factors and using the steps introduced by Wei et al. (2005), they concluded that the proposed selecting framework has benefits such as assures the consistency of the objective with goals and strategies and it is also reducing costs significantly. Finally, they found AHP as a reliable MCDM instrument for ERP selection.

Zavadskas and Turskis (2011) discussed about different MCDM methods in past decades in economics field while providing the name of authors and different methods and their criteria. They explained that the publications have increased in MCDM chronologically.

Alexander (2012) explained decision making using AHP and SAS/IML. Interactive Matrix Language (IML) is a matrix language similar to MATLAB. SAS/IML is powerful software that can perform complex calculations such as eigenvector generation or matrix inversion. He used AHP employing SAS/IML and brought an example of decision making for selecting a cellphone. He concluded that although there were different criticisms on AHP method, but still it has been used widely and it was used in important projects such as design of mission- success factors for MARS exploration by humans by NASA.

Chen (2012) studied about critical success factors and multisite aspect of ERP implementation in UAE. His case study consisted of two organizations which one is local and the other one is a global company. He states that the studies in the field of developing markets such as UAE are limited and there are not many. Also the available studies are mostly comparing the local and global markets within a country. He describes the common suggested ERP successful factors as top management support, implementation team, business process reengineering (BPR), strategic objectives and education and training. Finally, he concludes that Critical Success Factors differ from local to international companies and suggests further study in this regard.

Gajic, Stankovski, Ostojic, Tesic, and Miladinovic (2012) evaluate the impact of critical success factors on ERP implementation using a case study comparing two companies which one is large and other one is medium sized. By the method they proposed, they suggest organizations to integrate organizational and operating system specifics with CSFs and specifics of the implemented ERP.

A multi stage approach was introduced by Feili, Mirkazemi Mood, Rahmany Youshanlouei, and Sarabi (2012) to select ERP system. According to Feili et al. (2012), there were many studies tried to identify the most appropriate criteria for selecting an ERP system but many of them never mentioned how to select based on these criteria and they just counted the number of the criteria. Fili et al. (2012) presented a table of criteria proposed along with the authors. They used combination of three techniques of analytic network process (ANP), decision making trial and evaluation laboratory (DEMATEL) and exploratory factor analysis (EFA) for selecting, evaluating criteria and identifying criteria.

Rouyendegh and Erkan (2012) employed AHP method for selecting the most suitable supplier using 5 criteria of flexibility, quality, cost, variety and delivery. They got the conclusion that using AHP has 3 benefits of utilizing time by reducing documentation, reducing the cost and personnel of the department by using the supplier selection, and there will be a competition among the suppliers to increase the quality as they are being compared.

Salazar, Rivera, and Vázquez (2013) did a review on the literature documents of ERP selection in the recent time before 2013. Their focus was on small and medium sized companies and they analyzed research books, scientific papers and doctoral theses. They also studied about Critical Success Factors of ERP implementation.

Silva, Fernandes, Goncalves, and Cunha (2013) conducted two surveys for selecting Criteria for ERP selection by using AHP method. First they did study previous scientific documents in field of ERP selection and obtained the most important criteria and then they used surveys to select the best among them.

Velasquez and Hester (2013) analyzed the different Multi Criteria Decision Making methods by comparing them and finding advantages and disadvantages of them. They found that AHP method is easy to use and the hierarchical structure allows

usage of this method in different size of problems. But the negative side of AHP, as the alternatives and criteria are mutually depended; they can cause inconsistency among the ranking and judgment.

Erkan and Can (2014) used AHP and Fuzzy AHP for selecting the most suitable warehouse data collecting system using 4 criteria. They explain that AHP is not the optimal for decisions having uncertainties involved and they proposed Fuzzy AHP instead.

Haddara (2014) explained ERP selection using multi-attribute rating technique (SMART) method using a case study and he explained the process of ERP selection in detail.

Kashani (2014) discussed about a successful experience of ERP implementation by going through the stages step by step. He found the involvement of CEO from the beginning of project in this important task had great positive influence.

Martinovic and Delibasic (2014) proposed a combined AHP-Interpolative realization of Boolean algebra (IBA) approach for selecting the most suitable SAP consultant for an ERP system. They used IBA additionally to determine the weights of criteria and model the logical interactions of criteria. They did a case study based on SAP and their goal was to show combining IBA with AHP can benefit in the ranking on the consultants.

Rouyendegh, Bac, and Erkan (2014) proposed a hybrid AHP-TOPSIS method for sector selection for ERP implementation in order to have the most impact on supply chain performance. By this study their goal is to rank different sectors using the hybrid AHP-TOPSIS method based on their performance after successfully implementing ERP so that the managers of companies can have better understanding of their expectations before implementation.

Tyagi, Kumar, and Kumar (2014) also proposed a hybrid AHP-TOPSIS method regarding e-Supply Chain Management in an automobile industry in Delhi. They find that going towards web-based technology investments has the highest rank among other alternatives such as investing in advanced manufacturing technologies or role of supplier or role of top management.

Chang, Kuo, Wu, and Tzeng (2015) employed Fuzzy ANP method in order to select the risks of ERP implementation. They found involvement and support of top management as the highest risk factor and after that ineffective communication with users the second most important risk factor of ERP implementation.

Hamidi (2015) used Fuzzy AHP in order to select the most suitable ERP system because the chosen selection criteria were numerous and fuzzy. He explains that even using the same data, in different methods and approaches different outcomes may result and he used Fuzzy method because of the vagueness of his criteria.

Neves and Camanho (2015) explained the usage of AHP in prioritization of IT projects with a case study in oil and gas field. The firm was located in Brazil and they obtained the data using a survey and interview with the key personnel involved.

CHAPTER 3

ENTERPRISE RESOURCE PLANNING (ERP)

In this part, first the definition of ERP is explained, then some studies in ERP field and the benefits and history of ERP are explained. In the section after, the market shares of ERP in 2013 is presented using Gartner's report (Garnter, 2013). And finally in the last section the studies of critical success factors of ERP implementation are discussed about.

3.1 What is ERP?

ERP is all-inclusive packaged software seeking for integrating the complete ranges, processes of a business and the functions in order to show a total view of the business from IT structure (Klaus et al., 2000).

ERP is considered as the backbone of businesses. It automates many internal functions of an organization and makes them cross functional with each other especially manufacturing, finance, accounting, logistics, human resource, and distribution functions of the organization (Erkan, 2011). Not only ERP is an IT solution but it is also a business strategy solution (Dezdar et al., 2010).

Since 1990 ERP systems were become important need of organizations as they can improve requirements of agility in order to expedite responding to customers, better service, improve quality of the products and speed up production. Hence many organizations go after information system technologies such as ERP to have benefit from such advantages (Rouyendegh et al., 2011).

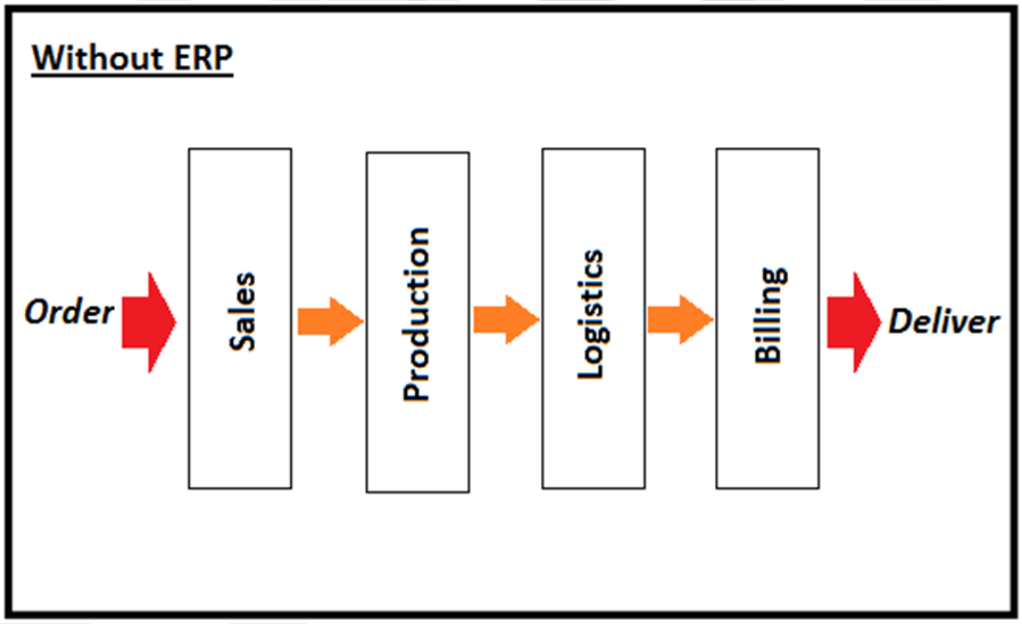
Comparing ERP systems with previous IS systems we can find 3 differences (Mishra et al., 2011):

a. ERP permits the integrating management of a business and the purpose is to corporate single functional systems such as finance, procurement, manufacturing and distribution.

b. The implementation of ERP imposes challenges to enterprises, because so many of those implementations fail at the beginning or mainly overlap the cost of the project.

c. ERP is an initiative business because the business can be practiced better with ERP but it may also make the managers not satisfied with their old practices of IS department and hence they prefer to try their own method.

The idea of ERP is to be able to have access for everyone to real time data through an interface. This needs to have a single point of contact system. We can compare system of an organization sample before having ERP and after ERP graphically (Figure 3-1):



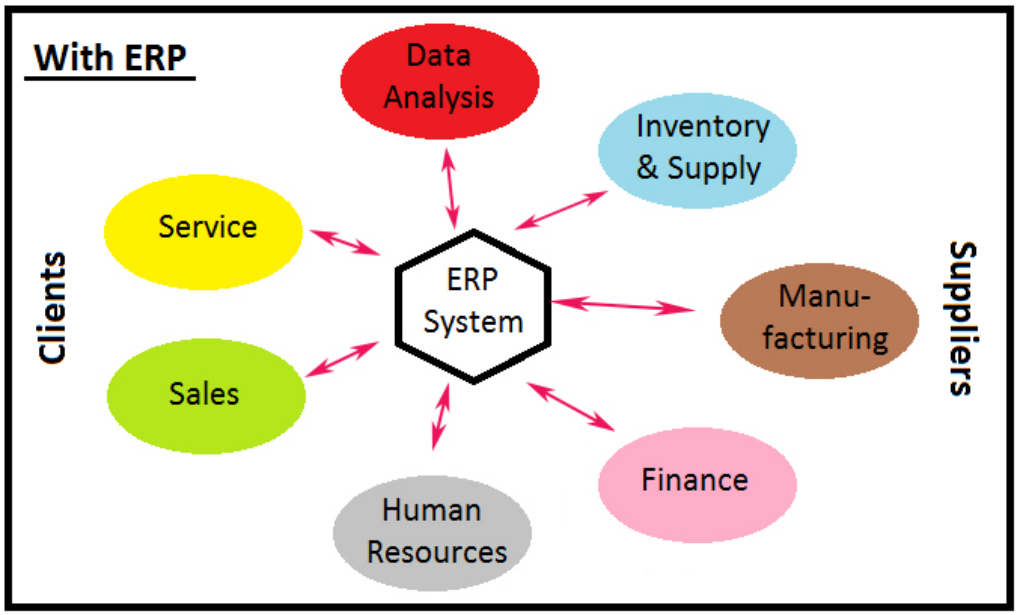


Figure 3-1 with and without of ERP system in an organization

3.2 History of ERP, how it began?

The integrated software packages history goes back to 1960 and early computers. In 1960s, the main focus of the enterprises was product volume to increase their product considering stable economic situation. At that time the new computerize system called ReOrder Point (ROP) was introduced which was focusing on the quantity and was able to satisfy preliminary Manufacturing Planning and Control (MPC) needs of the of the organizations. Material Requirement Planning (MRP) was born in late 1960 by efforts of a tractor and machinery manufacturing firm called J.I Case and IBM. This application was able to be used for planning and complex manufacturing products but the data had to be saved on large scale mediums and the files were being kept on tapes. Thanks to the random access memory availability, the MRP software was able to be made. At that time still there was no definition of the word 'database' in the vocabulary.

In the late 1970s, marketing became the competing arena which led to market focus strategies by emphasizing in better production and planning. As MRP systems were able to integrate between procurement, shop control, master scheduling and

forecasting, it was a decent system to satisfy these needs. This period also introduced IBM's new system called Communication Oriented Production Information and Control System (COPICS, cited in Robert Jacobs et al., 2007). Its purpose was a scheme approach to manufacturing control system which was integrated computer based. This was the shift to MRP II – Manufacturing Resource Planning system.

In the mid 1970 the birth of ERP system happened. In 1972 five engineers in Germany started up Systemanalyse und Programmentwicklung (SAP). Their goal was to create a standardize software to combine business solutions. In 1975 Lawson software was born. The business partners' aim was to create a ready-made software package having the ability to be customized. In 1977 J.D Edwards and Oracle were stablished. The first Structured Query Language (SQL) was introduced by Oracle.

IBM introduced a new system called as Manufacturing Management and Account System (MMAS). It was able to do many other functions such as updating inventories or providing manufacturing orders using bill of materials (BOM). Later in 1978 IBM introduced its newer IBM system and along with it released a software package which integrated applications and it was called Manufacturing, Accounting and Production Information and Control System (MAPICS). It took MMAS to a new level. It was able to do material requirements planning, invoicing and orders entry, sales analysis, inventory management, production monitoring and other controlling functions. In 1978 SAP also released other version which was known as SAP R/2 system. It used the full advantages of computer technologies at that time which was making it able to integrate between modules plus other capabilities including order tracking.

The 1980s was the era of MRP II. In the 1980s, the focus of IBM went more towards small and medium size enterprises by benefiting the use of portable disc drivers. Because MRP was able to cover many functions, its name became *manufacturing resource planning II* instead of material requirements planning and it was known as MRP II to show the new systems' capabilities. The objective of MRP II was to emphasize more in greater process control, international level manufacturing and reduction of overhead costs. Ollie Wight called these new systems as Business Requirements Planning (BRP) only to register this trademark in the early 1980s. MRP was the heart of MRP II but the difference was MRP II was written in modern

code. In 1987 Peoplesoft Company was found. This company contributed an innovation to Human Resource Management (HRMS) in 1988. At that time there were many major ERP software companies on the run but SAP, Baan, Oracle, IBM and Peoplesoft had the most contribution on the future developments of ERP.

1990s was MRP II and the beginning of ERP systems. The definition of ERP was to include the criteria for evaluating the extent that software was actually integrated both across and within the various functional silos (Robert et al., 2007).

Table 3-1 illustrates the summarized evolution of ERP.

Table 3-1 Summarize of evolution of ERP through decades (sysoptima, 2005)

1960s	Inventory Management and Control	Inventory Management and control is the integration of IT and business processes of maintaining the appropriate level of stock in a warehouse. The activities of inventory management include identifying inventory requirements, setting targets, providing replenishment techniques and options, monitoring item usages reconciling the inventory balances, and reporting inventory status.
1970s	Material Requirement Planning	Materials Requirement Planning (MRP) utilizes software applications for scheduling production processes. MRP generates schedules for the operations and raw material purchases based on the production requirements of finished goods, the structure of the production system, the current inventories levels and the lot sizing procedure for each operation.
1980s	Manufacturing Requirements Planning (MRP II)	Manufacturing Requirements Planning or MRP utilizes software applications for coordinating manufacturing processes, from product planning, parts purchasing, inventory control to product distribution.
1990s	Enterprise Resource Planning (ERP)	Enterprise Resource Planning employs multi module application software in order to improve the performance of processes of internal business. ERP systems combine business activities in functional departments such as product planning, inventory control, product distribution, fulfillment, parts purchasing and other tracking. ERP systems also may have modules for supporting marketing, accounting, human resource and finance.

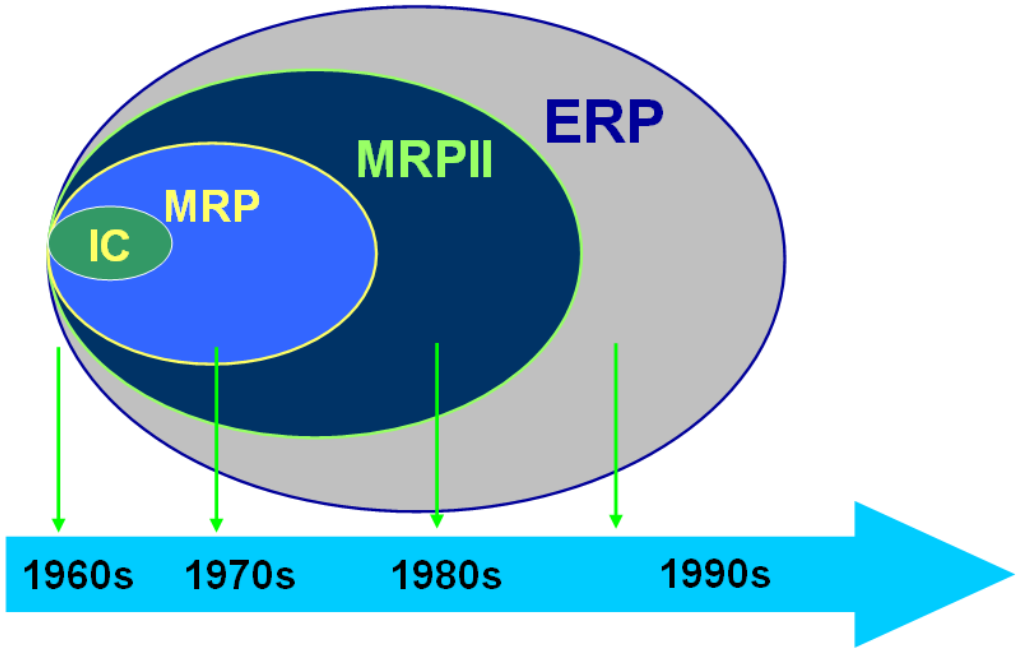


Figure 3-2 - ERP evolution

Figure 3-2 demonstrates the evolution of ERP graphically from 1960s. as it explained above, Inventory management and control (IC) was stablished in 1960s in order to increase the output. As the time passed, other integrated software packages were introduced and the above figure demonstrates that the new integrated software packages like MRP, MRP II and ERP were having the previous capabilities and also additional possibilities.

According to Erkan (2011), summarize of the main attribute focus of ERP systems in each decade is as below:

- 1960s: Quantity (Produce more)
- 1970s: Cost (Produce cheaper)
- 1980s: Quality (Produce better)
- 1990s: Lead time (Produce faster)
- 21st Sentry: Service

3.3 ERP Market share

There are many ERP system providers available for enterprises to choose from. Also the ERP systems are different in size and capabilities suitable for different uses. Looking in the past SAP was the top on the lead of ERP market share and was being used widely (Robert Jacobs et al., 2007).

According to Gartner reports, as of 2013 the world's ERP market share in percent wise can be summarize to Figure 3-3:

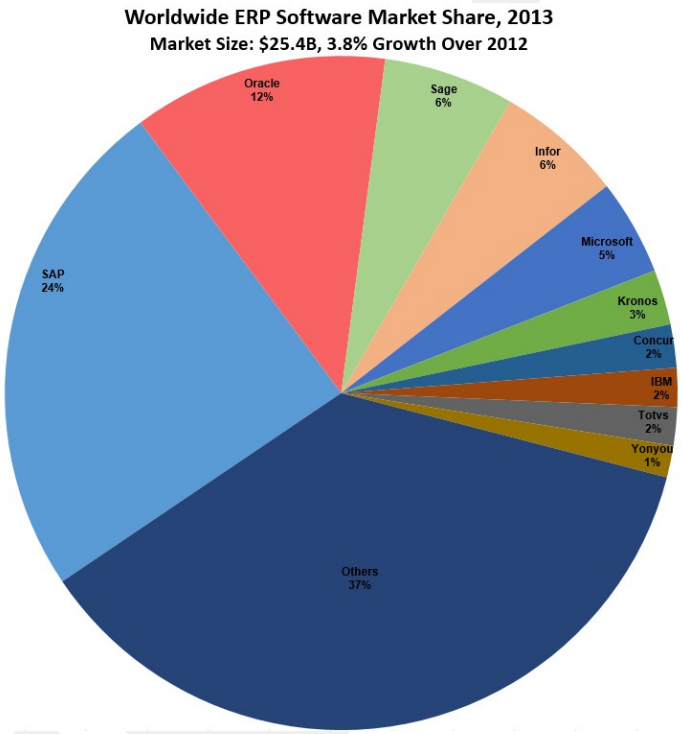


Figure 3-3 ERP world market share 2013 - Source: (Gartner, 2013)

As it is visible in Figure 3-3, the highest market share belongs to SAP as of 2013 and after that Oracle, Sage, Inferior and Microsoft dynamics follow and Kronos, Concur, IBM, Totvs and Yonyou are having a small percentage of the market share. Plus 37% of the market share belongs to other ERP software providers which cumulatively have significant amount.

3.4 Critical Success Factors (CSF)

According to Boynton and Zmud (1984) the Critical Success Factors (CSF) was first introduced in 1979 by John Rockart. These factors purpose is to assure the

performance of an organization. It is important for the managers to orderly observe the Critical Success Factor region as their result have a direct relation with the performance of organization (Rockart, 1979). There have been several studies on Critical Success Factors (Salazar et al., (2013) , Gajic et al.,(2012), (Nah and Lau, 2001), Umble (2003), Al-Mashar, Al-Mudimigh, and Zairi (2003), and Wei et al., (2005)). Their factors may vary but the common ERP critical success factors which most of the studies discussed about are clear goal and vision, top management support, user involvement, project team competence, use of consultant, minimal system customization, and business process reingeenering.

It is very important to select ERP before starting the implementation. The objectives must be set as it has great consequences if the ERP system was not selected properly.

According to Gajic et al. (2012) some specific critical success factors were identified for oil and gas field which are:

- Budgeting for Fiscal year for the whole company on a single, integrated basis.
- Harmonized material master records.
- Cost planning and collection on cost centers and for defined measures.
- Legacy systems connected via XI interfaces.
- Complete finances for the whole company.
- Centralized payment (in-house cash).
- Complete inventory (volumes and valuation).
- Closed purchasing loop (from requisition to payment).
- Credit limits check on a corporate level.

Table 3-2 demonstrates the critical success factors which were found during the literature review of Al-Mashari, Al-Mudimigh, and Zairi (2003), Umble, Haft, and Umble (2003), Motwani, Subramanian, Gopalakrishna (2005), Somers, and Nelson (2004) , Nah, and Lau (2001) and Zhang, Lee, Huang, Zhang, and Huang, (2005), for ERP implementation in this study.

Table 3-2 Critical success factors of ERP implementation

Critical Success Factor	Authors
Project management	Al-Mashari et al. (2003) , Nah et al. (2001), and Somers and Nelson (2004)
Business process reengineering (BPR)	Nah et al. (2001) , and Somers and Nelson (2004)
Change management	Motwani et al. (2005) , and Somers and Nelson (2004)
Communication	Al-Mashari et al. (2003) , and Nah et al. (2001)
Process management	Motwani et al. (2005) , and Somers and Nelson (2004)
A great implementation team Data accuracy	Umble et al. (2003)
Appropriate business & IT legacy systems	Nah et al. (2001)
Business plan & vision	Nah et al. (2001)
Business process change	Zhang et al. (2005)
Careful selection of the appropriate package	Somers and Nelson (2004)
Change management culture & program (user training and education)	Nah et al. (2001)
Clear understanding of strategic goals Commitment by top management	Umble et al. (2003)
Cultural & structural change	Al-Mashari et al. (2003)
Cultural readiness	Motwani et al. (2005)
Customization	Somers and Nelson (2004)
Data analysis & conversion	Somers and Nelson (2004)
Defining the architecture Dedicating resources	Somers and Nelson (2004)
Education and training	Zhang et al. (2005)
Education on new business processes	Somers and Nelson (2004)
ERP package selection	Al-Mashari et al. (2003)
ERP teamwork & composition Monitoring & evaluation of performance	Nah et al. (2001)
Establishing clear goals and objectives	Somers and Nelson (2004)
Excellent project management	Umble et al. (2003)
Extensive education & training Focused performance measures Multi-site issues	Umble et al. (2003)
Interdepartmental communication	Somers and Nelson (2004)
Interdepartmental cooperation	Somers and Nelson (2004)
IT leveragability and knowledge capability	Motwani et al. (2005)
Learning capacity	Motwani et al. (2005)
Legacy system management	Al-Mashari et al. (2003)
Management of expectations	Somers and Nelson (2004)
National or organizational culture	Zhang et al. (2005)
Organizational change management	Umble et al. (2003)
Project champion	Nah et al. (2001)
Relationship balancing	Motwani et al. (2005)

Software development	Nah et al. (2001)
Strategic initiatives	Motwani et al. (2005)
Systems integration	Al-Mashari et al. (2003)
Systems testing	Al-Mashari et al. (2003)
testing & troubleshooting	Nah et al. (2001)
Top management support	Nah et al. (2001)
Traditional IS implementation efforts (e.g. top management support)	Zhang et al. (2005)
Training & education	Al-Mashari et al. (2003)
User training & education	Somers and Nelson (2004)

GCRIS

CHAPTER 4

MCDM

4.1 What is MCDM?

Multi Criteria Decision Making (MCDM) is an important application of mathematical methods that can be used for selecting or ranking by using qualitative or quantitative criteria that has measurement units (Habenicht, Scheubrein, and Scheubrein, 2002).

Decision making process governed by multiple criteria is to concentrate on the aspect of decision making and the focus is on approaches which are determined by considering the problems of risk and uncertainty.

MCDM is used to deal with making decisions in conflicting objectives and the quality of the compromise which is the most important thing in MCDM depends on the preference of the decision maker. MCDM has many different elements depending on decision problems. At the stage of decision, it is the choice between various courses which are called alternatives. The decision maker should know about each alternative and the problems which are called variables and each of the decision variables is related a specific aspect of the alternatives. When the decision is made, the set of criteria which brings different consequences are appearing out of the choice of alternatives. Therefore, in MCDM more than one consequence is assumed which means each alternative can bring and M dimensional outcome. When considering the set of criteria, we need to take care of the following requirements (Habenicht et al., 2002): Integrity, no conflicting with each other, suitable accurate independence, prevention of redundancy and reliability.

When making decision, the decision maker should not look at the alternatives directly but at the outcome of the alternatives. This is called preferences. Also when

making decision, some problems might appear in many different ways such as choice problems, sorting problems and ranking problems.

During the 20th sentry, MCDM had enormous growth and many decision making methods were created. Table 4-1 illustrates some of important MCDM methods which were presented in 20th sentry.

Table 4-1 Important MCDM Methods (Thor et al., 2013)

Method name in full form	Method	Author and year
Analytical Hierarchy Process	AHP	Saaty (1980)
Simple Additive weighting	SAW	MacCrimon (1968)
ELImination and Choice Expressing Reality	ELECTRE	Roy (1991)
Technique for Ordering Preferences by Similarity to Ideal Solution	TOPSIS	Hwang & Yoon (1981)
Complex Proportional Assessment	COPRAS	Zavadskas et al., (1994)
Visekriterijumska optimizacija I Kompromisno Resenje in Serbian, which means Multicriteria Optimization and Compromise Solution	VIKOR	Opricovic (1998)
Preference Ranking Organization Method for Enrichment Evaluation	PROMEETHEE	Brans and Vincke (1985)

4.2 Overview of MCDM Methods

Many different MCDM methods have been presented till now (Guitoni and Martel, 1998). By using MCDM we can achieve a choice, classification, description, ranking, sorting and in many cases we can identify the order of the alternatives finding from least to most preferred (Liou, and Tzeng, 2012 and Roy 1996 and Zavadskas and Turskis, 2011). All of the MCDM methods follow these three stages (Triantaphyllou , 2000):

a. Determine the connected and related alternatives and criteria;

b. Assign numerical values according to the importance of the criteria and also the impacts which these alternatives have on the criteria;

c. Process the numerical values to determine a ranking of each alternative.

MCDM criteria can be qualitative and quantitative. The quantitative criteria are expert independent and can be used directly while qualitative criteria are expert dependent and they need to be converted to numerical values based on the scales provided to the experts (Mulliner, Malys, and Maliene, 2016). According to the data, there are different approaches of MCDM for decision making.

Different classification of MCDM methods are available based on the type of alternatives which can be either discrete or continuous (Zavadskas et al., 2011 and Hwang and Yoon 1981 and Zanakis, Solomon, Wishart, and Dublish, 1998). Discrete problems are distinct multi attribution option which usually have medium number of alternatives and called as Multi Attribute Decision Making (MADM) while continuous problems have infinite or immense number of decision alternatives and called as Multi Objective Decision Making (MODM) (Zavadskas et al., 2011 and Hwang et al., 1981). In this thesis, as the problem is selecting ERP system for oil and gas firms, the problem is a discrete problem and one of the MADM methods should be used.

The main steps of Multi criteria decision making can be summarized to (Zavadskas et al., 2011):

— Identifying the main purpose of the problem;

— Setting up the main criteria or objectives that the alternatives will be decided with

— Obtain the alternatives which can be used to achieve goals

— Assigning weight to each criterion of the decision. The decision maker has to assign importance level to each criterion and one of the approaches is to assign weights to criteria.

Velasquez et al. (2013) summarized the advantages and disadvantages MCDM methods and below are some important of them:

a. Analytic Hierarchy Process (AHP):

Advantages: Simple to use, possible to make scales, the hierarchy structure gives the ability to use in different problem sizes, does not concentrate on data

Disadvantages: because of interdependence of the criteria and alternatives, the problems can end up with inconsistencies between ranking criteria and judgment - rank reversal.

Areas of usage: Performance related applications, planning, political strategy, corporate policy and strategy, resource management, and public policy.

b. Fuzzy Set Theory:

Advantages: possibility of imprecise input, accepts insufficient information

Disadvantages: Difficult to use, may need several simulations prior to use.

Areas of usage: Engineering, social, management, economics, medical, and environmental.

c. ELECTRE:

Advantages: considers vagueness and uncertainty.

Disadvantages: It may be difficult to explain the process and outcome of it in layman's term. The strengths and weaknesses of alternatives may not be identified directly due to outranking.

Areas of usage: Energy, water management, environmental, and transportation.

d. TOPSIS:

Advantages: Simple process, easy to use and program, same number of steps regardless of number of attributes.

Disadvantages: Difficult to weight and keep consistency of judgment. Uses Euclidean Distance and doesn't consider the correlation of attributes.

Areas of usage: logistics and supply change management, business and marketing, engineering, manufacturing system, human resource, environmental, and water resources management.

4.3 Analytical Hierarchy Process (AHP)

One of the famous methods of solving decision making problems is AHP. It is a branch of Multi Attribute Decision Making (MADM) methods which has been used widely in many problems. In this method, the functions of pair wise comparison matrix and eigenvector are getting calculated to find the weights of the parameters in the problem and the obtained weights will help the decision maker to pick the optimum alternative (Rouyendegh et al., 2012). It is a technique to solve complex decision making problems and it uses pair wise comparison plus relative levels of the units in order to achieve the optimum solution (Saaty, 1990). Since 1970 which it was introduced by Saaty, it has been widely used and studied in researches (Bhushan and Kanwal, 2004). Also in this thesis, based on the literature reviews and practical investment AHP is proposed which is one of the most appropriate approaches for firms in oil and gas to select the right ERP system for their organizations. Also because of the fuzziness of the values, the result is compared with Fuzzy AHP method in the following stage of AHP. It is better to select the appropriate ERP system for the firms instead of trying to adapt to an available ERP system.

4.4 Fuzzy Analytical Hierarchy Process (FAHP)

Fuzzy AHP is an advanced technique of AHP. Although AHP can handle both qualitative and quantitative criterions of MCDM problems according to the decisions of decision makers, still vagueness and fuzziness can exist in the decisions of many decision makers and can effect on their decisions (Bouyssou, Marchant, Pirlot, Perny, Tsoukias, and Vincke, 2000). Zadeh first coined Fuzzy sets in 1965 which can be defined as a form of mathematical problem which will result in values between 0 and 1 (Cakir, Tozan, and Vayvay 2009). There have been different studies by researches proving that Fuzzy AHP is more promising in decision making rather than traditional AHP methods (Hamidi, 2015).

Yu (2002) utilized goal programming in order to solve Fuzzy AHP problem with group decision making. Kulak and Kahraman (2005) employed fuzzy AHP method as the MCDM tool for selecting transportation for companies. Sheu (2004) presented a hybrid fuzzy approach method for identifying global logistics strategies.

Judgement of decision makers is linguistic and vague in complex systems. Hence a better interpretation is required to make these linguistic judgements to quantitative data. These types of data can be interpreted by fuzzy set theory methods. AHP is employed for literally non-fuzzy decision problems and the unbalance judgements can effect on it (Hamidi, 2015). Consequently, the AHP method does not consider the uncertainties in the problem (Chang, Yang and Hwang, 1999). As AHP method is subjective judgment, the decision of decision makers can affect greatly on the success rate of the problem. Also because AHP cannot understand human thinking style, in order to avoid these problems, fuzzy theory of AHP is being used.

In order to make the final judgement stronger, the Fuzzy AHP method which was introduced by Chang (1992) is being used. This method relies on possibilities of each criterion. Based on the linguistic answers of the decision makers, triangular fuzzy values will be used in order to interpret them in fuzzy algorithm for pairwise comparison.

This fuzzy AHP algorithm is consisted of six stages using Chang's method (Chang 1996). This method is rather easier and simpler than other proposed fuzzy methods and can be benefited in many cases (Jian, Lee, Chen, and Jiao, 2012 and Büyüközkan, Çifçi, and Güleryüz 2011).

4.5 Procedure of selecting ERP system

To select the suitable ERP system, a stepwise procedure is introduced which we used in this thesis (Figure 4-1) (Wei et al., 2005). There are 7 steps which have to be followed:

Step 1- create a team for the project, gather all available information about every systems and providers in the market.

Step 2- Determine the characteristics of ERP system.

Step 3- Establish the list of objectives to be achieved to develop the fundamental-objective hierarchy and means-objective network.

Step 4- Exploit the attributes in order to evaluate the ERP systems from the structure of objectives.

Step 5- Remove the unqualified vendors by especial questions which were deigned at the time of system requirements.

Step 6- Using the AHP method Evaluate the ERP systems.

Step 7- Consider and talk about the results and choose the final solution.

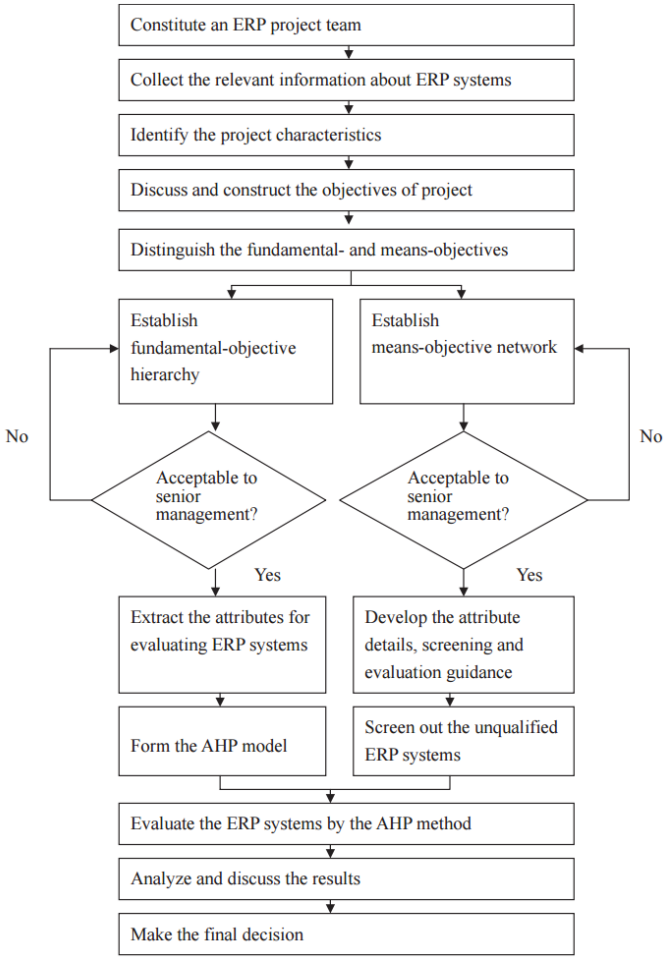


Figure 4-1 The procedure of selecting an ERP system (Wei et al., 2005)

The first step which is 'Form a project team' is to assign the decision makers by making a team of experts and seniors of each department. According to Ptak (2000) the success of an ERP system is significantly related with the support of the management. In order to select the ERP vendors, it is important to look in the Internet, professional magazines, exhibitions and other resources to be assured of not missing any important ERP system.

After forming the firm, the next step for each organization which seeks an ERP system implementation is to define the problem, identify the methods to achieve goals and related activities. In order to be assured of a smooth progress, the project team has to identify the project objectives, number of alternatives, project risks and other concerns. They have to identify the complex situations and create a plan for it.

After that they have to make the structure of objectives so that the team can explain the goal of the company in detail and put these objectives in the decision model. The project team has to consider the company policy, goals of the project, environment of the industry and business attributes in order to define the ERP (Wei et al., 2005).

4.5.1 Review of selection methods

There has been significant amount of ERP or other information system selection methods introduced such as ranking, scoring, multi criteria analysis and mathematical optimization (Wei et al., 2005). The scoring method which was presented by Lucas and Moore (1976) was a good start but it was just too simple for decision makers to rely on. A ranking approach was suggested by Buss (1983) but it had the same restrictions like the scoring method. They used mathematical optimization including 0-1 programming, goal programming and nonlinear programming to optimize the resource for selecting the information system. A nonlinear programming method was proposed by Santhanam and Kyparisis (1995 & 1996) considering interdependencies in information system selection processes of projects. It was mentioned by Lee and Kim (2000) that Santhanam's method lacked criteria. They used a 0-1 programming and Analytical Network Process (ANP) model together to select an information system project. A 0-1 programming model was presented by Badri and Davis (2001) considering many criteria for selecting an information system project but as these methods required complicated mathematical processes and some attributes in real world cannot be considered or the managers involved in decision making can't understand them and it focuses only in quantifiable attributes, they are not so strong.

The AHP method was introduced by Saaty in the 1970s which was addressing how to assign priority to a set of alternatives and attributes importance level in a MCDM problem. It has been used in many different problems (Wei et al., 2005) but the problem was that they didn't consider specific objectives of company's strategies to

fulfill company's requirements using the right criteria for evaluation. In this thesis our objective is to focus on oil and gas industries to find a relatively suitable selection for these firms.

4.5.2 Criteria Selection

In order to select ERP system using AHP method we need to consider some criteria to compare them. There are various studies about MCDM methods to be applied in the selection of software packages. One study for evaluation and selection of software packages has been done which contains a systematic review of methodologies for the techniques regarding selection of software packages and software evaluation. Their conclusion was that in many researches studies, applying AHP was successful in the evaluation of software package (Silva et al., 2013).

There are many advantages to use ERP in organizations regarding management and user productivity. By using ERP systems, the organizations want to be at a point where IT is used and they are able to plan and merge enterprise wide resources as well as combining the applications with the processes in different functions (Kumar Maheshwari, and Kumar, 2002).

Generally, there are two different classifications as functional and non-functional needs of the software (Karlsson, 1997). The functional needs are what the software users expect as the core, describing how the system is working. However, the functional needs explain the connection between valid (and-invalid) inputs and outputs of the system while non-functional requirements are the features of the systems which are hard to explain and test (Sen, Baracli, and Basligil, 2009). The size of the firms also matters. Based on a survey by (Bernroider and Koch, 2001), their findings is that some criteria such as organizational flexibility, relations of organization with suppliers and international section of ERP is not important for small medium size organizations.

In the beginning it was suggested eleven criteria for deciding the software quality (McCall, Richards, Walters, 1977). There have been many researches that expanded those eleven criteria to different studies. Alanbay (2005) suggested 15 main elements of selecting ERP systems based on the enterprises' needs, including real time changes, flexibility, customization, implement and maintenance ability, expenses,

services followed by training and support of the sales, financing options, other applications compatibility and etc. Karsak and Özogul (2009) suggested the six core criteria are the aspects of user-friendly, reputation of the vendor, total cost, service and support of the provider, functionality of the ERP system in the organization and flexibility also in ISO 9126 the six coral dimensions are known as efficiency, reliability, maintainability, usability, functionality and portability (Liang and Lien, 2007). Five core criteria of Reliability, User Friendliness, Functionality, Implementation and Total Cost for ERP system selection were suggested by Rouyendegh et al. (2011) for ERP system selection. Silva et al. (2013) did a study for criteria selection of ERP using AHP approach by conducting two surveys and by categorizing the criteria in two parts of ERP Vendor and ERP software package and 10 subgroups of Financial condition, Market share / scale of the vendor, Payment and financial terms, Portfolio, Guarantees, Implementation ability, Training, Consultancy services, Technical support quality, Technical team capability for ERP Vendor and 20 criteria of Stability and recover capability, Source code availability, Security, Customization, Scalability and upgrade ability, Function-fitness / module completion, Consultancy cost, Software acquisition cost, Maintenance cost, Integration/middleware cost, Hardware/infrastructure cost, Software licensing cost, Documentation in native language, Online help and tutorials, Documentation quality, User friendliness, Integration support, Database engine compatibility, Hardware requirements and Operating system compatibility were considered for ERP software package. Among these criteria and by having the survey done to IS Managers, IS staff or technicians, IT business manager / IS Consultant and other staff, they got the conclusion that five criteria of technical support quality, security, function fitness, technical team capability, and stability and recover capability where the essential criteria achieved by the survey and two criteria of source code availability and market position/sale were least in importance aspect and larger organizations ranked payment and financial terms and customization criteria more important than smaller organizations.

With the above studies and literature reviews and consulting with experienced IS personnel with ERP, we selected 6 main criteria and 8 sub-criteria which are explained below.

Functionality: According to Ehie and Madsen (2005) it is not possible for any ERP software package to satisfy the especial special needs or all of functionalities of an enterprise. Based on each firm, there are different requirements are available to satisfy as per their unique requirements. The usual requirements are Quality Control/Assurance, Human Resource Management, Sales, Maintenance Management, Supply Chain management, Transportation Management, Product and Distribution Management and Planning, Warehouse Management, Operations Management and etc. (Klaus et al., 2000 and Avraham, 2002). During a research study, it was found that only 50% of the implemented functionality is being used for the ERP systems of organizations and the rest of functions were not being used at all (Cliff, 2006). Hence the functionality criterion, in addition to the number of functions, means the quality of functions provided by the ERP system which are being used in an organization.

User Friendliness: this criterion means the easiness of the ERP system for the users to operate and learn. The user interface is important in order to give possibility to users to have access and interact with the functions easily and efficiently. The ERP system should be designed such way to support the organization for the ERP system's lifetime even if there were changes in the organization, if something was deleted, added or changed it should be able to adopt with it and it should match with the culture of the organization. According to Karsak, and Ozogul (2009) having self-explained and comprehendible menus and screen can reduce the process of adaptation for the users and also the basic training and it is essential for ERP software.

Vendor credentials: It was mentioned in approximately most of the studies as one of essential criteria disregarding the size of organizations whether they are small, medium or large enterprises. The size of organizations has no effect in this criterion. Vendor credentials consist of three sub-criteria as 'presentation of previous demonstrations', 'market share' and 'reputation of the vendor' which we discussed in our study. These main elements are important for oil and gas firms to decide selecting their required ERP provider. The element of presentation of previous implementation is important for the firms to observe their quality of work and the other two criteria of market share and the reputation of the vendor is accessible for the firms to obtain. To summarize it, the vendor credentials criterion expresses the

market's reputation and popularity of the vendor plus it can explain the dedication and devotion of the vendor for the task (Alanbay, 2005).

Maintenance: every firm needs to consider future maintenance of their ERP software and it is important to consider this fact in the implementation phase (Gross, 2010). By maintenance it means customer services after the sale, training and change in real time. In order to use the ERP software, training is required to be done to the staff also customer service after sale is important so the users can understand the functions of the system and how to use it. Not having these requirements can lead to negative effects for the organizations; effects such as not being able to upgrade the software, too many workarounds for the organization and also suspension of operations. It is obvious that this criterion points out at the after implementation services.

Finance: it consists of three sub criteria of "cost of upgrade and maintenance with consultation", "cost of implementation" and "software expenses". In order to select a suitable ERP provider, cost of implementation is significantly very important point for making the decision plus considering the services required after sale (if any) which could be some unexpected problems also training cost of the employees to teach them the usage of the software. According to a research by Celeste, Gable and Chan, (2003), they found that around 25% of the implementation cost of an ERP system is the cost of annual maintenance and about 25-33% of the cost of Implementation of an ERP system is the cost of upgrade. If we want to consider this amount for small or medium size companies, this much money may not be affordable for them. Consequently, the organizations must consider the financing aspects and the lifetime duration of an ERP system before deciding to use select it. Overall the financing criterion means the willing to pay total cost of an ERP system.

Implementation: according to Malhotra and Temponi (2010) almost all of the processes of an enterprise can be affected by the ERP system which is supporting the whole organization. The two sub-criteria of compatibility and customization are very important during the implementation of an ERP system because different organizations are using different applications and they need to transfer their data to the ERP system they are going to use and still use their previous software if they needed. Hence it is important for the ERP modules to be compatible with other

software that the organization was using before to be able to transfer the data (Loh and Koh, 2004) and also The ERP system should be ready to transfer the data with previous software applications and also some firms may not be ready or may not have the resources to import them to the ERP system considering the long duration of implementation (Nah and Lau, 2001). The implementation criteria means how well the ERP system is matching and compatible with the current system of the organization, the duration of implementation process and customization possibility of the new system with the ideal strategy of the business.

Table 4-2 shows the summarized criteria.

Table 4-2 Selected Criteria and Sub-Criteria for ERP System providers

Requirements	Criteria	Sub Criteria
Functional	Functionality (Fun)	-
	Implementation (Imp)	Compatibility (Comp)
		Customization (Custom)
	User Friendliness (UF)	-
Non-Functional	Vendor credentials (VenC)	Presentation of Previous Demonstrations (PrvDem)
		Market Share (MarS)
		Reputation of the Vendor (RepVen)
	Maintenance (Mnt)	-
	Finance (Fin)	Cost of Upgrade and Maintenance with Consultation (CstU)
		Cost of Implementation (CstI)
		Software Expenses (SE)

The above criteria and sub-criteria (Table 4-2) which were obtained through the literature review and discussion with the staff of the organizations that were using ERP system are being used for this study and also it can be used in any organization which they want to select ERP provider in oil and gas field using AHP method. Table 4-3 demonstrates the criteria which were used in the study of other authors.

Table 4-3 Criteria presented in other studies

Criterion	Literature Review
Finance	Alanbay (2005)-Silva, Fernandes, Goncalves, and Cunha (2013)-Perera and Costa (2008)
Functionality	Liang and Lien (2007)-Rouyendegh and Erkan (2011) -Tolga (2011)
User Friendliness	(Bernroider and Koch, 2001)-Karsak and Özogul (2009) -Rouyendegh and Erkan (2011)
Implementation	Silva, Fernandes, Goncalves, and Cunha (2013)-Rouyendegh and Erkan (2011) -Alanbay (2005)
Maintenance	Alanbay (2005)-(Liang and Lien, 2007)-Silva, Fernandes, Goncalves, and Cunha (2013)
Market Share	Jadhav and Sonar (2011). -Silva, Fernandes, Goncalves, and Cunha (2013)-Wei, Chien, & Wang (2005)
Presentation of Previous Demonstrations	Silva, Fernandes, Goncalves, and Cunha (2013)-Kumar, Maheshwari, and Kumar, (2002) -Hamidi (2015)
Cost of Upgrade and Maintenance with Consultation	Hamidi (2015)-Alanbay (2005)-Karsak and Özogul (2009)
Cost of Implementation	Alanbay (2005)-Karsak and Özogul (2009) -Hamidi (2015)
Compatibility	Karsak and Özogul (2009) -Silva, Fernandes, Goncalves, and Cunha (2013)-Alanbay (2005)
Vendor Credentials	Silva, Fernandes, Goncalves, and Cunha (2013)-Alanbay (2005)-Feili, Mirkazemi Mood, Rahmany Youshanlouei, & Sarabi, N (2012).
Reputation of the Vendor	Karsak and Özogul (2009) -Hamidi (2015)-Kumar, Maheshwari, and Kumar, (2002)
Software Expenses	Hamidi (2015)-Alanbay (2005)-Silva, Fernandes, Goncalves, and Cunha (2013)
Customization	Silva, Fernandes, Goncalves, and Cunha (2013)-Baki and Cakar (2005)-Alanbay (2005)

CHAPTER 5

METHODOLOGY

In this section the methodology of research used in this thesis and how the data and information gathered are explained.

5.1 Overview

In the beginning by presenting the literature review which they were obtained through Atilim University's library access to websites such as Web of Science and ScienceDirect and also using the EndNote program, multitude of previous studies were accessible. The keywords which were used for this study were "ERP", "AHP", "Oil and gas". The data for the criteria was obtained through a survey by oil and gas companies' staffs in direct approach with ERP system in United Arab Emirates. Also a case study is done in OGASCO L.L.C which is an oil and gas Equipment Manufacturing Company. In order for them to stay ahead in the market they had to choose and implement an ERP system. AHP was used as the decision making tool for achieving their goal and the results were compared with Fuzzy AHP method. Among the ERP providers, they selected two ERP providers which were offering Microsoft Dynamics and Oracle and finally by utilizing these two MCDM methods they chose Microsoft Dynamics as their final decision.

5.2 Collecting the Data

After gathering the information of how approaching quantitatively and qualitatively, the next step is to obtain data by creating research questions to obtain different information provided in the questions and categorize them (Creswell, 2007). As there are many different approaches available to obtain data and information, using data collection technique allows achieving the data required in a system-wise manner. The main purpose of this study is to find the problems oil and gas companies were

facing when they wanted to choose and implement an ERP system in their companies and how to overcome them by using a decision making method and identifying the most important criterions. However, the optimum approach is to discuss this matter with each firm's Information System's managers and staff in-charge to obtain this information. While it was not practical to do this, the survey was the best approach for the data collection approach.

5.3 Design of the Survey

The questionnaire was designed in 3 parts (Appendix I). The first part is the introduction of the criteria which criteria and sub-criteria and their properties which the participants were supposed to answer, were explained briefly. The second part is the explanation of the scale introduced by AHP for assigning preferences for comparing two criterions. The third part is consisted of two parts. Part one is the background information which those respondents who did not have experience in implementation of ERP system were not considered in the analysis and this section allowed me to identify them; and part two is the preference selection of the people participating in the survey. In this section, the participants compare the criteria which were explained to them beforehand for ERP system selection.

CHAPTER 6

ANALYSIS OF THE FINDINGS

In this part the summary of information received from the survey and interview are explained and then the obtained data are processed by AHP and Fuzzy AHP methods. Finally, at the end of this section a case study of two ERP providers in oil and gas field which were decided suitable for the organization are done based on the survey which was done for the criteria using AHP method and the results were compared with Fuzzy AHP method.

6.1 Data obtained from the survey

As explained before, many of the organizations are not prepared for implementing an ERP system for their firms because of lack of information and difficulty for selecting a convenient ERP software provider for their firms. These firms can use the hierarchy explained in AHP section (Figure 6-3) and use AHP or FAHP methods in order to select the most convenient ERP system for their firms. This research can be beneficial for the ERP software providers who are going to provide ERP system for the organizations in oil and gas field to understand which criteria they should focus most and make their system better.

The survey was sent to firms which were involved in oil and gas construction firms and were known to OGASCO L.L.C. The size of the firms were mainly medium sized companies, though the size did not consider in this study but it can have influence in selecting criteria for the decision making process if it varies. Among the 88 submitted surveys 38 of the firms filled them out and sent it back. Large percentage of them (87%) had ERP system implemented in their organizations and were medium sized companies which were considered credible in this study (33 firms) (Appendix IV). There are 22 pairwise comparisons for the decision makers

and the geometric mean of each pairwise comparison is considered as the final value. (Dong, Y., Zhang, G., Hong, W.-C. & Xu, Y., 2010).

6.2 Steps for analyzing data using AHP method

The four steps of AHP calculation method can be summarized to below stages (Hamidi, 2015):

Step 1: *Set up the hierarchical system by decomposing the problem into a hierarchy of interrelated elements.* Which the problem is decomposed to attributes and each attribute to sub attributes to the bottom (Figure 6-1).

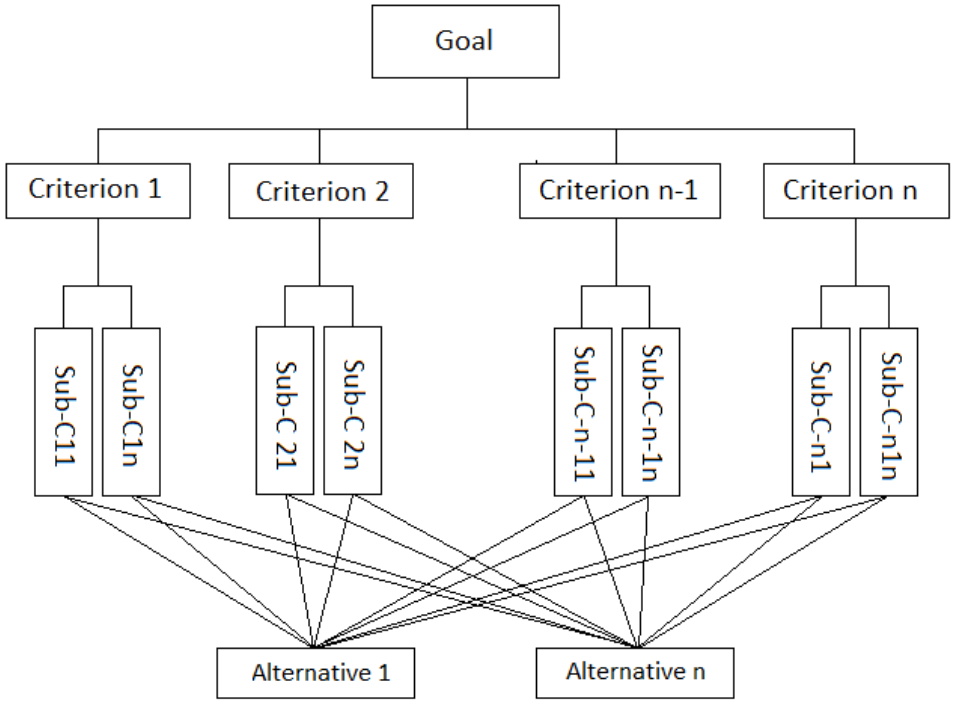


Figure 6-1 General form of AHP hierarchical structure (Saaty, and Vargas, 2000).

Step 2: *Compare the comparative weight between the attributes of the decision elements to form the reciprocal matrix.* This can be achieved by comparing

preferences of every two attributes and sub-attributes using the table introduced by Saaty (Table 6-1).

Table 6-1 Preference scale of two attributes (Saaty et al., 2000)

Preference weights (level of importance)	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	Used to represent compromise between the preferences listed above
Reciprocals	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with I - A reasonable assumption	

In order for the decision makers to compare two attributes, according to the above table, they will compare each of two attributes together. For example, if we consider attribute A is preferred strongly to attribute B then attribute A will have value of 5 and attribute B will be considered less importance and will have value of 1/5 (Figure 6-2)

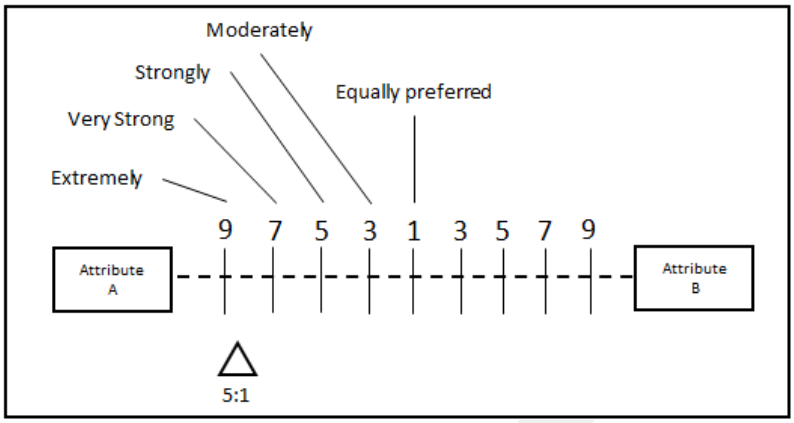


Figure 6-2 scale of comparing two attributes of A and B

Step 3: *Synthesize the individual subjective judgment and estimate the relative weight.* In order to calculate the relative weight of each attribute or Priority Vector (PV), the result of attributes has to be summed and then they have to be divided by the achieved sum. Table 6-2 is an example of calculation for the attribute 1 and 2 in above.

Table 6-2 Sample Matrix of PV calculation for Attributes A and B

	Attr 1	Att 2	Priority Vector (PV)
Att 1	1	5	0.833 = (5/6)
Att 2	1/5	1	0.166 = (1/6)
	1.2	6	

The same way it can be calculated to achieve the PV values of each alternative. Below Table 6-3 and Table 6-4 demonstrate example of PV calculation for Alternatives 1 and 2.

Table 6-3 Calculation sample of alternatives Matrix of PV based on attribute A

	Alt 1	Alt 2	Priority Vector (PV)
Alt 1	1	1/3	0.25
Alt 2	3	1	0.75
	4	1.33	

Table 6-4 Calculation sample of alternatives Matrix of PV based on attribute B

	Alt 1	Alt 2	Priority Vector (PV)
Alt 1	1	1/4	0.20
Alt 2	4	1	0.80
	5	1.25	

Then calculation of the overall priority scale of each alternative can be achieved by multiplying the weights of attributes according to the goal, to the weight of attributes according to each alternative in order to achieve priorities.

Hence for the above examples the results are:

Priority goal of Alternative A = 0.833 * 0.25 + 0.166 * 0.20 = 0.24145

Priority goal of Alternative B = 0.833 * 0.75 + 0.166 * 0.80 = 0.75755

Step 4: *Aggregate the relative weights of the elements to determine the best alternatives/strategies.* This is the final step or selecting phase. After the previous step the best choice in the alternatives can be achieved.

Calculating the consistency of data:

Coyle (2004) explains that in this step the consistency of the judgment is assured by comparing it with large samples of random judgments. According to Saaty, the Consistency Index (CI) can be calculated to find the consistency of our instinctive judgment. The formula for calculating Consistency index is

$$CI = \frac{(\lambda max - n)}{(n-1)} \quad (1)$$

where λmax is the highest eigenvector and n is number of criteria.

Later in 2000, Saaty changed this approach and introduced Consistency Ratio (CR). It can be calculated by calculating the biggest eigenvector and multiplying the PV of each column to the sum of each row and then finding the Consistency index (CI) by the above formula and dividing it to the Random Consistency Index (RCI).

$$CR = \frac{CI}{RCI} \quad (2)$$

The RCI depends on the order of matrıx and number of executions of the simulation (Kannan, 2008). Table 6-5 is derived from Saaty (2000) for matrices ordered from 1-10 by using random indices of a size 500 sample.

Table 6-5 RCI of 1 to 10 (Saaty,et al., 2000)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Acceptable evaluation shall have CR≤0.1. If CR is above 0.1, it shows that there is inconsistency in the judgment and the process of evaluation should be repeated (Crowe, Noble, and Machimada, 1998).

The calculation steps for finding the CR is explained through the below example:

Table 6-6 Attributes table example to calculate Consistency Ratio (CR)

	Crt A	Crt B	Crt C	n^{th} root of products	Eigenvector
Crt A	1	1/5	1/7	0.306	0.078
Crt B	5	1	1	1.710	0.435
Crt C	7	1	1	1.913	0.487
Total				3.929	

Considering Table 6-6 as a sample table of compared 3 attributes, the fourth column which is titled as '*n*th root of products' is calculated by multiplying the values of each row and taking their nth root. For example, for the first row it is calculated as:

(1 * 1/5 * 1/7) ^ (1/3) = 0.306

Then the eigenvector elements are being found by diving each obtained value to total. For example, for the first row it is calculated as:

0.306 / 3.929 = 0.078

The eigenvectors of the relative importance of A, B and C are calculated as (0.078, 0.435, 0.487). Hence C is the most valuable, after it B and A is not significantly important.

The next stage is to calculate λmax in order to find CI and then CR.

First the right hand side of the table is multiplied to eigenvectors to obtain a new vector. For the first row it is calculated as below:

(1 * 0.078) + (1/5 * 0.435) + (1/7 * 0.487) = 0.234

And the other two rows were calculated the same way and provided the values of 1.311 and 1.467. So for the three elements the values (0.234, 1.311, 1.467) were obtained. Then by dividing each element to the corresponding eigenvector the estimation of λmax. the first element is calculated as below:

0.234 / 0.0780 = 3.0125

The other two elements in this example provided the same results. Hence the estimated λmax for the three elements are (3.0125, 3.0125, 3.0125). By taking the mean of these values the λmax value can be obtained which is 3.0125. A test to check whether the calculations were correct or no is to see if any of obtained values are less than *n* or in this sample 3, which if it was true, it would show a mistake in calculation.

Then the consistency index or CI is calculated through the Eq. (1) and as *n* is equal to 3 in this sample, the final value is 0.0062. Finally using Table 6-5 and the Eq.(2) , the CR value is calculated as below:

CR = 0.0062 / 0.58 = 0.0108

Which shows the CR value is less than 0.1 and as explained previously, the attributes in the sample are consistent.

6.2.1 Analysis of the data obtained from the survey using AHP method

As per the first step introduced in the previous section, the hierarchy of ERP selection is created based on the selected criteria and alternatives.

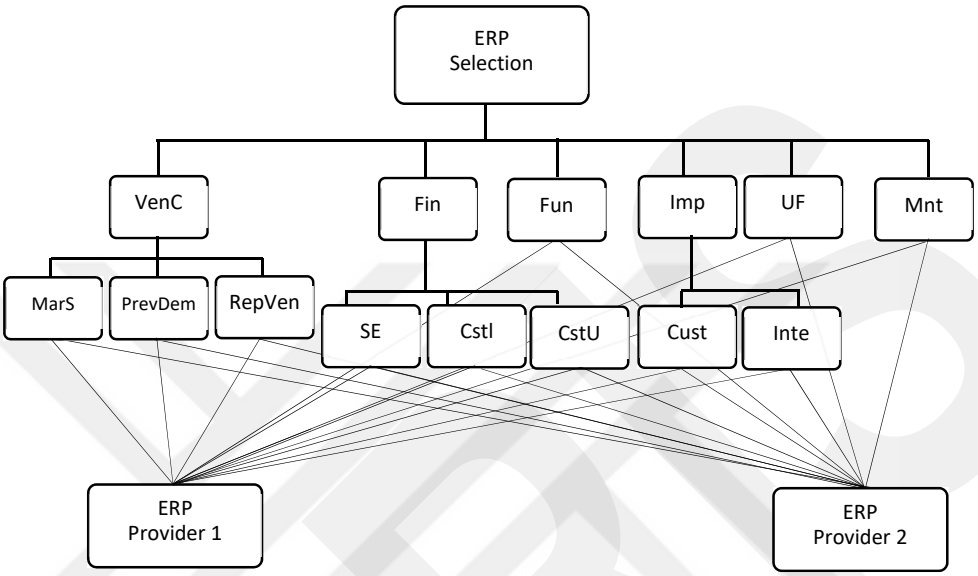


Figure 6-3 Decision making model of selecting ERP system for oil and gas firms using AHP

As the decisions were being made by 33 firms, in order not to neglect any decision and aggregate the judgments of individuals, the weighted geometric mean method (WGMM) should be used (Aczél and Saaty, 1983). In order to calculate the weighted geometric mean of the judgments of *n* decision makers for comparisons of a_{ij}, which *i* and *j* represent the two compared criterions, the below geometric mean formula is being used which demonstrates the aggregated group decisions:

$$WGM_{a_{ij}} = \left[\prod_{a_{ij}=1}^{m} a_{ij}\right]^{\frac{1}{m}}, \qquad m = 1, \dots, n. \tag{3}$$

Using Equation (3) the below data is achieved from appendix IV (Table 6-7):

Table 6-7 Geometric means of obtained comparison preferences of the criteria from the surveys

Compared Criterions	Geometric mean
Finance VS Functionality	0.9720203
Finance VS User Friendliness	1.05515063
Finance VS Implementation	3.467167
Finance VS Maintenance	0.66206067
Vendor Credentials VS Finance	0.49940882
Vendor Credentials VS Functionality	0.71305534
Vendor Credentials VS User Friendliness	0.66344413
Vendor Credentials VS Implementation	0.86846404
Vendor Credentials VS Maintenance	1.75379893
Functionality VS Implementation	0.71674235
Functionality VS Maintenance	1.92330009
Functionality VS User Friendliness	0.54191893
Implementation VS Maintenance	0.52824652
Implementation VS User Friendliness	0.87049179
User Friendliness VS Maintenance	3.3355606
Reputation of the Vendor VS Market Share	0.8002406
Reputation of the Vendor VS Presentation of Previous Demonstrations	1.65723315
Presentation of Previous Demonstrations VS Market Share	1.28875884
Software Expenses VS Cost of Upgrade and Maintenance with Consultation	1.01298258
Software Expenses VS Cost of Implementation	0.82105338
Cost of Upgrade and Maintenance with Consultation VS Cost of Implementation	0.47674718
Customization VS Compatibility	0.6809515

Table 6-7 shows the geometric mean of pairwise comparison data of the 14 criteria (main and sub) obtained from the survey. The next step is to compare the main criteria and sub-criteria pairwise in matrices. Table 6-8 to Table 6-11 are demonstrating putting the values of geometric means in the table in order to compute the criteria in the next stages:

Table 6-8 Comparison pairwise matrix of main attributes

	VenC	Fin	Fun	UF	Imp	Mnt
VenC	1.00	0.50	0.71	0.66	0.87	1.75
Fin	2.00	1.00	0.97	1.06	3.47	0.66
Fun	1.40	1.03	1.00	0.54	0.72	1.92
UF	1.51	0.95	1.85	1.00	1.15	3.34
Imp	1.15	0.29	1.40	0.87	1.00	0.53
Mnt	0.57	1.51	0.52	0.30	1.89	1.00

Table 6-9 Comparison pairwise matrix of Vendor Credential sub-criteria

VenC	RepVen	MarS	PrvDem
RepVen	1.00	0.80	1.66
MarS	1.25	1.00	0.78
PrvDem	0.60	1.29	1.00

Table 6-10 Comparison pairwise matrix of Finance sub-criteria

Fin	SE	CostU	CostI
SE	1.00	1.01	0.82
CostU	0.99	1.00	0.48
CostI	1.22	2.10	1.00

Table 6-11 Comparison pairwise matrix of Implementation sub criteria

Imp	Custom	Comp
Custom	1	0.68
Comp	1.47	1

By further calculating in Excel, the obtained data from the analysis shows that User friendliness (UF) and Finance (Fin) have the highest values (0.23 and 0.216) among other criteria and hence they are the most important criterions that the organizations

and ERP providers need to focus on. Table 6-12 shows the relative weight calculated after normalizing the matrices.

Table 6-12 Calculated Relative weight of criteria and sub criteria after normalizing using AHP

Criteria	Relative weight using AHP	Sub-criteria	Relative weight using AHP
VenC	0.129	RepVen	0.36
		MarS	0.33
		PrvDem	0.31
Fin	0.216	SE	0.31
		CostU	0.25
		CostI	0.44
Fun	0.157		
Imp	0.131	Custom	0.41
		Comp	0.59
UF	0.23		
Mnt	0.138		

Also by calculating the CR value for the main criteria and sub criteria (Appendix II), the CR value is calculated below 0.1 for each matrix and is shows that the data has consistency and acceptable.

After obtaining the relative weights and consistency of the criteria obtained from the survey, the relative weights can be used to assess among ERP providers using AHP method. In the next section the two ERP providers which were suitable for OGASCO L.L.C are introduced and finally using AHP method the most optimized decision is presented.

6.3 Steps for analyzing data using FAHP method

In this thesis Chang's extent analysis is used (Chang, 1996). Chang's extent analysis, Fuzzy AHP method is established in a six steps which is a popular Fuzzy AHP approach. This method comparing to other proposed Fuzzy AHP methods is relatively easier and has been used widely in different scenarios (Büyüközkan et al. 2011). Let $X=\{x_1,x_2,\ldots,x_n\}$ be an object set and $G=\{g_1,g_2,\ldots,g_n\}$ be a set of goals. Based on the Chang's extent analysis method, extent analysis is being done for each goal as per each object respectively. Hence, m extent analysis values for each object of $M^1_{gi}, M^2_{gi},\ldots, M^m_{gi}$, where i=1,2,…,n can be achieved, where M^j_{gi} *(j*=1,2,…,*m)* are the triangular fuzzy numbers (Hamidi 2015).

In engineering applications, the triangular fuzzy number (TFN) is one of the most popular membership functions. Triangular fuzzy number can be represented by $\tilde{M}$ = *(l, m, u)* and demonstrated in Figure 6-4.

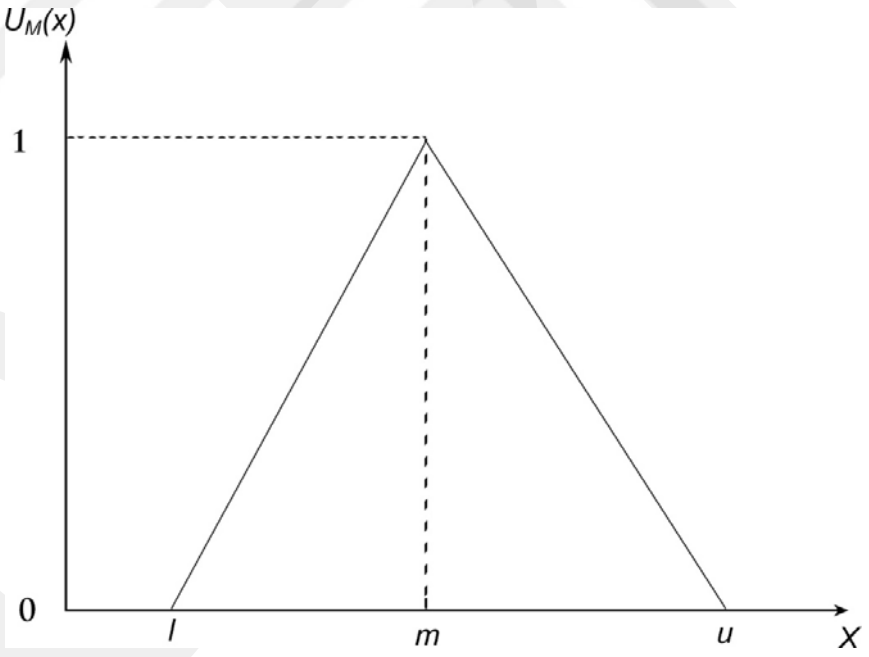


Figure 6-4 Triangular Fuzzy Number (Javanbarg et al., 2012)

In a triangular fuzzy number, the smallest and largest values are denoted by the parameters *l* and *u*, and the most promising value of which describes the fuzzy event is denoted by *m*. On the left and right side of each triangular fuzzy number there is a linear representation. A TFN *M* can be demonstrated by *(I, m, u)* and t its

membership function can be demonstrated as the following ((Chang, 1996; Zimmermann, 1996):

$$\mu_M(x) = \begin{cases} (x-l)\ /\ (m-l), & x \in [l,m] \\ (u-x)\ /\ (u-m), & x \in [m,u] \\ 0, & Otherwise \end{cases} \quad (4)$$

Where *x* is the mean value of *M* and *I, m, u* are real numbers.

6.3.1 Aggregation of group decisions

The first step is to aggregate the evaluation of decision makers and in order to achieve this and not neglect any decision, geometric means of participant decisions are calculated and considered as the decision value of each compared. Fuzzy pairwise comparison can be calculated using the following algorithm (Büyüközkam and Feyzioğlu, 2004, Chang et al., 2009):

$$l_{ij} = \min\left(l_{l_{ijk}}\right), m_{ij} = \left[\prod_{k=1}^{K} m_{ijk}\right]^{\frac{1}{K}}, u_{ij} = \max\left(u_{ijk}\right) \quad (5)$$

Where $(l_{ijk}, m_{ijk}, u_{ijk})$ are the samples of fuzzy decisions of k (k=1,2,…,K) individuals. However, using min and max may cause problems if the decisions are not homogeneous and also it can exceed the range of 0-1 (Mikhailov, 2003,). In order to avoid this issue, the geometric mean for l_{ij} *and* u_{ij} were also calculated. The below algorithms demonstrate the calculation method for pairwise criteria used in this thesis (Meixner, 2009):

$$l_{ij} = \left[\prod_{k=1}^{K} l_{ijk}\right]^{\frac{1}{K}}, m_{ij} = \left[\prod_{k=1}^{K} m_{ijk}\right]^{\frac{1}{K}}, u_{ij} = \left[\prod_{k=1}^{K} u_{ijk}\right]^{\frac{1}{K}} \quad (6)$$

Chang extent analysis steps can be presented as below (Kahraman, Cebeci, and Ruan, 2004):

a. The AHP framework is consisted of a goal and some criteria and sub-criteria which they are connected in a one direction manner according to their relations.

b. using pairwise comparison the local weights of the criteria and sub- criteria are getting calculated. The criteria are getting compared considering there is no dependency between them.

c. the possibility level of a convex fuzzy number greater than k convex fuzzy numbers of M_i (i=1,2,…,k).

d. the vectors shall be normalized.

e. determining the weights of criteria and sub- criteria.

f. the final decision of the alternatives

There are several linguistic scales of Fuzzy AHP available. According to a study by (Lee, 2016) Table 6-13 was identified as a common linguistic table of Fuzzy AHP and was used in this study.

Table 6-13 Fuzzy Fundamental Scale (Lee 2016)

Saaty Scale	Linguistic scale	Triangular fuzzy scale	Inverse Triangular fuzzy scale
1	**Just Equal**	(1,1,1)	(1,1,1)
2	**Intermediate value**	(1, 2, 3)	(1/3, 1/2, 1)
3	**Moderate Important**	(2,3,4)	(1/4,1/3,1/2)
4	**Intermediate value**	(3, 4, 5)	(1/5, 1/4, 1/3)
5	**Strong Important**	(4,5,6)	(1/6,1/5,1/4)
6	**Intermediate value**	(5, 6, 7)	(1/7, 1/6, 1/5)
7	**Very Strong Important**	(6,7,8)	(1/8,1/7,1/6)
8	**Intermediate value**	(7, 8, 9)	(1/9, 1/8, 1/7)
9	**Extremely Important**	(8,9,10)	(1/10,1/9,1/8)

As fuzzy is considered as a more precise technique in complex researches, fuzzy AHP method is employed also in order to check the final results. For achieving this, according to the explanations provided before, the fuzzy AHP method of Chang (1996) is being used.

The first step is to convert the survey obtained to Fuzzy scale provided in Table 6-7 to triangular fuzzy numbers (Table 6-14).

In order to achieve the aggregation of group decisions, using geometric mean approach which is rather a new approach is used (Meixner, 2009).

Considering two triangular fuzzy numbers (TFN) of M_1 and M_2 which $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, the main operation laws which were used for triangular fuzzy numbers in this thesis, are as follow:

a. $M_1 \oplus M_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$

b. $M_1 \otimes M_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) \approx (l_1 l_2, m_1 m_2, u_1 u_2)$

c. $M_1^{-1} = (l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1)$

After calculating the triangular fuzzy numbers, by using the Chang extent analysis, the following steps are utilized for the calculation (Chang 1996).

Step 1: The value of fuzzy synthetic extent with respect to the i_{th} object is defined as the following formula:

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=i}^{m} M_{g_i}^{j} \right]^{-1} \quad (7)$$

where g_i are the goals of the decision hierarchy and $M_{g_i}^{j}$ is the triangular fuzzy numbers for i = 1,2, …, n and j = 1,2, … ,m and n objects and m goals or decision alternatives and S_i is a fuzzy number.

In order to calculate $\sum_{j=1}^{m} M_{g_i}^{j}$, the addition fuzzy operation of m extent analysis values is being used for the respected matrix as below:

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=i}^{m} m_j , \sum_{j=i}^{m} u_j \right) \tag{8}$$

And to obtain the second part of the formula which is $\left[\sum_{i=1}^{n} \sum_{j=i}^{m} M_{g_i}^{j}\right]^{-1}$, the fuzzy addition operation of $M_{g_i}^{j}$ (j= 1,2,3,…,m) shall be done as below:

$$\sum_{i=1}^{n} \sum_{j=i}^{m} M_{g_i}^{j} = \left(\sum_{i=1}^{n} \sum_{j=1}^{m} l_i , \sum_{i=1}^{n} \sum_{j=1}^{m} m_i , \sum_{i=1}^{n} \sum_{j=1}^{m} u_i \right) \tag{9}$$

And then the above formula will be inversed completely as below:

$$\left[\sum_{i=1}^{n} \sum_{j=i}^{m} M_{g_i}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} u_i}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} m_i}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} l_i} \right) \tag{10}$$

Step 2: Considering $\tilde{M}_1=(l_1, m_1, u_1)$ and $\tilde{M}_2=(l_2, m_2, u_2)$ are two triangular fuzzy numbers, The degree of possibility of $M_2=(l_2, m_2, u_2) \geq M_1=(l_1, m_1, u_1)$ is defined as

$$V(\tilde{M}_2 \geq \tilde{M}_1) = \sup_{x \geq y} [\min(\mu_{\tilde{M}_1}(x), \mu_{\tilde{M}_2}(y))] \tag{11}$$

Where sup represents supremum, it follows that $V(\tilde{M}_2 \geq \tilde{M}_1) = 1$. Since M_1 and M_2 are fuzzy convex numbers defined by TFNs, it can be equivalently expressed as the below membership function:

$$V(M2 \geq M1) = hgt\,(M1 \cap M2) = \mu_{\tilde{M}_2}(d) = \begin{cases} 1, & if\ b_2 \geq b_1 \\ 0, & if\ a_1 \geq c_2 \\ \dfrac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)}, & otherwise \end{cases} \tag{12}$$

where d is the coordinate of the point which has the highest membership value in the intersection of μ_{M_1} & μ_{M_2}as described in Figure 6-5.

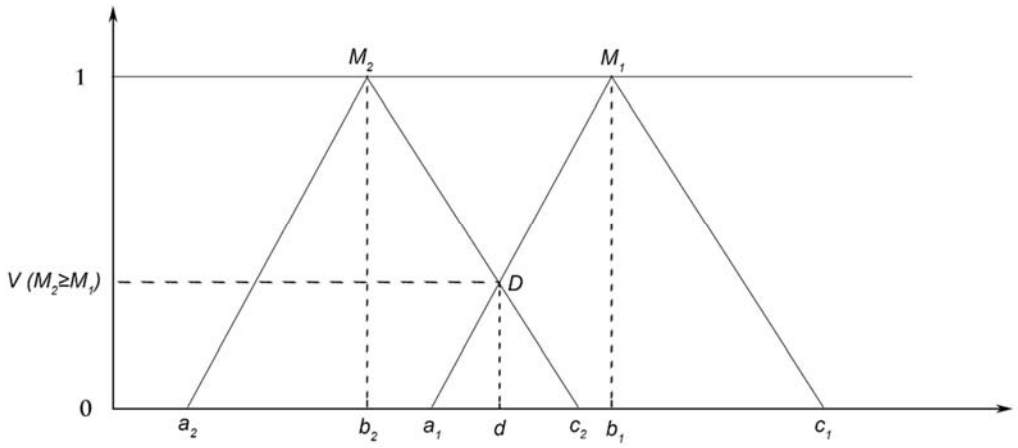


Figure 6-5 The intersection between M1 and M2 (Chang 1996)

in order to make comparison between M_1 and M_2, both values of $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$ are required to be calculated.

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers of M_i $(i = 1,2,\ldots..,\ k)$ *is defined as:*

$$V(M \geq M_1, M \geq M_2, \ldots., M \geq M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots (M \geq M_k)] = \min V(M \geq M_i),\ (i = 1, 2, 3, \ldots., k) \quad (13)$$

Assuming that $d'(A_i) = \min V(S_i \geq S_k)$, *where* $k = 1, 2, 3, \ldots., n;\ k \neq i.$ and n is the number of criteria, then a weight vector is given by

$$W' = (d'(A_1), d'(A_2), \ldots.., d'(A_n))^T \quad (14)$$

Where A_i are n elements.

Step 4: By normalizing the values of previous vector, the normalized weight vectors are calculated by:

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \quad (15)$$

where W is a set of non-Fuzzy numbers.

6.3.2 Analysis of the data obtained from the survey using FAHP method

Using triangular fuzzy scale (Table 6-13) the data of survey converts to linguistic form (Appendix IV) and then by Using equation 3, the geometric means of triangular fuzzy numbers are calculated for the main criteria (Table 6-15).

Table 6-14 Geometric mean of fuzzy values for the compared criterions

Compared Criterions	Geometric Mean
Vendor Credentials VS Finance	(0.4,0.5,0.65)
Vendor Credentials VS Functionality	(0.57,0.71,0.93)
Vendor Credentials VS User Friendliness	(0.49,0.66,0.91)
Vendor Credentials VS Implementation	(0.7,0.87,1.08)
Vendor Credentials VS Maintenance	(1.4,1.75,2.16)
Finance VS Functionality	(0.75,0.97,1.27)
Finance VS User Friendliness	(0.82,1.06,1.36)
Finance VS Implementation	(2.65,3.47,4.3)
Finance VS Maintenance	(0.54,0.66,0.81)
Functionality VS Implementation	(0.58,0.72,0.89)
Functionality VS Maintenance	(1.55,1.92,2.34)
Functionality VS User Friendliness	(0.44,0.54,0.7)
Implementation VS Maintenance	(0.44,0.53,0.65)
Implementation VS User Friendliness	(0.69,0.87,1.1)
User Friendliness VS Maintenance	(2.75,3.34,3.98)
Reputation of the Vendor VS Market Share	(0.64,0.8,1.03)
Reputation of the Vendor VS Presentation of Previous Demonstrations	(1.28,1.66,2.11)
Presentation of Previous Demonstrations VS Market Share	(1.07,1.29,1.54)
Software Expenses VS Cost of Upgrade and Maintenance with Consultation	(0.8,1.01,1.27)
Software Expenses VS Cost of Implementation	(0.66,0.82,1.06)
Cost of Upgrade and Maintenance with Consultation VS Cost of Implementation	(0.38,0.48,0.62)
Customization VS Compatibility	(0.55,0.68,0.87)

Using the triangular geometric means, the pairwise comparison matrices are put in the table for next calculation stages as follow (Table 6-15 to Table 6-18):

Table 6-15 Triangular values for pairwise comparison of main criteria

	VenC	Fin	Fun	UF	Imp	Mnt
VenC	(1,1,1)	(0.4,0.5,0.65)	(0.57,0.71,0.93)	(0.49,0.66,0.91)	(0.7,0.87,1.08)	(1.4,1.75,2.16)
Fin	(1.54,2,2.5)	(1,1,1)	(0.75,0.97,1.27)	(0.82,1.06,1.36)	(2.65,3.47,4.3)	(0.54,0.66,0.81)
Fun	(1.08,1.41,1.75)	(0.79,1.03,1.33)	(1,1,1)	(0.44,0.54,0.7)	(0.58,0.72,0.89)	(1.55,1.92,2.34)
UF	(1.1,1.52,2.04)	(0.74,0.94,1.22)	(1.43,1.85,2.27)	(1,1,1)	(0.91,1.15,1.45)	(2.75,3.34,3.98)
Imp	(0.93,1.15,1.43)	(0.23,0.29,0.38)	(1.12,1.39,1.72)	(0.69,0.87,1.1)	(1,1,1)	(0.44,0.53,0.65)
Mnt	(0.46,0.57,0.71)	(1.23,1.52,1.85)	(0.43,0.52,0.65)	(0.25,0.3,0.36)	(1.54,1.89,2.27)	(1,1,1)

By using the Eq. (7) the values of fuzzy synthetic extent for each criterion is calculated as follow:

S_{VenC}=(4.56,5.49,6.73) x $(34.55,42.1,51.06)^{-1}$ = (0.09,0.13,0.19)

S_{Fin}= (7.3,9.16,11.24) x $(34.55,42.1,51.06)^{-1}$ = (0.14,0.22,0.33)

S_{Fun}= (5.44,6.62,8.01) x $(34.55,42.1,51.06)^{-1}$ = (0.11,0.16,0.23)

S_{UF}= (7.93,9.8,11.96) x $(34.55,42.1,51.06)^{-1}$ = (0.16,0.23,0.35)

S_{Imp}= (4.41,5.23,6.28) x $(34.55,42.1,51.06)^{-1}$ = (0.09,0.12,0.18)

S_{Mnt}= (4.91,5.8,6.84) x $(34.55,42.1,51.06)^{-1}$ = (0.1,0.14,0.2)

Using Eq. (12) the following calculations were made:

$V(S_{VenC} > S_{Fin}) = 0.357143$

$V(S_{VenC} > S_{Fun}) = 0.727272727$

$V(S_{VenC} > S_{UF}) = 0.230769231$

$V(S_{VenC} > S_{Imp}) = 1$

$V(S_{VenC} > S_{Mnt}) = 0.9$

$V(S_{Fin} > S_{VenC}) = 1$

$V(S_{Fin} > S_{Fun}) = 1$

$V(S_{Fin} > S_{UF}) = 0.944444444$

$V(S_{Fin} > S_{Imp}) = 1$

$V(S_{Fin} > S_{Mnt}) = 1$

$V(S_{Fun} > S_{VenC}) = 1$

$V(S_{Fun} > S_{Fin}) = 0.6$

$V(S_{Fun} > S_{UF}) = 0.5$

$V(S_{Fun} > S_{Imp}) = 1$

$V(S_{Fun} > S_{Mnt}) = 1$

$V(S_{UF} > S_{VenC}) = 1$

$V(S_{UF} > S_{Fin}) = 1$

$V(S_{UF} > S_{Fun}) = 1$

$V(S_{UF} > S_{Imp}) = 1$

$V(S_{UF} > S_{Mnt}) = 1$

$V(S_{Imp} > S_{VenC}) = 0.9$

$V(S_{Imp} > S_{Fin}) = 0.285714286$

$V(S_{Imp} > S_{Fun}) = 0.636363636$

$V(S_{Imp} > S_{UF}) = 0.153846154$

$V(S_{Imp} > S_{Mnt}) = 0.8$

$V(S_{Mnt} > S_{VenC}) = 1$

$V(S_{Mnt} > S_{Fin}) = 0.428571429$

$V(S_{Mnt} > S_{Fun}) = 0.818181818$

$V(S_{Mnt} > S_{UF}) = 0.307692$

$V(S_{Mnt} > S_{Imp}) = 1$

And finally by utilizing using Eq. (14) and (15) the weight vector of main criteria is:

$W' = (0.23, 0.94, 0.5, 1, 0.15, 0.3)^T$

$W = (0.07, 0.3, 0.16, 0.32, 0.05, 0.1)$

Figure 6-6 illustrates the compared column chart of the weights of main criteria

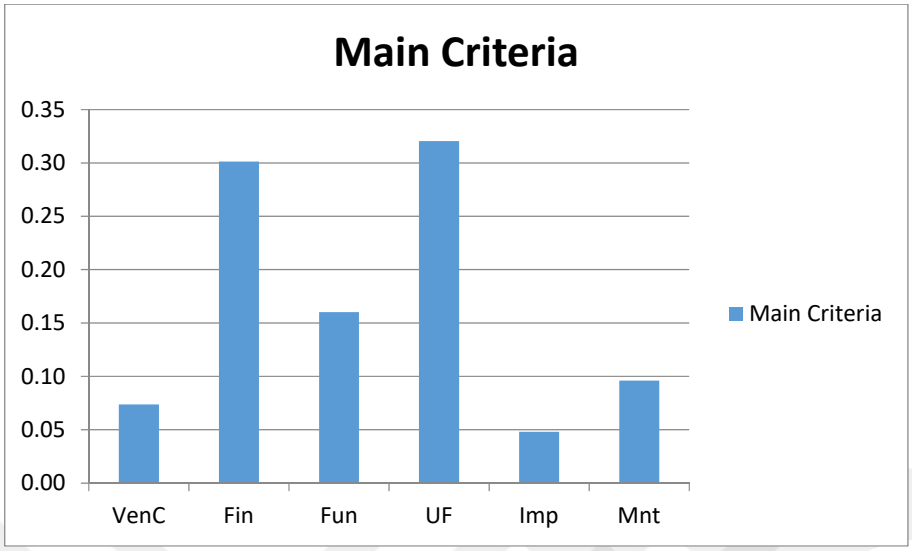


Figure 6-6 Comparison of the weights of Main Criteria

The same way for sub-criteria, the calculations are done using Eq. (7) to (15) as per below:

Table 6-16 Triangular values for pairwise comparison of Sub-Criteria of Vendor Credential

Venc	Repven	MarS	PrvDem
Repven	(1,1,1)	(0.64,0.8,1.03)	(1.28,1.66,2.11)
MarS	(0.97,1.25,1.56)	(1,1,1)	(0.65,0.78,0.93)
PrvDem	(0.47,0.6,0.78)	(1.07,1.29,1.54)	(1,1,1)

S_{Repven}= (2.92,3.46,4.14) x $(8.08,9.38,10.95)^{-1}$ = (0.27,0.37,0.51)

S_{MarS} = (2.62,3.03,3.49) x $(8.08,9.38,10.95)^{-1}$ = (0.24,0.32,0.43)

S_{PrvDem}= (2.54,2.89,3.32) x $(8.08,9.38,10.95)^{-1}$ = (0.23,0.31,0.41)

$V(S_{Repven} > S_{MarS}) = 1$

$V(S_{Repven} > S_{PrvDem}) = 1$

$V(S_{MarS} > S_{Repven}) = 0.761904762$

$V(S_{MarS} > S_{PrvDem}) = 1$

$V(S_{PrvDem} > S_{Repven}) = 0.7$

$V(S_{PrvDem} > S_{MarS}) = 0.944444444$

$W' = (1, 0.76, 0.7)^T$

W = (0.41, 0.31, 0.28)

Table 6-17 Triangular values for pairwise comparison of Sub-Criteria of Finance

Fin	SE	CostU	CostI
SE	(1,1,1)	(0.8,1.01,1.27)	(0.66,0.82,1.06)
CostU	(0.79,0.99,1.25)	(1,1,1)	(0.38,0.48,0.62)
CostI	(0.94,1.22,1.52)	(1.61,2.08,2.63)	(1,1,1)

S_{SE}= (2.46,2.83,3.33) x $(8.18,9.6,11.35)^{-1}$ = (0.22,0.29,0.41)

S_{CostU} = (2.17,2.47,2.87)x $(8.18,9.6,11.35)^{-1}$ = (0.19,0.26,0.35)

S_{CostI}= (3.55,4.3,5.15) x $(8.18,9.6,11.35)^{-1}$ = (0.31,0.45,0.63)

$V(S_{SE} > S_{CostU}) = 1$

$V(S_{SE} > S_{CostI}) = 0.384615385$

$V(S_{CostU} > S_{SE}) = 0.8125$

$V(S_{CostU} > S_{CostI}) = 0.173913043$

$V(S_{CostI} > S_{SE}) = 1$

$V(S_{CostI} > S_{CostU}) = 1$

W' = $(0.38, 0.17, 1)^T$

W = (0.25, 0.11, 0.64)

Table 6-18 Triangular values for pairwise comparison of Sub-Criteria of Implementation

Imp	Custom	Comp
Custom	(1,1,1)	(0.55,0.68,0.87)
Comp	(1.15,1.47,1.82)	(1,1,1)

S_{Custom} = (1.55,1.68,1.87) x $(3.7,4.15,4.69)^{-1}$ = (0.22,0.29,0.41)

S_{Comp} = (2.15,2.47,2.82) x $(3.7,4.15,4.69)^{-1}$ = (0.19,0.26,0.35)

$V(S_{Custom} > S_{Comp}) = 0.2$

$V(S_{Comp} > S_{Custom}) = 1$

$W' = (0.2, 1)^T$

$W = (0.17, 0.83)$

Like previous presentation, for Fuzzy AHP Table 6-19 describes the weights of criteria.

Table 6-19 Relative weights of criteria using FAHP

Criteria	Relative weight using FAHP	Sub-criteria	Relative weight using FAHP
VenC	0.07	RepVen	0.41
		MarS	0.31
		PrvDem	0.28
Fin	0.3	SE	0.25
		CostU	0.11
		CostI	0.64
Fun	0.16		
Imp	0.05	Custom	0.17
		Comp	0.83
UF	0.32		
Mnt	0.1		

Comparing FAHP and AHP methods, it can be observed that both methods are giving almost similar result in ranking with slight differences in percentages. Table 6-20 demonstrates the comparison of FAHP and AHP ranking.

Table 6-20 Comparison of AHP and FAHP weights and rankings

	Criteria	Relative weight using FAHP	Relative weight using AHP	FAHP Ranking	AHP Ranking
	Main Criteria				
Main	UF	0.32	0.23	1	1
	Fin	0.3	0.216	2	2
	Fun	0.16	0.157	3	3
	Mnt	0.1	0.138	4	4
	VenC	0.07	0.129	5	6
	Imp	0.05	0.131	6	5
	Sub Criteria				
Venc	RepVen	0.41	0.36	1	1
	MarS	0.31	0.33	2	2
	PrvDem	0.28	0.31	3	3
Fin	CostI	0.64	0.44	1	1
	SE	0.25	0.31	2	2
	CostU	0.11	0.25	3	3
Imp	Comp	0.83	0.59	1	1
	Custom	0.17	0.41	2	2

As Table 6-20 demonstrates, comparing the rankings of FAHP and AHP, except in one case which is highlighted, is identical and the percentages are different.

6.4 Case Study

6.4.1 Background information

OGASCO L.L.C was established in 1994 and is specialized in most type of steel fabrication and mechanical engineering fields as per international standards. The company is located in Abu Dhabi which is the capital of United Arab Emirates (UAE). It is considered as medium size company and the projects are oil and gas and generally petroleum related such as fabrication of pipes, vessels, heat exchangers, buoys and steel structures. The company is also qualified for off-shore construction equipment in addition to onshore. Simultaneously there are 15-30 projects getting executed. In this company there are about 200 main staff members working and it consists of different departments (Appendix III) which are interacting with each other. As it can be observed in Appendix III that the organization is quite large and there are many sections with requirements of coordinating with each other. Previously the information was getting registered by using usual Microsoft software applications for data management such as MS. Excel and in some cases MS. access, but it was not sufficient for the firm.

As one of the key points of winning the proposals by the organizations was the reputation of the company, and there were audits being done to the organization before offering a project, the management came up with the idea to go to the next level by implementing an ERP system. The organization decided to implement ERP system in 2014.

6.4.2 Introduction of the two ERP providers used in this case study

By referring to the above studies and the result of survey, two of the most mentioned ERP software packages in the survey were considered and will be discussed in this study in order to apply AHP method to find the most suitable provider among them. These two ERP providers are called as ERP 1 and ERP 2 as Microsoft Dynamics and Oracle. Their details are available in the following section. While AHP method was used just for two providers, it is still possible to use it for more than 2. In order to make the calculations easier, two ERP providers were selected in this case study.

ERP 1 (Microsoft Dynamics): The software has many features but there are few features missing which are essential for the organization. It is very user friendly. Customization is possible but it needs the ERP provider to do it and the organization has to rely on the ERP provider. They have offered one-year free customization service and after that the cost starts from 2,500 Dollars which depends on the customization feature. The purchasing price of the ERP system is about 45,000 to 100,000 Dollars based on the requested functions by the organization. Overall cost of training, consultation and implementation is about 80,000 Dollars. The duration of implementation is from 4 to 8 months but it depends on the features which the organization needs. Among these two ERP providers, ERP 1 had the higher market share during the previous year.

ERP 2 (Oracle): it has lower market share comparing the other ERP provider. It has most of the features that the organization requires and there's no need of interference of the ERP provider and it can be customized by the organization itself. Performance wise this ERP system is quite fast comparing to the other ERP system. The cost of this ERP system is about 80,000 to 120,000 Dollars excluding the other features the firm needs. The cost of training, implementation and consultation is about 130,000 Dollars for 6 months plus customer's support after the sale. The duration of implementation is about 8 to 10 months.

6.4.3 Comparison data between two ERP providers using AHP

In order to compare the two ERP providers, the obtained information data which are qualitative plus the quantitative data has to be converter to values as per the Saaty table (Table 6-1). Table 6-21 shows the calculated values of the data of pairwise comparison of the two ERP systems.

Table 6-21 matrices of pairwise comparison between ERP 1 and ERP 2

Reputation of the Vendor	ERP 1	ERP 2	Relative Weight
ERP 1	1	3	0.75
ERP 2	1/3	1	0.25
Market Share	ERP 1	ERP 2	Relative Weight
ERP 1	1	3	0.75
ERP 2	1/3	1	0.25
Presentation of Previous Demonstrations	ERP 1	ERP 2	Relative Weight
ERP 1	1	7	0.875
ERP 2	1/7	1	0.125
Functionality	ERP 1	ERP 2	Relative Weight
ERP 1	1	1/2	0.33
ERP 2	2	1	0.67
Software Expenses	ERP 1	ERP 2	Relative Weight
ERP 1	1	6	0.857
ERP 2	1/6	1	0.143
Cost of Implementation	ERP 1	ERP 2	Relative Weight
ERP 1	1	4	0.80
ERP 2	1/4	1	0.20
Cost of Upgrade and Maintenance with Consultation	ERP 1	ERP 2	Relative Weight
ERP 1	1	5	0.83
ERP 2	1/5	1	0.17
User Friendliness	ERP 1	ERP 2	Relative Weight
ERP 1	1	2	0.67
ERP 2	1/2	1	0.33
Maintenance	ERP 1	ERP 2	Relative Weight
ERP 1	1	1	0.50
ERP 2	1	1	0.50
Compatibility	ERP 1	ERP 2	Relative Weight
ERP 1	1	1/2	0.33
ERP 2	2	1	0.67
Customization	ERP 1	ERP 2	Relative Weight
ERP 1	1	1/3	0.25
ERP 2	3	1	0.75

Using the above data and data acquired before from the survey and AHP the most suitable ERP system provider for OGASCO L.L.C can be calculated. Figure 6-7 illustrates the calculated values of ERP 1 and 2 and by observing the final values it shows that ERP 1 is preferred to ERP 2 having 60% while ERP 2 has 40% preference.

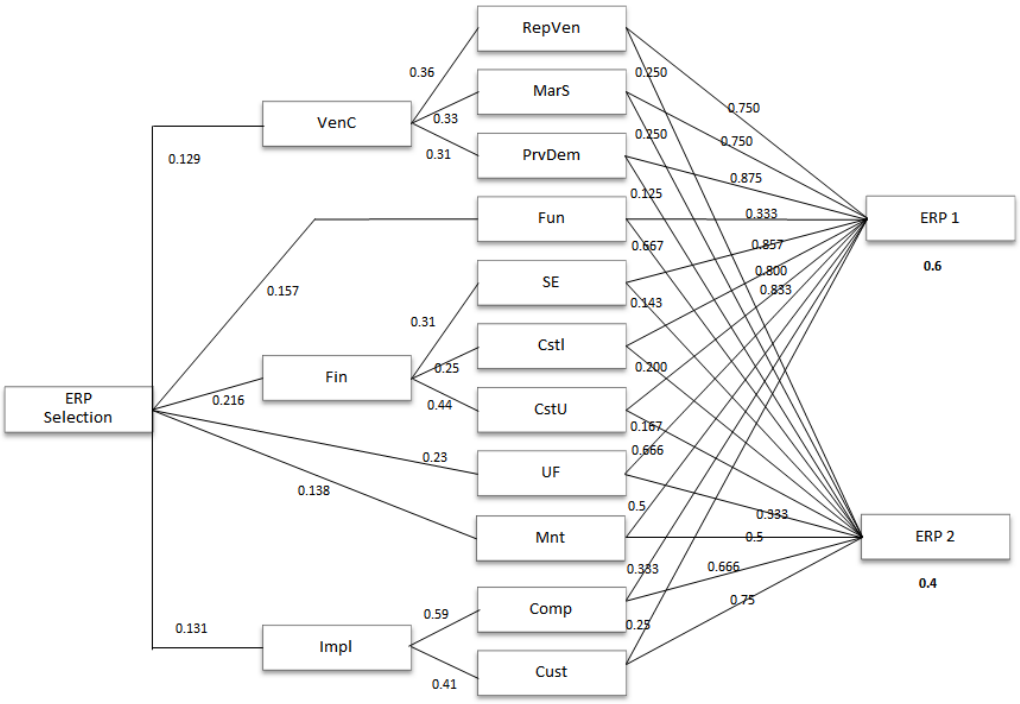


Figure 6-7 ERP 1 and ERP 2 provider selection using AHP

The calculation process for each ERP system is by multiplying the weights of each system individually and adding them up. For example, for Reputation of the Vendor (RepVen) of ERP 1, the relative weights of VenC and RepVen and ERP 1 has to be multiplied which will be 0.129*0.36*0.75 = 0.03483. The same way it is calculated other criteria and also for ERP 2 and in the end values of each ERP summed up together individually.

6.4.4 Comparison data between two ERP providers using FAHP

Like AHP, the same way each alternative is compared with the 11 criterions. As Fuzzy AHP is useful for fuzziness and at least 3 alternatives are required in order to use this method, the answers achieved from these comparisons for the two alternatives are resulting usually 100 and 0. Table 6-22 demonstrates the calculated relative weights of alternatives based on each criterion and also compares them to the previous calculations of alternatives of AHP.

Table 6-22 Comparison of relative weights of FAHP and AHP for each alternative based on 11 criterions

Reputation of the Vendor	**ERP 1**	**ERP 2**	**Relative Weight of FAHP**	**Relative Weight of AHP**
ERP 1	(1,1,1)	(2,3,4)	1	0.75
ERP 2	(1/4,1/3,1/2)	(1,1,1)	0	0.25
Market Share	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(2,3,4)	1	0.75
ERP 2	(1/4,1/3,1/2)	(1,1,1)	0	0.25
Presentation of Previous Demonstrations	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(6,7,8)	1	0.875
ERP 2	(1/8,1/7,1/6)	(1,1,1)	0	0.125
Functionality	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(1/3,1/2,1)	0.31	0.33
ERP 2	(1,2,3)	(1,1,1)	0.69	0.67
Software Expenses	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(5,6,7)	1	0.857
ERP 2	(1/7,1/6,1/5)	(1,1,1)	0	0.143
Cost of Implementation	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(3,4,5)	1	0.8
ERP 2	(1/5,1/4,1/3)	(1,1,1)	0	0.2
Cost of Upgrade and Maintenance with Consultation	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(4,5,6)	1	0.83
ERP 2	(1/6,1/5,1/4)	(1,1,1)	0	0.17
User Friendliness	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(1,2,3)	0.69	0.67
ERP 2	(1/3,1/2,1)	(1,1,1)	0.31	0.33
Maintenance	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(1,1,1)	0.5	0.5
ERP 2	(1,1,1)	(1,1,1)	0.5	0.5
Compatibility	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(1/3,1/2,1)	0.31	0.33
ERP 2	(1,2,3)	(1,1,1)	0.69	0.67
Customization	ERP 1	ERP 2	Relative Weight	Relative Weight
ERP 1	(1,1,1)	(1/4,1/3,1/2)	0	0.25
ERP 2	(2,3,4)	(1,1,1)	1	0.75

Accordingly, like AHP, the final calculations for finding the most preferred alternative is done as per the Figure 6-8:

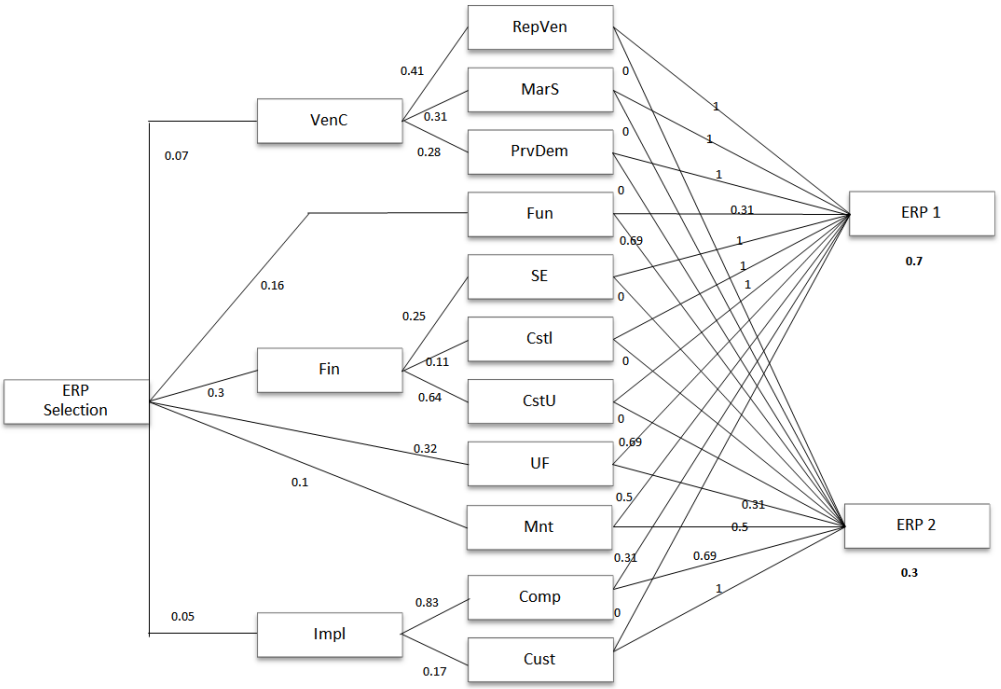


Figure 6-8 ERP 1 and ERP 2 provider selection using FAHP

After multiplying all the weights of each criterion for each alternative and adding them up together, ERP 1 shows 70% preference comparing to ERP 2 and the same result like AHP is achieved.

CHAPTER 7

CONCLUSION, LIMITATIONS AND FURTHER STUDIES

This study was conducted in the UAE and only 33 of the participant which replied to the questionnaire were considered qualified and this was done focusing only on one industry. Hence considering the available resources and the study just in one country, it may not be very accurate to cover all of the oil and gas industries in the world. Therefore, other criterions or conditions might be involved or have preferences in different parts of the world. Also there were only 6 main criteria and 8 sub-criteria chosen for this study which may not have covered all of the possibilities and requirements in different conditions. Hence having further studies in this subject using different methods is interesting to see if their outcome is the same.

In this thesis, the six criteria of Vendor credentials, Finance, User friendliness, Maintenance, Functionality and implementation where chosen as the main criteria and eight criteria of Reputation of vendor, Market share, Presentation of Previous demonstrations, Software expenses, Cost of implementation, Cost of Upgrade and Maintenance, Customization and Compatibility were chosen as the sub criteria for selecting an ERP provider for an organization in oil and gas field through literature studies and discussion with experts. Through the survey filled by IS representatives in the UAE, the criterions of User Friendliness and Finance showed the highest attention and preference among other criteria by the participants in this study. As described in the criteria selection section, user friendliness means easiness of the ERP software for end-users to operate with and it also reduces the process of adaptation and basic training for the users. Finance also explained as the expenses of ERP system including cost of upgrade and maintenance, cost of implementation and software expenses. As there are many organizations competing in oil and gas field and one of the important priorities of project management of organizations is to

reduce cost, it is important for them to spend efficiently purchasing the ERP software package based on their needs. They also have to consider the cost in long run depending on their projects and income and that is why it shows a high attention among the decision makers. While cost is important factor for firms and organizations, user friendliness also has positive effect on the cost as reducing the training period and easiness of usage of the software can increase productivity and reduce the cost also.

By presenting the AHP method and Chang's extended Fuzzy AHP method, it showed the value and usage of these decision making methods in different sections and most importantly in ERP software selection. As it was observed, the mathematical and calculations of AHP is simple and easy to learn while Fuzzy AHP is a bit more complicated. AHP constructs the problem into hierarchical structure and by giving weights to criterions and alternatives; it makes calculations possible to conclude a decision. While AHP supports both qualitative and quantitative problems, in fuzzy and uncertain environments where the decision makers need to use linguistic variables and fuzziness comes in, using Fuzzy AHP enables decision makers to make more precise and accurate decision. In our study as the AHP results were compared with Fuzzy AHP results, it didn't effect on the final outcomes, but the preference percentages were different and only in the ranking of two of the sub-criteria, there were difference. While in this thesis there were not many alternatives and the problem was not very complicated, it did not change the final outcome of the result, but it should keep in mind although Fuzzy AHP is more difficult, but in such cases it is preferred to be used.

Presenting these methods in this thesis, enables organizations in oil and gas field to use the methods in future in order to select an ERP provider for their organizations and also the ERP providers can get benefit from this study by focusing more on the preferred criterions for improving and being able to stay ahead and preferred in their market.

As explained in this thesis, the criteria depend on time period and other conditions and may vary in different situations, hence in the future or other places than UAE the result may differ. Also as there is no single MCDM method which is transcendent to

other MCDM methods, this study can furtherly be reviewed and studied by using other decision making methods or combined/hybrid methods to check the result.

Throughout the research, there were different software applications available for doing AHP calculations, but as there are different fuzzy methods and calculations are more complicated, I did not cross with any software application in this regard. Having a software application created for this purpose can benefit many firms and researches and a study in this case is appreciated.

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APPENDICES

A. Questionnaire

Note: These questions shall be answered by Information System manager of the organization or a person who is responsible and in the managements section of Information system in the organization.

This questionnaire is sent to your organization for aiding our studies in Enterprise Resource Planning (ERP) selection for oil and gas industries. We'd like to appreciate your time and effort for filling the questions based on your experience in order to help one of our employees to complete his dissertation and also we can provide you with the final results of this research if you would like in order to help you to select an ERP software package in later stages if you don't have or if you already have an ERP system in your organization, this research can provide you additional information which might become useful to you.

All of the answers you provide will be recorded as anonymous and will be used to analysis the most important factors of ERP systems which organizations need to focus.

In the beginning of this questionnaire, the main criteria which you need to determine importance value based on a specific scale will be explained and then according to a scale which was introduced by Saaty as a Multiple Criteria Decision Making Method you can assign importance values based on your knowledge.

Kindly after filling the survey, send it back to the email address: Qa-Qc@ogasco.ae for evaluating your data.

You can contact for any clarification or additional information if you required.

Sincerely yours,

Seyed Hajir Lesani

Explanation:

Part 1: Selected Criteria:

In total 6 main and 10 sub criteria were chosen according to previous studies in this field. The criteria are shown in Table.1:

Requirements	Criteria	Sub Criteria
Functional	Functionality (Fun)	-
	User Friendliness (UF)	-
Non-Functional	Vendor credentials (VenC)	Presentation of Previous Demonstrations (PrvDem)
		Market Share (MarS)
		Reputation of the Vendor (RepVen)
	Maintenance (Mnt)	-
	Finance (Fin)	Cost of Upgrade and Maintenance with Consultation (CstU)
		Cost of Implementation (CstI)
		Software Expenses (SE)
	Implementation (Imp)	Compatibility (Comp)
		Customization (Custom)

Table1. Main and Sub Criteria of ERP software selection

Our aim is to find which criteria are more important to you. The criteria are explained below:

Functionality: It is not possible for any ERP software package to satisfy the especial special needs or all of functionalities of an enterprise. Based on each firm, there are different requirements are available to satisfy as per their unique requirements. The usual requirements are Quality Control/Assurance, Human Resource Management, Sales, Maintenance Management, Supply Chain management, Transportation Management, Product and Distribution Management and Planning, Warehouse Management, Operations Management and etc. During a research study, it was found that only 50% of the implemented functionality is being used for the ERP systems of organizations and the rest of functions were not being used at all. Hence the functionality criterion, in addition to the number of functions, means the quality of functions provided by the ERP system which are being used in an organization.

User Friendliness: this criterion means the easiness of the ERP system for the users to operate and learn. The user interface is important in order to give possibility to users to have access and interact with the functions easily and efficiently. The ERP system should be designed such way to support the organization for the ERP system's lifetime even if there were changes in the organization, if something was

deleted, added or changed it should be able to adopt with it and it should match with the culture of the organization. Having self-explained and comprehendible menus and screen can reduce the process of adaptation for the users and also the basic training and it is essential for ERP software.

Vendor credentials: It was mentioned in approximately most of studies as one of essential criteria disregarding the size of organizations whether they are small, medium or large enterprises. The size of organizations has no effect in this criterion. Vendor credentials consist of three sub-criteria as 'presentation of previous demonstrations', 'market share' and 'reputation of the vendor' which were discussed in this study. These main elements are important for oil and gas firms to decide selecting their required ERP provider. The element of presentation of previous implementation is important for the firms to observe their quality of work and the other two criteria of market share and the reputation of the vendor is accessible for the firms to obtain. To summarize it, the vendor credentials criterion expresses the market's reputation and popularity of the vendor plus it can explain the dedication and devotion of the vendor for the task

Maintenance: every firm needs to consider future maintenance of their ERP software and it is important to consider this fact in the implementation. By maintenance it means customer services after the sale, training and change in real time. In order to use the ERP software, training is required to be done to the staff also customer service after sale is important so the users can understand the functions of the system and how to use it. Not having these requirements can lead to negative effects for the organizations; effects such as not being able to upgrade the software, too many workarounds for the organization and also suspension of operations. It is obvious that this criterion points out at the after implementation services.

Finance: it consists of three sub criteria of "cost of upgrade and maintenance with consultation", "cost of implementation" and "software expenses". In order to select a suitable ERP provider, cost of implementation is significantly very important point for making the decision plus considering the services required after sale (if any) which could be some unexpected problems also training cost of the employees to teach them the usage of the software. The organizations must consider the financing

aspects and the lifetime duration of an ERP system before deciding to use select it. Overall the financing criterion means the willing to pay total cost of an ERP system.

Implementation: Almost all of processes of an enterprise can be affected by the ERP system which is supporting the whole organization. The two sub-criteria of compatibility and customization are very important during the implementation of an ERP system because different organizations are using different applications and they need to transfer their data to the ERP system they are going to use and still use their previous software if they needed. Hence it is important for the ERP modules to be compatible with other software that the organization was using before to be able to transfer the data. Plus the ERP system should be ready to transfer the data with previous software applications and also some firms may not be ready or may not have the resources to import them to the ERP system considering the long duration of implementation. The implementation criteria means how well the ERP system is matching and compatible with the current system of the organization, the duratoin of implementation process and customization possibility of the new system with the ideal strategy of the business.

Part 2: Scale

According to the above explained criteria, you can assign values to each criterion from 1/9 to 9 which is least to most preferred attribute. The scale was introduced by Saaty for Analytical Hierarchy Process method. Table.2 explains the scale and values and their importance.

Table-2 Scale for preference of attributes

Preference weights (level of importance)	**Definition**	**Explanation**
1	Equally preferred	Two criterions equally to the select the ERP provider
3	Moderately	Experience and judgment slightly favor one criterion over another
5	Strongly	Experience and judgment strongly or essentially favor one criterion over another
7	Very Strongly	A criterion is strongly favored over another and its dominance demonstrated in practice.
9	Extremely	The evidence favoring one criterion over another is of the highest degree possible of affirmation.
2,4,6,8	Intermediate values	Used to represent compromise between the preferences listed above
Reciprocals	Reciprocals for inverse composition	

Part3: Questions:

Background:

1- Please write you organization's field of work (i.e. Oil and gas, Pressure vessel/Pipe manufacturing, etc.).

2- Please write your position in the organization (i.e. Information System Manager).

2- Have you had any previous experience of involvement in ERP system implementation? If yes, please mention your role.

4- Are you currently using any ERP system in your organization? If yes, please indicate the name of ERP software package you are using.

Criterion preferences:

As explained above, please fill the table in the next page according to best of your knowledge as per Table.2. For example, comparing between Finance and Functionality, if you think Finance is strongly preferred to Functionality mark under the value 5 or if you think finance is strongly preferred to vendor credentials, mark 1/5 instead.

	1/9	1/7	1/5	1/3	1	3	5	7	9	
Finance										Functionality
Finance										User Friendliness
Finance										Implementation
Finance										Maintenance
Vendor Credentials										Finance
Vendor Credentials										Functionality
Vendor Credentials										User Friendliness
Vendor Credentials										Implementation
Vendor Credentials										Maintenance
Functionality										Implementation
Functionality										Maintenance
Functionality										User Friendliness
User Friendliness										Maintenance
Implementation										Maintenance
Implementation										User Friendliness
Sub Criteria										
Presentation of Previous Demonstrations										Market Share
Reputation of the Vendor										Market Share
Reputation of the Vendor										Presentation of Previous Demonstrations
Cost of Upgrade and Maintenance with Consultation										Cost of Implementation
Software Expenses										Cost of Upgrade and Maintenance with Consultation
Software Expenses										Cost of Implementation
Customization										Compatibility

If you have any other criterion in your mind that you think is important and is not stated, kindly add it under the table.

Thank you.

B. Calculations of Criteria

Calculation steps using MS-Excel for main criteria

CR Value = 0.098 OK

Pairwise comparisons

Item Number	Item Number	1	2	3	4	5	6
	Item Description	VenC	Fin	Fun	UF	Imp	Mnt
1	VenC	1.00	0.50	0.71	0.66	0.87	1.75
2	Fin	2.00	1.00	0.97	1.06	3.47	0.66
3	Fun	1.40	1.03	1.00	0.54	0.72	1.92
4	UF	1.51	0.95	1.85	1.00	1.15	3.34
5	Imp	1.15	0.29	1.40	0.87	1.00	0.53
6	Mnt	0.57	1.51	0.52	0.30	1.89	1.00
7							
8							
9							
10							
	Sum	7.63	5.27	6.45	4.43	9.09	9.20

STANDARDIZED MATRIX

		VenC	Fin	Fun	UF	Imp	Mnt	**Weight**
1	VenC	0.13	0.09	0.11	0.15	0.10	0.19	**12.9%**
2	Fin	0.26	0.19	0.15	0.24	0.38	0.07	**21.6%**
3	Fun	0.18	0.20	0.16	0.12	0.08	0.21	**15.7%**
4	UF	0.20	0.18	0.29	0.23	0.13	0.36	**23.0%**
5	Imp	0.15	0.05	0.22	0.20	0.11	0.06	**13.1%**
6	Mnt	0.07	0.29	0.08	0.07	0.21	0.11	**13.8%**

CI and CR worksheet

		VenC	Fin	Fun	UF	Imp	Mnt	SUM	SUM/Weight
1	VenC	0.13	0.11	0.11	0.15	0.11	0.24	0.86	6.65
2	Fin	0.26	0.22	0.15	0.24	0.45	0.09	1.41	6.56
3	Fun	0.18	0.22	0.16	0.12	0.09	0.26	1.04	6.63
4	UF	0.19	0.20	0.29	0.23	0.15	0.46	1.53	6.65
5	Imp	0.15	0.06	0.22	0.20	0.13	0.07	0.83	6.36
6	Mnt	0.07	0.33	0.08	0.07	0.25	0.14	0.94	6.79

Saaty's CIr values for matrices are given by the following table

Size of Matrix	Random Consistency (CIr)
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
7	1.32
8	1.41
9	1.45
10	1.49

count	6.00
lambda max	6.608
CI	0.122
CR	**0.098**
constant	1.24

Calculations of Vendor Credentials sub criteria

CR Value = 0.093				OK
	Pairwise comparisons			
Item Number	**Item Number**	1	2	3
	Item Description	RepVen	MarS	PrevDem
1	RepVen	1.00	0.80	1.66
2	MarS	1.25	1.00	0.78
3	PrevDem	0.60	1.29	1.00
	Sum	2.85	3.09	3.43

	STANDARDIZED MATRIX				
		RepVen	MarS	PrevDem	**Weight**
1	RepVen	0.35	0.26	0.48	**36.4%**
2	MarS	0.44	0.32	0.23	**32.9%**
3	PrevDem	0.21	0.42	0.29	**30.7%**

	CI and CR worksheet					
		RepVen	MarS	PrevDem	SUM	SUM/Weight
1	RepVen	0.36	0.26	0.51	1.14	3.12
2	MarS	0.45	0.33	0.24	1.02	3.10
3	PrevDem	0.22	0.42	0.31	0.95	3.10

count	3.00
lambda max	3.108
CI	0.054
CR	**0.09**
constant	0.58

Calculations of Finance sub criteria

CR Value = 0.027 OK

Pairwise comparisons

Item Number	**Item Number**	1	2	3
	Item Description	SE	CostU	CostI
1	SE	1.00	1.01	0.82
2	CostU	0.99	1.00	0.48
3	CostI	1.22	2.10	1.00
4				
5				
6				
7				
8				
9				
10				
	Sum	3.21	4.11	2.30

STANDARDIZED MATRIX

		SE	CostU	CostI	**Weight**
1	SE	0.31	0.25	0.36	**30.5%**
2	CostU	0.31	0.24	0.21	**25.3%**
3	CostI	0.38	0.51	0.44	**44.2%**

CI and CR worksheet

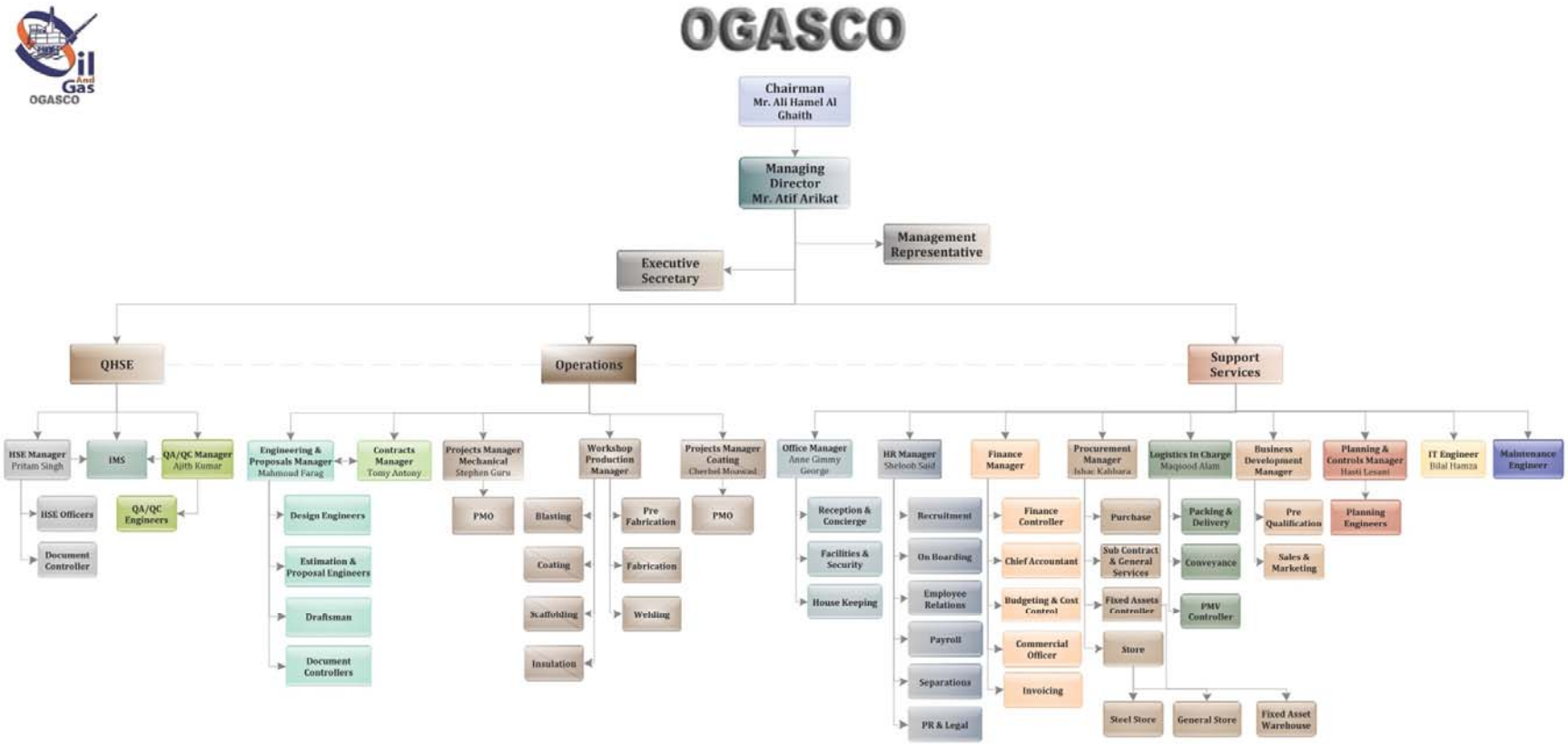
		SE	CostU	CostI	SUM	SUM/Weight
1	SE	0.31	0.26	0.36	0.92	3.03
2	CostU	0.30	0.25	0.21	0.76	3.02
3	CostI	0.37	0.53	0.44	1.34	3.04

count	3.00
lambda max	3.031
CI	0.016
CR	**0.03**
constant	0.58

Calculations of Implementation sub criteria

	Pairwise comparisons			
Item Number	**Item Number**	1	2	
	Item Description	Custom	Comp	
1	Custom	1.00	0.68	
2	Comp	1.47	1.00	
	Sum	2.47	1.68	
	STANDARDIZED MATRIX			
		Custom	Comp	**Weight**
1	Custom	0.41	0.41	**40.5%**
2	Comp	0.59	0.59	**59.5%**

C. the Company of case study – OGASCO L.L.C Organization Chart 2014



D. Data of the survey completed by participants

Decision Makers	Vendor Credentials VS Finance	Vendor Credentials VS Functionality	Vendor Credentials VS User Friendliness	Vendor Credentials VS Implementation	Vendor Credentials VS Maintenance	Finance VS Functionality	Finance VS User Friendliness	Finance VS Implementation	Finance VS Maintenance	Functionality VS Implementation	Functionality VS Maintenance	Functionality VS User Friendliness	Implementation VS Maintenance	Implementation VS User Friendliness	User Friendliness VS Maintenance	Reputation of the Vendor VS Market Share	Reputation of the Vendor VS Presentation of Previous Demonstrations	Presentation of Previous Demonstrations VS Market Share	Software Expenses VS Cost of Upgrade and Maintenance with Consultation	Software Expenses VS Cost of Implementation	Cost of Upgrade and Maintenance with Consultation VS Cost of Implementation	Customization VS Compatibility
1	1	1/5	1	1	7	3	1/3	3	5	1/3	1/3	3	1/5	1/7	7	1/7	7	1/5	1/3	1/3	1/5	1/7
2	3	1/7	3	1/5	5	1/3	1/3	3	5	1/3	5	1	3	1/5	7	1/5	1/5	3	3	1/3	1/3	1/3
3	1/7	1	1/3	3	1/3	1/7	1/5	3	5	5	5	3	1/5	1/5	9	1/3	3	1/3	3	1/7	1/3	1/7
4	1/7	1/7	5	1/3	5	3	1/3	1/5	1/7	1/3	5	1/3	1/3	1/3	9	3	3	3	5	1/3	1/3	1/3
5	1/3	1/5	3	3	1/7	1/3	1/3	3	3	1/3	1/3	1	1/5	1/3	5	1/5	5	3	1/5	1	1/3	5
6	1	7	3	1/7	1/5	1/3	1/3	5	3	1/3	1	1/3	1/3	7	5	1/3	5	1	1/5	7	1/3	7
7	1/7	1/3	3	1	3	1	1/5	7	1/7	3	3	3	1/5	1/3	7	1/3	3	1/5	1	1/5	1	1/3
8	5	1/5	1/5	3	5	1/5	3	9	1/9	3	1	1/3	1/5	5	7	1/7	3	1	1/5	7	1/5	1/7
9	1/3	1/3	1/5	1/5	3	3	1/5	5	1/7	7	7	1/7	1/7	1	7	1/3	1/5	1	1/5	1/3	1/3	1/7
10	1/3	7	3	5	7	1/3	5	7	3	1/3	1/5	1/3	5	1/3	3	7	5	1	3	3	3	1/7
11	1/3	1/3	1/3	1/3	5	3	1	5	5	7	1/3	1	1/7	7	1/5	1/3	1/7	3	3	1/3	5	1/3
12	1/3	1/3	3	1/5	3	7	1/3	7	1/7	1/7	5	1/3	5	1	5	3	3	1/3	1/3	5	1/3	1/3
13	1/3	5	1/3	1/3	1/5	1/3	5	3	7	3	3	1/7	3	5	7	7	5	7	1/5	5	1/3	1
14	1/3	3	3	1/7	1/5	1/3	3	3	1/7	1/7	5	1/3	1/7	7	5	7	3	1/3	1/7	7	1	7
15	3	1/5	3	1/3	5	1/3	5	7	5	1	1	1/7	5	1/5	5	1/3	3	1	5	1	1	3
16	5	1/5	1/3	3	7	1	1/5	3	1/3	1	1/7	1/5	1/3	3	9	1/3	3	1	1/3	1/7	1	1/5

Decision Makers	Vendor Credentials VS Finance	Vendor Credentials VS Functionality	Vendor Credentials VS User Friendliness	Vendor Credentials VS Implementation	Vendor Credentials VS Maintenance	Finance VS Functionality	Finance VS User Friendliness	Finance VS Implementation	Finance VS Maintenance	Functionality VS Implementation	Functionality VS Maintenance	Functionality VS User Friendliness	Implementation VS Maintenance	Implementation VS User Friendliness	User Friendliness VS Maintenance	Reputation of the Vendor VS Market Share	Reputation of the Vendor VS Presentation of Previous Demonstrations	Presentation of Previous Demonstrations VS Market Share	Software Expenses VS Cost of Upgrade and Maintenance with Consultation	Software Expenses VS Cost of Implementation	Cost of Upgrade and Maintenance with Consultation VS Cost of Implementation	Customization VS Compatibility
17	1/3	1/3	1/3	3	3	7	1/5	5	3	1/3	1	1/7	1/7	1/7	5	1/3	1/3	1	1/7	1/5	3	1/3
18	1/3	5	1/3	1/3	5	1/7	5	5	5	5	1/3	1/3	5	5	1/3	1/7	1	7	5	1/3	1/7	1/5
19	1/7	1/3	3	5	5	1/7	3	3	1/7	1/7	1/3	1/3	1/7	1/5	1/5	1	5	3	1	3	1/5	7
20	1	1/3	1/3	1	7	1/5	7	3	1/7	5	1	3	5	3	7	1	1/3	1	7	3	1/7	1/3
21	1/3	1/3	1/5	5	1/5	7	3	9	1/7	1/7	7	1/7	1/7	1/3	3	3	1/3	3	1/7	5	1/7	1/3
22	1/3	1/3	1/3	1	1/3	1/5	3	1/3	7	1/7	3	1	1	1/3	7	3	3	1/3	5	1/3	1/7	3
23	1/3	1/3	1/3	1	7	3	7	5	7	3	5	1/3	1/7	1/5	7	5	1/3	1	1/7	1/3	1/3	1/5
24	1	3	1/3	1/3	5	3	1/5	1/5	3	5	1	1/5	1/3	3	5	1/5	5	1/3	5	7	1/7	7
25	1/5	7	3	7	1	7	5	3	1/3	1/7	7	1/3	1	3	1/5	7	1/3	7	5	1/3	3	1/3
26	7	7	1/3	1	3	3	1/3	7	1/3	1	3	1/3	1	3	1/5	1/3	7	7	5	1	7	5
27	3	3	1/3	1	5	1/3	5	7	1/9	1/5	3	7	1	3	9	1/3	3	3	7	1/5	1/3	1/7
28	1/5	1/3	1/3	1	1/3	1/3	1/5	5	1/7	7	3	1/5	1	1	3	5	7	1	3	1	3	1
29	1/3	1/3	1/3	1/5	1/3	3	1	5	1/7	1/7	7	7	1	3	7	1	5	1	1/3	1/3	1/3	3
30	1/7	7	1/5	3	5	1/3	3	3	1/5	1/7	5	1/3	1/7	1/7	7	3	1	1	1/5	1/5	1/3	5
31	1/7	1/7	1/5	3	1	3	1/5	3	1/7	1/7	7	1/3	1/3	1/7	7	1/3	7	3	5	1/3	1/5	1/3
32	1/3	5	1/3	1/3	1/7	3	3	5	1/7	3	7	1/5	1/3	3	9	1/3	1/5	5	3	1/3	1/7	1/3
33	1/3	1/7	1/5	1/3	7	7	3	5	1/7	1/7	3	7	1/3	1/5	1/5	1	1/3	1/3	1/3	3	1/3	1

Converted data of the survey to triangular values (Fuzzified)

Decision Makers	Vendor Credentials VS Finance	Vendor Credentials VS Functionality	Vendor Credentials VS User Friendliness	Vendor Credentials VS Implementation	Vendor Credentials VS Maintenance	Finance VS Functionality	Finance VS User Friendliness	Finance VS Implementation	Finance VS Maintenance	Functionality VS Implementation	Functionality VS Maintenance	Functionality VS User Friendliness	Implementation VS Maintenance	Implementation VS User Friendliness	User Friendliness VS Maintenance	Reputation of the Vendor VS Market Share	Reputation of the Vendor VS Presentation of Previous Demonstrations	Presentation of Previous Demonstrations VS Market Share	Software Expenses VS Cost of Upgrade and Maintenance with Consultation	Software Expenses VS Cost of Implementation	Cost of Upgrade and Maintenance with Consultation VS Cost of Implementation	Customization VS Compatibility
1	(1,1,1)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(6,7,8)	(2,3,4)	(1/4,1/3,1/2)	(2,3,4)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(6,7,8)	(1/8,1/7,1/6)	(6,7,8)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/8,1/7,1/6)
2	(2,3,4)	(1/8,1/7,1/6)	(2,3,4)	(1/6,1/5,1/4)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(6,7,8)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
3	(1/8,1/7,1/6)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(2,3,4)	(4,5,6)	(4,5,6)	(4,5,6)	(2,3,4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(8,9,10)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(2,3,4)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1/8,1/7,1/6)
4	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(2,3,4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(8,9,10)	(2,3,4)	(2,3,4)	(2,3,4)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
5	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(2,3,4)	(2,3,4)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(4,5,6)	(1/6,1/5,1/4)	(4,5,6)	(2,3,4)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(4,5,6)
6	(1,1,1)	(6,7,8)	(2,3,4)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(6,7,8)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(1,1,1)	(1/6,1/5,1/4)	(6,7,8)	(1/4,1/3,1/2)	(6,7,8)
7	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(2,3,4)	(1,1,1)	(1/6,1/5,1/4)	(6,7,8)	(1/8,1/7,1/6)	(2,3,4)	(2,3,4)	(2,3,4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(6,7,8)	(1/4,1/3,1/2)	(2,3,4)	(1/6,1/5,1/4)	(1,1,1)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)
8	(4,5,6)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(2,3,4)	(4,5,6)	(1/6,1/5,1/4)	(2,3,4)	(8,9,10)	(1/10,1/9,1/8)	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(4,5,6)	(6,7,8)	(1/8,1/7,1/6)	(2,3,4)	(1,1,1)	(1/6,1/5,1/4)	(6,7,8)	(1/6,1/5,1/4)	(1/8,1/7,1/6)
9	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(2,3,4)	(2,3,4)	(1/6,1/5,1/4)	(4,5,6)	(1/8,1/7,1/6)	(6,7,8)	(6,7,8)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1,1,1)	(6,7,8)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/8,1/7,1/6)
10	(1/4,1/3,1/2)	(6,7,8)	(2,3,4)	(4,5,6)	(6,7,8)	(1/4,1/3,1/2)	(4,5,6)	(6,7,8)	(2,3,4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(2,3,4)	(6,7,8)	(4,5,6)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)	(1/8,1/7,1/6)
11	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(2,3,4)	(1,1,1)	(4,5,6)	(4,5,6)	(6,7,8)	(1/4,1/3,1/2)	(1,1,1)	(1/8,1/7,1/6)	(6,7,8)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)
12	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1/6,1/5,1/4)	(2,3,4)	(6,7,8)	(1/4,1/3,1/2)	(6,7,8)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(1,1,1)	(4,5,6)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)
13	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(4,5,6)	(2,3,4)	(6,7,8)	(2,3,4)	(2,3,4)	(1/8,1/7,1/6)	(2,3,4)	(4,5,6)	(6,7,8)	(6,7,8)	(4,5,6)	(6,7,8)	(1/6,1/5,1/4)	(4,5,6)	(1/4,1/3,1/2)	(1,1,1)
14	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(4,5,6)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(6,7,8)	(4,5,6)	(6,7,8)	(2,3,4)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(6,7,8)	(1,1,1)	(6,7,8)
15	(2,3,4)	(1/6,1/5,1/4)	(2,3,4)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(6,7,8)	(4,5,6)	(1,1,1)	(1,1,1)	(1/8,1/7,1/6)	(4,5,6)	(1/6,1/5,1/4)	(4,5,6)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(4,5,6)	(1,1,1)	(1,1,1)	(2,3,4)
16	(4,5,6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(2,3,4)	(6,7,8)	(1,1,1)	(1/6,1/5,1/4)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(2,3,4)	(8,9,10)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1,1,1)	(1/6,1/5,1/4)
17	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)	(6,7,8)	(1/6,1/5,1/4)	(4,5,6)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(2,3,4)	(1/4,1/3,1/2)
18	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(1/8,1/7,1/6)	(4,5,6)	(4,5,6)	(4,5,6)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(4,5,6)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1,1,1)	(6,7,8)	(4,5,6)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1/6,1/5,1/4)
19	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(2,3,4)	(4,5,6)	(4,5,6)	(1/8,1/7,1/6)	(2,3,4)	(2,3,4)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(4,5,6)	(2,3,4)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(6,7,8)
20	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(6,7,8)	(1/6,1/5,1/4)	(6,7,8)	(2,3,4)	(1/8,1/7,1/6)	(4,5,6)	(1,1,1)	(2,3,4)	(4,5,6)	(2,3,4)	(6,7,8)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(6,7,8)	(2,3,4)	(1/8,1/7,1/6)	(1/4,1/3,1/2)
21	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(4,5,6)	(1/6,1/5,1/4)	(6,7,8)	(2,3,4)	(8,9,10)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(6,7,8)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(2,3,4)	(1/8,1/7,1/6)	(4,5,6)	(1/8,1/7,1/6)	(1/4,1/3,1/2)
22	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(2,3,4)	(1/4,1/3,1/2)	(6,7,8)	(1/8,1/7,1/6)	(2,3,4)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(6,7,8)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(2,3,4)
23	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(6,7,8)	(2,3,4)	(6,7,8)	(4,5,6)	(6,7,8)	(2,3,4)	(4,5,6)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(6,7,8)	(4,5,6)	(1/4,1/3,1/2)	(1,1,1)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)
24	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(2,3,4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(2,3,4)	(4,5,6)	(1,1,1)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(2,3,4)	(4,5,6)	(1/6,1/5,1/4)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(6,7,8)	(1/8,1/7,1/6)	(6,7,8)
25	(1/6,1/5,1/4)	(6,7,8)	(2,3,4)	(6,7,8)	(1,1,1)	(6,7,8)	(4,5,6)	(2,3,4)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(6,7,8)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(6,7,8)	(1/4,1/3,1/2)	(6,7,8)	(4,5,6)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)
26	(6,7,8)	(6,7,8)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(6,7,8)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(6,7,8)	(6,7,8)	(4,5,6)	(1,1,1)	(6,7,8)	(4,5,6)
27	(2,3,4)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(4,5,6)	(1/4,1/3,1/2)	(4,5,6)	(6,7,8)	(1/10,1/9,1/8)	(1/6,1/5,1/4)	(2,3,4)	(6,7,8)	(1,1,1)	(2,3,4)	(8,9,10)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)	(6,7,8)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/8,1/7,1/6)
28	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(4,5,6)	(1/8,1/7,1/6)	(6,7,8)	(2,3,4)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(2,3,4)	(4,5,6)	(6,7,8)	(1,1,1)	(2,3,4)	(1,1,1)	(2,3,4)	(1,1,1)
29	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(2,3,4)	(1,1,1)	(4,5,6)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(6,7,8)	(6,7,8)	(1,1,1)	(2,3,4)	(6,7,8)	(1,1,1)	(4,5,6)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)
30	(1/8,1/7,1/6)	(6,7,8)	(1/6,1/5,1/4)	(2,3,4)	(4,5,6)	(1/4,1/3,1/2)	(2,3,4)	(2,3,4)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(4,5,6)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(6,7,8)	(2,3,4)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(4,5,6)
31	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)	(2,3,4)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(6,7,8)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(6,7,8)	(1/4,1/3,1/2)	(6,7,8)	(2,3,4)	(4,5,6)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/4,1/3,1/2)
32	(1/4,1/3,1/2)	(4,5,6)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(2,3,4)	(2,3,4)	(4,5,6)	(1/8,1/7,1/6)	(2,3,4)	(6,7,8)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(2,3,4)	(8,9,10)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(4,5,6)	(2,3,4)	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1/4,1/3,1/2)
33	(1/4,1/3,1/2)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(6,7,8)	(6,7,8)	(2,3,4)	(4,5,6)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(2,3,4)	(6,7,8)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)

Appendix II: Calculations of Criteria

Calculation steps using MS-Excel for main criteria

CR Value = 0.098 OK

Pairwise comparisons

Item Number	Item Number	1	2	3	4	5	6
	Item Description	VenC	Fin	Fun	UF	Imp	Mnt
1	VenC	1.00	0.50	0.71	0.66	0.87	1.75
2	Fin	2.00	1.00	0.97	1.06	3.47	0.66
3	Fun	1.40	1.03	1.00	0.54	0.72	1.92
4	UF	1.51	0.95	1.85	1.00	1.15	3.34
5	Imp	1.15	0.29	1.40	0.87	1.00	0.53
6	Mnt	0.57	1.51	0.52	0.30	1.89	1.00
7							
8							
9							
10							
	Sum	7.63	5.27	6.45	4.43	9.09	9.20

STANDARDIZED MATRIX

		VenC	Fin	Fun	UF	Imp	Mnt	Weight
1	VenC	0.13	0.09	0.11	0.15	0.10	0.19	**12.9%**
2	Fin	0.26	0.19	0.15	0.24	0.38	0.07	**21.6%**
3	Fun	0.18	0.20	0.16	0.12	0.08	0.21	**15.7%**
4	UF	0.20	0.18	0.29	0.23	0.13	0.36	**23.0%**
5	Imp	0.15	0.05	0.22	0.20	0.11	0.06	**13.1%**
6	Mnt	0.07	0.29	0.08	0.07	0.21	0.11	**13.8%**

CI and CR worksheet

		VenC	Fin	Fun	UF	Imp	Mnt	SUM	SUM/Weight
1	VenC	0.13	0.11	0.11	0.15	0.11	0.24	0.86	6.65
2	Fin	0.26	0.22	0.15	0.24	0.45	0.09	1.41	6.56
3	Fun	0.18	0.22	0.16	0.12	0.09	0.26	1.04	6.63
4	UF	0.19	0.20	0.29	0.23	0.15	0.46	1.53	6.65
5	Imp	0.15	0.06	0.22	0.20	0.13	0.07	0.83	6.36
6	Mnt	0.07	0.33	0.08	0.07	0.25	0.14	0.94	6.79

Saaty's CIr values for matrices are given by the following table

Size of Matrix	Random Consistency (CIr)
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
7	1.32
8	1.41
9	1.45
10	1.49

count	6.00
lambda max	6.608
CI	0.122
CR	**0.098**
constant	1.24

Calculations of Vendor Credentials sub criteria

CR Value = 0.093 OK

Pairwise comparisons

Item Number	**Item Number**	1	2	3
	Item Description	RepVen	MarS	PrevDem
1	RepVen	1.00	0.80	1.66
2	MarS	1.25	1.00	0.78
3	PrevDem	0.60	1.29	1.00
	Sum	2.85	3.09	3.43

STANDARDIZED MATRIX

		RepVen	MarS	PrevDem	**Weight**
1	RepVen	0.35	0.26	0.48	**36.4%**
2	MarS	0.44	0.32	0.23	**32.9%**
3	PrevDem	0.21	0.42	0.29	**30.7%**

CI and CR worksheet

		RepVen	MarS	PrevDem	SUM	SUM/Weight
1	RepVen	0.36	0.26	0.51	1.14	3.12
2	MarS	0.45	0.33	0.24	1.02	3.10
3	PrevDem	0.22	0.42	0.31	0.95	3.10

count	3.00
lambda max	3.108
CI	0.054
CR	**0.09**
constant	0.58