DEVELOPMENT OF PARTNER SELECTION ALGORITHMS IN FORMING VIRTUAL ENTERPRISE CONSORTIUMS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

SHAHRZAD NIKGHADAM

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
MECHANICAL ENGINEERING

JULY 2015

Approval of the thesis:

DEVELOPMENT OF PARTNER SELECTION ALGORITHMS IN FORMING VIRTUAL ENTERPRISE CONSORTIUMS

Submitted by **SHAHRZAD NIKGHADAM** in partial fulfillment of the requirement for the degree of **Master of Science in Mechanical Engineering Department, Middle East Technical University** by,

Prof. Dr. Gülbin Dural Ünver ___________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Tuna Balkan ___________________
Head of Department, **Mechanical Engineering**

Prof. Dr. Metin Akkök ___________________
Supervisor, **Mechanical Engineering Dept., METU**

Assist. Prof. Dr. H. Özgür Ünver ___________________
Co- Supervisor, **Mechanical Engineering Dept., TOBB ETÜ**

Examining Committee Members:

Prof. Dr. Y. Samim Ünlüsoy ___________________
Mechanical Engineering Dept., METU

Prof. Dr. Metin Akkök ___________________
Mechanical Engineering Dept., METU

Assist. Prof. Dr. Ali Emre Turgut ___________________
Mechanical Engineering Dept., METU

Prof. Dr. S. Engin Kılıç ___________________
Manufacturing Engineering Dept., Atılım University

Assist. Prof. Dr. H. Özgür Ünver ___________________
Mechanical Engineering Dept., TOBB ETÜ

Date: ___________________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name : Shahrzad Nikghadam

Signature :

ABSTRACT

DEVELOPMENT OF PARTNER SELECTION ALGORITHMS IN FORMING VIRTUAL ENTERPRISE CONSORTIUMS

Nikghadam, Shahrzad
MSc., Department of Mechanical Engineering
Supervisor: Prof. Dr. Metin Akkök
Co-Supervisor: Asst. Prof. Dr. H. Özgür Ünver

July 2015, 143 pages

Recent developments in information technologies and internet based applications provide a reliable infrastructure for enterprises to communicate and corporate with each other. In order to take advantage of these facilities, individual companies may cooperate with each other within a consortium framework, to share their resources with the aim of responding to a customer demand. Virtual Enterprise is such a collaboration concept established on the basis of these features.

Not surprisingly, success of VE as a cooperation platform is directly influenced by the performance of its partners. So selecting appropriate members is a crucial step in forming up VE. In this respect, a multi-step partner selection technique is proposed which evaluates and selects the VE partners based on customers' attitude and their vague preferences. Each step is embedded in the model in order to respond to a certain requirement for an unbiased, dynamic and reliable partner selection.

First two steps of the algorithm identify the qualified enterprises in terms of technical necessities and customer prerequisites. Then, inefficient candidates are recognized and eliminated from invitation list. Then, by receiving the bidding proposals the main decision making steps begin. These steps would be based on customer's attitude and preferences. Customers are classified into three classes; passive, standard and assertive. And based on customer's type appropriate decision making technique is adapted. Fuzzy logic, fuzzy-AHP TOPSIS and Goal programming based techniques are all incorporated in this step. Once the candidate enterprises are evaluated, winners of the upcoming consortium are announced to take role in the project. Implementing the proposed model to the case study of a partner selection problem in Ontology based Multi-Agent Virtual Enterprise (OMAVE) system and analyzing the results validates the reliability of the model. Finally some discussions have been made highlighting the conclusions and perspectives for future studies.

Keywords: Virtual Enterprise, Partner selection, Fuzzy logic, Fuzzy AHP, TOPSIS, Goal Programming

ÖZ

SANAL FABRİKA ÜYE SEÇİMİ ALGORİTMASININ GELİŞTİRİLMESİ

Nikghadam, Shahrzad
Master, Makina Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Metin Akkök
Ortak Tez Yöneticisi: Asst. Prof. Dr. H. Özgür Ünver

Temmuz 2015, 143 sayfa

Bilişim Teknolojileri ve Ağ tabanlı uygulamaların son zamanlardaki gelişmeleri, firmalar arası iletişim ve iş birliği için güvenilir ve uygun bir altyapı oluşturulmasına olanak sağlamaktadır. Bu teknolojilerin getirdiği avantajlardan yararlanıp, firmalar bir şirketler birliği çatısı altında kaynaklarını paylaşıp belli bir ticari amaca ulaşmak için iş birliği yapmaları mümkündür. Sanal fabrika kavramı, bu teknolojilerden faydalanarak ağ tabanlı, firmalar arası geçici bir iş birliği modeli olarak tanımlanır.

Açıkça bellidir ki böyle bir şirketler birliğinin başarılı olmasında en önemli rolü, konsorsiyumda yer alan firmaların performansı oynamaktadır. Bu nedenle sanal fabrikanın oluşum aşamasında en uygun firmaların seçilmesi oldukça önem arz etmektedir. Bu gayeye ulaşmak amacıyla bu araştırmada, müşterinin düşünceleri ve bulanık önceliklerine göre firmalar değerlendirilip ve çok aşamalı bir üye seçimi tekniği ile seçilmeleri önerilmiştir. Her aşamada firmalar belli filtrelerden geçerek istenilen ihtiyaçlara karşılık verebilmeleri denetlenir.

Algoritmaya göre ilk iki aşamada müşteriden gelen teknik ihtiyaçlar ve şartlar göz önüne alınarak aday firmalar değerlendirilir. Bu aşamada istenilen şartları karşılamakta yetersiz kalan firmalar, teklif verebilen firmalar listesinden çıkartılır. Daha sonra aday firmalardan teklifler alınarak esas karar verme mekanizması çalışmaya başlayacaktır. Bu aşamada, bulanık mantığı (Fuzzy Logic), bulanık-AHP TOPSIS (Fuzzy AHP- TOPSIS) ve hedef programlama (Goal Programming) temelli teknikler kullanılmıştır. Müşteri türüne göre en uygun seçim tekniği seçilip ve aday firmalar seçilen metoda göre değerlendirilip sıralanırlar. Birinci sırada yer alan firma kazanan firma olarak seçilir ve konsorsiyumun üyesi olarak ilan edilir.

Önerilen üye seçimi tekniği çok-etmenli ontoloji temelli sanal fabrika projesinde (OMAVE) uygulanıp, test edilip, sistemin çalışması ve alınan sonuçlar doğrulanmıştır. Bu tezin en son kısmında bu araştırmadan elde edilen sonuçlar ve birikimler tartışılıp ve gelecek adımlar için potansiyel araştırma konuları önerilmiştir.

Anahtar Kelimeler: Sanal-Fabrika, Üye seçimi, Bulanık mantık, Bulanık-AHP, TOPSIS, Goal programming

To My Parents,

For their endless love and support

ACKNOWLEDGEMENTS

This thesis owes a great deal to the efforts of a number of people. Foremost, I offer my deepest gratitude to my supervisor, Prof. Dr. Metin Akkök, for his precious caring, patience and understanding. I doubt that I will ever be able to convey my appreciation fully, for his supports. I would also like to extend my gratitude to Prof. Dr. S. Engin Kılıç for his guidance. It is a great honor to work under his supervision.

I place on record, to thank my co-supervisor, Assist. Prof. Dr. H. Özgür Ünver, for his contributions at different stages of my studies. I wouldn’t have chance to join the team of this project without his support. I would also like to express my sincerest thanks to Assist. Prof. Dr. A. Murat Özbayoğlu for his original tips and comments in developing the solution methodologies. His involvement with the topic has triggered and nourished the ideas behind the proposed models. I must also thank Dr. Bahram Lotfi Sadigh for his instructions.

I acknowledge the contribution of Prof. Dr. Y. Samim Ünlüsoy and Assist. Prof. Dr. Ali Emre Turgut for serving as my committee members.

I would also acknowledge Turkish Ministry of Science, Technology and Industry for their technical and financial support for Virtual Enterprise project.

I am extraordinarily fortunate in having my dear friends Reyhan Yaka, Sema Zabci and Burcu Yelen who made my life here in Turkey an enjoyable adventure. I thank them for all the memories we have shared. I would like to especially thank Nastaran Deljavan, Nigar Madani and Ezgi Tekin for their motivations during preparation of this thesis work.

Words cannot express how grateful I am to my parents, Rashid Nikghadam and Zhila Taghizadeh, for all of the sacrifices they have made. I am so privileged to have them in my life.

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CHAPTER 1

INTRODUCTION

1.1 Background

In today's global manufacturing environment, companies should satisfy the customer preferences wisely to survive the extremely competitive business market. In respond to customer demands, companies should provide the high quality product with inexpensive price within short time frames. Moreover, companies should be able to provide wide variety of products to be able to satisfy the diverse customer requests. Fulfilling all of these challenging necessities, requires plentiful investment. Generally big enterprises have adequate financial, technological and human resources but they suffer from lack of flexibility. Their organizational structure usually prevent them from being adapt to rapidly changing business environment. On the other hand, Small and Medium-Sized Enterprises (SMEs) are dynamic but without enough resources. Designing a platform which can maintain its flexibility while possessing diverse range of resources will set light to solve many issues in this respect. This is why several production strategies such as Supply Chain management (SC), Virtual Enterprise (VE), Lean manufacturing, Just In Time (JIT) and etc. have been emerged in recent decades.

Additionally, recent developments in Information Technology (IT) and internet based applications facilitate the reliable infrastructure for enterprises to communicate and corporate with each other. Taking the advantage of all these, by forming up a consortium companies could be able to share their resources and respond quickly to customer preferences and gain mutual benefit. Virtual Enterprise (VE) concept is established on the basis of these principles.

1.2 Virtual Enterprise

The concept of VE was first introduced by Davidow and Malone in 1992 (Davidow & Malone, 1992). They defined VE as a temporary collaboration between autonomous enterprises to reach a certain goal. Later, further development of Information and Communication Technologies (ICT) supported the VE's communication infrastructure and helped it to grow even more (Camarinha-Matos & Afsarmanesh, 2009). The basic principle behind VE is that dissimilar enterprises cooperate with each other, via an internet-based network, to work together and accomplish a certain market opportunity. This synergic cooperation provides mutual benefit for both enterprises and customers. A single handed SME may not be able to fulfill all the manufacturing requirements of a product, due to lack of resources. Participating in a consortium, enterprises share their core competences and take the responsibility of the tasks which they have mastered. On the other hand, customers would probably be more satisfied, because they could get what they demanded with higher quality, cheaper price and in shorter time. Therefore, VE platform helps its participants to accomplish their goals quickly and efficiently.

1.3 VE Structure

VE system needs to go through several key activities within its lifecycle. These activities are classified to three main phases; formation, operation and dissolution.

1.3.1 Formation Phase

A request from a customer triggers a formation of VE. Mission of VE system is defined as a project which should be completed to respond to the specified customer demand. Let's assume that buyer orders a product. In order to produce the product variety of manufacturing operations may need to be performed. Based on the manufacturing necessities, the overall project is decomposed into tasks. As a key principal of VE, each task would be allocated to a best possible VE member (Camarinha-Matos & Afsarmanesh, 2009). The central question here is that, which enterprise is the best candidate and how could it be identified?

Generally enterprises are evaluated based on their bidding proposals when the auctioning is started. Volunteered members of Virtual Breeding Environment (VBE) answer the call for proposals if they wish to take role in VE's forthcoming project. VE system operator gathers and evaluates the proposals and selects the partners. When consortium partners are identified and confirmed the operation phase could be started.

1.3.2 Operation Phase

When the project members are set up, VE can start to perform. Now enterprises should fulfill their responsibilities. These tasks could be manufacturing process or designing or transportation or providing a service. If everything is completed successfully, the mission of the project is met.

1.3.3 Dissolution Phase

When the goal is accomplished and customer demand is satisfied VE project is finalized and it can be dissolved. This is exactly why VE is meant to be a **temporary** cooperation framework. Dissolution phase also contains the partner performance evaluation step. Each partner would be scored (either penalized or rewarded) based on its level of commitments. This step provides a feedback oriented tool which helps the VE management to recognize the successful enterprises for continual improvement of the system in the future.

Consequently, the main stages of VE is depicted schematically in Figure 1.1.

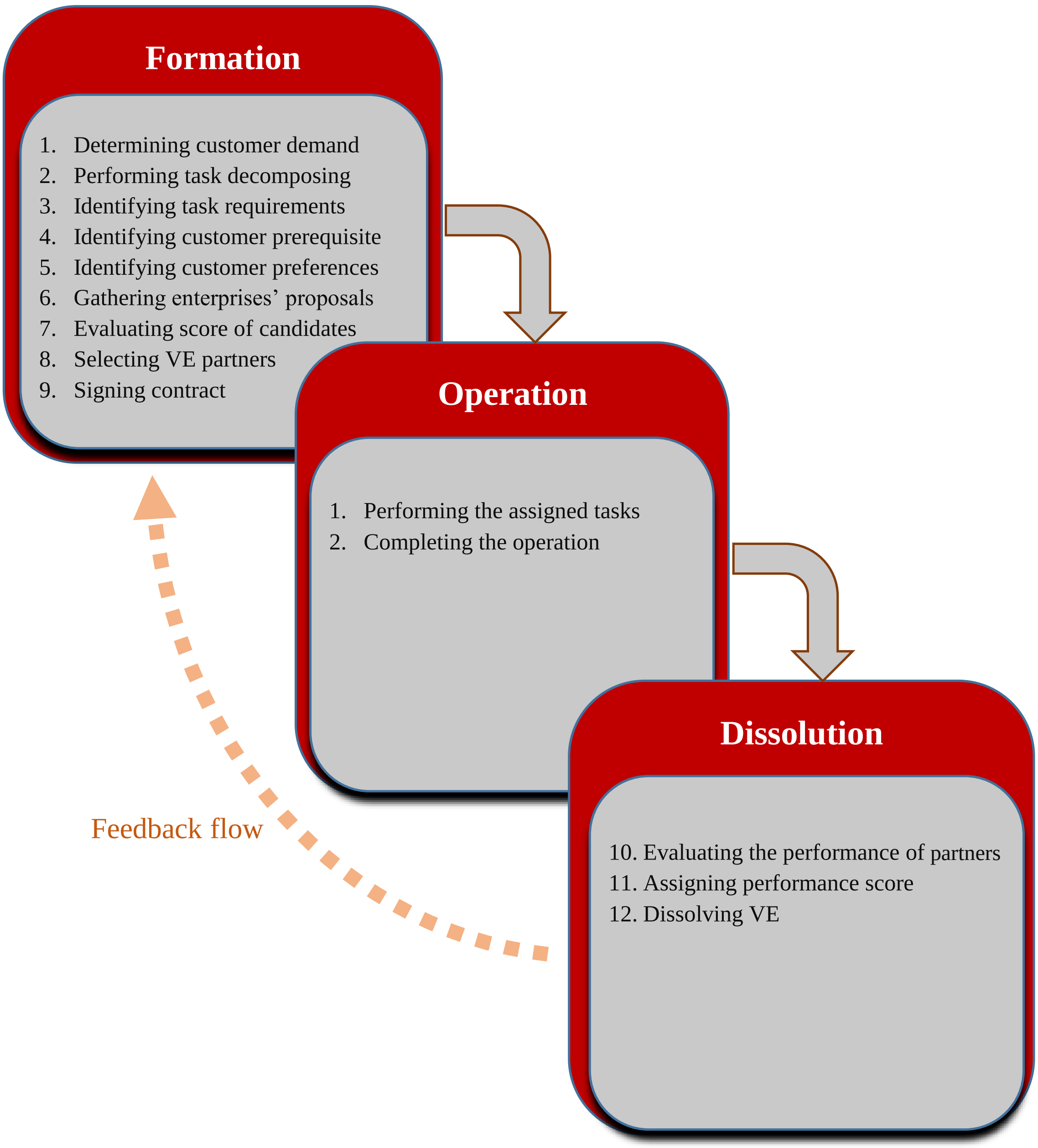


Figure 1.1.VE life cycle phases

1.4 Importance of VE's Partner Selection and Challenges Ahead

As the overall performance of a VE as a system directly depends on the performance of its participants, selecting appropriate set of partners is a crucial step in forming a successful VE. This is why there are lots of research conducted in this field. Evaluating the volunteer enterprises based on their bid proposals and past performance is not an easy task. This difficulty is due to the following reasons:

Partner's evaluation is conducted based on the set of criteria called evaluation criteria. Selecting the appropriate set of parameters is essential since it should be comprehensive so that it can be able to consider and investigate the partners in all main aspects. Neglecting even an important evaluation parameter will lead to unreliable results. On the other hand, including too many unnecessary detailed factors in evaluation process makes the problem grow in size and complexity. Therefore, organizing the criteria set to be concise and precise is a very first issue in partner selection process.

Criteria can be classified into two main groups; quantitative and qualitative criteria. Quantitative criteria are factors which can be measured (considering their units) and represented by numbers such as price and time. There are also called tangible criteria. On the other hand, there is a group of criteria which denote to abstract meanings called qualitative criteria. Assigning numeric values to these factors are not an easy task since they are subjective in nature. As an example, in the context of our study, reputations and communication skills are considered as qualitative factors. In order to have broad insight into problem, both quantitative and qualitative criteria have to be incorporated in evaluation process. But as it is difficult to represent qualitative criteria with numbers, handling the qualitative criteria in mathematical formulations is a challenge.

Like all the decision making problems, partner selection is the problem of deciding between varieties of conflicting criteria, for instance if there is an alternative providing a high quality product with a cheap price, certainly it is the ideal solution but usually this is not the case in real life. High quality products offered for sale with high price. So the customer has to decide which one, price or quality, is outweigh more and then make a trade between these two. In other words, the decision maker have to sacrifice a criterion to get some amount from another criterion. Here, the problem is that human judgments are usually uncertain and this vagueness shouldn't be neglected as all the decision making system is constructing on the basis of customer preferences. Ignoring this fundamental fact may lead to unreliable outcomes at the end. Likewise, not only buyer's preferences but also partners' performance scores are uncertain due to incomplete information or knowledge.

To sum up, partner selection dilemmas can be listed as follows:

- Including adequate but not excessive number of evaluation criteria
- Handling qualitative criteria
- Considering uncertainty of decisions both on customer preferences and companies' performance scores

1.5 Purpose of the Study

The purpose of this thesis is to propose a rational algorithm to be applied in forming the consortium of Ontology based Multi- Agent Virtual Enterprise (OMAVE). OMAVE is an innovative VE system model which is recently developed by researchers of METU and TOBB ETU universities. OMAVE system is a VE model which is supported by ontologies. System's agents are all interact with other via agent ontology. Detailed information regarding the OMAVE system and its properties could be found in the doctoral thesis by Lotfi (Lotfi Sadigh, Design and development of an ontology based Virtual Enterprise system, 2015).

The partner selection method would implement in OMAVE system to evaluate the volunteer candidate enterprises based in their bidding proposals and their background performance. Decision parameters should be selected properly to take into account all of the important aspects in evaluating organizations. Customer preferences and uncertainty of the judgments should not be ignored.

The algorithm should be easy to implement on computer networks so that it can be called and applied when system needs.

In this thesis work, a multi-step partner selection algorithm is designed, developed and tested. It adapts different decision making techniques depending on the customer's attitude. This approach enhances the model's flexibility in facing various VE projects.

1.6 Thesis Outline

The thesis is organized as follows; first a comprehensive explanation of the studies within the research domain of partner selection in virtual enterprises is given. Articles are analyzed highlighting their strength and limitations. Once the research gaps are identified, a new solution methodology is proposed based on problem's requirements. Partner selection problem's description and decision making methodology are presented in Chapters 3 and 4 respectively. Proposed algorithms are stepwise algorithms which contain different types of decision making techniques. Three evaluation techniques are Fuzzy-AHP-TOPSIS, Fuzzy Logic and Fuzzy-AHP IGP. Characteristics of each approach is described in detail and validity of method is tested and verified by applying on a sample case study in chapter 4. Finally, chapter 5 concludes the study and recommends some future works.

CHAPTER 2

LITERATURE REVIEW OF RELATED WORKS

Before investigating the new methodologies to solve the partner selection problem, published articles of researchers in this field are reviewed so that we can be inspired by strength of their ideas while detecting the limitations and trying to find a solution to overcome them.

2.1 Search Methodology

In this literature survey, only articles which specifically address the partner selection problem in VE are considered. Search keywords were "virtual enterprise" and "partner selection". Studies related to supply chain, strategic alliances were all excluded. Selection of partner enterprises in creation of virtual enterprise has much in common with supplier selection of the supply chain management. They both evaluate the companies and try to find the best alternative with respect to a number of factors. However they are not completely identical. VE is more dynamic in comparison to SC. Supplier selection of SC designed for a specific set of processes, while VE can emerge for fulfilling different types of projects and customers so VE is more dynamic in comparison to SC.

Meanwhile, articles published in languages other than English are not included in reviewed literature either.

Due to the multi-disciplinary nature of virtual enterprise topic, the articles are located in computer, industrial, mechanical and manufacturing engineering, mathematics, economics, informatics, business, management journals. Most of the papers are published in International Journal of Production Research followed by International Journal of Advanced Manufacturing Technology and Computer Integrated Manufacturing.

2.2 Categorical Review of Literature

Based on 46 articles collected to be reviewed, their proposed solution methodologies can be classified into three main categories; optimization approaches, Multi-Criteria Decision Making (MCDM) approaches and other. Detailed subclasses of these main categories are demonstrated in Figure 2.1.

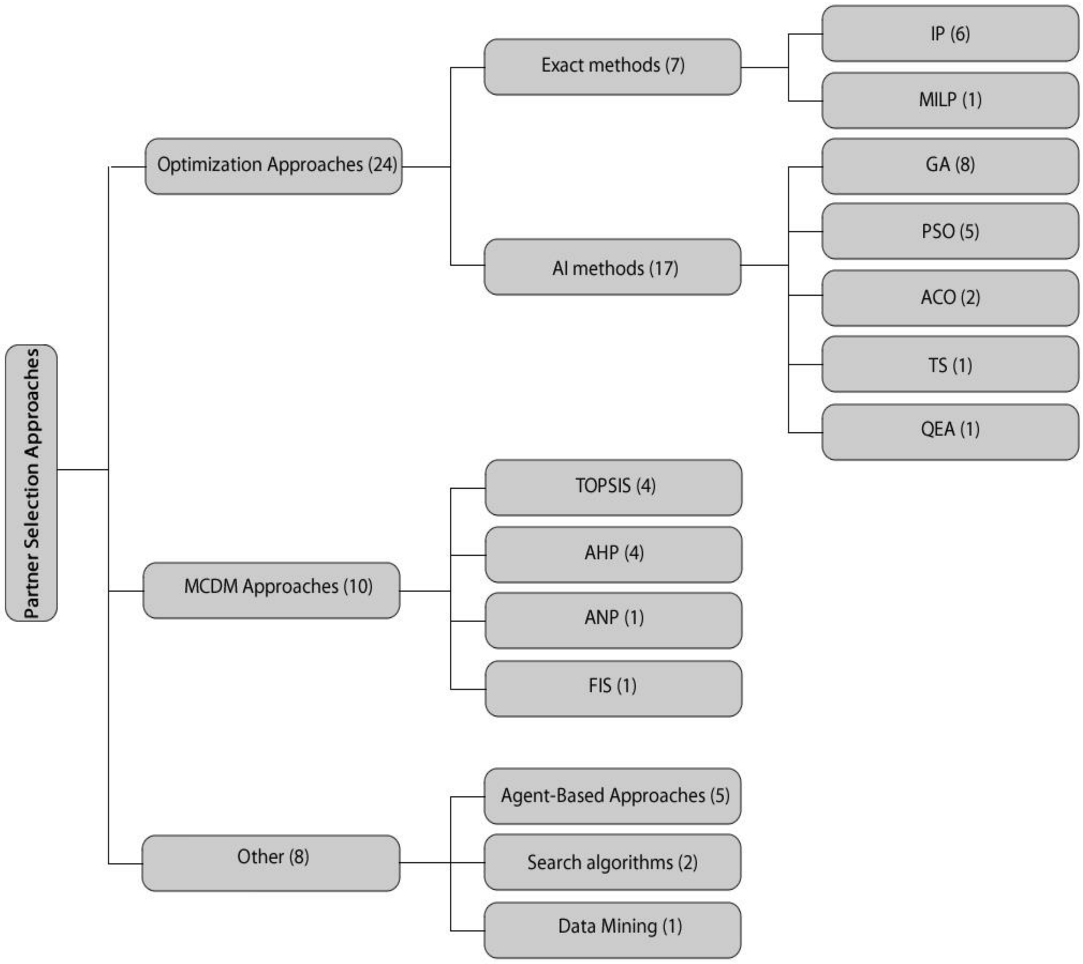


Figure 2.1. Classification of partner selection approaches

Before focusing on detailed explanation of solution methodologies in the literature, a brief introduction to fuzzy set theory is given in the next chapter. This concept provides a notation that can be applied when dealing with uncertain or ambiguous data.

2.3 Introduction to Fuzzy Sets Theory

Most of the classical mathematical computing are employing crisp and deterministic values. Regarding this logic, an element can either belong to a group or not. Though in reality a case can belong to a group to some extent. Classical binary approach assumes that the information about the facts are precise. This assumption neglects the inevitable vagueness of real life. In 1965 Zadeh was who first introduced the fuzzy sets theory which is specifically developed to mathematically represent uncertainty (Zadeh, 1965). A fuzzy set A in X is characterized by a membership function $\mu_A(x)$.

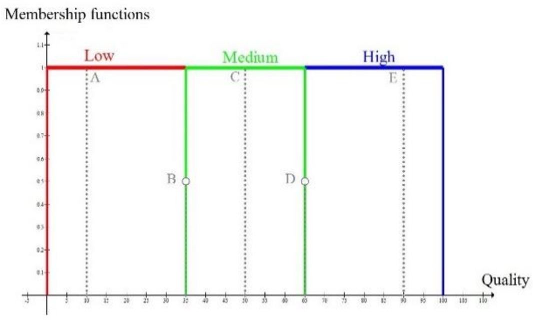
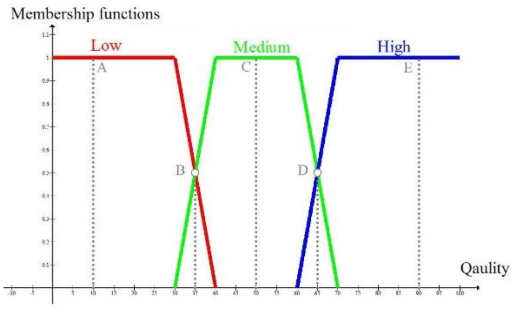
$$\mu_A(x):\ X \rightarrow [0,1] \qquad \text{Eq. 2.1}$$

$$A = \{(x, \mu_A(x)) |\ x \in X\} \qquad \text{Eq. 2.2}$$

Each $\mu_A(x)$ value is associated with a fuzzy membership formulas. Triangular, trapezoidal and Gaussian are the most frequently used fuzzy membership functions.

Intangible factors are usually expressed with subjective (verbal) terminations resulting in uncertainty. To deal with uncertainty of these problems fuzzy sets can be employed. In the context of this study, for example quality of a product can be expressed with three membership functions “low”, “medium” and “high”. As an instance, a crisp set, fuzzy set and their membership functions are illustrated in the following figures to point out the contrast between these two theories.

Table 2.1. Membership functions of fuzzy vs. crisp set

Membership functions of a crisp set	Membership functions of a fuzzy set
	
A: low Quality B: Medium Quality C: Medium Quality D: Medium Quality E: High Quality	A: 100 % Low Quality B: 50% low, 50% Medium Quality C: 100 % Medium Quality D: 50% Medium, 50% High Quality E: 100 % High Quality

Due to the fact that, in decision making problems qualitative criteria assessments are represented in linguistic variables applying fuzzy set theory could be beneficial. This is why this concept is applied frequently in variety of partner selection approaches.

2.4 Optimization Approaches

Partner selection problem can be considered as an optimization problem in which the objective is to maximize the customer satisfaction degree. In order to maximize the customer satisfaction, benefit factors such as quality, service level, reliability and etc. should be maximized. While cost type factors such as price, delivery time, risk and etc. should be minimized. These are the objectives of the model. Mathematical formulations may have just one or more than one objectives called single and multi-objective respectively. Furthermore, there exists some constraints enforced by resource limitations. For instance, in order to define the task sequence (obliged by manufacturing process necessities) time is generally modeled as a constraint. Eq. 2.3 is a mathematical representation of a sample minimization problem.

$$\min\ (f_1(x), f_2(x), \dots, f_k(x))$$
$$\text{Subject to: } x \in X \qquad \text{Eq. 2.3}$$

To sum up, optimum solution is a point which satisfies the objectives ideally while considering constraints.

Optimization approach is the most widely used approach because there are variety of techniques such as exact methods and Artificial Intelligence (AI) techniques to solve these optimization problems.

2.4.1 Exact Methods

There are different methods which are proposed to find the exact solution for the mathematical problems.

2.4.1.1 Integer Programming

Integer programming is a mathematical solution methodology in which objectives and constraints have to be integer. Generally assigning tasks are demonstrated with {0, 1}. In the case of partner selection problem 1 represents that the task is assigned to partner while 0 represents the task is not allocated to the partner (Ip, Yung, & Wang, 2004)

One of the earliest studies in this area is conducted by Wu et al. proposing an integer programming model with the objective of minimizing the sum of the cost for performing all tasks and the transportation cost. The problem could be solved exactly in the integer programming formulation. However in order to reduce the complexity of the model it is transformed into graph-theory formulation by taking the advantage of the precedence relationship between the tasks. So the problem can be solved by a polynomial bounded algorithm. (Wu, Mao, & Qian, 1999). In this study the only objective was cost.

By inclusion of due date, authors developed a new model based on the previous study. An integer programming method is developed to minimize the cost under time constraint for solving the new model. The IP formulation is transformed into graph-theory formulation and a two-phase algorithm is developed to solve the problem (Wu & Su, 2004).

Ip et al. implement branch and bound algorithm to obtain the solution of a model described by integer programming with the cost minimization objective function. The governing cost is the sum of job costs, loan interest to bank and tardiness penalty cost. The limitation of branch and bound method is that it cannot solve large scale problem in an acceptable time (Ip, Yung, & Wang, 2004).

Hsieh et al. developed a framework for partner selection of reverse auctions to minimize the cost of VE project task. A solution algorithm is developed based on Lagrangian relaxation technique however the algorithm cannot guarantee the generation of optimal solution, it often heads to optimal or near optimal solutions (Hsieh & Lin, 2012).

Zeng et al. proved that the partner selection problem with due date constraint is NP-complete. NP stands for "Nondeterministic Polynomial time" and this kind of problems can be solved in polynomial time (Korte & Vygen, 2000). Zeng et al. constructed the cost minimization nonlinear integer programming model for their models which is solved by Branch and Bound (Zeng, Li, & Zhu, 2006).

In a model developed by Sha et al. IP is integrated with AHP and Multi-Attribute Utility Theory (MAUT). AHP is implemented to evaluate the weights of criteria based on decision maker's priorities, and MAUT is applied to construct the single utility functions. Then the normalized utility values is used to define the objective function of IP model (Sha & Che, 2004).

2.4.1.2 Mixed Integer Linear Programming

Beside integer programming models mentioned above, partner selection problem can be modeled through mixed integer linear programming. In contrast to Integer Programming the unknowns of mixed integer programming (MIP) can be either integer or non-integer. In the study published by Jarimo et al. fixed and variable costs, risks of capacity shortfall and inter-organizational dependencies are taken into account. The additive value function of the model reflects the decision makers' preferences with respect to each criterion. Subsequently the set of Pareto-efficient configurations are identified. As this method's output is not an absolute ranking of candidates and the final decision is made by decision maker, it could be considered as a weakness of the proposed model (Jarimo & Salo, 2009).

As it is mentioned before, using exact algorithms such as branch and bound generally do not give satisfactory solution in a reasonable computational time and could not be advised to be implemented in large scale and complex problems.

2.4.2 Artificial Intelligence Methods

In order to deal with complexity of large problems, Artificial Intelligence methods which are computer-aided systems are adapted. Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Tabu Search (TS) are examples of such techniques.

2.4.2.1 Genetic Algorithm

Genetic algorithm (GA) is an intelligent searches algorithm that mimics the process of natural selection. As genetic algorithm search the solution domain randomly, it is more suitable to solve discrete problems such as partner selection problem. Other AI methods such as Particle swarm optimization and ant colony optimization are suitable for solving continuous solution problems (Zhang, et al., 2012). This is why GA is the most frequently used technique among artificial intelligence techniques to select the partners in virtual enterprise. There are eight papers which are using GA and its revised or integrated forms for partner selection problem.

Ip et al. proposed a model that aims to select the optimal combination of partners in order to minimize the risk of the project including the risk of failure and the risk of tardiness. Objective of the problem is a nonlinear, not convex, and not differentiable. So it cannot be solved by general mathematical programming methods. Therefore rule-based genetic algorithm is introduced to solve the problem (Ip, Huang, Yung, & Dingwei, 2003). The criteria considered in optimization process of this article are risk of failure and time, neglecting all qualitative criteria. Later, again a risk oriented model is proposed by Wang et al. They include 'benefit of task' in objective function. Benefit of each partner for each task represents its quality and service level. Moreover, unlike many other researches who study the partner selection for a single task, the main focus of this paper is on collaboration patterns between partners. For solving this optimization problem, collaboration cost, benefit, loss and risk functions are defined as the main criteria and GA is applied to solve the model (Wang, Xu, & Zhan, 2009).

GA may lead to prematurity and local convergence. Therefore, in an article Hybrid Genetic Algorithm (HGA) is proposed to solve the model which takes cost, time and risk into account. HGA is compared with standard GA and other revisions of GA. Finally regarding these comparisons, the efficiency of HGA is confirmed (Jian, Bo, Xiubo, & Cong, 2010).

Implementing an adaptive GA, with step size adaptation, to the same model showed the faster convergence compared to traditional GA (Simona & Raluca, 2011). These models are improved by adding further criteria. The method proposed by Tao et al. finds the best partner by minimizing two criteria; the total cost and risk, and maximizing other two parameters; quality and flexibility while the budget and deadline are constraints. The model is solved by an evolutionary genetic algorithm GA- Binary Heap and Transitive Reduction (RGA-BHTR). Different from the traditional GA, authors claim that GA-BHRT does not converge quickly to a local solution (Tao, Qiao, Zhang, & Nee, 2012). Like many other models, since there is no reliable method used to control weight parameters of objectives and constraints the results may not be accurate. For further improvements, a green partner selection model is developed by Zhang et al. by introducing two new green criteria, carbon emission and lead content. The objective of the model is to minimize cost, time and carbon emission while maximizing quality. Constraints in this model are cost, time, quality, reliability, carbon emission, lead content. A new Pareto genetic algorithm was designed in order to obtain the set of non-inferior solutions rather than a single optimum solution (Zhang, et al., 2012).

Beside the studies conducted on modelling the partner selection problem, some authors tried to improve the search methodologies. For instance a hybrid algorithm which integrates GA to ACO is developed by Zhong et al. and it is used to minimize a single objective which could be either cost, time, or risk. Authors claim that the GA-ACO integrated algorithm is superior to GA (Zhong, Jian, & Zijun, 2009). A fairly novel approach is proposed by Cheng et al. The Performance Parameters of the Manufacturing Tasks (PPMT) are introduced in order to model the problem. Prospective PPM is determined by the core company and completed PPMT is the response to the bidding invitations. The objective is to minimize the gap between these two PPMTs. Three factors of performance parameters are cost, time and quality. Quality score in this method is demonstrated as percentage. The weights of the performance parameters of the subtasks are determined by applying Analytical Hierarchy Process (AHP) or Analytical Network Process (ANP) and the model is solved by Adaptive GA (Cheng, Ye, & Yang, 2009).

2.4.2.2 Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a population-based stochastic search algorithm inspired by the social behavior of bird flocking or fish schooling. As stated in previous chapter Jian et al. have proposed a HGA model and claimed that HGA is superior to GA. This time, Gao et al. developed an algorithm based on discrete binary-PSO for the same criteria cost, time and failure risk and showed that PSO has faster converging speed than GA as well (Gao, Gui, Zhao, & Liu, 2006). An article by Mahapatra et al. also implement discrete version of PSO for partner selection problem and claim that discrete PSO is more effective because it avoids the particle velocity in standard PSO (Mahapatra, Nayak, Prasanna, & Beriha, 2011).

In another study by Zhao et al. a particle swarm optimization algorithm is adapted to solve the partner selection model with precedence and due date constraints. Authors claim that PSO is more effective compared to GA and B&B methods (Zhao, Zhang, & Xiao, 2008).

Xio et al. added two more evaluation criteria, trust and quality to the previous criteria list which were cost, time and risk. They transformed the multi objective problem by using weighted sum of objectives to a single objective problem. An adaptive quantum swarm evolutionary algorithm is applied to optimize this model (Xio, Liu, Huang, &

Cheng, 2014). The fact neglected in the previous studies was the uncertainty of information. To deal with this problem Huang et al. used fuzzy set, while the objective was to maximize the minimum agreement index of satisfaction degree with precedence, cost, due date constraints. The model is optimized by adaptive PSO (Huang, Gao, & Chen, 2011). Among the Artificial Intelligence methods, PSO is the second most frequently used optimization technique. There are 5 articles addressing PSO and its revised forms.

2.4.2.3 Ant Colony Optimization

Ant Colony Optimization is a probabilistic technique for finding the optimal path through graphs (Niu, Ong, & Nee, 2012). For optimizing the partner selection problem by ACO, all the offers for subtasks network are illustrated with a directed graph from source to drain. The objective function value is calculated by maximizing the cumulated AHP-values (Fischer, Jahn, & Teich, 2004). Unlike previous article, Niu et al. developed a model which takes both quantitative and qualitative attributes into account to evaluate the candidate partners. Quantitative objectives are cost, time and quality and qualitative objectives are risk and reputation. Fuzzy set theory is adapted for two proposes. First; obtaining the weights of criteria, second; representing the linguistic terms in numbers. An enhanced ACO is developed to obtain the solution (Niu, Ong, & Nee, 2012).

2.4.2.4 Tabu Search

Tabu search is a meta-heuristic search method for mathematical optimization by using a local or neighborhood search procedure. The article published by Ko et al. is the only research which constructed its selection methodology on Tabu search method. The authors developed four Tabu search based heuristic algorithms to get an optimal or near optimal solutions for cost minimization model (Ko, Kim, & Hwang, 2001). Yet this is not the only method which uses Tabu search. There are two papers published by Crispim et al. which integrates Tabu search with TOPSIS (Crispim & Sousa, 2010), (Crispim & Sousa, 2009). The author prefers to categorize them in the chapter of TOPSIS based methods because in these studies TOPSIS is the core evaluation method and Tabu search is used as an aiding tool to ensure the feasibility of the solution. These articles will be studied in detail in the related chapter.

2.4.2.5 Quantum-inspired Evolutionary Algorithm (QEA)

A novel evolutionary algorithm based on principles and concepts of quantum computing are introduced by Han et al. in 2002 (Han & Kim, 2002). Tao et al. proposed a quantum multi-agent evolutionary algorithm by combining agents and quantum-bit for cost minimization model of partner selection problem in virtual enterprise (Tao, Zhang, Zhang, & Nee, 2010).

Finally, it can be argued that, partner selection problem is not a straightforward optimization problem (Camarinha-Matos & Afsarmanesh, 2007). Optimization approaches force the decision makers to specify their preferences in terms of mathematical formulations while it is actually a process of making decisions among number of alternatives and based on some criteria, which can be subjective.

2.4.3 MCDM approaches

Partner selection problem of VE can be considered as a Multiple Criteria Decision Making (MCDM) problem since the decision maker aims to choose the best candidate enterprise considering the multiple-conflicting criteria. In order to come up with MCDM problems various decision supporting tools such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) and VIKOR have been developed. These techniques allow the decision maker to evaluate and outrank the alternatives based on decision indicators.

In the following chapters MCDM methods which were implemented in the literature of partner selection of VE are presented. Strength and limitations of each method will be highlighted and their integrations are briefly presented. On the other hand, the methods which we used to develop our models are described in more detail by explaining their steps.

2.4.3.1 Analytic Hierarchy Process

Exclusive characteristics of Analytic Hierarchy Process (AHP) made this method the most frequently used MCDM approach for both supplier selection in supply chain management and partner selection for virtual enterprise (Chai, Liu, & Ngai, 2013).

In a study conducted by Chu et al. AHP is employed for partner evaluation considering cost, time, quality, customer service and financial stability factors (Chu, Tso, Zhang, & Li, 2002). However, assigning trustworthy values for partners' score with respect to intangible criteria is not an easy task. Sari et al. proposed an AHP based partner selection method which uses Artificial Neural Network (ANN) to assess the overall past performance of each partner and implemented Program Evaluation Review Technique (PERT) to calculate the completion probability of each task. Beside past performance and completion probability, unit cost and caution cost are also considered as evaluation criteria. Caution cost is actually a measure for demonstrating level of the commitment (Sari, Sen, & Kilic, 2007) . Yet assigning the exact numeric scores for expressing the preferences among criteria is another challenge for decision maker. One of the main contributions to solve partner selection problem is done by introducing fuzzy analytical approach by Mikhailov. He used fuzzy intervals in order to assess uncertain weights of selection criteria in the framework of AHP (Mikhailov, 2002). Later, Wang et al. developed a technique which could reduce the number of pairwise comparisons of Mikhailov's Fuzzy-AHP method (Wang & Chen, 2007).

In some papers, AHP is used as a tool to derive the weights of each criteria, when the models objective function is using additive sum of objectives.

2.4.3.2 Analytic Network Process

The Analytic Network Process (ANP), a more advanced form of AHP, introduced by Saaty in 1996 (Saaty T. , 1996) . Both approaches use pairwise comparisons to derive weights and to rank the alternatives. However, in AHP, each factor of the hierarchy structure is considered to be independent of all others; ANP allows interconnections between these factors. Furthermore, ANP overcomes the issue of rank reversal which is well-known limitation of AHP. A powerful partner selection platform for constructing a virtual enterprise should consider both tangible and intangible measures along with complex incorporation relationships among those factors. Since ANP is a methodology to respond these requirements, Sarkis et al. suggested ANP for solving partner selection problem of VE (Sarkis, Talluri, & Gunasekaran, 2007). However it should be stated that, same problem can be solved by each of ANP or AHP methods, but in ANP number of required pairwise comparisons are much more than AHP and this cause an excessive complexity.

2.4.3.3 TOPSIS

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a MCDM technique developed by Hwang and Yoon in 1981. TOPSIS is the second most popular MCDM method to solve the partner selection problem in VE.

Deviation degree based and risk factor based TOPSIS are two extended TOPSIS models for group decision making proposed by Ye. Cost, time, trust, risk and quality are selected as evaluation criteria (Ye & Li, 2009) . A year later, in 2010, regarding the fact that the information about the criteria for each candidate may be incomplete or uncertain and expressing the judgments with exact crisp numbers may not be accurate; he developed a fuzzy-TOPSIS model (Ye, 2010).

TOPSIS is capable of just dealing with numbers, not linguistic definitions. Therefore if one would like to apply TOPSIS for qualitative criteria should implement a tool to quantify the subjective terminations.

Crispim et al. proposes a fuzzy TOPSIS approach improved by Tabu search meta-heuristics. Fuzzy approach makes possible to consider qualitative criteria, quality and trust beside cost and delivery time. Tabu search is used just to find the conflicts between activities while assigning to alternatives and ensures that the solution is feasible (Crispim & Sousa, 2010).

The other algorithm proposed by Crispim et al. is capable of dealing with 20 criteria. The method is fuzzy TOPSIS base, integrated with Cluster analysis, Case Based Reasoning (CBR) and multi objective Tabu search. Cluster analysis, well-known data mining technique, is applied to restrict the search according to decision maker preferences. Case-based reasoning is a learning technique implemented to construct partner configurations by reusing knowledge from the past. Multi objective Tabu search is designed to find the good approximation of Pareto front and a fuzzy TOPSIS is implemented to rank the alternative VE configurations (Crispim & Sousa, 2009). TOPSIS still requires the specification of weights of objectives. Thus, a method like AHP is still required in order to determine proper objective weights. Furthermore, like AHP, TOPSIS in its standard form is deterministic and does not consider uncertainty in weights. Therefore in order to eliminate this shortcoming of TOPSIS method authors integrate TOPSIS with fuzzy set theory.

2.4.3.4 Fuzzy Inference Systems

Fuzzy Inference System (FIS) is published by Lotfi A. Zadeh in 1965 in extension to fuzzy sets (Zadeh, 1965). FIS itself is admitted as an effective MCDM method by Vakesquez et al. (Vakesquez & Hester, 2013).

Fuzzy Inference system is a popular reasoning framework based on the concepts of fuzzy set theory, fuzzy logic and fuzzy IF-THEN rules. Fuzzy Inference systems make decisions based on inputs in the form of linguistic variables derived from membership functions. These variables are then matched with the preconditions of linguistic IF-THEN rules called fuzzy logic rules, and the response of each rule is obtained through fuzzy implication as a crisp value.

Mun et al. proposed a trust based partner selection approach. Trust is considered as output of the model while inputs are quality and due date. By adapting fuzzy Inference reasoning the output of the model is derived from set of fuzzy if-then rules which are based on logical facts (Mun, Shin, Lee, & Jung, 2009). Below there is a sample fuzzy rule:

IF 'due date violation is average' AND 'number of defects are average' THEN 'Trust is high'

The model's reliability depends on stablishing reasonable fuzzy rules. Then in order to get reasonable results from developed model rules should be established correctly and precisely. Otherwise, untrustworthy rules lead to unreliable outcomes.

2.4.4 Other Approaches

There exist several studied in literature which apply neither optimization nor MCDM technique. These articles would be presented in this chapter.

2.4.4.1 Agent-based Approaches

One of the earliest studies in the field of partner selection applied agent based concept to enable the information flow infrastructure. In this study five types of agents are implemented in virtual enterprise network (Lau & Wong, 2001). Another agent-based approach for partner selection problem in VE formation, combines constraint solving and quality modelling techniques (Norman, et al., 2004). A paper by Kim et al. investigates on configuration process of VE and a simulation-based configuration is presented. This research does not focuses on finding the optimal or near-optimal partners (Kim, Son, Kim, & Kim, 2008). In a research by Choi et al. a multi agent task assignment system is proposed. It addresses the selection of partners and assigning tasks to them (Choi, Kim, & Doh, 2007). In these articles price, time and quality have been taken into account neglecting all other criteria such as past performance, communication openness and so on. Conversely, a two stage partner selection framework proposed by Huang et al. divides the evaluation criteria into two groups; hard and soft factors. Hard factors are studied in the first stage, finding the partners which can complete a certain task on time with high quality and low price. Soft factors are considered in second stage, evaluating the cooperation potentiality of partners (Huang, Wong, & Wang, 2004).

2.4.4.2 Search Algorithms

Two of reviewed papers have developed new decision making algorithms toward solving VE partner selection problem. First, paper written by Feng and Yamashiro a comprehensive cost function containing both direct and indirect costs is developed. Here authors interpret indirect costs as processing and transportation cost. Also in order to include time criterion in cost function authors transformed time factor to a cost type factor by applying earliness and tardiness penalties. An optimal process with minimum comprehensive cost is found by applying step by step pragmatic approach. First step of the algorithm eliminates the partners regarding the qualitative inadequacies. Next, the cost of eligible corporation sets are calculated and the set with the minimum cost is selected (Feng & Yamashiro, 2006).

Second paper of this category developed by Chen et al. and here authors present a two stage qualitative search algorithm. The first stage searches for alternative schemes of VE enterprises based on the manufacturing requirements. In the second stage these schemes are expressed mathematically. Using this model three search algorithms are developed and enterprises are ranked (Chen, Chen, & Lee, 2007).

2.4.4.3 Data Mining Based Techniques

Only one paper considered data mining method for partner selection problem of VE. Data mining is a computational process of extracting information and patterns from a data set and interpreting them into a regulated structure.

Neural On-line Analytical Processing System is introduced in this paper. Online Analytical Processing System (OLAP) is a data mining tool which aims to convert the clusters of complex data into useful information. In next step these data is used as input layer nodes in training process of Neural Network. Although the model provides a feasible prediction for the problem, it requires massive amount of data to train the network and develop a reliable module (Lau, Chin, Pun, & Ning, 2000).

The summary of all 46 reviewed papers are tabulated in Table 2.2 based on the solution methodology they adopt.

Table 2.2.Summary of partner selection methods in literature

Index	Core Technique	Method	Precedence*	Literature
	Optimization Approaches			
Op1	Integer Programming	IP, Graph Theory	✓	(Wu, Mao, & Qian, 1999)
Op2	Integer Programming	IP, Graph Theory	✓	(Wu & Su, 2004)
Op3	Integer Programming	IP, B&B	✓	(Ip, Yung, & Wang, 2004)
Op4	Integer Programming	IP, Lagrangian relaxation	-	(Hsieh & Lin, 2012)
Op5	Integer Programming	B&B	✓	(Zeng, Li, & Zhu, 2006)
Op6	Integer Programming	IP,MAUT, AHP	✓	(Sha & Che, 2004)
Op7	Mixed Integer Programming	B&B	✓	(Jarimo & Salo, 2009)
Op8	Genetic Algorithm	Fuzzy R-GA	✓	(Ip, Yung, & Wang, 2004)
Op9	Genetic Algorithm	GA	✓	(Wang, Xu, & Zhan, 2009)
Op10	Genetic Algorithm	HGA	✓	(Jian, Bo, Xiubo, & Cong, 2010)
Op11	Genetic Algorithm	Adaptive GA	✓	(Simona & Raluca, 2011)
Op12	Genetic Algorithm	GA-BHRT	✓	(Tao, Qiao, Zhang, & Nee, 2012)
Op13	Genetic Algorithm	Pareto GA	✓	(Zhang, et al., 2012)
Op14	Genetic Algorithm	GA-ACO	✓	(Zhong, Jian, & Zijun, 2009)
Op15	Genetic Algorithm	Adaptive GA, AHP/ANP	-	(Cheng, Ye, & Yang, 2009)
Op16	PSO	Discrete binary PSO	✓	(Gao, Gui, Zhao, & Liu, 2006)
Op17	PSO	Discrete PSO	✓	(Mahapatra, Nayak, Prasanna, & Beriha, 2011)
Op18	PSO	PSO	✓	(Zhao, Zhang, & Xiao, 2008)
Op19	PSO	Adaptive quantum,PSO	✓	(Xio, Liu, Huang, & Cheng, 2014)
Op20	PSO	Adaptive fuzzy PSO	✓	(Huang, Gao, & Chen, 2011)

Table 2.2 Continued

Op21	ACO	ACO, AHP	✓	(Fischer, Jahn, & Teich, 2004)
Op22	ACO	Fuzzy Enhanced ACO	✓	(Niu, Ong, & Nee, 2012)
Op23	TABU	TABU	✓	(Ko, Kim, & Hwang, 2001)
Op24	QEA	Multi agent QEA	✓	(Tao, Zhang, Zhang, & Nee, 2010)
	MCDM Approaches			
MC1	AHP	AHP	-	(Chu, Tso, Zhang, & Li, 2002)
MC2	AHP	AHP, ANN	-	(Sari, Sen, & Kilic, 2007)
MC3	AHP	Fuzzy AHP	-	(Mikhailov, 2002)
MC4	AHP	Fuzzy AHP	-	(Wang & Chen, 2007)
MC5	ANP	ANP	-	(Sarkis, Talluri, & Gunasekaran, 2007)
MC6	TOPSIS	Interval valued TOPSIS		(Ye & Li, 2009)
MC7	TOPSIS	Fuzzy TOPSIS	-	(Ye, 2010)
MC8	TOPSIS	Fuzzy TOPSIS Tabu	-	(Crispim & Sousa, 2010)
MC9	TOPSIS	Fuzzy TOPSIS Tabu, CBR, CA		(Crispim & Sousa, 2009)
MC10	Fuzzy Inference System	FIS	-	(Mun, Shin, Lee, & Jung, 2009)
	Other Approaches			
Ot1	Agent-Based		-	(Lau & Wong, 2001)
Ot2	Agent-Based		-	(Norman, et al., 2004)
Ot3	Agent-Based		-	(Kim, Son, Kim, & Kim, 2008)
Ot4	Agent-Based		-	(Choi, Kim, & Doh, 2007)
Ot5	Agent-Based		-	(Huang, Wong, & Wang, 2004)
Ot6	Search Algorithms		-	(Feng & Yamashiro, 2006).
Ot7	Search Algorithms		-	(Chen, Chen, & Lee, 2007).
Ot8	Data mining technique			(Lau, Chin, Pun, & Ning, 2000)

2.5 Observations and Analysis of Literature Review

From the extensive review of the published papers in the field of partner selection in virtual enterprise, addressed in previous chapter, some worthwhile findings can be extracted. These observations are highlighted in the following subsections.

2.5.1 Most Popular Solution Methodologies

Regarding the total of 46 reviewed articles, researchers mostly treat partner evaluation and selection as an optimization problem rather than a Multi-Criteria Decision Making problem. To solve optimization problems AI techniques are preferred rather than the exact method. GA is the most frequently used AI techniques to solve partner selection problem. However, author claims that this is not necessarily proves GA is the best solution methodology. This is not necessarily denoting the superior performance of GA. This could be due to the fact that, steps of GA are flexible and this helps researchers to purpose the variety of adaptive forms of GA.

The other remarkable point is that there are plenty of articles adapting fuzzy approach. Unlike the era of mass production, in recent years manufacturing is more conducted on basis of customer satisfaction. Assessing service-like criteria are always contain some degrees of uncertainty. Fuzzy set theory seems to be an effective tool to deal with the vagueness of data. There are ten articles proposing the integrated forms of fuzzy set with decision making approaches which is shown in Table 2.3. Also, Figure 2.2 demonstrates the distribution of hybrid approaches of fuzzy with three most popular methods in solving VE partner selection problem.

Among these methods fuzzy-AHP method proposed by Mikhailov has attracted the significant attention of researchers being cited over 281 times so far. The most frequently cited articles and their proposed methods are shown in Table 2.4. Google scholar is chosen as a reference to collect the number of citations. Interestingly, the second most popular article is a paper by Wang et al. which propose an enhanced form of Mikhailov’s FAHP method by reducing the number of pairwise comparisons.

Table 2.3. Fuzzy integrated approaches

Method	Literature
Fuzzy ACO	(Niu, Ong, & Nee, 2012)
Fuzzy TOPSIS	(Ye & Li, 2009)
Fuzzy TOPSIS	(Ye, 2010)
Fuzzy TOPSIS	(Crispim & Sousa, 2009)
Fuzzy TOPSIS TABU	(Crispim & Sousa, 2010)
Fuzzy R-GA	(Ip, Yung, & Wang, 2004)
Fuzzy AHP	(Mikhailov, 2002)
Fuzzy AHP	(Wang & Chen, 2007)
Fuzzy PSO	(Huang, Gao, & Chen, 2011)
Fuzzy Inference System	(Mun, Shin, Lee, & Jung, 2009)

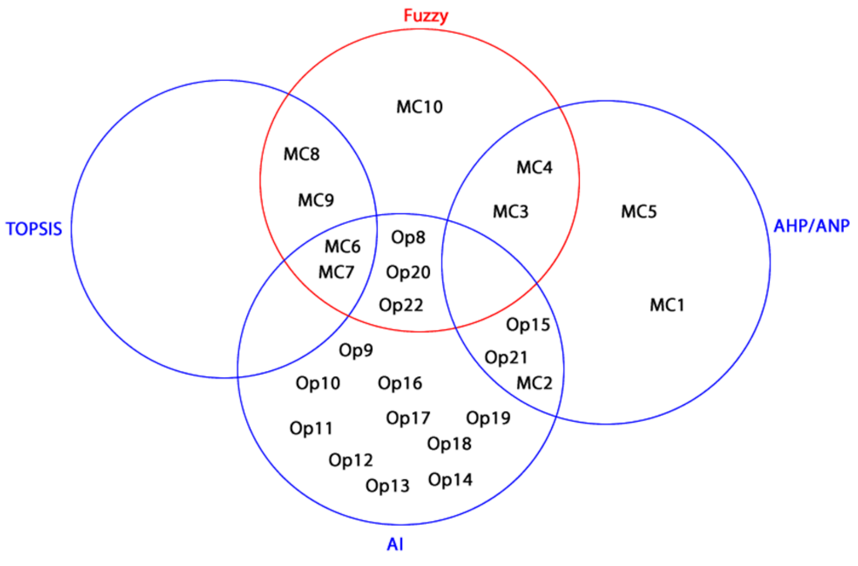


Figure 2.2. Integration of fuzzy set theory with most popular approaches.

Table 2.4. Most popular articles based on citation number

Rank	Literature	Method	Total no. of citations	No. of citations per year
1	(Mikhailov, 2002)	Fuzzy AHP	281	23.4
2	(Wang & Chen, 2007)	Fuzzy AHP	156	22.3
3	(Ip, Huang, Yung, & Dingwei, 2003)	Fuzzy R-GA	230	21
4	(Norman, et al., 2004)	Agent based	205	20.5
5	(Ye, 2010)	Fuzzy TOPSIS	79	19.7
6	(Wu & Su, 2004)	IP, graph theory	149	16.5
7	(Ye & Li, 2009)	Fuzzy TOPSIS	78	15.6
8	(Fischer, Jahn, & Teich, 2004)	ACO AHP	128	12.8
9	(Camarinha-Matos & Afsarmanesh, 2007)	-	83	11.8
10	(Sarkis, Talluri, & Gunasekaran, 2007)	ANP	81	11.5

In order to find the pattern of developments in the field of partner selection in VE a retrospective look is taken to its publication since its inception in 1997. Figure 2.3 is demonstrating the chronological distribution of articles in literature.

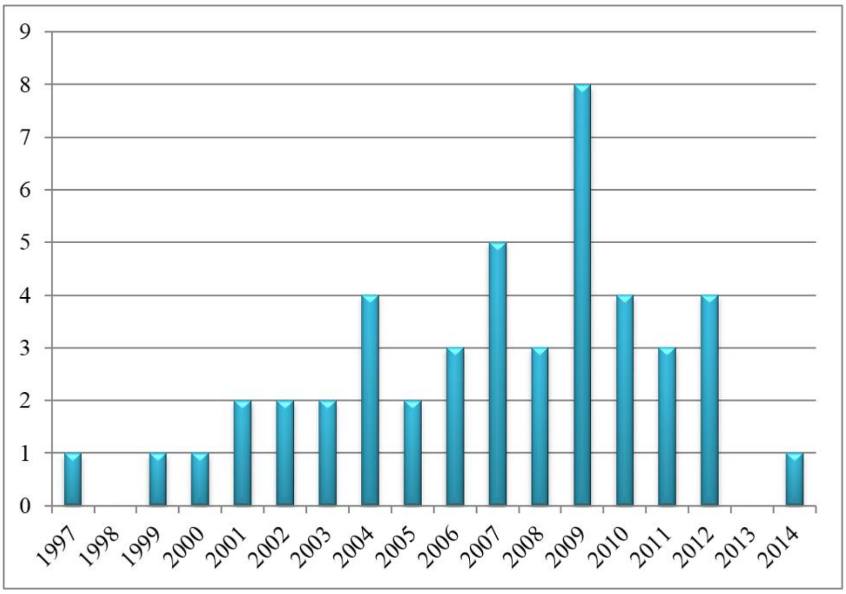


Figure 2.3. Chronological distribution of articles

2.5.2 Most popular Evaluation criteria

It has been discussed that the selection of right partners is a crucial step in success of virtual enterprise and since partners are evaluated with respect to criteria, choosing appropriate set of criteria is important as well. One of the studies which aids the decision maker to find appropriate set of evaluation criteria is proposed by Baldo et al. The developed framework is a knowledge base model which uses Performance Indicators (PIs) to bias the criteria (Baldo, Rabelo, & Vallejos, 2009). From our analysis of the literature we found that although there are tens of different criteria adapted by researchers, cost (and cost related factors) is the most popular criterion which is addressed in 38 articles out of 46. Second and third important criteria are time and quality.

Table 2.5. Most important criteria of partner selection articles

Literature	**Cost**	**Time**	**Quality**	**Risk of failure**	**Service**	**Trust/ reliability**	**Financial Stability**	**Completion probability**	**Flexibility**	**Past performance/**	**Carbon Emission**	**Caution Cost**	**Collaboration**
(Wu, Mao, & Qian, 1999)	✓												
(Wu & Su, 2004)	✓	✓											
(Ip, Yung, & Wang, 2004)	✓	✓											
(Hsieh & Lin, 2012)	✓												
(Zeng, Li, & Zhu, 2006)	✓												
(Sha & Che, 2004)	✓	✓	✓		✓								
(Jarimo & Salo, 2009)	✓			✓						✓			
(Ip, Yung, & Wang, 2004)		✓		✓									
(Wang, Xu, & Zhan, 2009)	✓		✓	✓	✓								
(Jian, Bo, Xiubo, & Cong, 2010)	✓	✓		✓									
(Simona & Raluca, 2011)	✓	✓		✓									
(Tao, Qiao, Zhang, & Nee, 2012)	✓		✓	✓					✓				
(Zhang, et al., 2012)	✓	✓	✓			✓					✓		
(Zhong, Jian, & Zijun, 2009) *****	✓	✓		✓									
(Cheng, Ye, & Yang, 2009)	✓	✓	✓										
(Gao, Gui, Zhao, & Liu, 2006)	✓	✓		✓									
(Mahapatra, Nayak, Prasanna, & Beriha, 2011)	✓	✓		✓									
(Zhao, Zhang, & Xiao, 2008)	✓	✓											
(Xio, Liu, Huang, & Cheng, 2014)	✓	✓	✓	✓		✓							
(Huang, Gao, & Chen, 2011)	✓	✓											
(Fischer, Jahn, & Teich, 2004)	✓	✓						✓					
(Niu, Ong, & Nee, 2012)	✓	✓	✓										
(Ko, Kim, & Hwang, 2001)	✓												
(Tao, Zhang, Zhang, & Nee, 2010)	✓												
(Chu, Tso, Zhang, & Li, 2002)	✓	✓	✓		✓		✓						
(Sari, Sen, & Kilic, 2007)	✓							✓		✓		✓	
(Mikhailov, 2002)	✓		✓		✓		✓						
(Wang & Chen, 2007)	✓		✓		✓		✓						
(Ye & Li, 2009)	✓	✓	✓	✓		✓							
(Ye, 2010)	✓	✓	✓	✓		✓							
(Crispim & Sousa, 2010)	✓		✓						✓				
(Mun, Shin, Lee, & Jung, 2009)													
(Lau, Chin, Pun, & Ning, 2000)													
(Norman, et al., 2004)	✓	✓	✓										
(Kim, Son, Kim, & Kim, 2008)	✓	✓	✓										
(Choi, Kim, & Doh, 2007)	✓	✓	✓										
(Huang, Wong, & Wang, 2004)	✓	✓	✓										✓
(Feng & Yamashiro, 2006)	✓	✓											
Total	35	24	17	12	5	4	3	2	2	2	1	1	1

2.5.3 Conclusions of literature review

Most important findings derived from carefully reviewing the published articles in partner selection domain is summarized as follows:

- Optimization approaches are the only methods which can take subtask's sequence into account. None of MCDM, agent based methods or any other is capable of dealing with precedence of subtasks.
- In order to solve optimization problems, AI techniques are more frequently used in comparison to exact methods and among all the AI techniques GA is the most frequently used technique regarding the number of published articles.
- Not only, AHP is found to be the most popular MCDM technique, but also it can be used as a tool to determine the weights that reflects the relative importance of evaluation criteria.
- Fuzzy-AHP and fuzzy-TOPSIS are two most widely accepted MCDM methods.

Although there are quite extensive literature addressing various aspects of partner selection techniques in VE, each method is quite inadequate in some respects. Limitations of each approach are specified exclusively in the previous chapter. To sum up, the drawbacks of main approaches are listed below;

- Most of the methods applying AHP have complex hierarchy structure which requires numerous pairwise comparisons. Providing trustworthy answers to these comparisons is a tedious task for decision maker. If the comparisons are not accurate the results would not be consistent. So a lot of questions in questionnaire may lead to decrease in reliability of the method.
- Majority of studies considered just quantitative evaluation criteria, neglecting the qualitative factors. For instance in most of the optimization based approaches cost is the only criterion which is taken into account. Ignorance of essential evaluation parameters surely will diminish the truthfulness of the method.

All these limitation dragged the author's attention to focus on finding the solution methodology which most suits the flexibility of OMAVE system's partner selection.

CHAPTER 3

MODELING OF PARTNER SELECTION METHODOLOGIES

Each time, VE is formed to accomplish a project it might be dealing with different necessities. Each project has its own customer, partner companies, production processes and etc. A reliable VE should be able to adapt itself to changes and this is why ‘flexibility’ is the main issue in constructing a VE platform. An inflexible structure may work in some specific cases but it cannot maintain its applicability for all types of projects. Accordingly, formation phase of VE must be flexible too. It means different customer attitudes, project requirements and enterprise capabilities needs to be considered in evaluation and selection process of partners. Therefore, all of these are required to be considered in modeling the partner selection problem.

3.1 OMAVE Framework

Recently an Ontology based Multi Agent Virtual Enterprise (OMAVE) system is proposed by Lotfi Sadigh (Lotfi Sadigh, 2015). In contrast to traditional VE, OMAVE conducted on the basis of Ontology model. Semantic rules are defined to be applied in reasoning process for deducing a list of candidate enterprises. The other characteristic of OMAVE system is its Multi Agent System (MAS) based structure. Once the potential partners are identified the results are sent to system administrator to activate the negotiation procedure by deploying agents. Project manager agent, task manager agent, enterprise agent and customer agent are incorporated in multi agent negotiation structure each one is responsible for certain tasks. In this respect, project manager agent is responsible for getting the information regarding the features of main project and its subprojects. All the required steps from preparing the list of qualified companies and starting the negotiation followed by evaluating the bidding proposals of volunteer enterprises are conducted under supervision of task manager agent.

Customer agent extracts the weights of customer preferences to be used in evaluating enterprises. For volunteered enterprises, enterprise agent collects the bidding information from company authorities to propose for bid. Figure 3.1 demonstrates the agents working structure in OMAVE system (Lotfi Sadigh, 2015).

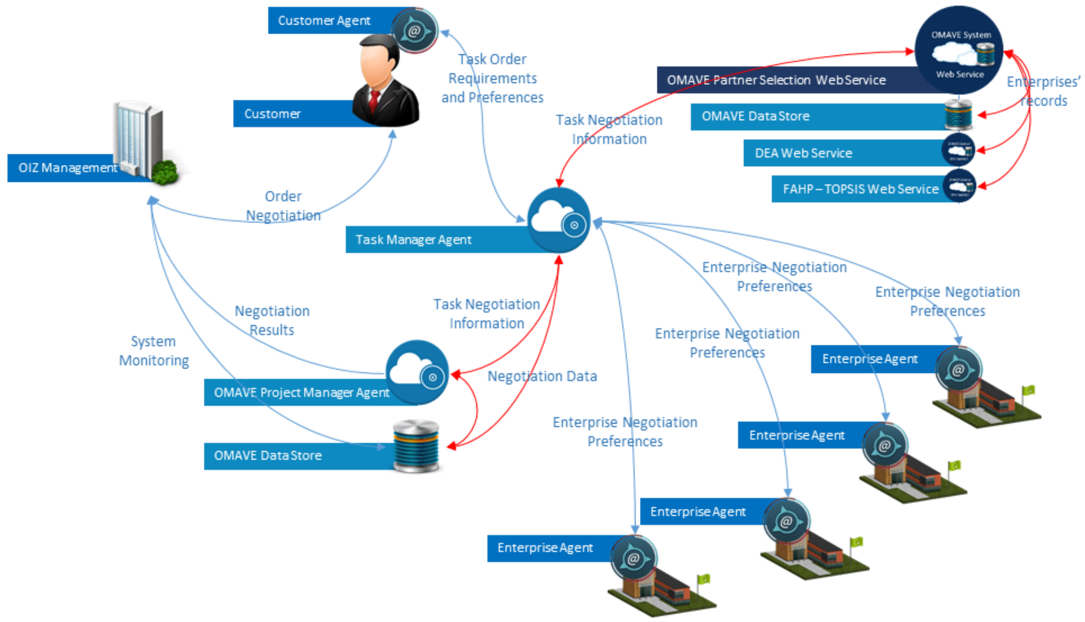


Figure 3.1. OMAVE Multi-Agent system Architecture

Employing agents helps the VE structure to collects data more systematically, however establishing a reliable partner evaluation structure is still a challenge.

3.2 Problem description

A flexible partner selection model should meet the aspects listed below simultaneously;

- Model should be capable of handling both quantitative and qualitative factors.
- Evaluation criteria set should be constructed properly. Including too many criteria increase the problems complexity unnecessarily, while neglecting even an important criterion would result in misleading outcomes.

- Partner selection should be based on each customer's preferences since each customer has its own particular priorities.
- The information is generally incomplete or vague. Uncertainty of data should not be neglected in modeling the problem.

The aim of this thesis work is to develop a trustworthy partner selection algorithm considering all of the above mentioned aspects.

In order to model the problem, let's assume that VE has a project aimed to be accomplished. This project is composed of q $(q = 1, 2, \ldots)$ subprojects. Subprojects are distinguished with each other based on the sector which they address. Each subproject is composed of tasks and each task itself is a group of manufacturing operations. Figure 3.2 shows this multi-level structure schematically.

Figure 3.2. Main project's multi-level decomposition

Deciding on the level which project would be broken down into activities needs great care. Referring to the book written by Mol, author obtained a pattern displayed in Figure 3.3 claiming that there is a negative curvilinear relation between overall performance and number of outsourced activities (Mol, 2007).

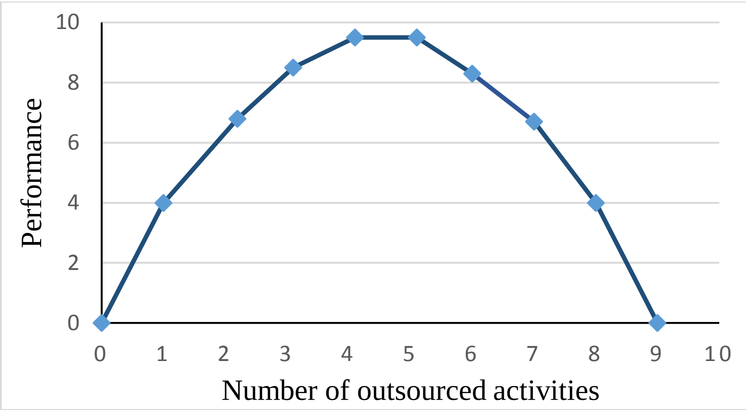


Figure 3.3. Simplified example on effects of number outsourced activities on firm's performance (Mol, 2007).

Gathering companies to fulfill a certain part of the main project (activities) is advantageous since each individual can focus on its core competencies resulting in increasing overall efficiency. Though, involving excessive number of partners would cause incongruity problems.

In this study, the author investigated the solution methodologies for evaluating the n $(n = 1, 2, \ldots)$ alternative enterprises based on m $(m = 1, 2, \ldots)$ evaluation criteria and allocate the q $(q = 1, 2, \ldots)$ subprojects to the suitable partners.

It should be noted that, methods can be applied in upper levels of work breakdown too (for example project tasks).

- Main projects properties' are asked from a customer and based on the obtained information a specialist arranges the subproject's time table and budget.
- Sequence of subprojects and manufacturing process plan of tasks are known.
- Enterprises are allowed to bid for participating in more than one sub-project if they trust their capabilities.
- This study focuses on finding the best partner for each subproject independently without considering its relation with other tasks. And since the method is generic it can be applied to all the subprojects of the main project.

- Costs of transportation and the required time for shipping are counted in bidding proposals received from enterprises. Though, in a VE projects with long distance cooperation, transportation can be investigated as a single subproject and opened for negotiation.

3.3 Evaluation Criteria

The first and foremost important problem in modeling the partner selection is choosing appropriate set of evaluation criteria. Because candidates' assessment would be based on evaluation parameters and neglecting even a single role playing criterion ends up with biased results.

As mentioned earlier, VE has some characteristics that makes this stage much harder in comparison to other concepts such as supply chain (Baldo, Rabelo, & Vallejos, 2009). VE's flexibility allows different types of customers and partners (with different attitude and culture) to participate. Also different regulations, standards and preferences may be adapted. Therefore a comprehensive set of evaluation criteria set needed to be taken into account. Conversely considering excessive number of criteria overgrows size of the problem and makes it difficult handle. The other important issue is selecting appropriate set of conflicting criteria to enhance the model's robustness and reliability.

Among tens of evaluation parameters, highlighted in the literature, following criteria were chosen. Each of those are involved in particular level of decision making procedure.

1) Company's efficiency
2) Bidding Price proposal
3) Bidding Delivery time proposal
4) Company's performance in terms of product quality
5) Company's performance in terms of delivering product on time
6) Company's after sale service
7) Company's background in terms of communications skills and responsiveness
8) Environmental friendliness

The list is believed to be adequately comprehensive and sensible due to following reasons;

- Evaluation of enterprises based on their efficiency may give chance to small companies to compete with big manufacturing firms if they work effectively. For instance, a small firm may suffer from lack of resources in a broad domain, however it might be a competitive candidate in a specific field. VE should help all of its skilled members to attest their potentials while benefiting from their achievements.
- Bidding price and delivery time are two factors which represent the candidate's strategy in negotiation. Yet, we do not want to risk the consortium by relying on an enterprise with poor background. To fill this gap, past performance factor is embedded in the hierarchy. It shows the level of commitment of enterprise regarding the works it participated. More the enterprise's past performance score, more it can be trusted.
- In today's marketing environment customer satisfaction is one of the most role playing elements. Service oriented aspects such as Guaranty, Warranty and communication skills directly influence the customer's consent. Actually, nowadays there are lots of people willing to pay more money to get higher levels of service. Similarly, environmentally conscious customers would not ignore the ecological aspects.

While the first factor, company's efficiency, is investigated through Data Envelopment Analysis (DEA) technique, the rest are organized into a hierarchical structure shown in Figure 3.4. This hierarchy will be used later when determining the customer's priorities.

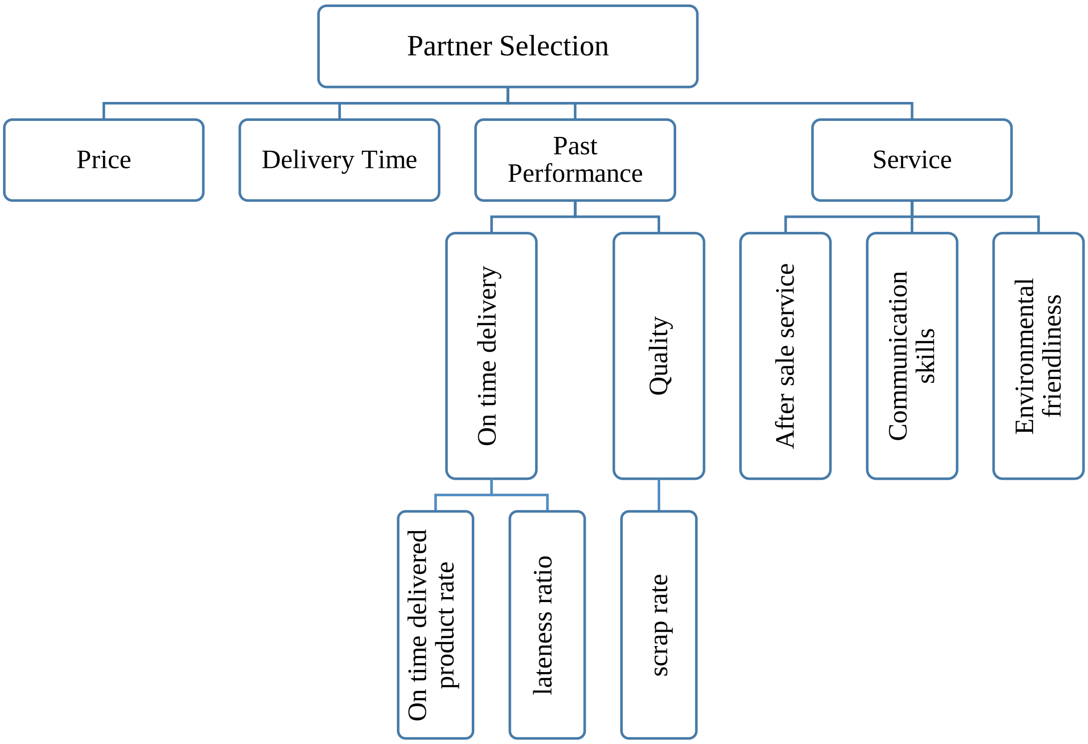


Figure 3.4. Evaluation criteria hierarchy

Regarding Figure 3.4, there are four main parameters which specifies enterprise score, bidding price, proposed delivery time, past performance and service level. First two factors are received from enterprises during negotiation and the last two are called from system's data base regarding their previous works in the past.

In classical VE framework enterprises propose bidding price manually, however in OMAVE system final bidding price is obtained as a result of negotiation among enterprise agents regarding certain formulas. Price proposed by enterprise agent is influenced by several parameters tabulated in Table 3.1.
According to an article by Lotfi, Arikan et al. final bid of an enterprise is calculated regarding Eq. 3. 1 (Lotfi Sadigh, Arikan, Ozbayoglu, Unver, & Kilic, 2014).

Table 3.1. Notations used in Enterprise agent's pricing formulation

Notation	Description
a_i	Next iteration price of enterprise
b_{i-1}	Best price in last iteration
Epp	Past performance of enterprise
Cp	Severity of the negotiation process to enterprise
D_r	Constant equal to a constant percentage of best price
a_{min}	Minimum price of the enterprise in the negotiation process
α	Enterprise strategy

$$a_i = b_{i-1}.\left\{\frac{1 - Epp.Cp}{2}\right\} + \left\{\left\{\frac{1 - D_r}{2}(a_{min} - b_{i-1})\right\}\{0.004\alpha^3 - 0.06\alpha^2 + 0.3\alpha\} + \frac{a_{min} + b_{i-1}}{2}\right\}.\left\{\frac{1 + Epp.Cp}{2}\right\} \quad \text{Eq. 3.1}$$

Each agent's strategy is influenced by the enterprise strategy to win the negotiation in any price or maximize its profit. This parameter is represented by α and β factors which that α+ β=10. Figure 3.5 demonstrates the company's strategy for proposing price schematically.

Figure 3.5. Company's strategy scheme for price

Information regarding enterprises delivery dues are received from enterprises manually. But, calculating the past performance and service scores of enterprises are not straight forward. Because the enterprise assessment should consider how the enterprises worked in previous projects and whether they fulfilled what they promised. Past performance of candidates are studied in two aspects, quality and on time delivery each formulated by Eq. 3.2 and Eq. 3.3 respectively.

$$Quality\ score = \frac{number\ of\ accepted\ parts}{total\ number\ of\ parts\ ordered} \quad \text{Eq. 3.2}$$

$$On\ time\ delivery\ \ score = 1 - r_i\ e^{l_i} \quad \text{Eq. 3.3}$$

Where;

$$r_i = \frac{number\ of\ late\ delivered\ parts}{total\ number\ of\ parts\ ordered} \quad \text{Eq. 3.4}$$

$$l_i = \frac{delay\ duration}{total\ delivery\ time} \quad \text{Eq. 3.5}$$

Term $r_i\ e^{l_i}$ in Eq. 3.3 formulates the penalty function of late delivery with an exponential function. As shown in Figure 3.6. The penalty increases exponentially by increasing the delay duration.

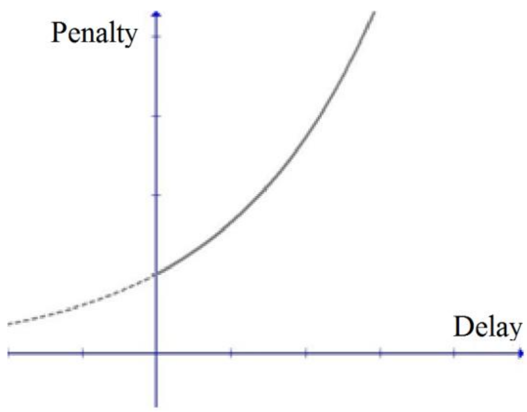


Figure 3.6. Penalty- delivery delay diagram

Service score of enterprises are simply average of three sub-criteria, after sale service, communication skills and environmental friendliness. The information regarding each of these factors are extracted from analyzing customer's feedback after receiving the order.

Figure 3.7 shows where the evaluation parameters are incorporated in the model and how the agents interact within OMAVE framework.

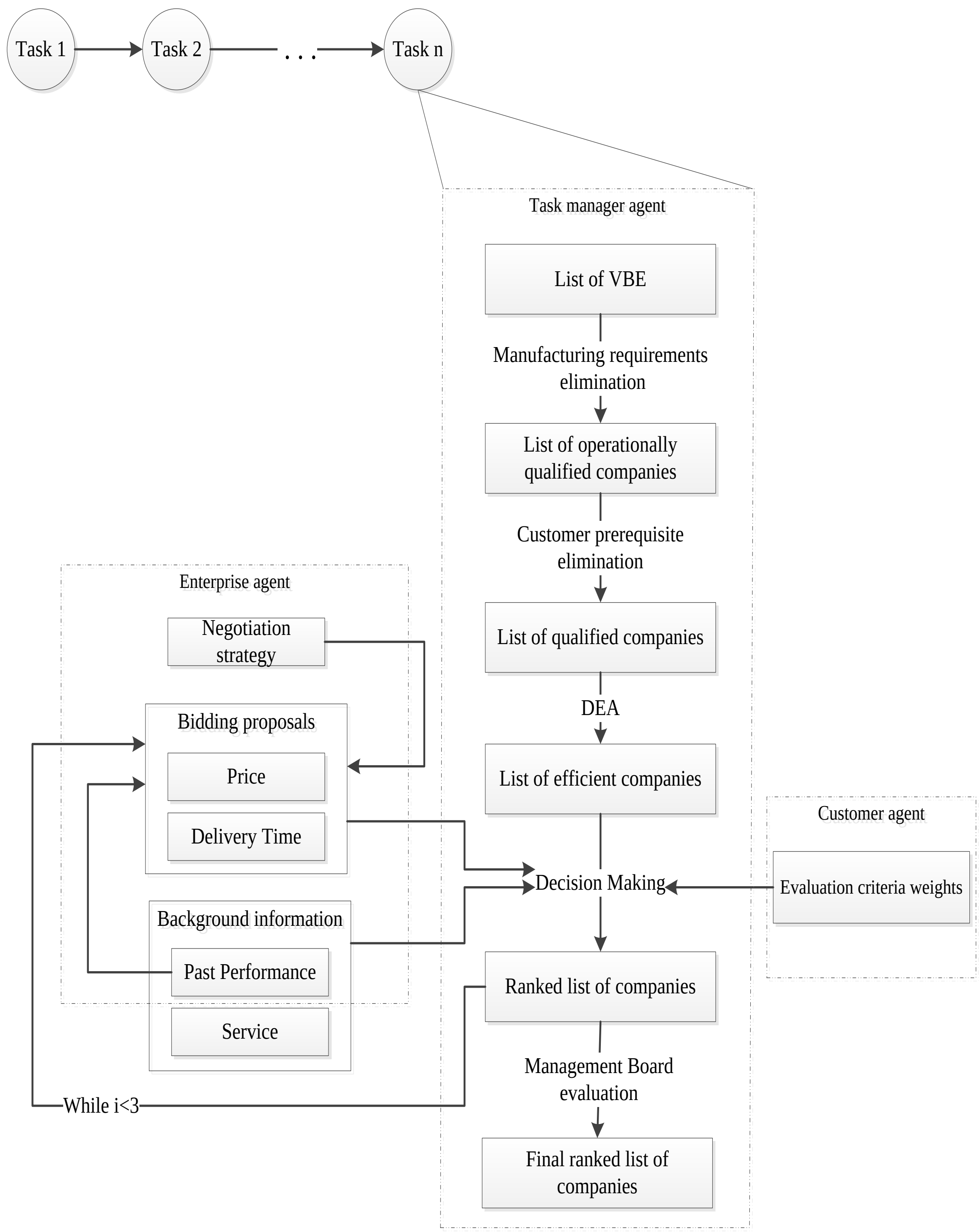


Figure 3.7. Agents' interactions in OMAVE system

3.4 Technical Elimination

When the project's working scheme is well stablished and it is decomposed into subprojects, VE would search for potential partners capable of operating the manufacturing requirements of the subprojects. After analyzing the VBE members, technically unqualified enterprises would be eliminated from the enterprises pool. In more detailed elimination phases, companies may be checked if they own specific machinery or human skills.

Furthermore, companies should be inspected with respect to customer's prerequisites. For instance, if a customer strictly obligates having ISO 9001 standard, organizations without this certificate would directly filtered out from the enterprise pool.

Applying these steps results in obtaining a list of qualified enterprises (as shown in Figure 3.7.) Though, the purpose of partner selection is not only to find the operationally capable companies but also it tries to find the best alternative among candidates. From the next chapter on, enterprise evaluation and decision making methodologies are going to be proposed to pick the best possible case for taking role in VE consortium.

3.5 Data Envelopment Analysis (DEA)

By studying the literature, it is found that even the most effective partner selection models collapse when the number of participant companies outgrow. To overcome this issue, a technique is embedded in the model to filter out the weak enterprises before entering the main decision making step. This technique should be able to compare the candidates and detect the less efficient ones. Since this stage would be placed prior to negotiation step, it should be independent of preference weights. In this respect, DEA seems to be a suitable method for satisfying all of these aspects.

DEA is a mathematical programming method first proposed by Charnes and Cooper to calculate the relative efficiency of a Decision-Making Unit (DMU) in comparison to other DMUs (Charnes, Cooper, & Rhodes, Measuring the efficiency of decision making units, 1978). DEA is advantageous in this respect because it does not need a specifically defined objective function. The other eminent advantage of DEA is that, it can handle multiple inputs and outputs. DEA compares the efficiency of candidates and derive the ‘efficiency frontier’ similar to the sample shown in Figure 3.8. Nodes under the curve are inefficient (or less efficient) candidates and they would be excluded from the enterprise pool.

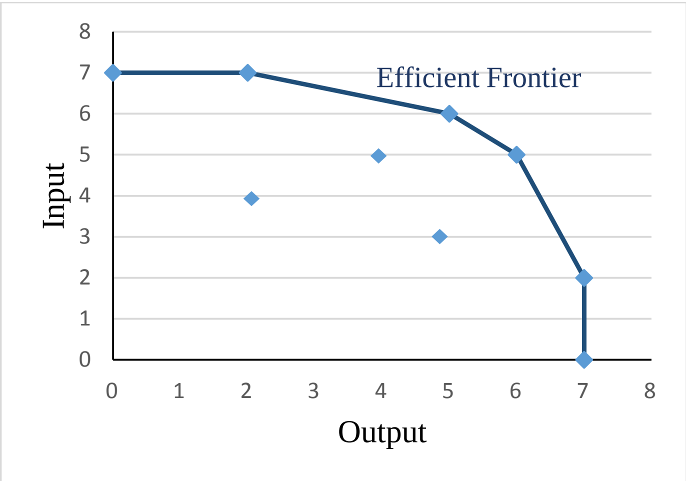


Figure 3.8. DEA's efficient frontier

Among variety of assets each manufacturing unit employ to acquire the outputs, three inputs and two outputs are selected as representative of their performance, illustrated in Figure 3.9.

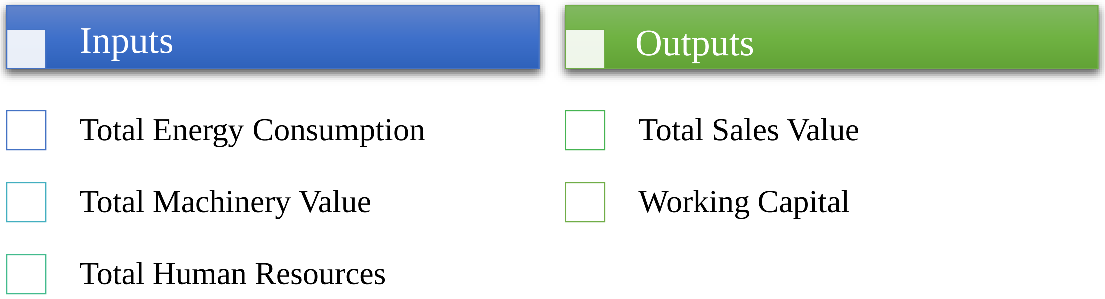


Figure 3.9 DEA's inputs and outputs

In DEA's modeling scheme, efficiency score of each DMU is defined as a ratio of weighted sum of outputs to the weighted sum of inputs. It calculates the weights of inputs and outputs in a way that the highest possible efficiency of DMU is obtained while the efficiency score of all other DMUs do not exceed 1 with those set of weights. By adapting the DEA model to partner selection case, the primal mathematical model of the problem is formulated as Eq. 3.6. (Charnes & Cooper, 1961)

$$Max\ E = \frac{\sum_{k=1}^{K} Y_{ok} v_k}{\sum_{j=1}^{J} X_{oj} u_j} \qquad \text{Eq. 3.6}$$

Subject to:

$$\frac{\sum_{k=1}^{K} Y_{ik} v_k}{\sum_{j=1}^{J} X_{ij} u_j} \leq 1, \qquad i = 1, \dots, I$$

$$v_k \geq 0, \qquad k = 1, \dots, K$$

$$u_j \geq 0, \qquad j = 1, \dots, J$$

Where,

I: Number of alternatives(enterprises)

J: Number of inputs (assumed to be 3)

K: Number of outputs (assumed to be 2)

E: Efficiecy ratio of the alternative

X_{ij}: Amount of input j, used by alternative i

Y_{ik}: Amount of output k, generated by alternative i

u_j: Coefficient assigned by DEA to input j

v_k: Coefficient assigned by DEA to output k

X_{oj}: Amount of observed input

Y_{ok}: Amount of observed output

The primal mathematical model of the problem is nonlinear, though the dual model can be transformed into a linear programming by setting the denominator of the objective function to 1 and moving the denominator of the first constraint to the right-hand side of the equation. Consequently, the dual can be modeled as Eq. 3.7. (Charnes & Cooper, 1961).

$$Max\ E = \sum_{k=1}^{K} Y_{ok} v_k \qquad \text{Eq. 3.7}$$

Subject to:

$$\sum_{k=1}^{K} Y_{ik} v_k - \sum_{j=1}^{J} X_{ij} u_j \le 0$$

$$\sum_{j=1}^{J} X_{oj} u_j = 1$$

$$v_k , u_j \ge 0$$

Eq. 3.7 is a simple linear mathematical model which can be solved by Operation Research techniques. We applied LINGO 14.0 software to obtain the results. Once the efficiency score of each enterprise is obtained, the inefficient enterprises are filtered out from the VE pool if the bidding is competitive and there are too many qualified partners. However, DEA elimination, is not a mandatory step. Model may skip this step if the number of candidates are manageable.

It is worthwhile to highlight that, since DEA finds the efficiency scores of candidates by comparing them with each other, the efficiency score of each alternative not only depends on its own performance it is also dependent on the performance of its competitors. Therefore, even an inaccurate information in any candidate's performance (exaggerated or underestimated value) would affect the result of all members. This is why, it is necessary to provide a trustworthy data to DEA. Otherwise, the outcomes would not be accurate.

After employing DEA (if necessary) and eliminating the inefficient member. Call for proposals are sent to the remaining efficient candidates. Volunteer enterprises respond to the bid, offering their price and delivery time to fulfill the specified subprojects responsibilities. On the other hand, enterprises background information (past performance and service) are called from system's database. All of these information would be involved in determining companies rank by applying different partner selection methodologies for different scenarios. Chapters 3.7, 3.8 and 3.9 propose three different approaches to how to rank the enterprises to elect the winner.

3.6 Partner Selection Flowchart

Figure 3.10, Figure 3.11 demonstrate the stepwise partner identification and selection technique designed in this thesis. Each step is embedded in the algorithm to respond to a particular aspect of enterprise evaluation which are highlighted previously in chapter 3.2. Moreover, different decision making methodologies are applied in order to enable the system to cope with different customer attitudes. For example, if the customer is passive, the information about decision maker's preferences is highly uncertain so none of FAHP-TOPSIS or FAHP-GP methods can be used.

Each step of this structure will be described in details in the following chapters.

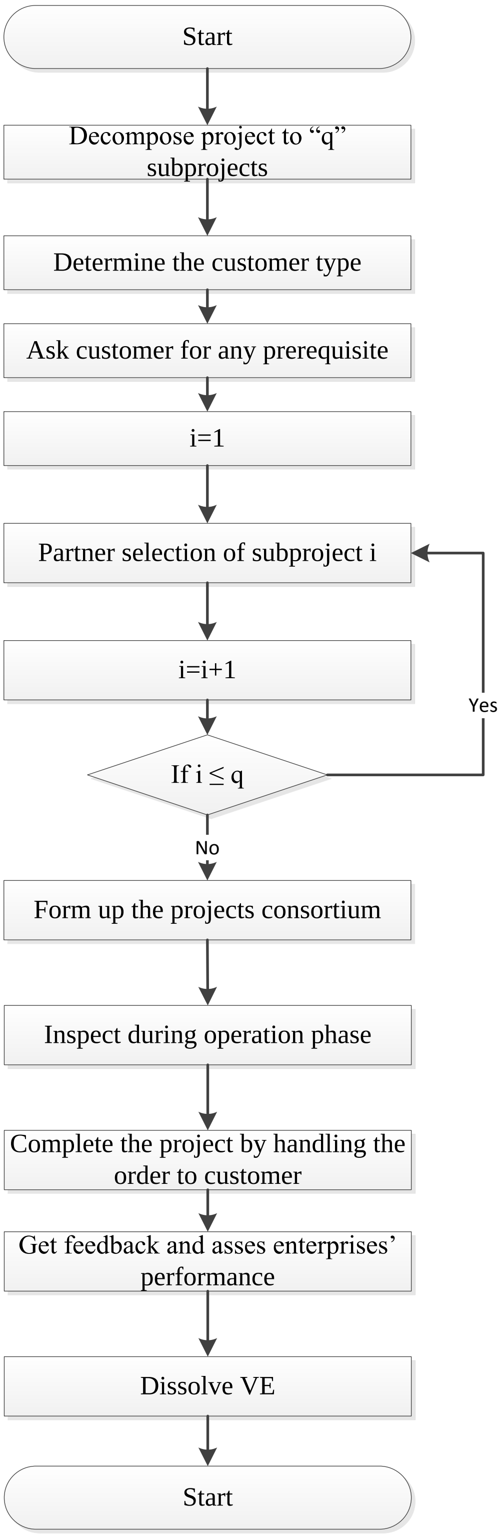


Figure 3.10. Partner selection flowchart for main project

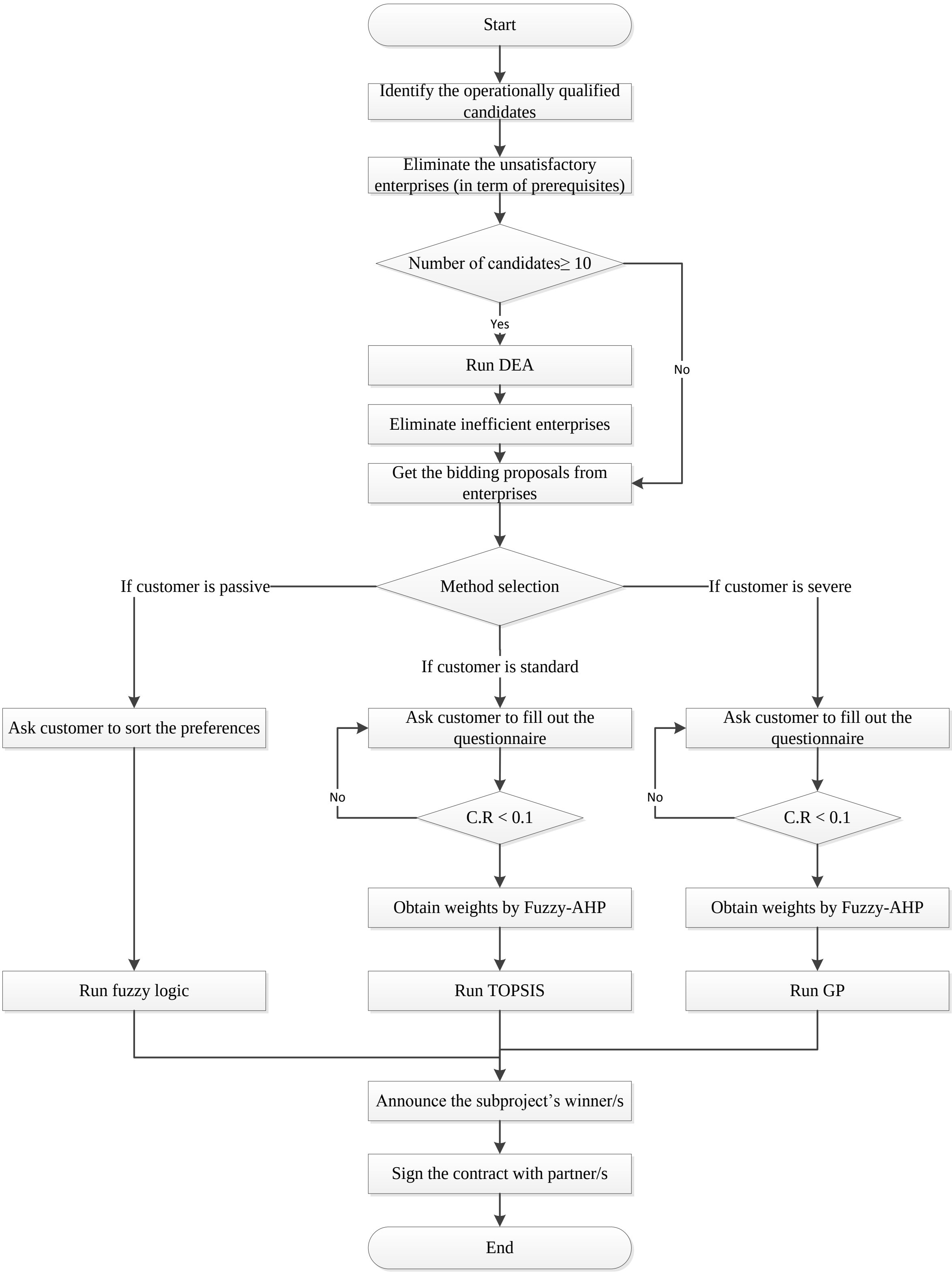


Figure 3.11. Partner selection flowchart for each subproject

3.7 Fuzzy Logic for Partner Selection Modeling

As it was intended, the primary target of this study is to propose a method to rank the bidder enterprises with respect to “uncertain customer preferences”. Therefore, the best tool to deal with uncertainty, Fuzzy sets theory, and its extension, Fuzzy logic, would be a proper approach to be applied in partner selection structure. Fuzzy logic was proposed by Lotfi. A. Zadeh, in 1965 (Zadeh, 1965).Fuzzy logic is a many-valued reasoning method considering vagueness of linguistic variables.

Fuzzy Inference System (FIS) is a framework which uses fuzzy sets, fuzzy logic and fuzzy rules. FIS maps inputs of the system to outputs. FIS aims to map inputs of the system to the outputs. The linguistic input variables are featured by membership functions applying fuzzy sets. Then these variables are matched with their corresponding fuzzy logic rules. Then the result of each rule would determine the output of the system (Shing & Jang, 1993).

Output of FIS is obtained by going through the four main steps;

1. Fuzzification of input
2. Rule Evaluation
3. Aggregation of the rule outputs
4. Defuzzification.

The first step of fuzzy inference system is to calculate the membership degree of inputs to their belonging fuzzy sets. In the second step fuzzified values of inputs are used to evaluate fuzzy rules. Fuzzy rules contain fuzzy operators (AND or OR). The next step is aggregating the fuzzy outputs of all rules. The last step of fuzzy inference process is defuzzifying the output, concluding the final crisp value and giving the results.

Mamdani is the most frequently used FIS introduced in 1975 (Kaur & Kaur, 2012). Regarding the brief introduction, summarily FIS takes several imprecise data (inputs) and based on certain rules decide on the system’s output (Mamdani E. , 1976).

If we consider the score of each enterprise with respect to each of four main evaluation criteria, the model would have 4 inputs. Once the crisp value of these inputs and their corresponding fuzzy scores are nourished to FIS, by applying fuzzy rules, the output of the model could be derived. Model output is the overall score which will represent each enterprise in ranking list.

The detailed description of variables fuzzification and fuzzy rules implementation are given in following chapters. It is necessary to highlight that, different membership functions are defined for each variable because the characteristic of each variable is different from others.

3.7.1 Input Variables of Fuzzy Logic Model

The parameters which enterprises evaluation would be conducted on those criteria are defined as input variables of the model. In fuzzy logic model of this thesis, main criteria are; unit price, delivery time, past performance and service. The first two variables come from bidding and the last two need to be taken from the system database. These values are normalized using Euclidean normalization technique so all of them are within the range of (0,1).

3.7.1.1 Unit Price Membership Functions

Appropriate fuzzy set of price, should consist of linear membership function. Even one dollar less, means cheaper price and in order to maintain the competitiveness between candidates this should not be ignored. Consequently, three triangular membership functions are used to model the fuzzy behavior of unit price proposed by enterprises, as shown in Figure 3.12. The membership functions are as follows:

Inexpensive (0; 0; 0.5)

Moderate $(a_1; 0.5; b_1)$

Expensive (0.5; 1; 1)

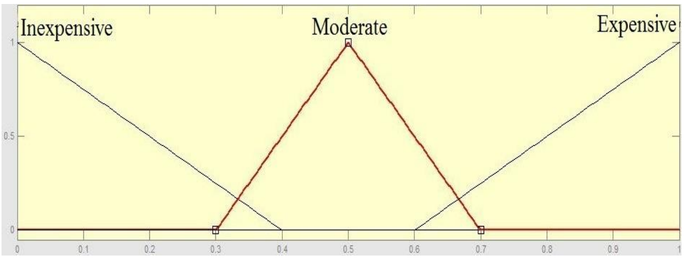


Figure 3.12. Membership functions of "price"

3.7.1.2 Delivery Time Membership functions

Generally, in planning a timetable of a project and its subprojects, with techniques such as Project Evaluation Review Technique (PERT), the due dates of subprojects are usually determined with two parameters earliest finish and latest finish time. And the range between these two are the favorable domain.

On the other hand, if a task cannot be completed on time it will be back ordered imposing some penalty charges (Nikghadam, et al., 2011). If lateness exceeds, the customer may give up and the order will be lost. Once the lost sales occur it does not matter how much it has exceeded the maximum acceptable late delivery point (h_2 of Figure 3.13), the order is already dropped. This trend is also valid in the case of too early delivery because of excessive inventory costs. Regarding these features, membership functions of delivery time should has indifference domains shown by a horizontal line.

To provide these requirements trapezoidal membership functions shown in Figure 3.13 are used to model the behavior of delivery time.

Early $(0; 0; a_2; c_2)$

Favorable $(b_2; d_2; e_2; g_2)$

Late $(f_2; h_2; 1; 1)$

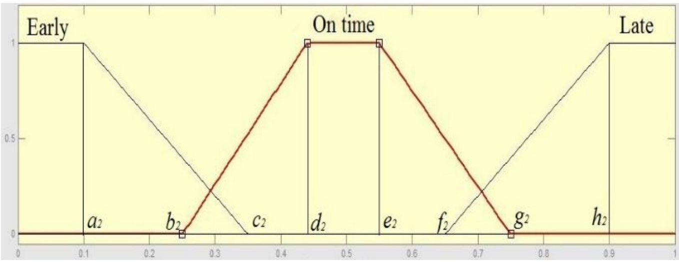


Figure 3.13. Membership functions of "delivery time"

3.7.1.3 Past Performance Membership Functions

Past performance of a company is a factor representing the level of commitment in fulfilling its previous duties. Score of past performance is influenced by two factors, acceptable product rate in terms of quality and delivery time. The past performance graph do not follow the linear trend due to marginality. In other words achieving higher levels of past performance level is more demanding at higher scores. Figure 3.14 illustrates three Gaussian membership functions used to model its membership function. a_3 and b_3 parameters are determining the shape of curves.

Poor (0; 0.2)

Fair (0.5; 0.2)

Good (1; 0.2)

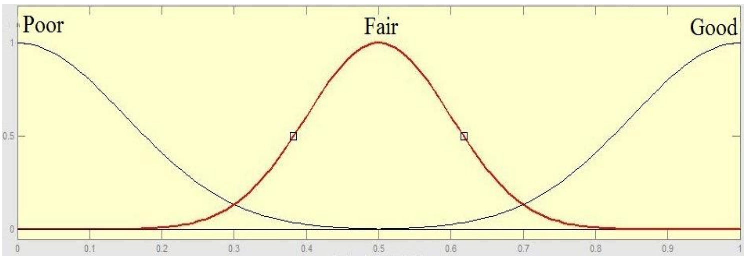


Figure 3.14. Membership functions of "past performance"

3.7.1.4 Customer Service Membership Functions

Customer's satisfaction is highly dependent on the service offered by the company. Service is a subjective representation of many parameters such as after sale service, communication skills and environmental friendliness. Similar to the nonlinear trend of past performance, membership functions of service are nonlinear due to the marginality of judging the score of this subjective criterion. Two simple Gaussian membership functions are defined. These membership functions are shown in Figure 3.15. Parameter a_4 is specifying the shape of the curves.

Unsatisfactory (a_4; 0)

Satisfactory (a_4; 1)

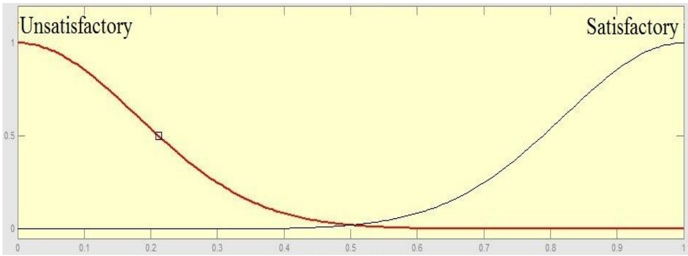


Figure 3.15. Membership functions of "Service"

Four input variables of FIS and their corresponding membership functions are defined. Now output of the system is going to be presented.

3.7.2 Output Variable of Fuzzy Logic Model

Output of the model is the target which model is designed for. So, partner's acceptance chance to join the consortium is defined as output variable of the model.

This score is calculated by evaluating the performance of enterprises with respect to four input variables. Consequently, enterprise with higher overall score would have higher chance to be picked up as a winner to take role in virtual enterprise rather than other rival enterprises.

Three triangular membership functions are used to define the fuzzy set of "Partnership chance" as illustrated in Figure 3.16. Usually enterprises violating the project requirements belong to the first membership function and their partnership chance are low. The third membership function members are those which can satisfy almost all the necessities of four inputs and the enterprises belonging to this set are most likely to be accepted as partner. While the members of second membership function, are potential partner enterprises which cannot classified in first or third membership function groups and have the moderate partnership chance.

Low (0; 0; 0.5)

Average (a_5; 0.5; b_5)

High (0.5; 1; 1)

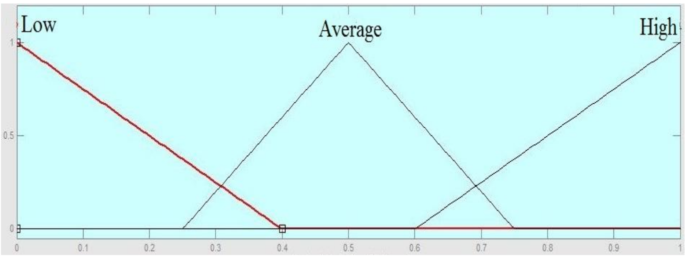


Figure 3.16. Membership functions of "Partnership chance"

3.7.1 Rules of Fuzzy Logic Model

Fuzzy rules are the step which customer's attitude is implied into the system by defining IF-THEN statements. Structure of fuzzy rules is as shown below;

If *(input 1 is membership function1)* AND/*OR (input 2 is membership function 2)* THEN *(Output n is membership function n)*

These rules are established based on customer's priorities. This step is the most important step of the method since even a single improper rule will cause untrustworthy results. A sample rule for partner selection model is given below;

If *(Price is Expensive)* AND *(Delivery time is Late)* AND *(Past performance is Poor)* AND *(Service is Unsatisfactory)* THEN *(Partnership chance is Low)*

It is not realistic to expect customers to define all the rules by themselves one by one due to these reasons; First, rule construction is not a simple task and the rule set should be defined carefully. For a customer unfamiliar with the process, surely it would be tiresome. Second, all the possible combinations of rules should be considered. Nevertheless, the model may not be consistent.

Knowing all these, customers are just asked, to rank the evaluation criteria based on their preferences in descending order, from the most important to the least important criterion. Then the template of Table 3.2 is used to establish the corresponding rule set. This template is inspired by lexicographic technique however, it does not completely follow the same trend.

In this table, termination “constructive” represents a membership function which has constructive effects on partnership chance of enterprise. While, “Destructive” is representing the membership function with negative impact on partnership chance. “Neutral” is a membership function which is not determinant by itself. In parameters with three membership functions, “Neutral” is usually the one which is placed between the “Constructive” and “Destructive” membership functions.

For instance, considering price, “Constructive”, “Destructive” and “Neutral” membership functions are “Inexpensive”, “Moderate” and “Expensive”. However, considering past performance, “Constructive”, “Destructive” and “Neutral” membership functions are “Poor”, “Fair” and “Good”.

Table 3.2 is a template to establish the fuzzy rules set for each customer’s preferences. For more detailed instructions, a descriptive example of fuzzy rules will be presented in the case study.

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Table 3.2. Fuzzy logic rules of the model

	IF							THEN
	1st most important criterion		2nd most important criterion		3rd most important criterion		4th most important criterion	Output
1	Constructive	AND	Constructive					High
2	Constructive	AND	Neutral	AND	Constructive			High
3	Constructive	AND	Neutral	AND	Neutral			Medium
4	Constructive	AND	Neutral	AND	Destructive			Medium
5	Constructive	AND	Destructive					Average
6	Neutral	AND	Constructive	AND	Constructive	AND	Constructive	High
7	Neutral	AND	Constructive	AND	Constructive	AND	Neutral	Average
8	Neutral	AND	Constructive	AND	Constructive	AND	Destructive	Average
9	Neutral	AND	Neutral	AND	Constructive			Average
10	Neutral	AND	Neutral	AND	Neutral			Average
11	Neutral	AND	Destructive					Low
12	Destructive	AND	Constructive	AND	Constructive			Average
13	Destructive	AND	Constructive	AND	Neutral	AND	Constructive	Average
14	Destructive	AND	Constructive	AND	Neutral	AND	Neutral	Low
15	Destructive	AND	Constructive	AND	Neutral	AND	Destructive	Low
16	Destructive	AND	Constructive	AND	Destructive			Low
17	Destructive	AND	Neutral					Low
18	Destructive	AND	Destructive					Low

According to these fuzzy rules, fuzzy inputs will be combined and evaluated by Mamdani's fuzzy inference system to find the partnership chance as this model's output. Fuzzy logic toolbox of MATLAB software is used to construct and run the model.

The advantage of fuzzy logic technique is that it can easily be applied in situations with high uncertainty. It does not enforce the customer to fill out any questionnaire yet it gives satisfactory solution.

Moreover, adjusting rules based on the project's properties is also possible and this opportunity facilitate the VE to be extremely flexible. For instance in metal manufacturing sector early delivery of the order might be an advantage, however it can be extremely unusual and even disadvantageous in the food sector. By defining logical fuzzy rules, the model is capable of handling both cases.

In designing the partner selection model with fuzzy logic, only the rank of criteria are taken into account, neglecting how much criterion one is more important than the second one. Fuzzy rules are established on this basis too. This trend is a simple yet effective way to set up rules. However, in the case when customers strictly emphasize on their preferences this may cause some inaccuracies. The second model, described in next chapter, is proposed to be applied in these circumstances and obviously it requires more detailed investigations on customers' attitudes. Customer is asked to fill out the questionnaire so the importance weight of each criterion could be calculated carefully.

3.8 Fuzzy AHP- TOPSIS for Partner Selection Modeling

Once the efficient enterprises are detected the main decision making process starts. Regarding the necessities highlighted previously to construct the reliable partner selection, the most central aspect is to conduct the evaluation with respect to customer primacies. Yet, not only assessing candidates with respect to these preferences are difficult, but also understanding what customer wants is problematic too. This is mainly due to the fact that, human judgments are normally so abstract which makes it tough to interpret. Naturally, it is very figurative to expect a person to specify his/her preference weights for couple of parameters (for instance; price, delivery time, past performance and service weights are 0.3, 0.3, 0.2 and 0.2 respectively). What actually required is to ask simple, straightforward yet handy questions. Then by analyzing the questionnaire we could check if the respondent is consistent about his/her preferences or not. If the answers are reasonable the criteria weights can be derived by applying techniques such as AHP or ANP, first introduced by Saaty et al (Saaty T. , 1996), (Saaty T. , 1980).

3.8.1 AHP

The main idea behind the Saaty's AHP method is to decompose each problem into its elements; the goal, criteria, sub-criteria and alternatives and then comparing them two by two.

The first level of the hierarchy is the specific goal which this structure is designed for. Criteria which contribute to the main goal is arranged in second level. Following the same trend (if necessary) each criterion is divided into its sub-criteria and finally alternatives are positioned in last level of hierarchy. The general form of AHP structure is illustrated in Figure 3.17.

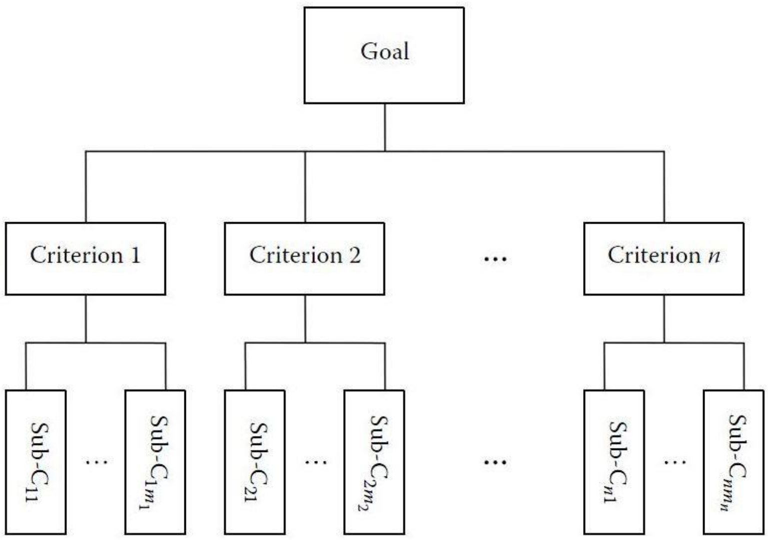

Figure 3.17. Hierarchical structure of the AHP ((Tzeng & Huang, 2011)

Main steps of the AHP is summarized as follows (Tzeng & Huang, 2011);

Step1: Once the hierarchy levels are settled the comparison matrices should be constructed. Entries of these reciprocal matrices are the values assigned by applying pairwise comparisons at each level. i.e. the decision maker should clarify how much element A is more important than element B regarding Saaty's nine point scale given in Table 3.3.

Table 3.3. Scales of AHP

Definition	**Intensity of importance**
Equally important	1
Weakly important	3
Strongly important	5
Very strongly important	7
Extremely important	9
Intermediate values between two judgments	2, 4, 6, 8

Step2: After organizing all the matrices, relative weights are obtained by applying Eigen vector method. The problem is in the form of Eq. 3.8. Where *A* is the comparison matrix, *w* is weight vector and *n* is the Eigen value (Saaty T. , 1980).

$$[A].[w] = n.[w] \quad \text{Eq. 3.8}$$

$$([A] - n.[I]).[w] = [0] \quad \text{Eq. 3.9}$$

Eq. 3.9 should be solved in order to solve the Eq. 3.8. And λ_{max} should be found such that Eq. 3.10 is satisfied. λ_{max} is the largest Eigen value of the matrix A (Saaty T. , 1980).

$$[A].[w]=\lambda_{max}.[w] \quad \text{Eq. 3.10}$$

Furthermore, to check the consistency and accuracy of the comparisons two indexes consistency index (C.I.) and consistency ratio (C.R.) are suggested. Its governing equation is expressed in Eq. 3.11 (Saaty T. , 1980).

$$C.I. = \frac{\lambda_{max} - n}{n-1} \quad \text{Eq. 3.11}$$

In above equation n refers to the numbers of attributes.

$$C.R. = \frac{C.I.}{R.I.} \qquad \text{Eq. 3.12}$$

Eq. 3.12 is used to obtain C.R. where R.I. is random consistency index which should be chosen considering the order of matrix as Table 3.4 . To ensure the reliability of results C.R. should be C.R. ≤ 0.1. When C.R. is more than acceptable value, judgments should be reviewed and revised. The acceptable value of C.R. indicates the high levels of accuracy and reliable judgments.

Table 3.4. Random Index (Saaty T. , 1980)

Order	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
R.I.	0	0	0.5	0.8	1.1	1.2	1.3	1.4	1.4	1.4	1.5	1.5

If the consistency of the model is proven, by applying AHP alternatives are ranked.

AHP is considered to be a powerful MCDM technique due to the reasons listed below.

- It is capable of dealing with both tangible and intangible factors.
- The hierarchy structure of AHP, provide the systematic framework to include the evaluation parameters in decision making process.
- Comparing the elements two by two is a logical approach to determine the priorities.
- AHP can aggregate the judgments of a group of decision makers.
- Accuracy of the decision maker’s judgments can be verified by checking consistency ratio index.

Beside all the strength, AHP suffers from some limitations such as;

- Rank Reversal issue is the most important weakness of AHP method. It is to say that, the results obtained from AHO may change when another alternative, even dominated one, is added to the initial group of alternatives compared (Stern, Mehrez, & Hadad, 2000).

- Number of pairwise comparisons increase drastically as the number of hierarchy elements increase. This will cause the problem to boost in size and complexity.
- In a large-sized problems the decision maker have to fill out the questionnaire with lots of pairwise comparisons which can be tedious and tiring act some times.
- It might be difficult for decision makers to specify their exact preferences as they might be uncertain about their decisions.

However, by defining the appropriate structure of criteria hierarchy these shortcomings could be controlled except its inability to deal with ambiguity. To overcome the limitation of AHP in terms of uncertainty an extended form of AHP is proposed by Buckley (Buckley, 1985).

3.8.2 Fuzzy -AHP

Buckley proposed Fuzzy AHP method, which integrates fuzzy approach with AHP (Buckley, 1985). Unlike, traditional AHP with crisp values, Fuzzy AHP uses triangular fuzzy membership functions to denote linguistic terminations. Table 3.5 shows the linguistic terminations and their corresponding fuzzy numbers for setting values to pairwise comparisons.

Table 3.5. Pairwise comparisons of linguistic variables using fuzzy numbers

Linguistic scale for importance	Fuzzy numbers	Triangular fuzzy scale
Equally important	$\tilde{1}$	(1,1,3)
Weakly important	$\tilde{3}$	(1,3,5)
Strongly important	$\tilde{5}$	(3,5,7)
Very strongly important	$\tilde{7}$	(5,7,9)
Extremely important	$\tilde{9}$	(7,9,9)

Customer fills out the questionnaire by answering questions containing comparisons of criteria two by two (in the case of our problem four main criteria price, delivery time, past performance and service). As a result of these comparisons and applying fuzzy scales the evaluation matrix A is constructed. Matrix A is a $n \times n$ matrix where n is the number of criteria (in our model n=4).

$$[\widetilde{A}]= \begin{bmatrix} \widetilde{a_{11}} & \cdots & \widetilde{a_{1j}} & \cdots & \widetilde{a_{1n}} \\ \vdots & & & & \vdots \\ \widetilde{a_{i1}} & \cdots & \widetilde{a_{ij}} & \cdots & \widetilde{a_{i1}} \\ \vdots & & & & \vdots \\ \widetilde{a_{n1}} & \cdots & \widetilde{a_{nj}} & \cdots & \widetilde{a_{nn}} \end{bmatrix} \qquad \text{Eq. 3.13}$$

In matrix of Eq. 3.13, $\widetilde{a_{ij}} \odot \widetilde{a_{ji}} = 1$ (Buckley, 1985).

Then geometric mean method is employed to calculate the fuzzy weights of each criterion as follows (Buckley, 1985).

$$\widetilde{w_i} = \widetilde{u_i} \odot (\widetilde{u_1} \oplus \widetilde{u_2} \oplus \cdots \oplus \widetilde{u_n})^{-1} \qquad \text{Eq. 3.14}$$

Where;

$$\widetilde{u_i} = (\widetilde{a_{i1}} \odot \widetilde{a_{i2}} \odot \cdots \odot \widetilde{a_{in}})^{1/n} \qquad \text{Eq. 3.15}$$

Fuzzy weights are defuzzified by the Center of Area (COA) defuzzification method so the final weight of each criterion is obtained. The preference weight of each criterion denotes by $w = \{w_j \mid j = 1, \dots, m\}$. The greater the weight of criterion, the more affective it is.

By employing fuzzy-AHP we satisfy what we promised initially in terms of; first, finding the customer’s preferences among four main criteria and next, considering the vagueness of buyer’s decision.

3.8.3 TOPSIS

After determining the weight of each criterion, it is time to assess the candidates based on these preferences. To do so, TOPSIS method would be used. Tough, TOPSIS is going to use the weights obtained from fuzzy-AHP. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a MCDM technique developed by Hwang and Yoon in 1981. The concept of TOPSIS is that the chosen alternative should be closest to the Positive Ideal Solution (PIS) and the farthest from the Negative

Ideal Solution (NIS) (Hwang & Yoon, 1981). Figure 3.18 schematically illustrates TOPSIS method with two evaluation criteria.

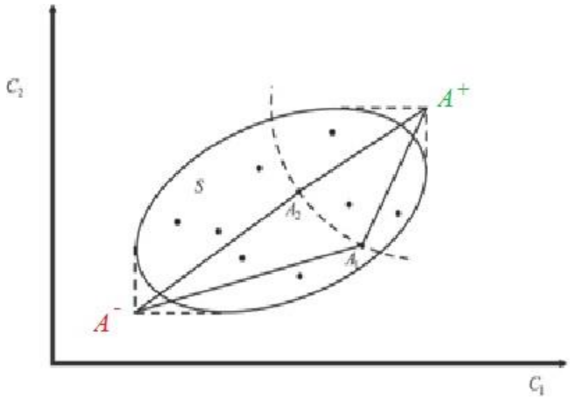

Figure 3.18. Scheme of TOPSIS method (Tzeng & Huang, 2011)

Given m alternatives which will be ranked with respect to n criteria, an $m \times n$ performance matrix 'X' is created as Eq. 3.16. Elements of matrix X shows the score of each alternative with respect to each criterion.

$$[X]= \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad \text{Eq. 3.16}$$

Normalization of matrix X is necessary, to remove the impact of units. For instance, price has a large variance (10000-15000 $) while delivery time has smaller variance (12-15 days). Without normalization model will load on large variance variable neglecting the effects of small variance variable. In this case results would be inaccurate.

Elements of normalized performance matrix are calculated using Euclidean normalization technique by applying Eq. 3.17.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \text{Eq. 3.17}$$

This step is where the results of fuzzy-AHP is incorporated in TOPSIS. Here, the weights acquired from applying fuzzy-AHP ($w = \{w_j |\, j = 1, \dots, m\}$) are multiplied by elements of normalized performance matrix as Eq. 3.18.

$$v_{ij} = w_j r_{ij} \qquad \text{Eq. 3.18}$$

Positive ideal solution (PIS) and negative ideal solution (NIS) are identified regarding Eq. 3.19 and Eq. 3.20.

$$PIS = A^{+} = \left(max_i v_{ij} \middle|\, j \in J\right), \left(min_i v_{ij} \middle|\, j \in J'\right) \mid i = 1,2, \dots, m \qquad \text{Eq. 3.19}$$

$$NIS = A^{-} = \left(min_i v_{ij} \middle|\, j \in J\right), \left(max_i v_{ij} \middle|\, j \in J'\right) \mid i = 1,2, \dots, m \qquad \text{Eq. 3.20}$$

Where;

J= {j=1, 2,…, n| j associated with benefit criteria} and

J'= {j=1, 2,… , n| j associated with cost criteria}.

The separation value of each alternative from PIS and NIS is measured by Euclidean distance as follows:

$$S_{i^{+}} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_i^{+})^2} \qquad \text{Eq. 3.21}$$

$$S_{i^{-}} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_i^{-})^2} \qquad \text{Eq. 3.22}$$

Closeness of an alternative to PIS is obtained by Eq. 3.23. This means that an alternative with closer C_i^{+} to 1, is closer to PIS.

$$C_i^{+} = \frac{S_i^{-}}{S_i^{+} + S_i^{-}} \qquad \text{Eq. 3.23}$$

Where;

$C_i^{+} \epsilon [0,1]\ \forall\ i = 1, \dots, n.$

Therefore, now enterprise can be ranked according to the decreasing order of C_i^+. Hereby, enterprise which is ranked first is a winner of the negotiation and the subprojects responsibilities would be given to subprojects winner.

Conclusively, the method developed by integrating fuzzy-AHP and TOPSIS, technique provides the ranked list of enterprises based on customer preferences obtained from fuzzy-AHP method and implementing them in TOPSIS's conventional model.

3.9 Fuzzy AHP- GP for Partner Selection Modeling

Both of techniques presented in previous chapters are addressing the "single sourcing" case for partner selection problem. It is to say that each subproject is going to be allocated to only one enterprise. Though, this might now be always the case. In reality, in some strict bidding situations, when the deadlines are too tight for high volumes of demand, the capacity limitations of manufacturing units may not allow them to fulfill the whole job individually. In these extreme situations, VE has to search for more than one partners for each subproject, called "multiple sourcing". In this case the problem is actually finding the best "team" of enterprises which can accomplish the subproject's necessities.

When a subproject may be shared among multiple partners the problem's characteristics changes slightingly due to following reasons;

1. Bidding proposals (price and delivery time) are dependent to the quantity of order. Therefore different proposals for different order quantities should be taken from enterprises (instead of just a single proposal).
2. In multiple sourcing, the problem is not just identifying the best company anymore. Besides, it also tries to find the best team of enterprises and how many products does each have to manufacture? To establish an appropriate platform for the model to search and evaluate the infinitely many combinations of solutions, multiple sourcing partner selection is formulated as an optimization problem.

Finding the best team of enterprises which can accomplish the subproject's necessities within the specified due dates, at lowest risk, with lower price and higher service support can be interpreted as a multi objective optimization problem. The mathematical representation of partner selection problem with respect to four aforementioned criteria is formulated as below;

$$Min \sum_{i=1}^{m}\sum_{k=1}^{K} P_{ik}X_{ik}Y_{ik} \qquad \text{Eq. 3.24}$$

$$Max \sum_{i=1}^{m}\sum_{k=1}^{K} DT_{ik}X_{ik}Y_{ik} \qquad \text{Eq. 3.25}$$

$$Max \sum_{i=1}^{m}\sum_{k=1}^{K} PP_{i}X_{ik}Y_{ik} \qquad \text{Eq. 3.26}$$

$$Max \sum_{i=1}^{m}\sum_{k=1}^{K} S_{i}X_{ik}Y_{ik} \qquad \text{Eq. 3.27}$$

Subject to:

$$\sum_{i=1}^{m}\sum_{k=1}^{K} X_{ik} = D_T \qquad \text{Eq. 3.28}$$

$$L_{ik}Y_{ik} \leq X_{ik} \leq U_{ik}Y_{ik} \qquad \forall\ i = 1, \dots, m\ \ and\ k = 1, \dots, K \qquad \text{Eq. 3.29}$$

$$\sum_{j=1}^{K} Y_{ik} \leq 1 \qquad \forall\ i = 1, \dots, m \qquad \text{Eq. 3.30}$$

$$Y_{ij} = \begin{cases} 1, & If\ job\ is\ allocated\ to\ jth\ bid\ of\ enterprise\ i \\ 0, & If\ job\ is\ not\ allocated\ to\ jth\ bid\ of\ enterprise\ i \end{cases} \qquad \text{Eq. 3.31}$$

$$X_{ik} \in Z \qquad \text{Eq. 3.32}$$

Where;

Eq. 3.24 represents the cost minimization objective function. Eq. 3.25 is the objective function maximizing the trust score of on time (or earlier) delivery. Eq. 3.26 and Eq. 3.27 are past performance and service objective functions respectively. Constraint Eq. 3.28 guarantees the fulfillment of total demand. Constraint Eq. 3.29 controls each bids quantity to remain within the indicated domain. Constraint Eq. 3.30 stipulates that no more than one bid is selected from various bidding proposals of each enterprise.

Eq. 3.31 is the variable constraint. Number of products cannot be non-integer values, this constraint is defined in Eq. 3.32. Table 3.6 demonstrates the notation used in formulating these equations.

Table 3.6. Notations used in single and multi-objective models' formulation

Notation	Description
P_{ik}	Unit price proposed by k^{th} bid of enterprise i
DT_{ik}	Delivery trust score of k^{th} bid of enterprise i
PP_{ik}	Past performance score of enterprise i
S_{ik}	Service score of enterprise i
X_{ik}	Number of products ordered from k^{th} bid of enterprise i
Y_{ik}	Decision variable for selecting k^{th} bid of enterprise i
L_{ik}	Lower limit of product number proposed by enterprise i for k^{th} bid
U_{ik}	Upper limit of product number proposed by enterprise i for k^{th} bid
D_T	Total demand from customer
i	Number of enterprises
k	Number of bid proposals for different quantities of order

The solution obtained from solving multi objective problem is not a unique optimum point.

One major limitation of multi objective problem is that the solution obtained from solving the model is not a single optimum point. It gives a set of non-dominated solutions called "Pareto efficient solution". Although these types of solutions may be useful in some problems it cannot be applicable in partner selection of our model. Multi objective problem formulated by equations Eq. 3.24- Eq. 3.32 can be transformed to single objective problem by multiplying each objective with its corresponding weight. Hereby, all of the objectives are aggregated in one objective function Eq. 3.34. And the resultant single objective mathematical model can be solved by simple Operations Research (OR) techniques such as Branch and Bound or AI approaches like GA. Converting a multi objective problem to a single objective is a traditional approach to solve these kind of problems. Articles published by Ip et al. and

Zeng et al are two samples of this approach in literature (Ip, Yung, & Wang, 2004), (Zeng, Li, & Zhu, 2006).

Eq. 3.33- Eq. 3.39 show the single objective mathematical formulation of partner selection problem.

$$Min \sum_{i=1}^{m}\sum_{k=1}^{K}(W_p P_{ik} X_{ik} Y_{ik} - W_{DT} DT_{ik} X_{ik} Y_{ik} - W_{pp} PP_i X_{ik} Y_{ik} - W_s S_i X_{ik} Y_{ik}) \qquad \text{Eq. 3.33}$$

Subject to:

$$\sum_{i=1}^{m}\sum_{k=1}^{K} X_{ik} = D_T \qquad \text{Eq. 3.34}$$

$$L_{ik} Y_{ik} \le X_{ik} \le U_{ik} Y_{ik} \qquad \forall\, i = 1, \dots, m \;\; and \;\; k = 1, \dots, K \qquad \text{Eq. 3.35}$$

$$\sum_{j=1}^{K} Y_{ik} \le 1 \qquad \forall\, i = 1, \dots, m \qquad \text{Eq. 3.36}$$

$$Y_{ij} = \begin{cases} 1, & If\ job\ is\ allocated\ to\ j^{th}\ bid\ of\ enterprise\ i \\ 0, & If\ job\ is\ not\ allocated\ to\ j^{th}\ bid\ of\ enterprise\ i \end{cases} \qquad \text{Eq. 3.37}$$

$$X_{ik} \ge 0 \qquad \text{Eq. 3.38}$$

$$X_{ik} \in Z \qquad \text{Eq. 3.39}$$

Where;

Eq.4.27 is representing the objective function of a single objective mathematical model. Where $W_j = (W_p, W_{DT}, W_{pp}, W_s)$. W_p, W_{DT}, W_{pp}, W_s are importance weight for each criterion price, delivery time, past performance and service respectively. Eq. 3.34- Eq. 3.37 are representing the constraints of the single objective model which are exactly same as multi objective formulation constraints.

The single objective model is a simple yet practical approach to solve partner selection problem capable of handling variety of evaluation parameters. This is why, the vast majority of VE formation articles in the literature implement this technique to model their problems. However, the author of this thesis believes that, a vital point is neglected in these models.

The very critical responsibility of VE is to gain the customer's consent at its highest, while it does not want to lose enterprises faith by always being in buyer's side. In other words, although customer satisfaction is extremely important, it does not justify to take enterprises for granted.

Partner selection of a successful VE, should be able to impartially compromise between customers and enterprises. For example, when a customer accepts to pay P_g dollars for an order there is no need for the model to search for cheaper bids. This aspect cannot be considered in single objective programming, unless specific goal points are defined and model is solved using goal programming technique proposed by Charnes and Cooper (Charnes & Cooper, 1961).

In this chapter we are going to implement Goal Programming (GP) method to partner selection problem of VE for the first time. Actually, the developed model is the integrated form of GP, introduced by, Charnes and Cooper, and fuzzy-AHP, studied in previous chapter.

The GP based partner selection method is advantageous in several aspects. First, it can consider different combinations of goals for evaluation parameters. For example, a customer may declare admitting to pay 100$ for order if the delivery date is within 10-12 days. If not, only 60$ would be paid for 12-15days delivery. Each of these scenarios are evaluated and the optimum partnering case is determined.

The main principal of GP is to set a goal value for each objective and try to minimize the deviations from goals. In this respect the multi objective mathematical model of Eq. 3.24- Eq. 3.32 is transformed to GP of Eq. 3.40- Eq. 3.50.

$$Min\ W_p D_p^{+} + W_{DT} D_{DT}^{-} + W_{pp} D_{pp}^{-} + W_s D_s^{-} \qquad \text{Eq. 3.40}$$

Subject to:

$$\sum_{i=1}^{m} \sum_{k=1}^{K} P_{ik} X_{ik} Y_{ik} - D_p^{+} + D_p^{-} = P_g \qquad \text{Eq. 3.41}$$

$$\sum_{i=1}^{m}\sum_{k=1}^{K} DT_{ik}X_{ik}Y_{ik} - D_{DT}^{+} + D_{DT}^{-} = DT_g \qquad \text{Eq. 3.42}$$

$$\sum_{i=1}^{m}\sum_{k=1}^{K} PP_{ik}X_{ik}Y_{ik} - D_{pp}^{+} + D_{pp}^{-} = 1 \times D_T \qquad \text{Eq. 3.43}$$

$$\sum_{i=1}^{m}\sum_{k=1}^{K} S_{ik}X_{ik}Y_{ik} - D_{s}^{+} + D_{s}^{-} = 1 \times D_T \qquad \text{Eq. 3.44}$$

$$\sum_{i=1}^{m}\sum_{k=1}^{K} X_{ik} = D_T \qquad \text{Eq. 3.45}$$

$$L_{ik}Y_{ik} \le X_{ik} \le U_{ik}Y_{ik} \qquad \forall\, i = 1,\dots,m \;\; and \;\; k = 1,\dots,K \qquad \text{Eq. 3.46}$$

$$\sum_{k=1}^{K} Y_{ik} \le 1 \qquad \forall\, i = 1,\dots,m \qquad \text{Eq. 3.47}$$

$$Y_{ik} = \begin{cases} 1, & If\ job\ is\ allocated\ to\ j^{th}\ bid\ of\ enterprise\ i \\ 0, & If\ job\ is\ not\ allocated\ to\ j^{th}\ bid\ of\ enterprise\ i \end{cases} \qquad \text{Eq. 3.48}$$

$$X_{ik}, D_j^{+}, D_j^{-} \ge 0 \qquad \text{Eq. 3.49}$$

$$X_{ik} \in Z \qquad \text{Eq. 3.50}$$

Objective function of goal programming model is minimizing the weighted sum of deviations from goals. W_j's are representing the penalties assigned to deviations, D_js. in our model, W_j's are weights of criteria derived by applying Fuzzy-AHP. Eq. 3.40 demonstrates the objective function of the model. Eq. 3.41- Eq. 3.44 determine the deviations from price, delivery time, past performance and service goals respectively.

Values of first goals are inquired from customer, while past performance and service goals are set as their maximum possible value (or 1). The rest of constraints, are exactly same as previous models. Constraint Eq. 3.45 ensures that the total demand is fulfilled. Constraint Eq. 3.46 controls each bids quantity to remain within the indicated domain. Constraint Eq. 3.47 stipulates that no more than one bid is selected from various bidding proposals of each enterprise. Eq. 3.48 is the variable constraint. Constraint Eq. 3.49 imposes the non-negativity of X_{ik}, D_j^{+} and D_j^{-}. Constraint Eq. 3.50 shows that

X_{ik} only can take integer values. The notations used in formulation of these equations is tabulated in Table 3.7.

Table 3.7. Notations used in goal programming formulation

Notation	Description
P_g	Price goal specified by customer
DT_g	Delivery time goal specified by customer
D_p^+	Deviation above the price goal
D_p^-	Deviation under the price goal
D_{DT}^+	Deviation above the delivery time goal
D_{DT}^-	Deviation under the delivery time goal
D_{pp}^-	Deviation under the past performance goal
D_s^-	Deviation under the service goal
j	Number of evaluation criteria (4)

The mathematical model of GP is also a mixed integer linear programming which can be solved by OR techniques such as B&B. We used LINGO software which is a useful software to solve these type of problems.

As previously stated, the forcing engine behind the multi sourcing is inflexible due dates (even a low capacity firm can manufacture the bulky order in a long term!). So this model is mostly designed for the bids with specific emphasize on delivery time criterion. To improve the applicability of this model to unsteady real life market environment, some editions in previous delivery time scoring would be beneficial.

In first two techniques, Fuzzy logic and Fuzzy AHP -TOPSIS, we simply trust the "delivery time" proposals of bidders and evaluate the candidates by using these values directly. Though, in this technique by applying a simple modification we could be able to calculate the "delivery time's reliability score".

Let's now describe precisely how the reliability score of delivery time's proposal is calculated. Assume that decision maker's favorable delivery range is [a,b]. a is the early due date, b is the end of due date. It means that products delivered within this time interval is one time, while before ‘a’ and after ‘b’ are considered as early and late delivery domains respectively. Enterprises delivery time proposals are going to be evaluated and scored based on [a,b] domain. (OR this domain is the reference to calculate and score the delivery time proposals of enterprises.

Enterprises propose for the subproject by specifying the delivery domain [T_{ik}, F_{ik}] for certain pack of product. The on time delivery probability of each enterprise’s proposal is calculated based on this domain.

By just knowing the delivery domain and adapting normal distribution function one could estimate the chance of earliness and tardiness regarding Eq. 3.51- Eq. 3.53.

$$\mu_{ik} = \frac{F_{ik} + T_{ik}}{2} \qquad \text{Eq. 3.51}$$

$$\sigma_{ik} = \frac{F_{ik} - T_{ik}}{6} \qquad \text{Eq. 3.52}$$

$$DT_{trust} = \begin{cases} f(b, \mu_{ik}, \sigma_{ik}) = \frac{1}{\sigma_{ik}\sqrt{2\pi}}\, e^{-\frac{(b-\mu_{ik})^2}{2\sigma_{ik}^2}} & if \quad F_{ik} > b \\ 1 & if \quad F_{ik} < b \end{cases} \qquad \text{Eq. 3.53}$$

By applying the normal distribution function, delivery time’s trust score of each enterprise can be estimated by 99.7%, since 99.7% of the values are within 3 standard deviation. The values derived from employing these equations are put in the performance table under delivery time trust score column.

Using these formulations, instead of directly using delivery time proposals, we actually reward the enterprises which are more definite about their punctual delivery time promises.

The most beneficial aspect of GP is that, it allows the buyers to set several goals for their preferences. For instance, assume that a customer declares that, It could be affordable to pay P_g $ for the order if the delivery is within [a,b] ,which is the most favorable delivery date. On the other hand, it is acceptable to get the products within within [a',b'] only if the price is no more than P'_g $. Once the GP model is solved for each set of goals and their corresponding optimum solution are found they are presented to the decision maker and know it can be easily decided which alternative is more desirable.

To sum up, we could list the advantages of modelling partner selection problem with GP as below;

- It provides a suitable platform to multi-sourcing in extreme conditions such as very close delivery dues for high volumes of demand.
- It finds the solution considering the buyer's goal. In the case that customer submits various set of goals the corresponding solution of each set of goals are obtained and offered to the customer. Now, customer could more precisely choose from alternatives.
- GP is a reliable approach to make a balance between buyer's desire and enterprises benefits. It is to say that, there is no need to push the model to enterprises limits as long as customer's goals (in terms of price and delivery time) are accomplished. By doing this VE gains not only customer satisfaction but also enterprise contentedness.
- Uncertainty of information is also considered by applying fuzzy-AHP to find out the penalty weights of criteria in GP's objective function.

All of these advantages, makes the integrated fuzzy AHP- GP approach a reliable technique to find the best team of enterprises for oncoming VE, if multiple sourcing is required.

In this chapter, a multi- step algorithm was proposed for partner selection of VE. The first step was recognizing inefficient companies via DEA and eliminating them from the pool. The efficient enterprises proposed for bid and evaluated based on customer's preferences. The main target of this chapter was to describe three different approaches for this strategic decision making step. Summarily, if the customer of VE does not eager to take the questionnaire, this customer is classified as passive customer and fuzzy logic based partner selection methodology should be applied to deal with highly uncertain data. If customer is conscious enough to take the survey for finding the preferences more accurately and delivery dues of the order is not too tight, the customer is standard and FAHP-TOPSIS should be applied to solve the partner selection problem. But if the customer request and order which is hard to fulfill in terms of delivery dues, customer is assertive and FAHP-GP based model should be used to find the partners of upcoming VE.

CHAPTER 4

APPLICATIONS OF PARTNER SELECTION TECHNIQUES

To demonstrate the application of partner selection methodology proposed in the previous chapter of this thesis work, a sample case study is carried on.

Production process specialists decompose the manufacturing of this box to its subprojects. The subprojects are different with each other in terms of industry sector they appeal to. This project of VE is composed of 3 subprojects; Metal cutting process, plastic forming and coating. These jobs will be allocated to the manufacturers to accomplish certain responsibilities. Which enterprise should be given the job and how should it be identified constitute the main scope of our research and they already have been presented theoretically in the previous chapters.

We will go through all the partner selection steps for subproject 1 comprehensively, but we will skip some detailed calculation for subproject 2 and 3 in order to avoid repetition.

4.1 Main Project and the Subprojects

Virtual enterprise is assumed to have received an order from customer to manufacture the sample assembly product shown in Figure 4.1. Consequently, production of this product is defined as the main project for the upcoming VE.

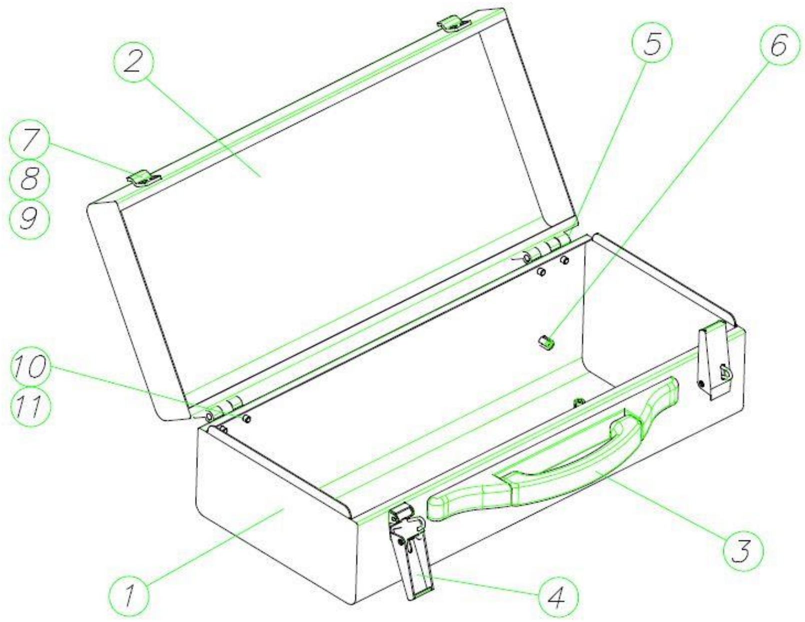

Figure 4.1. Sample assembly product of the case study (toolbox)

Bill of material for manufacturing the tool box of Figure 4.1 is tabulated in Table 4.1. Regarding the manufacturing necessities, each operation is assigned to a specific subproject.

Table 4.1. Bill of Material for the case of VE project

Part no	Number of parts	Part name	Manufacturing processes	Assigned subproject
1	1	Lower body	Sheet metal cutting Sheet metal bending Spot welding Drilling Coating	Subproject 1 Subproject 1 Subproject 1 Subproject 1 Subproject 3
2	1	Upper lid	Sheet metal cutting Sheet metal bending Spot welding Drilling Coating	Subproject 1 Subproject 1 Subproject 1 Subproject 1 Subproject 3
3	1	Handle	Plastic moulding Drilling	Subproject 2 Subproject 1
4	2	Lock	Sheet metal cutting Sheet metal bending	Subproject 1 Subproject 1
5	2	Hinge	Cutting Bending Spot welding	Subproject 1 Subproject 1 Subproject 1
6	6	Foot	Plastic moudling	Subproject 2
7	8	Bolt	Cutting Threading Forging	Subproject 1 Subproject 1 Subproject 1
8	14	Washer M4	Cutting	Subproject 1
9	8	Nut M4	Cutting Forging	Subproject 1 Subproject 1
10	8	Nut M5	Cutting Forging	Subproject 1 Subproject 1
11	8	Washer M5	Cutting	Subproject 1

VE experts decompose the manufacturing of this toolbox to its subprojects as revealed in the design and management of Figure 4.2. Determining the subprojects needs a great skill on production processes design and management. Experts should roughly estimate the time needed to perform each subproject. Subprojects are different from each other in terms of industry sector they appeal to. For example, this project of VE is composed of 3 subprojects; metalworking operations, plastic moulding and coating. These jobs will be allocated to operationally qualified manufacturers to take the responsibility.

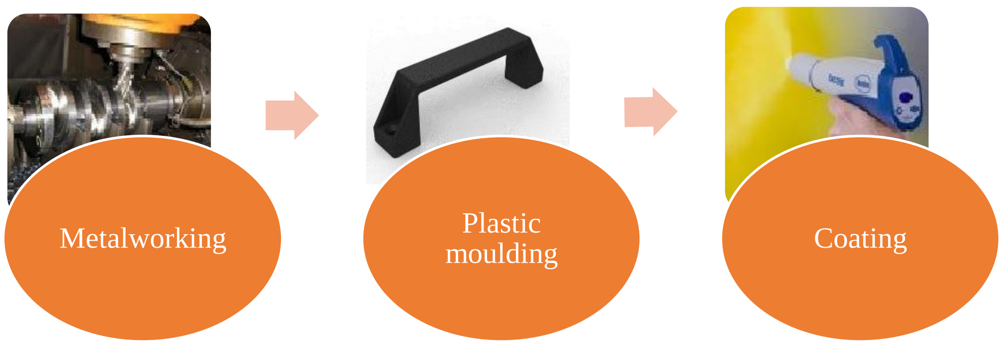

Figure 4.2. Subprojects of manufacturing the toolbox

The very first step of the selection is to search the VBE detecting the enterprises working in the same industry cluster as the subproject and eliminate the unfitted members. The result of this step list all the enterprises capable of operating the corresponding subproject. Which enterprise is the most suitable alternative and how should it be identified are the main scopes of this research and they already have been presented theoretically in previous chapters.

In this chapter, step by step implementation of partner selection methodologies will be presented. Though, some detailed calculations may be skipped in order to avoid unnecessary repetition.

Once the subprojects and their potential partners are recognized, customer attitudes should be discovered to be incorporated in future partner selection steps.

4.2 Customer Attitudes for Partner Selection

Each customer coming to VE has its own principals and each order has its obligations. These are influencing the trend which would be followed in forming the VE.

So three aspects needed to be clarified studying the buyer.

1. Does the customer have any indispensable obligation for the order?
2. Is the customer eager to take the survey finding his/her preferences more accurately?
3. Are the order’s conditions assertive? If yes, what are the customer’s goals?

Different answers to these questions will lead us to use different approaches for partner selection. In order to cover all the possibilities in the case study we reflect three types of customers to implement the methodologies and form the consortium for each. Finally the results of these three cases are obtained, compared and discussed.

Let’s assume that, Customer I is a passive customer, who does not want to take time to fill out the questionnaire.

4.2.1 Scenario I - Passive Customer

In this case, a customer I is a passive customer, who does not want to take time to participate in survey of finding accurate preferences. This customer asserts that, roughly cares more about price followed by past performance of in-charge enterprises. In his/her opinion delivery time and service are his/her third and fourth important factors respectively.

In analyzing the customer attitude, first of all, VE system operator asks customer, the quantity of demand and preferred delivery date. In this sample test, buyer declares requesting 120 parts within 28 days. Analyzing the manufacturing necessities by OMAVE experts, operation time to complete the order are estimated and it is found that 28 days would be enough to complete the production of 120 boxes and this order is not hard to fulfill in terms of delivery dues.

Customer also put emphasis on importance of cooperating with enterprises that own ISO 9001. Information related to customer's requests are gathered in Table 4.2 so to be used in next steps of decision making.

We also ask customer to reveal his prerequisite if there is any. And customer I emphasized on cooperating only with firms certified by ISO 9001 standard. The information of customer I is gathered in Table 4.2 so to be used in next steps of decision making.

Table 4.2. Customer I 's attitude

Prerequisite	ISO 9001			
Customer type	Passive			
Criteria preference	P	Past. P	Del. T	S
Criteria preference weight	-	-	-	-

As previously described, for modeling the partner selection problem when the customer is passive, fuzzy logic technique would be used. So fuzzy rules should be established considering customer I's preferences. Referring to the Table 3.2 of chapter 3.7.1 fuzzy rules would be as shown in Table 4.3

Table 4.3. Fuzzy rules for scenario I

IF				**THEN**
Price	Past performance	Delivery time	Service	Partnership chance
Inexpensive	Good			High
Inexpensive	Fair	On time		High
Inexpensive	Fair	Early		Average
Inexpensive	Fair	Late		Average
Inexpensive	Poor			Average
Moderate	Good	On time	Satisfactory	High
Moderate	Good	On time	Unsatisfactory	Average
Moderate	Fair	On time		Average
Moderate	Fair	Early		Average
Moderate	Poor	Late		Low
Expensive	Good	On time		Average
Expensive	Good	Early	Satisfactory	Average
Expensive	Good	Early	Unsatisfactory	Low
Expensive	Good	Late		Low
Expensive	Fair	On time	Satisfactory	Average
Expensive	Fair	Early	Unsatisfactory	Low
Expensive	Fair	Late		Low
Expensive	Poor			Low

The information of these two tables will be used later for selecting partners for each subproject. Next chapter illustrates the steps for selecting partner of subproject 1, and the other subprojects' partner selection procedure will be given afterwards.

4.2.1.1 Fuzzy Logic based Partner Selection of Subproject 1 for Scenario I

Subproject 1 is defined as a group of tasks to operate metal working processes by VE experts.

Step 1. Technical elimination:

The very first step of partner identification is to determine the list of manufacturers working in the corresponding industry sector. In the case study, the search in VE pool of enterprises results in 12 member qualified for the tasks defined in subproject I

Step 2. Customer prerequisite check:

The next step is to check which enterprises are meeting customer's ISO 9001 certificate obligation. Among 12 enterprises, 10 of them have this certificate and accepted to remain in the selection process. Those companies are named as enterprises A-J (A, B, C, D, E, F, G, H, I, J).

Step 3. DEA:

In DEA elimination step, efficiency ratio of enterprises A-J would be derived. (This step would be skipped if the number of enterprises were less than 10.) The information regarding enterprises input utilization and output return is as shown in Table 4.4 By applying Eq. 3.7 to inputs and outputs of enterprises tabulated in Table 4.4, the efficiency ratio of each enterprise is obtained as shown in Table 4.5.

Table 4.4. Inputs and Outputs of subproject 1's candidates

	Inputs			Outputs	
Enterprise	Total Energy Consumption (TL)	Total Machinery value (TL)	Total working hours (TL)	Total sales volume (TL)	Working capital (TL)
A	788,000	1,170,000	1,200,000	18,000,000	8,830,000
B	400,000	770,000	600,000	8,600,000	6,500,000
C	845,000	940,000	2,500,000	18,800,000	9,200,000
D	1,520,000	2,120,000	400,000	22,000,000	8,400,000
E	1,205,000	830,000	906,000	25,000,000	8,200,000
F	940,000	753,000	1,400,000	12,050,000	8,500,000
G	925,000	1,470,000	800,000	8,050,000	4,500,000
H	1,440,000	553,000	1,300,000	9,050,000	9,500,000
I	840,000	684,000	1,850,000	4,750,000	16,350,000
J	825,000	4,250,000	2,200,000	7,050,000	5,500,000

Table 4.5. Efficiency of subproject 1's candidates

Enterprise	Efficiency ratio	Inefficient members	Efficient members
A	100 %		✓
B	100 %		✓
C	100 %		✓
D	100 %		✓
E	100 %		✓
F	100 %		✓
G	70%	✓	
H	100 %		✓
I	100 %		✓
J	60%	✓	

Based on the table above, Enterprises G and J are detected as less efficient enterprises. Hence, all the enterprises except G and J are allowed to participate in bidding for subproject 1.

Step 4. Bidding:

Call for proposals are sent to 8 efficient enterprises and volunteer enterprises which respond to bid by submitting their price and delivery time proposals for fulfilling all the necessities of subproject 1. Enterprise background information in terms of past performance and service are called from OMAVE system's database. These data are gathered in a table like Table 4.6.

Table 4.6. Bidding information of subproject 1

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
A	60000	13	0.82	0.9
B	59000	13	0.92	0.8
C	58500	14	0.84	0.8
D	61000	12	0.85	0.76
E	58000	14	0.6	0.72
F	56000	16	0.58	0.55
H	53500	13	0.5	0.65
I	62000	14	0.7	0.64
Min	53,500	12.00	0.50	0.55
Max-Min	8,500	4.00	0.42	0.35

Table 4.6 is normalized according to Min-Max normalization technique. Accordingly, the normalized matrix of bidding scores would be as Table 4.7 .

Table 4.7. Normalized bidding information of subproject 1

Enterprise	Price	Delivery time	Past performance	Service
A	0.765	0.250	0.762	1.000
B	0.647	0.250	1.000	0.714
C	0.588	0.500	0.810	0.714
D	0.882	0.000	0.833	0.600
E	0.529	0.500	0.238	0.486
F	0.294	1.000	0.190	0.000
H	0.000	0.250	0.000	0.286
I	1.000	0.500	0.476	0.257

After this, the core decision making step begins to aggregate these data into a single score for each enterprise.

Step 5. Fuzzy Logic:

In this step Mamdani's fuzzy inference system would be employed. First, crisp values of Table 4.7 would be fuzzified based on their corresponding membership functions. Then fuzzy rules are applied to evaluate and aggregate the inputs. The resultant value is the partnership chance of candidates. Fuzzy logic tool box of MATLAB software is used to conduct these calculates and the final result is obtained as shown in Table 4.8.

Table 4.8. Partnership chance of candidates of subproject 1 for scenario I

Enterprise	Partnership Chance
A	0.5
B	0.642
C	0.6818
D	0.4981
E	0.3172
F	0.5048
H	0.5
I	0.2818

The final scores are sorted in descending order as Table 4.9 and Enterprise C is announced as the winner of bid for subproject 1.

Table 4.9. Ranking list of candidates of subproject 1 for scenario I

Rank	Enterprise	Partnership Chance %
1	C	68.18
2	B	64.2
3	F	50.48
4	C	50
5	H	50
6	I	49.81
7	E	31.72
8	F	28.18

Now, the enterprise responsible for subproject 2 should be detected.

4.2.1.2 Fuzzy Logic based Partner Selection of Subproject 2 for Scenario I

Subproject 2 is the group of tasks for producing a plastic handle of the toolbox. Now the algorithm, searches for qualified candidates to join the bidding and choose the best alternative among them.

Step 1, 2 and 3. Technical, prerequisite and DEA eliminations:
VE enterprise pool, has 5 members working in plastic moulding industry cluster and all of them own ISO 9001 certificate. Hence all of them are eligible to bid for the subproject. (Notice that, DEA stage is skipped, since the method is capable of handling 5 alternatives without any eliminations).

Step 4. Bidding:
Bidding proposals of subproject 2 and their normalized values are gathered in Table 4.10 and Table 4.11 respectively.

Table 4.10. Bidding information of subproject 2

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
L	41000	7	0.9	0.7
M	38200	8	0.82	0.75
N	40100	7	0.88	0.8
O	42000	6	0.68	0.65
P	35200	9	0.72	0.7
Min	35,200	6.00	0.68	0.65
Max-Min	6,800	3.00	0.22	0.15

Table 4.11. Normalized bidding values of subproject 2

Enterprise	Price	Delivery time	Past performance	Service
L	0.853	0.333	1.000	0.333
M	0.441	0.667	0.636	0.667
N	0.721	0.333	0.909	1.000
O	1.000	0.000	0.000	0.000
P	0.000	1.000	0.182	0.333

Step 5. Fuzzy Logic:

According to customer I's preferences fuzzy rules are established and by applying Mamdani's technique in fuzzy logic toolbox of MATLAB, partnership chance of each candidate enterprise is calculated. And consequently enterprise M is accepted as the winner of this bid as demonstrated in Table 4.12 and Table 4.13.

Table 4.12. Partnership chance of candidates of subproject 2 for scenario I

Enterprise	Partnership Chance
L	0.4267
M	0.5617
N	0.5569
O	0.13
P	0.5

Table 4.13. Ranking list of candidates of subproject 2 for scenario I

Rank	Enterprise	Partnership Chance %
1	M	57.1
2	N	55.7
3	P	50
4	L	42.6
5	O	13

4.2.1.3 Fuzzy Logic based Partner Selection of Subproject 3 for Scenario I

Subproject 3 is the operation of painting the toolbox. Following the same procedure, model searches for enterprises which will take the responsibility of subproject 3.

Step 1, 2 and 3. Technical, prerequisite and DEA eliminations:

Exploring the VE pool reveals that there are four technically qualified enterprises certified with ISO 9001. Without the need for DEA elimination, negotiation starts and proposals are collected.

Step 4. Bidding:

Table 4.14 and Table 4.15 illustrate raw and normalized scores of bidders.

Table 4.14. Bidding information of subproject 3

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
R	11800	6	0.8	0.58
S	12000	5	0.68	0.46
T	12500	5	0.72	0.48
U	11400	6	0.7	0.44
Min	11,400	5.00	0.68	0.44
Max-Min	1,100	1.00	0.12	0.14

Table 4.15. Normalized bidding values of subproject 3

Enterprise	Price	Delivery time	Past performance	Service
R	0.36	1.0	1.0	1.0
S	0.54	0.0	0.0	0.14
T	1.0	0.0	0.33	0.29
U	0.0	1.0	0.17	0.0

Evaluation of bids will be done in the next step.

Step 5. Fuzzy Logic:

By applying proposed fuzzy logic technique and obtaining Table 4.16 and Table 4.17, Enterprise R is detected as winner of subproject 3.

Table 4.16. Partnership chance of candidates of suproject 3

Enterprise	Partnership Chance
R	0.8283
S	0.1885
T	0.1739
U	0.5

Table 4.17. Ranking list of candidates of subproject 3 for scenario I

Rank	Enterprise	Partnership Chance %
1	R	82.8
2	S	50
3	T	18
4	U	17

4.2.1.4 Consortium of Scenario I

According to partner selection of subprojects 1, 2 and 3, enterprises C, M and R are chosen as the best candidates to enroll in consortium of upcoming VE project. For the passive customer who out-weighted price of the product followed by the past performance score of manufacturer, the overall characteristics of the main project would be as Table 4.18.

Table 4.18. Details of the consortium for scenario I

	Sub project 1				**Sub project 2**				**Sub project 3**				**Main project**			
	Price	Delivery time	Past performance	Service	Price	Delivery time	Past performance	Service	Price	Delivery time	Past performance	Service	**Price**	**Delivery time**	**Past performance**	**Service**
Partner	C				M				R				C-M-R			
Scores	58,500	14	0.84	0.8	38,200	8	0.82	0.75	11,800	6	0.8	0.58	**108,500**	**28**	**0.82**	**0.71**

Therefore, the finished cost of this OMAVE project is 108,500 TL and it will be finished in 28 days. The average past performance and service scores of partners are 0.82 out of 1 and 0.71 out of 1 respectively.

Figure 4.3. VE consortium for scenario I

Although fuzzy logic gives satisfactory results for highly uncertain situations, usually customers are concerned enough to take the survey for acquiring more reliable results.

4.2.2 Scenario II - Standard customer

Considering the customer attitude, first of all, VE system operator asks buyer, the quantity of demand and preferred delivery date. In this sample test, customer II declares that he/she wants 120 parts within 28 days. Analyzing the manufacturing necessities, operation time to complete the order are estimated. It is found that, individual enterprises would be able to take the responsibility of the subproject and there is no need to multi-sourcing

The next step is to know that if the customer is willing to carry on the questionnaire to find out the weights for his preferences. Customer declares that he eagerly take time to answer the questions. Hence, Customer II is a typical customer of VE.

Table 4.19 shows the answers of customer II to the pairwise comparisons of evaluation criteria. These data are gathered in a Matrix as Eq. 4.1.

Table 4.19. Customer II's questionnaire

Criterion A	Criterion A is Extremely more important than B	Criterion A is Very Strongly more important than B	Criterion A is Strongly more important than B	Criterion A is Weakly more important than B	Criterion A is Equally important as Criterion B	Criterion B is Weakly more important than A	Criterion B is Strongly more important than A	Criterion B is Very Strongly more important than A	Criterion B is Extremely more important than A	Criterion B
Product's Price	☐	☐	☐	☐	☑	☐	☐	☐	☐	Order's Delivery time
Product's Price	☐	☐	☐	☑	☐	☐	☐	☐	☐	Manufacturer's Past performance
Product's Price	☐	☐	☑	☐	☐	☐	☐	☐	☐	Manufacturer's Service level
Order's Delivery time	☐	☐	☐	☐	☑	☐	☐	☐	☐	Manufacturer's Past performance
Order's Delivery time	☐	☐	☐	☑	☐	☐	☐	☐	☐	Manufacturer's Service level
Manufacturer's Past performance	☐	☐	☐	☐	☑	☐	☐	☐	☐	Manufacturer's Service level

$$A_I = \begin{bmatrix} \tilde{1} & \tilde{1} & \tilde{3} & \tilde{5} \\ 1/\tilde{1} & \tilde{1} & \tilde{1} & \tilde{3} \\ 1/\tilde{3} & 1/\tilde{1} & \tilde{1} & \tilde{1} \\ 1/\tilde{5} & 1/\tilde{3} & 1/\tilde{1} & \tilde{1} \end{bmatrix}$$ Eq. 4.1

First row and column of Matrix A are price. Delivery time, past performance and service factors are assigned to second, third and fourth rows and column of this matrix respectively.

In matrix A, $a_{12}=\tilde{3}$. This denotes that, the customer believes that price is weakly more important than delivery time. Similarly, $a_{23}=\tilde{5}$ means, delivery time is strongly important than past performance.

Prior to pursuing to the next step the reliability of respondent's answers should be checked regarding Eq. 3.11 and Eq. 3.12. Considering matrix A, λ_{max} is equal to 4.203. Equations below show the governing calculations to derive the Consistency Ratio (C.R). Random Index (R.I) for 4 parameters is equal to 0.9 (Saaty T. , 1980).

$$C.I. = \frac{\lambda_{max} - 4}{4 - 1} = \frac{4.203 - 4}{4 - 1} = 0.068$$ Eq. 4.2

$$C.R. = \frac{C.I.}{R.I.} = \frac{0.068}{0.9} = 0.075$$ Eq. 4.3

Since $C.R. < 0.1$ the consistency check validates the answering logic. If C.R. was greater or equal to 0.1, the customer we be asked to judge and decide again more carefully.

The elements of Matrix A was fuzzy numbers which have to be converted to triangular fuzzy scales shown with Eq. 4.4.

Eq. 4.4

$$A_I = \begin{bmatrix} (1,1,1) & (1,1,3) & (1,3,5) & (3,5,7) \\ (0.33,1,1) & (1,1,1) & (1,1,3) & (1,3,5) \\ (0.2,0.33,1) & (0.33,1,1) & (1,1,1) & (1,1,3) \\ (0.14,0.2,0.33) & (0.2,0.33,1) & (0.33,1,1) & (1,1,1) \end{bmatrix}$$

Now, Buckley's fuzzy-AHP method could be applied regarding Eq. 3.14 and Eq. 3.15. Consequently, aggregated fuzzy weight of each criterion is calculated as Eq. 4.5.

$$\begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \end{bmatrix} = \begin{bmatrix} (0.18,0.43,1.11) \\ (0.1,0.29,0.68) \\ (0.07,0.17,0.45) \\ (0.04,0.112,0.26) \end{bmatrix} \quad \text{Eq. 4.5}$$

These fuzzy weights are defuzzified, applying "center of area defuzzification method". Then, they are normalized so that they sum up to 1. Table 4.20 demonstrates the final results of discovering customer preferences.

Table 4.20. Preference weights of customer II

	Fuzzified weights	**Normalized weights**
Price	0.573	**0.441**
Delivery time	0.358	**0.275**
Past performance	0.230	**0.177**
Service	0.139	**0.107**

These mean that, customer II, focuses on price, about 44% of all the factors while deciding for a purchase, caring about delivery time, past performance and service by 27%, 17% and 10% respectively.

Customer is also asked to reveal the prerequisite if there is any. And customer II has emphasized on cooperating with firms certified by ISO 9001 standard only. The information of customer II is gathered in Table 4.21 so to be used in the next steps of decision making.

Table 4.21. customer II's attitude

Prerequisite	ISO 9001			
Customer type	Standard			
Criteria preference	P	Del. T	Past. P	S
Criteria preference weight	44.1%	27.5%	17.7%	10.7%

4.2.2.1 F-AHP TOPSIS based Partner Selection of Subproject 1 for Scenario II

Subproject 1 is defined as group of tasks to operate metal working processes.

Step 1, 2 and 3. Technical, prerequisite and DEA eliminations:

Similar to partner selection of subproject 1 in the previous scenario (passive customer), technically eligible partners which own ISO 9001 are detected. There exists 12 qualified enterprises in the system, though DEA reveals that 2 of them are inefficient. Call for bids are sent to the efficient enterprises which are listed in Table 4.5 . These steps are exactly like what previously demonstrated in step 3 of chapter 4.2.1.1 so we do not repeat the calculations once more.

Step 4. Bidding:

Bidding proposals and performance scores of enterprises A, B, C, D, E, F, H and I are collected in Table 4.22.

Table 4.22. Bidding information of subproject 1

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
A	60000	13	0.82	0.9
B	59000	13	0.92	0.8
C	58500	14	0.84	0.8
D	61000	12	0.85	0.76
E	58000	14	0.6	0.72
F	56000	16	0.58	0.55
H	53500	13	0.5	0.65
I	62000	14	0.7	0.64
Sum of squares	27,430,500,000	1,495	4	4

Table 4.22 is normalized according to Euclidean normalization technique, so the normalized matrix of bidding scores are calculates as Table 4.23 .

Table 4.23. Normalized bidding values of subproject 1

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
A	0.362	0.336	0.392	0.433
B	0.356	0.336	0.439	0.385
C	0.353	0.362	0.401	0.385
D	0.368	0.310	0.406	0.366
E	0.350	0.362	0.287	0.346
F	0.338	0.414	0.277	0.265
H	0.323	0.336	0.239	0.313
I	0.374	0.362	0.334	0.308

From this step on, the core decision making step of partner selection begins.

Step 5. TOPSIS:

Customer II is a standard customer so TOPSIS technique would be used to evaluate the candidates.

Table 4.24. Weighted normalized valuess of candidates of subproject 1 for scenario II

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
A	0.160	0.093	0.069	0.046
B	0.157	0.093	0.078	0.041
C	0.156	0.100	0.071	0.041
D	0.162	0.085	0.072	0.039
E	0.154	0.100	0.051	0.037
F	0.149	0.114	0.049	0.028
H	0.142	0.093	0.042	0.033
I	0.165	0.100	0.059	0.033

Referring to the concept of TOPSIS method, Positive Ideal Solution and Negative Ideal Solution are defined from scores of Table 4.24. Hence, PIS and NIS are as below;

PIS= [0.142, 0.085, 0.078, 0.046] , NIS= [0.165, 0.114, 0.042, 0.028]

The overall score of each enterprise is dependent to its Euclidean distance from PIS and NIS and calculated regarding Eq. 3.21- Eq. 3.23.

Table 4.25. Subproject 1's candidate's closeness to ideal solutions

Enterprise	Distance from PIS	Distance from NIS	Closeness
A	0.021	0.039	0.657
B	0.017	0.044	0.721
C	0.021	0.036	0.628
D	0.022	0.043	0.659
E	0.034	0.022	0.387
F	0.045	0.017	0.279
H	0.038	0.032	0.450
I	0.035	0.023	0.391

Closeness ratio is the final score which enterprises are going to be ranked based on. Winner of the auction is the candidate with highest closeness ratio. Referring Table 4.26, Enterprise B is the candidate which suits more to what customer wants and it would be responsible to carry on the subprojects necessities in this round of VE consortium.

Table 4.26. Ranking list of candidates of subproject 1 for scenario II

Rank	Enterprise	Closeness (%)
1	B	72.1
2	D	65.9
3	A	65.7
4	C	62.8
5	H	45.0
6	I	39.1
7	E	38.7
8	F	27.9

By applying the integrated fuzzy-AHP TOPSIS technique the best enterprise to allocate the metal working subproject is identified. These evaluation steps should also followed to find the partners for two remaining subprojects; plastic moulding and coating.

4.2.2.2 F-AHP TOPSIS based Partner Selection of Subproject 2 for Scenario II

To implement the fuzzy-AHP TOPSIS methodology for subproject 2, it has gone through the same steps as subproject 1, for different set of participants.

Step 1, 2 and 3. Technical, prerequisite and DEA eliminations:

VE enterprise pool, has 5 members certified with ISO 9001 certificate and working in plastic forming industry cluster. The eligible enterprises are invited to submit their proposals for the subproject (Notice that DEA is skipped).

Step 4. Bidding:

After gathering the proposals for bid, Table 4.27 and Table 4.28 are organized.

Table 4.27. Bidding information of subproject 2

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
L	41000	7	0.9	0.7
M	38200	8	0.82	0.75
N	40100	7	0.88	0.8
O	42000	6	0.68	0.65
P	35200	9	0.72	0.7
Sum of squares	7,751,290,000	279	3	3

Table 4.28. Normalized bidding vales of subproject 2

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
L	0.466	0.419	0.500	0.434
M	0.434	0.479	0.456	0.465
N	0.455	0.419	0.489	0.496
O	0.477	0.359	0.378	0.403
P	0.400	0.539	0.400	0.434

Step 5. TOPSIS

Following tables show the TOPSIS method's calculations one by one, till concluding the final results based on descriptions of chapter 3.8.

Table 4.29. Weighted normalized vales of candidates of subproject 2 for scenario II

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
L	0.205	0.115	0.089	0.046
M	0.191	0.132	0.081	0.050
N	0.201	0.115	0.087	0.053
O	0.210	0.099	0.067	0.043
P	0.176	0.148	0.071	0.046
PIS	0.176	0.099	0.089	0.053
NIS	0.210	0.148	0.067	0.043

Table 4.30. Subproject 2's candidate's closeness to ideal solutions

Enterprise	Distance from PIS	Distance from NIS	Closeness
L	0.034	0.040	0.540
M	0.037	0.029	0.442
N	0.030	0.041	0.579
O	0.042	0.049	0.543
P	0.053	0.034	0.394

Table 4.31. Ranking list of candidates of subproject 2 for scenario II

Rank	Enterprise	Closeness (%)
1	N	57.9
2	O	54.3
3	L	54.0
4	M	44.2
5	P	39.4

According to Table 4.31 the winner of the negotiation for subproject 2 is enterprise "N" which proposed 40100 Liras for delivery within 7 days.

4.2.2.3 F-AHP TOPSIS based Partner Selection of Subproject 3 for Scenario II

In order to find the winner of coating tasks (subproject 3) the similar trend is followed.

Step 1, 2 and 3. Technical, prerequisite and DEA eliminations:

There exist just four enterprises, which are capable of coating operation and own ISO 9001 certificate. Similar to subproject 2, since the number of qualified enterprises are less than 10, DEA step is skipped and call for proposal is sent to candidates.

Step 4. Bidding:

Bidding proposals are gathered and normalized as Table 4.32 and Table 4.33.

Table 4.32. Bidding information of subproject 3

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
R	11800	6	0.8	0.58
S	12000	5	0.68	0.46
T	12500	5	0.72	0.48
U	11400	6	0.7	0.44
Sum of squares	569,450,000	122	2	1

Table 4.33. Normalized bidding values of subproject 3

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
R	0.494	0.543	0.551	0.588
S	0.503	0.453	0.468	0.467
T	0.524	0.453	0.496	0.487
U	0.478	0.543	0.482	0.446

Step 5. TOPSIS:

By applying TOPSIS technique as below tables, finally enterprise "S" is announced as the winner of the coating subproject.

Table 4.34. Weighted normalized values of candidates of subproject 3 for scenario II

Enterprise	Price (TL)	Delivery time (days)	Past performance	Service
R	0.494	0.543	0.551	0.588
S	0.503	0.453	0.468	0.467
T	0.524	0.453	0.496	0.487
U	0.478	0.543	0.482	0.446
PIS	0.211	0.125	0.098	0.063
NIS	0.231	0.149	0.083	0.048

Table 4.35. Subproject 3's candidate's closeness to ideal solutions

Enterprise	Distance from PIS	Distance from NIS	Closeness
R	0.026	0.025	0.488
S	0.023	0.027	0.542
T	0.025	0.026	0.507
U	0.032	0.020	0.393

Table 4.36. Ranking list of candidates of subproject 3 for scenario II

Rank	Enterprise	Closeness (%)
1	S	54.2
2	T	50.7
3	R	48.8
4	U	39.3

4.2.2.4 Consortium of Scenario II

Within the framework of this VE project, enterprise B, N and S will cooperate with each other to complete the production of the order. The final cost would be 111,000 TL and its delivery due is 25 days.

Figure 4.4. VE consortium for scenario II

Table 4.37. Details of consortium for scenario II

	Sub project 1				Sub project 2				Sub project 3				**Main project**			
	Price	Delivery time	Past performance	Service	Price	Delivery time	Past performance	Service	Price	Delivery time	Past performance	Service	**Price**	**Delivery time**	**Past performance**	**Service**
Partner	B				N				S				B-N-S			
Scores	59,000	13	0.92	0.8	40,100	7	0.88	0.8	12,000	5	0.68	0.46	**111,100**	**25**	**0.82**	**0.68**

4.2.3 Scenario III - Assertive customer

Dissimilar to previous customers, customer III rushes to VE administrative office asking for an order which cannot be fulfilled simply. This customer requests receiving 120 products within only 22 days. According to the schedule prepared by VE's production planning experts, this delivery due is equal to almost half of the time required to respond to the order and it is not possible unless more than one enterprises are involved in performing each subproject. Hence, this case requires multi- sourcing and it is going to be solved by GP- based approach.

In GP approach, not only criteria's importance weight should be submitted by customer, but also he should determine his delivery time dependent goals for price.

Customer III accepts paying 200,000 Liras for delivery within 22 days, however only 220,000Liras will be paid if the delivery is within 18 Days. So first request is recorded as Goal 1 and the latter is Goal 2.

The questionnaire filled out by customer III is as Table 4.38.

Table 4.38. Customer III's questionnaire

Criterion A	Criterion A is Extremely more important than B	Criterion A is Very Strongly more important than B	Criterion A is Strongly more important than B	Criterion A is Weakly more important than B	Criterion A is Equally important as Criterion B	Criterion B is Weakly more important than A	Criterion B is Strongly more important than A	Criterion B is Very Strongly more important than A	Criterion B is Extremely more important than A	Criterion B
Product's Price	☐	☐	☐	☐	☐	☐	☑	☐	☐	Order's Delivery time
Product's Price	☐	☐	☐	☐	☐	☑	☐	☐	☐	Manufacturer's Past performance
Product's Price	☐	☐	☐	☐	☑	☐	☐	☐	☐	Manufacturer's Service level
Order's Delivery time	☐	☐	☐	☑	☐	☐	☐	☐	☐	Manufacturer's Past performance
Order's Delivery time	☐	☑	☐	☐	☐	☐	☐	☐	☐	Manufacturer's Service level
Manufacturer's Past performance	☐	☐	☑	☐	☐	☐	☐	☐	☐	Manufacturer's Service level

These data are interpreted to create the matrix A_{III} shown with Eq. 4.6. In this matrix, $a_{21}=\tilde{5}$ and $a_{31}=\tilde{3}$ which denoting that customer believes that delivery time is strongly more important than price and weakly more important than past performance. And so on.

$$A_{III} = \begin{bmatrix} \tilde{1} & 1/\tilde{5} & 1/\tilde{3} & \tilde{1} \\ \tilde{5} & \tilde{1} & \tilde{3} & \tilde{7} \\ \tilde{3} & 1/\tilde{3} & \tilde{1} & \tilde{5} \\ 1/\tilde{1} & 1/\tilde{7} & 1/\tilde{5} & \tilde{1} \end{bmatrix} \quad \text{Eq. 4.6}$$

Consistency Ratio (C.R) of customer III's answers are 0.048 Hence, the judgements are trustworthy.

$$C.I. = \frac{\lambda_{max} - 4}{4 - 1} = \frac{4.13 - 4}{4 - 1} = 0.043 \quad \text{Eq. 4.7}$$

$$C.R. = \frac{C.I.}{R.I.} = \frac{0.43}{0.9} = 0.048 \quad \text{Eq. 4.8}$$

Following equations shows the governing calculations for deriving the customer's preference weights summarized in Table 4.39.

$$A_{II} = \begin{bmatrix} (1,1,1) & (0.14,0.2,0.33) & (0.2,0.33,1) & (1,1,3) \\ (3,5,7) & (1,1,1) & (1,3,5) & (5,7,9) \\ (1,3,5) & (0.2,0.3,1) & (1,1,1) & (3,5,7) \\ (0.33,1,1) & (0.11,0.14,0.2) & (0.14,0.2,0.33) & (1,1,1) \end{bmatrix} \quad \text{Eq. 4.9}$$

$$\begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \end{bmatrix} = \begin{bmatrix} (0.05, 0.09,0.28) \\ (0.24,0.57,1.19) \\ (0.11,0.27,0.69) \\ (0.03,0.07,0.14) \end{bmatrix} \quad \text{Eq. 4.10}$$

Table 4.39. Preference weights of customer III

	Fuzzified weights	**Normalized weights**
Price	0.141	**0.113**
Delivery time	0.668	**0.536**
Past performance	0.354	**0.284**
Service	0.083	**0.067**

These weights show that, not surprisingly, delivery time is the most role playing factor for customer III. The second most influential factor for customer's decision is the past performance of the company. Because past performance score is also representing the commitment level of the company in its previous works. Higher the past performance score is, Easier VE can trust the enterprise promises in terms of quality and delivery. So the next determinant parameter is past performance. Followed by price and service.

All the aspects influencing decision maker's attitude are gathered in Table 4.40.

Table 4.40. Customer III's attitude

Prerequisite	ISO 9001			
Customer type	Assertive			
Criteria preference sequence	Del. T	Past. P	P	S
Criteria preference weight	49.1 %	25.3%	20.5%	5%
Goal 1	22days		200,000 Liras	
Goal 2	18days		220,000 Liras	

Partner selection algorithm tries to bring together the best possible alternative based on customer's targets.

4.2.3.1 F-AHP GP Partner Selection of Subproject 1 for Scenario III

By knowing the customer attitude, now the appropriate set of partners should be selected for subproject 1. Initial steps are exactly like two previous partner selection methods.

Step 1, 2 and 3. Technical, prerequisite and DEA eliminations:

System collects the members which are qualified and efficient enough to participate in bid. (These steps have been presented in chapter 4.2.1.1 and the detailed calculations are skipped to avoid the repetition).

Step 4. Bidding

Call for bid is sent to the enterprises listed in Table 4.5. However, this time, bidding is unlike previous techniques. Enterprises C, H and I refuse to respond to the bid's invitations due to these reasons;

1. Enterprise C's management is not sure whether they can finish the job at until the due date. So they decide not to risk their reputation.
2. Enterprise H does not have empty capacity for operating the processes in near future.
3. Enterprise I's management do not want to change the production schedule which they have already planned for.

In contrary, rest of enterprises try to grab the chance to load their current unfilled capacities and gaining extra profit. Volunteered companies can propose different bids (price and delivery times) for different quantities of order. Bidding information gathered from enterprises are as Table 4.41.

Table 4.41. Bidding input data for subproject 1

Enterprise	indices	Quantity	Price Per part	Delivery domain Start	End	Past performance	Service
A	X_{11}	[5-30]	1300	5	6	0.82	0.9
	X_{12}	(30-70]	1060	6	8	0.82	0.9
	X_{13}	(70-100]	1100	8	11	0.82	0.9
B	X_{21}	[40-60]	1350	6	7	0.92	0.8
	X_{22}	(60-90]	1200	7	8	0.92	0.8
	X_{23}	(90-110]	1380	8	12	0.92	0.8
D	X_{31}	[15-40]	1250	4	5	0.85	0.76
	X_{32}	(40-75]	1100	5	7	0.85	0.76
	X_{33}	(75-110]	1300	7	12	0.85	0.76
E	X_{41}	[10-40]	1220	4	5	0.6	0.72
	X_{42}	(40-70]	1350	7	11	0.6	0.72
F	X_{51}	[70-100]	1280	8	10	0.58	0.55

Step 5. Goal programming:

It is beneficial to emphasis that, in severe bidding conditions, it is too risky to completely rely on what enterprises proposed for the delivery time. So it is suggested to apply normal distribution function to estimate the probability of delivering the order on time. Hence, raw data of Table 4.41 will be interpreted to what is going to be used in modeling. "Delivery reliability" score of each proposal is calculated regarding Eq. 3.51- Eq. 3.53 and accordingly Table 4.42 is constructed.

Table 4.42 contains the information which is going to be used in GP modelling.

Table 4.42. Bidding input data for subproject 1 interpreted by the system

Enterprise	indices	Quantity	Price per part	Delivery reliability for goal 1	Delivery reliability for goal 2	Past performance	Service
A	X_{11}	[5-30]	1300	1.000	1.00	0.82	0.9
	X_{12}	(30-70]	1060	1.000	1.00	0.82	0.9
	X_{13}	(70-100]	1100	0.999	0.84	0.82	0.9
B	X_{21}	[40-60]	1350	1.000	1.00	0.92	0.8
	X_{22}	(60-90]	1200	1.00	1.00	0.92	0.8
	X_{23}	(90-110]	1380	0.93	0.50	0.92	0.8
D	X_{31}	[15-40]	1250	1.00	1.00	0.85	0.76
	X_{32}	(40-75]	1100	1.00	1.00	0.85	0.76
	X_{33}	(75-110]	1300	0.96	0.73	0.85	0.76
E	X_{41}	[10-40]	1220	1.00	1.00	0.6	0.72
	X_{42}	(40-70]	1350	1.00	0.93	0.6	0.72
F	X_{51}	[70-100]	1280	1.00	1.00	0.58	0.55

GP model tries to find that, which enterprises should be chosen to perform the manufacturing operations of subproject 1 and how many products does each have to produce.

Based on goals determined by customer for the main project, VE experts calculate the goal sets for subprojects. So, GP model for subproject 1 has to be solved once for goal set of [price, delivery] = [120000 Liras, (9-11days)] and once for goal set of [price, delivery] = [140000 Liras, (7-10days)].

Mathematical model of this problem is formulated in Lingo software and solved once, for goal set 1, and optimal solution is obtained as below;

X_{12}=70, X_{32}=50

Next, the model is formulated for goal set 2, resulting in following solution;

X_{21}=30, X_{22}=90

Table 4.43 and Table 4.44 show the partners of subproject 1 for goal set 1 and 2 respectively.

Table 4.43. Selected partners of subproject 1 for goal set 1 of scenario III

Delivery goal	9-11 days					
Price goal	120,000 Liras					
Enterprises	A	B	D	E	F	
Order quantities	**70**	**0**	**50**	**0**	**0**	**120**
Price	1060	-	1100	-	-	**129200**
Delivery trust	1	-	1	-	-	**1**
Pat performance	0.82	-	0.85	-	-	**0.833**
Service	0.9	-	0.76	-	-	**0.842**

Table 4.44. Selected partners of subproject 1 for goal set 2 of scenario III

Delivery goal	7-10 days					
Price goal	140,000 Liras					
Enterprises	A	B	D	E	F	
Order quantities	**30**	**90**	**0**	**0**	**0**	**120**
Price	1060	1200	-	-	-	**139800**
Delivery trust	1	1	-	-	-	**1**
Pat performance	0.82	0.92	-	-	-	**0.9**
Service	0.9	0.8	-	-	-	**0.825**

The second goal of the customer is to pay more money for earlier delivery. And the results shown in Table 4.43 and Table 4.44 matches with these expectations. The model recommends a cooperation which provides earlier delivery with more reliable enterprises (in terms of past performance) if the customer accepts to pay more money for the order. Both alternatives would be presented to the decision maker to decide.

4.2.3.2 F-AHP GP based Partner Selection of Subproject 2 for scenario III

Partner selection of subproject 2 follows the same trend as previous subproject. First operationally qualified enterprises should be detected and invited to the negotiation.

Step 1, 2 and 3. Technical, prerequisite and DEA eliminations:

There are 5 enterprises existing in VBE who can fulfill the necessities of subproject 2. Enterprises L, M, N, O and P are invited to participate in negotiation. In spite of the tight schedule, luckily all of them are volunteered to take the job.

Step 4. Bidding

Each manufacturer has its own strategies to estimate the finished cost of operation so various quantity- based proposals are received from bidders and tabulated in Table 4.45.

Table 4.45. Bidding input data for subproject 2

Enterprise	indices	Quantity	Price Per part	Delivery domain Start-	End	Past performance	Service
L	X_{11}	[20-30]	590	1	2	0.9	0.7
	X_{12}	(30-60]	480	1	2	0.9	0.7
	X_{13}	(60-110]	520	4	6	0.9	0.7
	X_{14}	(110-120]	570	4	7	0.9	0.7
M	X_{21}	[40-60]	510	2	3	0.82	0.75
	X_{22}	(60-100]	500	4	5	0.82	0.75
N	X_{31}	[10-20]	560	2	3	0.88	0.8
	X_{32}	(20-80]	550	3	5	0.88	0.8
	X_{33}	(80-100]	520	4	5	0.88	0.8
O	X_{41}	[10-40]	510	1	3	0.68	0.65
	X_{42}	(40-90]	490	3	6	0.68	0.65
	X_{43}	(90-110]	520	3	7	0.68	0.65
P	X_{51}	[30-50]	530	3	4	0.72	0.7
	X_{52}	(50-90)	500	3	7	0.72	0.7

Due to the importance of delivery time in this case, on time delivery "reliability" is calculated according to the proposals. However, bids are evaluated based on the reliability score, rather than proposals itself. As an example, for goal 1 of customer, desired delivery domain is 4 to 6 days. Enterprise L proposed 4 to 7 day delivery due for producing 110 to 120 parts. In this circumstances, the probability of completing the task within 4 to 6 days by enterprise L is 84 %. On time delivery tryst score of each enterprise proposal is calculated with respect to, two different customer goals and the results are tabulated in Table 4.46.

Table 4.46. Bidding input data for subproject 2 interpreted by the system

Enterprise	indices	Quantity	Price Per part	Delivery reliability For goal 1	Delivery reliability For goal 2	Past performance	Service
L	X_{11}	[20-30]	590	1.00	1.00	0.9	0.7
	X_{12}	(30-60]	480	1.00	1.00	0.9	0.7
	X_{13}	(60-110]	520	0.99	0.50	0.9	0.7
	X_{14}	(110-120]	570	0.84	0.16	0.9	0.7
M	X_{21}	[40-60]	510	1.00	1.00	0.82	0.75
	X_{22}	(60-100]	500	1.00	1.00	0.82	0.75
N	X_{31}	[10-20]	560	1.00	1.00	0.88	0.8
	X_{32}	(20-80]	550	1.00	1.00	0.88	0.8
	X_{33}	(80-100]	520	1.00	1.00	0.88	0.8
O	X_{41}	[10-40]	510	1.00	1.00	0.68	0.65
	X_{42}	(40-90]	490	0.99	0.84	0.68	0.65
	X_{43}	(90-110]	520	0.93	0.50	0.68	0.65
P	X_{51}	[30-50]	530	1.00	1.00	0.72	0.7
	X_{52}	(50-90)	500	0.93	0.93	0.72	0.7

Step 5. Goal programming:

Adapting mathematical formulation of goal programming on Lingo software and running it for each goal set of customer results in Table 4.47 and Table 4.48.

For goal 1, X_{12}=60, X_{21}=40 and others are zero.

For goal 2, X_{12}=60, X_{21}=40, X_{32}=20 and others are zero.

Table 4.47. Selected partners of subproject 2 for goal set 1 of scenario III

Enterprises	L	M	N	O	P	
Order quantities	**60**	**60**	**0**	**0**	**0**	**120**
Price	480	510	-	-	-	**59400**
Delivery trust	1	1	-	-	-	**1**
Pat performance	0.9	0.82	-	-	-	**0.86**
Service	0.7	0.75	-	-	-	**0.725**

Table 4.48. Selected partners of subproject 2 for goal set 2 of scenario III

Enterprises	L	M	N	O	P	
Order quantities	**60**	**40**	**20**	**0**	**0**	**120**
Price	480	510	550	-	-	**60200**
Delivery trust	1	1	1	-	-	**1**
Pat performance	0.9	0.82	0.88	-	-	**0.87**
Service	0.7	0.75	0.8	-	-	**0.733**

4.2.3.3 F-AHP GP based Partner Selection of Subproject 3 for Scenario III

Similar to what has been studied in previous chapters, evaluation and selection of partners for third subproject would be carried on.

Step 1, 2, 3 and 4. Technical, prerequisite, DEA eliminations and Bidding:

By receiving the bidding proposals from enterprises which are eligible, efficient and agreed to perform the necessities of plastic moulding subproject, Table 4.49 is constructed.

Table 4.49. Bidding input data for subproject 3

Enterprise	indices	Quantity	Price Per part	Delivery domain Start- End		Past performance	Service
R	X_{11}	[10-50]	190	1	2	0.8	0.58
	X_{12}	(50-110]	200	2	3	0.8	0.58
S	X_{21}	[1-50]	185	1	2	0.68	0.46
	X_{22}	(50-100]	180	2	3	0.68	0.46
T	X_{31}	[80-120]	210	2	4	0.72	0.48
U	X_{41}	[10-60]	180	1	2	0.7	0.44
	X_{42}	(60-80]	170	1	3	0.7	0.44

Step 5. Goal programming:

As a job with 2-3 days' work, subproject 3 does not have a great impact on main project's delivery time so analyzing the proposals based on a single goal would be enough. Actually this decision is settled regarding the instructions of VE production scheduling experts. Needless to differentiate the two goal sets, model can be run and optimized regarding the data tabulated in Table 4.50 and Table 4.51.

Table 4.50. Bidding input data for subproject 3 interpreted by the system

Enterprise	indices	Quantity	Price Per part	On time Delivery reliability	Past performance	Service
R	X_{11}	[10-50]	190	1	0.8	0.58
	X_{12}	(50-110]	200	1	0.8	0.58
S	X_{21}	[1-50]	185	1	0.68	0.46
	X_{22}	(50-100]	180	1	0.68	0.46
T	X_{31}	[80-120]	210	0.5	0.72	0.48
U	X_{41}	[10-60]	180	1	0.7	0.44
	X_{42}	(60-80]	170	1	0.7	0.44

Table 4.51. Selected partners of subproject 3

Enterprises	R	S	T	U	
Order quantities	**0**	**40**	**0**	**80**	**120**
Price	0	190	0	170	**21200**
Delivery trust	0	1	0	1	**1**
Pat performance	0	0.68	0	0.7	**0.693**
Service	0	0.46	0	0.44	**0.446**

Regarding Table 4.51, enterprise S and U would be responsible for operating subproject 3.

4.2.3.4 Consortium of Scenario III

Two alternative collaborations of subproject 3 are shown in Table 4.52 and Table 4.53.

Table 4.52. Consortium of scenario III for goal 1

	Sub project 1				Sub project 2				Sub project 3				**Main project**			
	Price	Delivery trust (9,11)	Past performance	Service	Price	Delivery trust(4,6)	Past performance	Service	Price	Delivery trust(2,3)	Past performance	Service	**Price**	**Delivery time**	**Past performance**	**Service**
Partners	A-D				L-M				S-U							
Scores	129200	1	0.833	0.842	59400	1	0.86	0.725	21200	1	0.69	0.45	**209,800**	**1**	**0.8**	**0.67**

Table 4.53. Consortium of scenario III for goal 2

	Sub project 1				Sub project 2				Sub project 3				**Main project**			
	Price	Delivery trust (7,10)	Past performance	Service	Price	Delivery trust (4,5)	Past performance	Service	Price	Delivery trust(2,3)	Past performance	Service	**Price**	**Delivery time**	**Past performance**	**Service**
Partners	A-B				L-M-N				S-U							
Scores	139800	1	0.9	0.825	60200	1	0.87	0.73	21200	1	0.69	0.45	**221,200**	**1**	**0.82**	**0.67**

By presenting these two choices to the customer, the most preferred one could be selected. Customer III prefers to pay 11,000$ more to receive the order 4 days earlier so second goal set is accepted and enterprise A, B, L, M, N, S and U are announced as partners of upcoming consortium as shown in Figure 4.5.

Figure 4.5. VE consortium for scenario III

4.3 Results and Discussion

In this chapter a partner selection methodology of the OMAVE system is studied. In order to cover all the solution techniques developed in this thesis work, three different customers with different attitudes are taken into account. These customers request for same order but they have completely different manners.

The order is production of 120 parts of assembly product, which is defined as the main target of upcoming VE project. Production planning experts decompose the main project into three subprojects. Subproject 1 is the group of metal cutting processes, subproject 2 is coating operation and subproject is the act of producing the plastic handle. Afterwards, VE partner selection algorithm searches for the best partner companies to allocate each subproject.

First step is to find what customer wants and what his/her attitude is. Customer 1 is a passive customer who will not fill the questionnaire preferences but he/she declares caring more about price, past performance, delivery time and service respectively. In this case with high uncertainty, fuzzy logic technique is applied to evaluate the bids of enterprises. In this respect, OMAVE partner identification procedure finds out the eligible enterprises registered in VE and sends the bidding invitation to them. There are 10, 5, 4 volunteered enterprises for participating in performing subproject 1, subproject 2 and subproject 3 respectively.

Their bidding proposals along with their background information are used for evaluation with fuzzy logic method. And based on preferences of this customer, Enterprises C, M and R are selected to be responsible for subproject 1, subproject 2 and subproject 3 respectively. In other words, consortium of VE, for customer I is composed from cooperation of enterprise C, M and R. They operate the tasks they contracted and finish their duties under the inspection of VE supervisors. The assessment results are kept in the system’s database in order to be used in future. Finally, when the project is completed and handed to the customer, VE dissolves.

But, how about if the customer is concerned enough to take the questionnaire? This customer is studied under scenario II, standard type customer. First his preference weights for price, delivery time, past performance and service are 44%, 27 %, 18% and 11%. By having the same bidding proposals form enterprises this time decision making algorithm might suggest different consortium members. By applying fuzzy-AHP TOPSIS method enterprises B, N and S are chosen as winner of negotiations.

The third scenario is a hasty customer whose order cannot be fulfilled under normal conditions within the preferred due dates. So by the confirmation of VE experts, subprojects are opened for bidding. But this time it is not necessarily all of the job would be assigned to each partner, instead enterprises can win the bid for producing just some quantities of the main order. Unlike previous bidding, enterprises are allowed to send their proposals on quantity bases. In fact, it is normal that some enterprises do not agree to participate bidding since they may not have empty capacity or they are just uninterested to change their production schedule. But others try to maximize their profit by winning the bid.

Once the bids are gathered, the optimum combination of enterprises are found by applying GP. Customer III of the case study accepts to pay 221,000 Liras for delivery within 18 days, concluding in consortium of enterprises A, B, L, M, N, S and U.

Certainly, by having excessive number of partners in this VE consortium, it faces more challenges. Though in this way, it will also have chance to draw the customers of Just in Time manufacturing concept. Moreover, it provides a mutual benefit for both VE members with unfilled capacity and customers who are seeking to fulfill their critical request.

Table 4.54 demonstrates the results of applying each technique for each request.

Table 4.54. Comparisons of consortium's results for each case of the study

	Scenario I				Scenario II				Scenario III			
Customer Type	Passive Customer				Standard Customer				Assertive Customer			
Criteria Importance Sequence*	Price	Past Performance	Delivery Time	Service	Price	Delivery Time	Past Performance	Service	Delivery Time	Past Performance	Price	Service
Criteria Preference weight	?	?	?	?	44.1%	27.5%	17.7%	10.7%	49.1%	25.3%	20.5%	5%
Customer Goal	-	-	-	-	-	-	-	-	18days	220,000TL	-	-
Final Consortium's results	108,500TL	0.82	28days	0.71	111,100TL	25days	0.82	0.68	18days	0.82	221,000TL	0.67

* The most important criterion (in customer's view point) is placed in first column, second most important criterion in second column and so on.

When the consortiums are formed up, they perform their responsibilities and by completing all the planned necessities, products are handed to the customer. In last phase, participants of projects are assessed in term of quality of their finished products, their promised delivery dates, communication skills, environmental friendliness and so on. By asking the customer and related staff of VE, each enterprise’s performance score is calculated and saved into systems database to enrich the information regarding enterprises background to be used in future. The final phase inspects the order, handles it to the customer and finishes the project by dissolving the VE.

CHAPTER 5

CONCLUSIONS AND FUTURE WORKS

This study was set out to develop a partner selection methodology in forming VE consortiums. VE as a dynamic cooperation platform among individual SMEs, requires a highly flexibly structure for selecting its partners. Although this issue is a well-researched topic, studies in literature are mainly incapable of maintaining their applicability in different problems with different conditions. A need for a dynamic partner selection technique inspired author to focus on developing a decision making technique which can employ different solution methodologies when the problems characteristics are changed.

For developing a targeted model, Firstly, evaluation criteria hierarchy containing both tangible and intangible parameters is constructed so that enterprises could be evaluated base on four main parameters. Price and delivery time proposals, past performance and service level of responsible manufacturers are placed in first level of hierarchy. Customer's priorities are determined based on these criteria and used for evaluating bidding proposals of bidder enterprises.

The next essential necessity was to involve customer's attitude in decision making process. Hereby, VE customers were classified into three categories; Passive, standard and assertive customer. Passive customer is the one who does not take the questionnaire for finding the preferences. So his/her comments contain high levels of vagueness. The corresponding model for this customer, should be able to give reasonable outcomes even with uncertain inputs. The other type of customer, assertive customer, is the one who asks for fulfillment of his/ her demand in extremely tight time domain. Hence multi sourcing of the subprojects may be needed and partner selection should be able to find the optimum solution for order allocation as well.

Regarding the necessities of each case, three techniques were designed. Fuzzy logic, Fuzzy AHP TOPSIS and Fuzzy AHP Goal programming are the core decision making tools for the proposed multi step partner selection of OMAVE system.

Characteristics of each technique can be summarized as follows:

- Specific membership functions are designed for each input and output of fuzzy logic approach
- Fuzzy logic rules can be edited easily based on customer's preferences, enabling the model to change the policies in a way decision maker prefers.
- F-AHP TOPSIS is an easy programmable, yet effective method to apply in most of VE partner selection projects.
- Unlike fuzzy logic and F-AHP TOPSIS, results of GP are not "ranking" list of candidates. Instead, it shows which enterprises are chosen and how many products are contracted to them.
- In GP, bidding proposals are quantity based. In other words, enterprises propose different selling prices and different delivery dues for different quantities of order.
- In a demand with tight delivery due, enterprise proposals are evaluated regarding "on time delivery reliability" rather than "delivery time" itself.
- GP allows the customer to have different acceptable price limits for different delivery dues and accordingly formulates the problem for each.
- By defining a specific goal points, especially in severe bidding conditions, partner selection technique does not push the limits searching for cheaper bids if the customer accepts to pay more. This trend extends VE systems capability to compromise between customers and enterprises mutually.

The resultant outcomes of the models for variety of customers and various bidding proposals verified the trustworthy of proposed techniques. And finally, this study achieved what has been targeted at the beginning.

5.1 Contributions and limitations

Main novel contributions of this study can be briefly highlighted as follows;

- Developing a partner selection technique for OMAVE framework based on customer’s attitude and preferences.
- Proposing a fuzzy logic based bid evaluation methodology for VE formation under highly uncertain situations.
- Proposing a goal programming based approach for establishing the consortium in an extremely tight delivery dues.

Although this study has addressed the core partner evaluation and selection strategies, yet some complimentary aspects are not covered. For instance, it does not recommend any technique for how to evaluate and score the background performance of enterprises if the firm is a new member of VE without any record about its past. The next absent point is lack of any tool for inspecting the trustworthiness of proposals. Without a controlling system, an enterprise may overestimate its capabilities and suggest competitive proposals by being well ahead of its rivals, hereby it probably wins the bid. But, serious problems would emerge in operation phase.

5.2 Future works

This thesis work studied and proposed partner selection methods for each subproject individually. This work could be expanded, by adding reciprocal relation among partners. Since, firms with conflicting policies may not be able to construct a good cooperation although they are be the best member of their categories.

Moreover, one could search for techniques that do not just optimize an individual subproject but also a whole project. This would increase the complexity of the problem since job sequence and their precedence would need to be taken into account. But surely it will increase the overall performance of the consortium and VE system further.

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APPENDIX A

GENETIC ALGORITHM

Genetic algorithm is a search methodology which is mimics the process of natural selection to find the optimal solution. GA is one the most popular Artificial Intelligence techniques. This methods steps can briefly presented as below (Mitchel, 1999)

1. Encoding of the problem in a binary string
2. Random generation of a population
3. Calculating he fitness of each solution
4. Selecting pairs of parent strings based on fitness
5. Generating new string with crossover and mutation
6. Producing a new population

Steps 2 to 6 would be repeated until the satisfying solution is obtained. Figure A.1 illustrates the GA's flowchart.

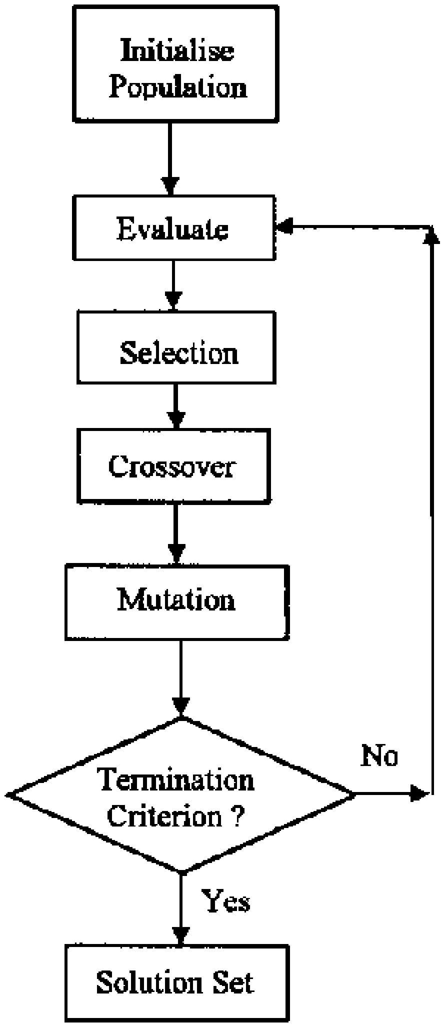

Figure A.1. Flowchart of GA (Mitchel, 1999)

APPENDIX B

MAMDANI FUZZY INFERENCE SYSTEM

To obtain the output of the Fuzzy Inference System (FIS) given the inputs, following steps have to be covered. (Mamdani & Assilian, 1975)

1. Defining the fuzzy rules set.
2. Fuzzifying the inputs with respect to corresponding membership functions.
3. Combining the fuzzified inputs according to the fuzzy rules to establish a rule strength.
4. Obtaining the outcome of the rule by combining the rule strength and the output membership function
5. Aggregating the outcomes to get the output distribution
6. Defuzzifing the output distribution

Figure B.1 illustrates how two rules of Mamdani FIS aggregate to derive the overall output Z by having two crisp inputs x and y.

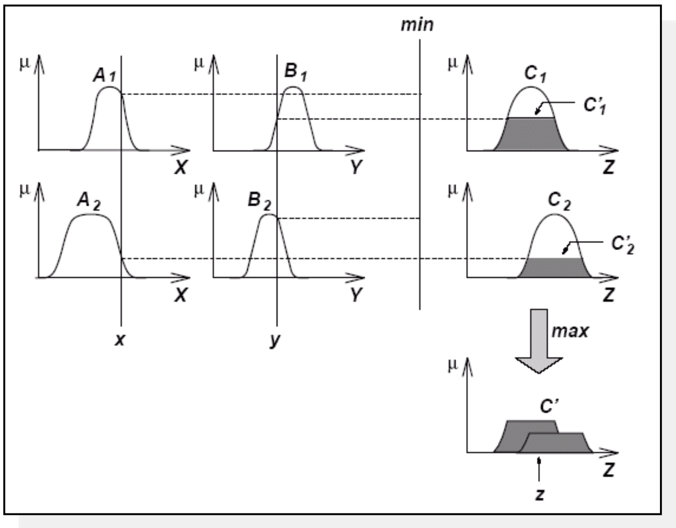

Figure B.1. Max-Min composition (Mamdani E. , 1976)

If max-product is applied instead of max-min composition the reasoning scheme would be as given in Figure B.2..

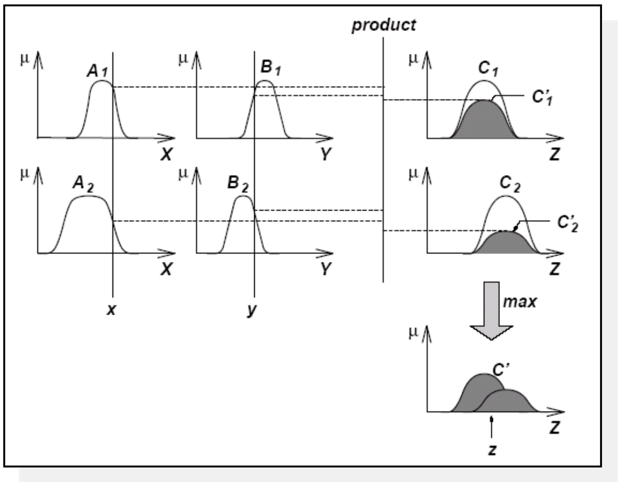

Figure B. 2. Max-Product composition

There are several techniques to defuzzify the results once they have aggregated. Formula for centroid of area defuzzification is as equation below.

$$^{z}COA = \frac{\int_{z} \mu_A(z) z \, dz}{\int_{z} \mu_A(z) \, dz}$$

APPENDIX C

BRANCH-AND-BOUND

Branch-&-Bound (B&B) is a "divide-and-conquer" framework to solve discrete optimization problems (Lee, 2004). As its name implies, B&B technique resembles a decision tree to solve an Integer Programming (IP) problem by using the simplex method along with an interactive process.

Following steps illustrates the logic behind the B&B method. (Kaiser & Messer, 2011)

1. Set up the problem as a Linear Programming (LP) model without integer constraints and computing the original Upper Bound (UB).
2. If the obtained solutions are all integers, the optimal solution is already found. Because, the optimal solution of IP is equal to LP.
3. If the obtained solution is not all integers, then round down all non-integer values (for a maximization problem) and calculate the Lower Bound (LB).
4. Compute the Maximum Percentage Error (MPE) regarding equation below.
   $$MPE = \frac{UB - LB}{UB} \times 100$$
5. If UB is equal to LB, the solution is optimal with the value equal to the lower and upper bound value. This is the stopping condition.
6. IF UB is greater than LB, then branch on the LP with the highest objective function value. If this is immediately following the initial LP, then branch on the non-integer variable that is the farthest away from being an integer. Generate two branches for the variable. One with $x_i \leq xi_i$ and the other with $x_i \geq xi_i+1$, where xi_i is the integer value of x_i.
7. Solve each branch as an LP problem without considering integer constraints.

8. Calculate UB and LBs. UB is LP's solution with largest objective function value and no branches. LB is the most recent (largest valued) all-integer solution.
9. Go to step 2 and repeat the calculations until stopping condition (step 5) is satisfied.

APPENDIX D

CUSTOMER'S QUESTIONNAIRE

Figure D.1 and Figure D.2. show the answers of customer II and III of the case study to the questionnaire, on OMAVE system interface which is designed to be as user-friendly as possible.

Figure D.1. Customer II's interface in OMAVE system

Figure D.2. Customer III's interface on OMAVE system