A MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR OPTIMAL ALLOCATION OF SUBCONTRACTORS IN CONSTRUCTION PROJECTS

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ABSTRACT

A MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR OPTIMAL ALLOCATION OF SUBCONTRACTORS IN CONSTRUCTION PROJECTS

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Achieving the success in a construction project requires ultimate harmony of numerous disciplines that are involved in. In a construction project, in order to reach the targeted cost, time and quality performance, the allocation of the appropriate subcontractors to the appropriate parts of the work is essential.

This thesis presents a multi-criteria decision support system using Analytical Network Process (ANP) and Pareto Front Optimization in order to select the most eligible subcontractors for core and shell works in a construction project. The main purpose of the thesis is to develop a multi-criteria decision support system for subcontractor selection in construction projects. For this purpose, a 4-module tool is created using MS Excel and Visual Basic for Applications (VBA) which assess the tendering stage of a core and shell project portfolio limited to 15 work parts and 35 candidate subcontractors. Within the process, the weights of the factors affecting the "credibility" of the candidate subcontractors are determined by the decision maker using 15 predefined credibility factors obtained from a comprehensive literature research. The relevant information is gathered from the candidate subcontractors and final credibility indexes of each subcontractor are determined using the Analytical Network Process. Finally, the bids are gathered from the candidate subcontractors and the tender matrix is constructed considering the eligibility of the subcontractors due to their limitations regarding project timing out, bank references, and work completion. The cumulative cost versus credibility plots belonging different allocation scenarios are drawn using a heuristic optimization algorithm and Pareto optimal solutions are presented. Two case studies for a private organization tendering process are used to illustrate the proposed subcontractor selection decision support system .

Keywords: Multi Criteria Decision Making, Subcontractor Selection, Analytical Network Process, Heuristic Optimization, Fuzzy System, Decision Support Systems

ÖZ

ALT YÜKLENİCİLERİN İNŞAAT PROJELERİNDE EN UYGUN ŞEKİLDE ATANMASINA YÖNELİK BİR KARAR DESTEK SİSTEMİ

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Bir inşaat projesinin başarısı, içerisinde yer alan çok sayıdaki farklı disiplinler arasındaki uyumu gerektirir. Bir inşaat projesinde, hedeflenen bütçe, zaman ve kalite performansının yakalaması için doğru alt yüklenicilerin doğru iş bölümlerine atanması önem arz etmektedir.

Bu tez kapsamında, Analitik Ağ Süreci (ANP) ve Pareto Sınır Optimizasyonu kullanılarak bir inşaat projesinde yer alan iş bölümleri içerisindeki kaba işler için en uygun alt yüklenicilerin belirlenmesine yönelik bir (çok kriterli) karar verme mekanizmasının geliştirilmiştir. Tezin ana amacı, inşaat projelerindeki alt yüklenici seçimi için çok kriterli bir karar destek sistemi geliştirmektir. Bu amaçla, MS Excel içerisinde yer alan Visual Basic (VBA) programı kullanılarak 15 iş bölümü ve 35 aday alt yüklenicinin ihale sürecinin değerlendirilmesine olanak sağlayan 4 modüllü bir karar verme aracı geliştirilmiştir. Bu süreçte, kapsamlı bir literatür araştırması neticesinde belirlenerek tanımlanan 15 güvenilirlik kriterinin önem katsayıları karar verici değerlendirmeleri ile belirlenmiştir. Aday alt yüklenicilerden ilgili bilgiler elde edilerek Analitik Ağ Süreci (ANP) ile her bir alt yükleniciye ait güvenilirlik endeksleri tespit edilmiştir. Son adımda, aday alt yüklenicilerden teklifler toplanmış ve aday yüklenicilere ait proje süresi aşımı, banka referansı eksikliği ve iş bitirme eksikliği hususları göz önünde bulundurularak bir teklif matrisi hazırlanmıştır.

Hüristik bir optimizasyon algoritması kullanılarak farklı alt yüklenici atama senaryoları için bir kümülatif bütçe-güvenilirlik saçılım grafiği çizilmiş ve Pareto optimal çözümler gösterilmiştir. Önerilen alt yüklenici seçimi karar destek sistemini örneklemek amacıyla özel sektör için uygulanan iki ihale süreci ele alınmıştır.

Anahtar Kelimeler: Çok Kriterli Karar Verme, Alt Yüklenici Seçimi, Analitik Ağ Süreci, Sezgisel Optimizasyon, Bulanık Küme Sistemi, Karar Destek Sistemleri

To My Beloved Family

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LIST OF ABBREVIATIONS

MS	Microsoft
DM	Decision Making
CR	Consistency Ratio
CI	Consistency Index
RI	Random Index
PM	Performance Metrics
AI	Artificial Intelligence
TL	Turkish Lira
ANP	Analytical Network Process
AHP	Analytical Hierarchy Process
VBA	Visual Basic for Applications
QBS	Qualification-Based Selection
AIM	Aspiration-Level Interactive Method
WSM	Weighted Sum Model
WPM	Weighted Product Model
BCR	Benefits, Costs and Risks
FDI	Foreign Direct Investment
SFM	Sustainable Forest Management
CRM	Customer Relationship Management
NPV	Net Present Value
MDCM	Multi Criteria Decision Making
ASAP	Accelerated Subcontracting and Procuring
FAHP	Fuzzy Analytical Hierarchy Process
QBPR	Quality-Based Performance Rating
CCPQ	Construction Contractor Prequalification
SPEM	Sub-Contractor Performance Evaluation Model
MODM	Multi-Objective Decision Making
MAVT	Multi-Attribute Value Theory
MAUT	Multi-Attribute Utility Theory
BOCR	Benefits, Opportunities, Costs and Risks

MAPM	Multi-Attribute Performance Measurement
LLNF	Locally Linear Neuro-Fuzzy
TOKI	Housing Development Administration of Turkey
MCDSS	Multiple-Criteria Decision Support System
EFNIM	Evolutionary Fuzzy Neural Inference Model
VIMDA	Visual Interactive Method for Discrete Alternatives
ANFIS	Adaptive Neuro-Fuzzy Inference Systems
WEBSES	Web-Based Sub-Contractor Evaluation System
TOPSIS	The Technique for Order Preference by Similarity to Ideal Solution
WASPAS-F	Weighted Aggregated Sum Product Assignment Method with Fuzzy Values
ELECTRE	Elimination and Choice Corresponding to Reality
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations

CHAPTER 1

INTRODUCTION

Construction projects include number of various disciplines and tasks in it. For the complete stability and functionality of the structure, perfect completion and conformity of all pre-construction and in-construction activities are vital. Although the liability limits are drawn based on the contract type signed with the employer, most of the time, the multi-disciplinal structure of the construction projects entails contractor to deal with all relevant tasks including design, construction, mechanical, electrical or trim works etc.

In parallel with the increasing complexity of today's construction practices, as expected, the term for the third party "subcontractor" have aroused beyond main parties: the employer and the contractor. Associating the subcontractor in the construction projects is such a common practice that Hinze and Tracy (1994) emphasized the involvement of the subcontractors up to the 80-90% of the total construction project completed especially for building projects. Nowadays, subcontractors constitute a building block for construction activities no matter what their sizes are or what kind of specialties they need.

The high importance of the subcontractors in the construction industry might bring the question of "to what extent do the subcontractors differ from the main contractor?" to the relevant' mind. In fact, it is a contractor who accepts the responsibility for the completion of a specified portion of the undertaken work with the desired functionality. Arditi et al. (2005) defined subcontractor as *"a construction firm that contracts with a general contractor to perform some aspect of the general contractor's work*". Therefore, rather than being accountable to project owner for the complete performance of the construction process, subcontractors become answerable to the main contractor for the partial achievement and functionality of the project which decreases the workload of the main contractor by preventing the direct involvement of him in any tiny particular construction work. Sharing the workload of the main contractor, subcontractor helps the main contractor to achieve rapid, more qualified and even cheaper production in the construction process depending its competence level. On the other hand, while subcontractors increase the available material, labor or equipment resources of the main contractor which would directly affect the project completion within the planned time and budget, they also serve for the financial supporters from where the main employer might run into debt so that the liquidity of the project budget can be managed in an organized way.

Accepting the construction process as a complex network, dividing it into small pieces makes it more manageable for the main contractor and the complete possession could be achieved. That is fairly understandable that, sharing the partial responsibilities among the subcontractors, the main contractor increases its superintendence over the entire project by mainly dealing with managerial and organizational issues and some basic constructional works. Arditi and Chotibhongs (2005) highlight the vital role of subcontractors hired for the specific tasks on a project and they claim that subcontractors perform the various special works while the general contractor executes the basic operations in the usual case of most construction projects.

Due to the fact that the controllability of the project decreases with the increasing project size, beyond the works requiring a subcontractor's specialization, main contractors assign their duties of planning, consulting and controlling to the subcontractors which make them simply the secondary employers commissioning major construction activities to the subcontractors. Humphreys et al. (2003) clearly described subcontractor's increasing involvement in site organization and managerial issues with an example about pre-construction project partnering. Although such an assignment does not retrieve the responsibility of the main contractor to the project owner for the complete achievement of the project, the desired quality standards of the undertaken project can be achieved with the correct assignment of planning, consulting or controlling subcontractors to the correct portions of the project where the main contractor cannot handle.

In brief, subcontractors help main contractors to cope with many problems including the requirement of special competence, scarcity of resources and restriction in financial issues (Elazouni & Metwally, 2000).

While the critical importance of the subcontractor assignment in the construction projects is accepted apparently by many authority carrying on their activities in the construction industry, the classical and monetary oriented approach for the tender stage of construction projects is still prevails. Rather than a detailed analysis of the tender participants, decision makers frequently focus purely on the bid prices without considering the complementary characteristics of candidate participants. However, the adopted approach entails some risks since the overall construction process does not being analyzed well during the tendering stage. Simply focusing on the lowest bid price without the credibility of the candidate subcontractor might end up with the bankrupt of the tender winner which might eventually cause the worse consequences such as delayed project delivery or exceeding of the budget.

While some precautions are adopted for the elimination of outliers (the subcontractors having extremely low or high bid prices), especially in governmental institutions and some institutionalized private organizations, the approaches followed for the determination of the correct credibility levels of candidate subcontractors are quite primitive and classical. Most of the time, the sense of experienced managers or directors plays the biggest role in the determination of such a measurement criterion. Although the opinion of the experienced decision makers stands as one of the most important criteria for the subcontractor eligibility, blending them with more rational and systematic approaches makes the assessment process more transparent and interrogable. By achieving that, any misinterpretations can be easily detected and corrected during the assessment stage and the continuous dependency of the experienced decision makers can be reduced to a certain extend by recording the common and constant judgments.

In the scope of current study, a tool is established for selecting the most eligible subcontractors for the core and shell works in a construction project including one or more parts. The tool is designed by knowing the challenge about the correct allocation of core and shell subcontractors to a construction project including different parts having different quantities. Within this purpose, a 4 module MS Excel Tool has been created using VBA (Visual Basic for Applications) which includes a heuristic optimization algorithm as well. A decision graph showing the cumulative cost vs credibility performances of subcontractor allocations has prepared using Analytical Network Process (ANP) approach and Pareto Front optimization during the selection process and the final decision is left to the decision maker depending on the project requirements or targets. With the aim of implicating the assessment of decision maker to the selection process, Fuzzy Approach is used and a more rational and subjective approach for the subcontractor evaluation during the tendering stage is achieved.

In this thesis, the chapters are organized as follows;

In *Chapter 1*, some basic definitions are given and the current practices are described for the selection process of candidate subcontractors during tendering stage. Additionally, the main purpose of the study is given and the created tool is described briefly.

In *Chapter 2*, the different decision making approaches for the subcontractor selection of the literature are presented.

In *Chapter 3*, the concept of Multi Criteria Decision Making (MDCM) is introduced, the classification of MDCM methods is presented and some of the application fields of MDCM are identified.

In *Chapter 4*, Analytical Network Process (ANP) is described and compared with Analytical Hierarchy Process (AHP). The methodology of ANP is explained in detail and the practical use of ANP in different industries is expressed.

In *Chapter 5*, the methodologies of Uncertainty and Fuzzy Methodology is described. The interpretation of linguistic terms using Fuzzy Methodology and a typical Fuzzy System is explained. Additionally, some of the Fuzzy examples from the Construction Industry are given and some of the advantages of using the Fuzzy system are proposed.

In Chapter 6, the concept of Optimization is described briefly. Basic terms and definitions about the optimization concept are introduced and the optimization problems are grouped under titles of single, multi objective and meta-heuristic optimization.

In *Chapter 7*, the application about the selection of the most eligible candidate core and shell subcontractors to the relevant parts of the project is described. The methodology used for determining the assessment criteria of subcontractor (module-1), the rating process of the candidate subcontractors (module-2), the development process of the tender project (module-3) and collecting of the bid prices and formation of the tender matrix (module-4) is expressed in detailed. At the last step, a heuristic optimization process is performed and the decision making plots are presented for the case studies.

In Chapter 8, the major findings of the study are presented and possible future studies are explained by discussing the limitations of the current study.

CHAPTER 2

LITERATURE REVIEW

In this chapter decision making mechanisms used for the subcontractor selection in literature are presented.

Lo and Yan (2009) introduced the qualification-based selection system (QBS) with the aim of dealing with subcontractors' tendency of optimistic bidding strategy. In the context, the attitude of giving super-low bid amounts of subcontractors by disregarding the possible detrimental outcomes in order to survive in the competitive market was discussed. The idea that arguing the adequacy of price-focused approach for achieving the most economical and qualified solution was adopted and a simulation model was created for evaluating the dynamic competition process and contractor's pricing behavior under QBS system. At the result stage, QBS system's vulnerability for the linkage between contractors' past performance and the evaluation of contractors' qualifications was discovered. Nevertheless, by the careful and constant screening of subcontractors' past performance, their opportunistic bidding attitude was reduced.

Shash and Abdul-Hadi (1993) investigated the factors influencing the bidding strategy of the subcontractor. The importance weight of each factor was examined and how the importance of these factors was changed depending on the size of the contractor was studied.

Elazouni and Metwally (2000) proposed a decision making support system helping the proper assigning of work packages allocated for subcontracting among subcontractors. Based mainly on the project schedule and financial terms of the contract and also paying regard to financial constraints work portions were distributed. In the system, linear programming module was used with the objection function of minimizing the total cost regarding the created constraints and financial analysis module was used for profit calculations and drawing overdraft profile. Sensitivity analysis module was also implemented into the system with the aim of making its usage appropriate for different conditions.

Tserng and Lin (2002) looked at the procedure of subcontractor selection from a different perspective and they claimed that using a global procurement system would be the appropriate way of achieving the optimal combination of candidate subcontractors for the assigned tasks. In this context, several methodologies belonging information technology and financial management are combined and Accelerated Subcontracting and Procuring (ASAP) model was asserted. In the scope of the model, developing a decision support system that allows the evaluation of risk-profit trade-off and performing the subcontracting and procurement process using the web were primal targets.

Arslan et al. (2008) proposed a web-based sub-contractor evaluation system (WEBSES) which provides the evaluation of subcontractor depending on combined criterion that previously determined. For the subcontractor eligibility, main and sub-criteria were obtained from the database of a mid-sized construction company and a virtual model was created where the subcontractors could be rated. The model requires a powerful database for the comprehensive evaluation; however, a remarkable amount of time and cost savings during subcontractor evaluation process could be achieved as long as the required raw data is sourced.

Abdelrahman et al. (2008) discussed a new concept of best-value modeling which emphasizes the contractor selection problem unique and tailored to each project. With the purpose of identifying best-value scores of contractors, first, the specific selection criteria were determined using the past records and the main parameters having an influence on the subcontractor selection process were identified and analyzed depending on the designed best-value model. For appraising process, weighted average method and Analytical Hierarchy Process (AHP) were both used in the model and a ranking tool was developed having the capability of quantifying subjective selection criteria using the above mentioned methodologies for the final decision making.

Bendana et al. (2008) developed a new fuzzy-logic-selection system for contractor selection process. Despite the fact that the system was specifically created for the private sector one-step selection process, the suitability of the used methodology for different clients, industries and contracts were emphasized. Considering the project specific conditions and clients' needs and objectives, the suitability of all candidates were evaluated both qualitatively and quantitatively by also taking the consideration of failure risk of candidates in the scope of the assessment process. A computer application is created and validated based on the experts' judgments whom actively involved in contractor selection process. In the system, various project objectives such as time, cost and quality were taken into consideration and a neural network model was developed for the system validity.

Singh and Tiong (2005) focused on the creation of more systematic evaluation procedure using fuzzy-set theory. Being aware of the inherent uncertainty in the construction projects, they demonstrated a bid evaluation exercise in order to help decision makers to perform proper assessment procedure of available candidate contractors. The biggest contribution of the proposed system was presenting a methodology allowing decision makers to express their judgments of candidates' performance on decision parameters which have the linguistic structure rather than being a crisp value. Sing and Tiong (2006) identified the contractor selection criteria and determined their relative weights using the preferences of Singapore construction practitioners. The study was carrying the aim of minimizing candidate contractor related failures using the systematic assessing process which allows the evaluation of multiple attributes of candidate contractors.

Cheng and Li (2004) used Analytical Network Process (ANP) methodology for the subcontractor selection practice. In fact, used model was somehow the extension of

Analytical Hierarchy Process (AHP) which allows the interdependency and inter-correlations among subcontractor evaluation parameters. Decision making process seemed as the complicated problem which shall be evaluated under the title of multi-criteria decision making process (MDCM).

Fong and Choi (2000) used Analytical Hierarchy Process (AHP) for the assessment of candidate contractor's performance from various perspectives including time cost, quality and safety rather than focusing solely on the lowest bid. Within the scope of methodology, the criteria contributing the candidate contractor eligibility determined and the importance weight of each criterion were determined by the questionnaire performed in public organizations in Hong Kong. The cumulative scores of each contractor were compared with each other and the most favorable contractor was selected as the main candidate who reached the highest score in the overall ranking.

Alarcon and Mourgues (2002) inserted additional elimination parameters to the candidate selection process and created a new model. The framework was formed both using available information from the previous projects and the estimates based on the experience in the sector. As an output of the system, the project performance outcomes of each contractor were generated and used for the contractor performance assessment.

Considering the ambitious nature of contractor selection procedure, Gholipour et al. (2014) combined fuzzy methodology with Analytical Hierarchy Process (AHP) which is called as Fuzzy Analytical Hierarchy Process (FAHP). Linguistic decision variables were turned into numerical values using triangular fuzzy numbers and evaluated combined with the quantitative ones which thereafter used for the building up the fuzzy pairwise comparison matrices. At the final stage, scores of the candidate contractors were generated and the decision making process was completed.

Russell and Skibniewski (1990) developed QUALIFIER-1 for candidate contractors' prequalification depending on the evaluation of embedded elimination criteria by each project owner. Based upon a comprehensive study about prequalification factors, elimination criteria were presented to project owners as readily-prepared for their assessment. As the output of the program, aggregated weighted ratings of each candidate contractor were calculated and rank ordered ratings were presented to the user together with some useful statistical data. Presented model enabled more systematic and analytical investigation of candidate contractor credentials which eventually served for making contractor evaluation approach more rational. In, 1990, the model was updated and QUALIFIER-2 was created with some additional functions.

Mahdi et al. (2002) defined a multiple-criteria decision support system (MCDSS) for determining the most eligible contractor. The system was used two different methodologies with the aim of incorporating project-specific characteristics with contractor qualifications and capabilities. Delphi method was used for securing reliable assessment data from contractors' evaluation and AHP was used for taking project-specific conditions into account.

Minchin and Smith (2005) produced an ingenious model named as Quality-Based Performance Rating (QBPR) system which incorporates various subjective and objective inputs together realizing the importance of any useful data in order to deal with vague nature of contractor selection problem. Using traditional acceptances and project materials, each project was scored and further used in order to generate quality of work indexes of candidate subcontractors over a specified time period.

Albino and Garavelli (1998) proposed a neural network application for subcontractor rating and claimed the suitability of neural networks since they would be able to learn directly from decision makers' judgments. Although, the result of the application found unsatisfactory because of different reasons including the scarcity of examples against learning process influenced by the complexity of decision making environment and not being able to attain the learning phase of the neural network to a specific decision making context, further investigation for researchers in this area was triggered.

Li et al. (2007) focused on construction contractor prequalification (CCPQ) process with the aim of assuring contractors' qualifications to cover the projects' requirements. For this purpose, fuzzy framework-based fuzzy number theory was used which contains the phases of decision criteria analysis, weight assessment and decision model development. In the study, the feasibility of fuzzy approaches was also tested using a case study.

Zavadskas et al. (2008) presented a model for performing the contractors' assessment and selection using multi-attribute methods. In the model, the interests and goals of stakeholders and the components affecting the construction efficiency were both taken into consideration and optimality criterion of multi-attribute evaluation of contractors was determined by using Hodges-Lehman rule which in fact allowed attaining a proper risk level to the selected contractor. Considering the risk level of candidate contractors, the ones having unqualified risk levels were eliminated primarily and the most appropriate contractor was selected considering the risk taking capability of stakeholder.

El-Abbassy et al. (2013) utilized Analytical Network Process (ANP) and Monte Carlo simulation and used for determining the most competitive contractor at the pre-bidding stage for highway projects. In the scope of the study, main and subcriteria having an impact for determining the best candidate contractors were determined using expert judgments and literature. A comprehensive questionnaire examining both the influence of the criteria on the contractor selection and the inter-correlations between those criteria was prepared and sent to the experts in highway projects. Based on the obtained ratings, the weights of pre-determined criteria for the contractor selection were determined by using ANP methodology. For the contractor assessment part, the ratings of the candidate subcontractor were made by experts and the qualified data obtained either expert judgment or project related were quantified which in fact provided comparing of available contractors possible. At the final step, final scores of the contractors were determined and sensitivity analysis was performed using Monte Carlo simulation. For verification of the study, four real cases of highway projects were tested and it was also concluded that choosing the contractor having the lowest bid as the sole criterion declaring the best contractor may not always result in an optimum solution.

Ko et al. (2006) proposed an innovative model named Subcontractor Performance Evaluation Model (SPEM) which ensures dismissing of subjective judgment during subcontractor evaluation to a certain degree. In the context of the developed model, Evolutionary Fuzzy Neural Inference Model (EFNIM) was used which contributes to the subcontractor evaluation process with its capability of learning and inference.

Al-Harbi (2001) used AHP methodology for subcontractor assessment. In the scope of the study, a hierarchical structure of the problem was established and prequalification criteria were set up using AHP in an ordered way. The sensitivity analysis was also implemented for measuring the vulnerability of the developed system against minor changes of input values.

Hadipour et al. (2014) discussed a case study of contractor selection by using ELECTRE method with Interval-Valued Fuzzy Sets. A sample problem including six pre-defined decision making criteria and three alternatives were created and evaluation procedure was followed. The results of the study were verified by the interpretations of competent decision makers and it is found out that the proposed methodology was quite satisfactory especially for managers of the organization whom would like to consider all aspects of assessment.

Abbasianjahromi et al. (2011) introduced a model using fuzzy preference selection index as an approach for subcontractor selection. In the scope of proposed methodology, weighting criteria phase of the subcontractor selection process was eliminated and decision makers' opinion on assessment of candidates were used for computing the relative importance of each aspect. Eliminating the weighting criteria phase, the model provided to obtain the own desired answers of method users in quite a small amount of time which decision makers usually prefer due to the reasons such as conflict opinions or lack of time, information or past data.

Obviously, there are many studies exist in the literature all having different perspectives serving for subcontractor/main contractor assessment process. Great numbers of decision making contributors are assessed by using different evaluation logics and the target is constructed based on proposing the final decision which supposed to be taken by the decision maker. Diversely, commonly-held assessment criteria are processed using a different approach in the scope of this study and rather than insisting on selecting the proposed one, final decision is left to decision maker by indicating optimal solutions based on predefined selection benchmarks.

CHAPTER 3

MULTI-CRITERIA DECISION MAKING

3.1 Introduction

In the changing and globalized world, individuals or corporations make vital decisions which even might affect their existence in business. As the competition grows up in accordance with the technology and many other returns of the free market, some organizations derive their profits excessively thanks to the appropriate investments and actions as the result of correct decisions while some others just go bankrupt. In most of the cases, irrelevant with technical, logistic or manpower of an organization, incorrect strategy and wrong decision might annihilate the whole enterprise. Therefore, the process of decision making has a vital role for an organization to survive.

Decision Making (DM) is a managerial process of selecting the most appropriate alternative among the many other through the detailed analysis of problem case with the purpose of achieving the predetermined targets. That means availability of the cluster of different alternatives is required for the process of decision making to make sense. Zeleny (1982) proposed two different approaches during decision making;

- *Result-Oriented Approach:* This approach is based on the idea that, if decision maker can exactly forecast the result, he already understood the decision making process. Therefore, the focus point is the result and the correct forecasting. In this approach, rather than the question of *how* the questions of *what* and *when* are asked.

- *Process-Oriented Approach:* This approach is based on the idea that, if decision maker can understand the decision making process, he forecast the result correctly. Therefore, the focus point is the decision making process itself. This approach supports the idea that knowing how to decide helps for how the decision should be made.

As a form of DM, Multi-Criteria Decision Making (MDCM) deals with the problems where more than one criteria or targets exist and which is more frequently encountered in the real world. In fact, many criteria are taken into consideration during decision making in practice and some of them conflict with each other. To exemplify, a house having good city scene and having high security probably would have the higher price which directs decision maker to make a trade-off between these three criteria. For the proper trading off among the decision making criteria, MDCM problem need be constructed and analyzed well. Tzeng and Huang (2011) advised to follow several steps in the cases where MDCM problem is encountered;

- Identify the problem
- Collect the data reflecting the decision maker's opinions and targets
- Construct the alternatives and strategies serving for decision maker to achieve targets
- Select the best method for assessing the performances of existing alternatives and rank them

3.2 General Structure of MDCM

For the purpose of understanding the general structure of MDCM, Metin (2012) built the following illustration showing general MDCM structure and its elements (Figure 3.1).

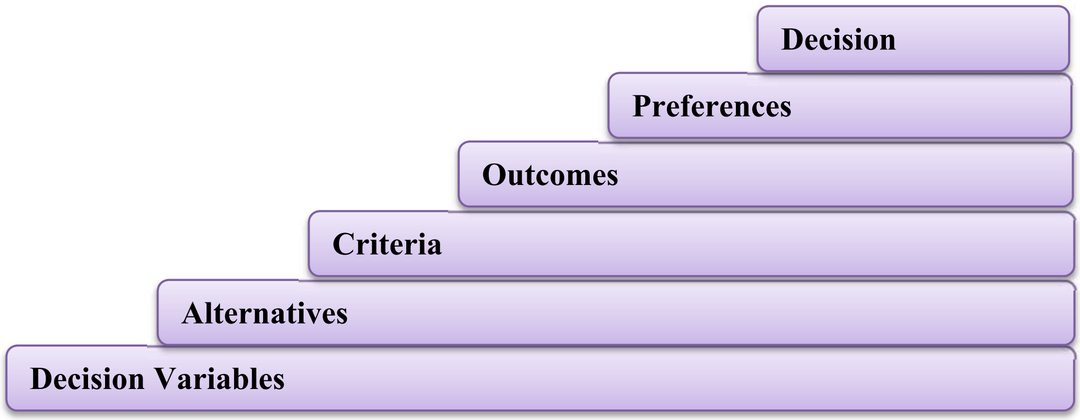


Figure 3.1: Elements of MDCM Models (Metin, 2012)

Decisions contain the problems appeared in different ways such as choice problems, sorting problems or ranking problem.

Preferences reflect the decision maker's targets which directly contributes the selecting of existing alternatives directly. Therefore, decision maker's preferences are defined in the outcomes space. During decision making stage, decision maker tries to maximize or minimize the targets by means of preferences.

Criteria and Outcomes represent the main elements of decision making matrix. Each alternative has an image in an m-dimensional outcome space and different consequences arising from alternative selection produces the set of criteria. For each of the relevant consequence, a function is defined as $c_i = (i = 1, .., m)$. Depending on the functions c_i, a vector–valued function cx: $(c_1x, c_2x, \dots, c_mx)$ could be defined assuring that $y = cx$ is termed as an outcome of x.

A sample decision matrix is seen in Figure 3.2

	C_1	C_2	C_3	.	.	.	C_m
A_1	x_{11}	x_{12}	x_{13}				x_{1m}
A_2	x_{21}	x_{22}	x_{23}				x_{2m}
A_3	x_{31}	x_{32}	x_{33}				x_{3m}
.							
.							
A_n	x_{n1}	x_{n2}	x_{n3}				x_{nm}
	W_1	W_2	W_3				W_m

Figure 3.2: Sample Decision Matrix (Çakın, 2013)

Where;

A_j are the alternatives in decision making problem (j=1,…,n)

C_k are the criteria for assessing the alternatives (k=1,…,m)

x_{ab} performances of the alternatives with respect to each criterion (a=1,…,n; b=1,…,m)

W_c importance weights of criteria (c=1,…,m)

For the comprehensive decision making, a well-defined set of criteria is essential. Metin (2012) summarized the requirements required for fulfilling the forming the set of criteria;

- Completeness
- Mutual exclusiveness
- Reliability
- Appropriate precision

- Independence
- Non-redundancy

Alternatives are directly contribute to the final decision since they simply constitute the existing policy of decision maker. In decision making problem, the numbers of alternatives might differ according to preferences of the decision maker and they are defined by a vector of x: $(x_1, x_2, \ldots, x_n)$.

Decision Variables are the components of $x: (x_1, x_2, \ldots, x_n)$ and they reflect the particular characteristics of the existing alternatives.

Abovementioned elements stand as the key for developing a comprehensive MDCM approach. However, Saaty's identifications about constructing an appropriate MDCM shall be clearly understood in order to avoid producing of MDCM structures including ambiguous and unnecessary details or not serving for their main purpose.

Saaty (2008);

Simple to construct

- Flexible for adapting both groups and individuals
- Natural to intuition and general thinking
- Encourage compromise and consensus building
- Not require inordinate specialization to master and communicate

3.3 Classification of MDCM Methods

Chen and Hwang (1992) emphasized the abundance of available MDCM methods in the literature. However, Triantaphyllou et al. (1998) classified MDCM methods using two different main approaches considering the type of data that they use, the number of decision makers involved in decision making process. Beyond this main classification, in-group classifications were also identified such as considering the salient features of the information that were treated.

MDCM methods shall be classified as *deterministic*, *stochastic* or *fuzzy* depending on the type of data that they use. However, while there exist MDCM methods that solely contain the deterministic, stochastic or fuzzy type of data, the methods combining a couple of those types are also available. Considering the number of decision maker involved in the decision making process, MDCM methods divide into two as *single* decision maker MDCM methods and *group* decision making MDCM methods. As obvious from the names, single and group decision making MDCM methods represents the approaches where one or more than one assessor have been involved in decision making process.

As a different perspective, Hajkowicz et al. (2000a) classified MDCM methods under two major groups namely *continuous* and *discrete* considering the nature of alternatives to be evaluated. Continuous MDCM methodology represents the cases where the decision space is continuous and it is specifically studied under the name of Multi-Objective Decision Making (MODM) methodology. This method aims to identify the optimal decision which can vary infinitely in the decision space. The techniques such as linear programming or goal programming can be given as an example of it which contains multi-objective functions. Discrete MDCM methodology, on the other hand, represents the cases where the decision space is discrete and finite amount of alternatives or sets of alternatives were previously determined. This method judges the predetermined alternatives and ranks them based on their suitability to the defined set of objectives or criteria (Hajkowicz et al., 2000b).

Nijkamp et al. (1990) subdivided discrete methods into weighting and ranking methods which subdivided further by Hajkowicz et al. (2000b) as qualitative, quantitative and mixed methods. In the subdivision, qualitative and quantitative methods use only linguistic and cardinal performance measures respectively while mixed methods use both.

From the value and utility-based perspective, Ananda and Herath (2009) claimed that Multi-Attribute Value Theory (MAVT), Multi-Attribute Utility Theory (MAUT) and the Analytical Hierarchy Process (AHP) are the most common approaches in the literature. The Analytical Hierarchy Process (AHP) developed by Saaty (1977,1980) works quite similar with MAVT except that it uses a different approach during estimating the relative weights of criteria and the scoring the alternatives over defined criteria. AHP also uses different variant such as geometric mean.

From the risk perspective, Ananda and Herath (2009) summarized the MDCM classifications as a risky category which contains the MAUT and ELECTRE (Elimination and Choice Corresponding to Reality) and riskless category which contains MAVT. In the scope of applying learning systems approach to MDCM, Kornohen (1988) and Lotfi et al. (1992) developed the methods of VIMDA (Visual Interactive Method for Discrete Alternatives) and AIM (Aspiration-level Interactive Method).

Many other MDCM methods such as WSM (Weighted Sum Model), WPM (Weighted Product Model) and TOPSIS (The Technique for Order Preference by Similarity to Ideal Solution) exist in the literature frequently. However, the methodology of Analytical Network Process (ANP) (A specialized form of AHP) is the main subject as a MDCM method in this study and it will be explained in detailed in the upcoming parts together with the reasons for its selection.

3.4 Application Fields of MDCM

As an operational research methodology, MDCM is frequently used in industrial engineering applications. According to Ananda and Herath (2009), MDCM is used in integrated manufacturing (Putrus, 1990), in the evaluation of technology investment decisions (Boucher & McStravic, 1991), in flexible manufacturing systems (Wabalickis, 1998), layout design (Cambron & Evans, 1991) and also in many other engineering problems (Wang & Raz, 1991).

In 2010, an illustrative study was performed by Behzadian et al. and the application of PROMETHEE in 14 main areas as one of the most frequent MDCM method was studied;

- Environment Management
- Hydrology and Water Management
- Business and Financial Management
- Chemistry
- Logistics and Transportation
- Manufacturing and Assembly
- Energy Management
- Social service
- Other Topics: Agriculture, Design, Medicine, Education, Sport and Government

As stated above, MDCM strictly meshes with many problems that are met in real life. Since the various reasons for the selection of the best alternative carries different meanings to different people in different times, decision making problems become complex and MDCM techniques are frequently used in many governmental operations, industries and business activities especially if the required data for the appropriate decision making are hard to obtain.

CHAPTER 4

ANALYTICAL NETWORK PROCESS (ANP)

4.1 Definition

Analytical Network Process (ANP) is a theory established on Analytical Network Process (AHP) by introducing the additional consideration of taking interdependence and feedback relations of decision making criteria into consideration. In 1996, Thomas L. Saaty introduced ANP methodology with a book named as *"Decision Making in Complex Environments – The Analytic Network Process for Decision Making with Dependence and Feedback"* which later on revised and extended by him in 2001. By ANP methodology, rather than considering simply the unidirectional relationships among criteria, multidirectional relationships were also included in the decision making process and more rational solutions for sophisticated problems were provided.

ANP methodology proposes a decision network which includes clusters, elements and links in it. In the network, while cluster describes a group of elements that are somehow connected to each other, link describes the dependencies either between clusters or elements. On the other hand, while all the interactions within a cluster named as "inner dependencies", the interactions between clusters are named as "outer dependencies" (Saaty, 1999a).

4.2 Comparison among ANP and AHP

Considering the decision network, ANP might seem as the specialized statement of AHP consideration simply because both methodologies contain clustered type of decision making solution mechanisms and pairwise comparisons of factors with the aim of measuring one's weight over the other. However, the distinctive characteristics of ANP methodology which takes the inter-correlations between clusters and elements into account make it quite competent compared with AHP. In fact, decision making problems that frequently encountered in current practice mainly involve a complex structure which contains a variety of dependencies in it. For decision making problem, AHP approach forms a hierarchy structure which contains decision making criteria and the alternatives and it performs pairwise comparisons on hierarchic structure assuming decision criteria and alternatives are independent of one another. On the other hand, ANP approach forms a network structure and introduces the dependent analysis into the dependent structure of solution phase which results in the raising of a more realistic solution. To illustrate this relationship, a man planning to buy a house which has the decision criteria of "good and centered location", "safety", "good condition" and "price" could be considered. Both AHP and ANP would give the most proper alternative that decision maker should select according to introduced decision criteria. However, while AHP would evaluate each house independently on decision making criteria, ANP would realize the dependency between those criteria and evaluate the problem considering that the house being in good condition and having centered and safety location would probably cost more. Figure 4.1 and Figure 4.2 below clearly describes the schematic structure of AHP and ANP.

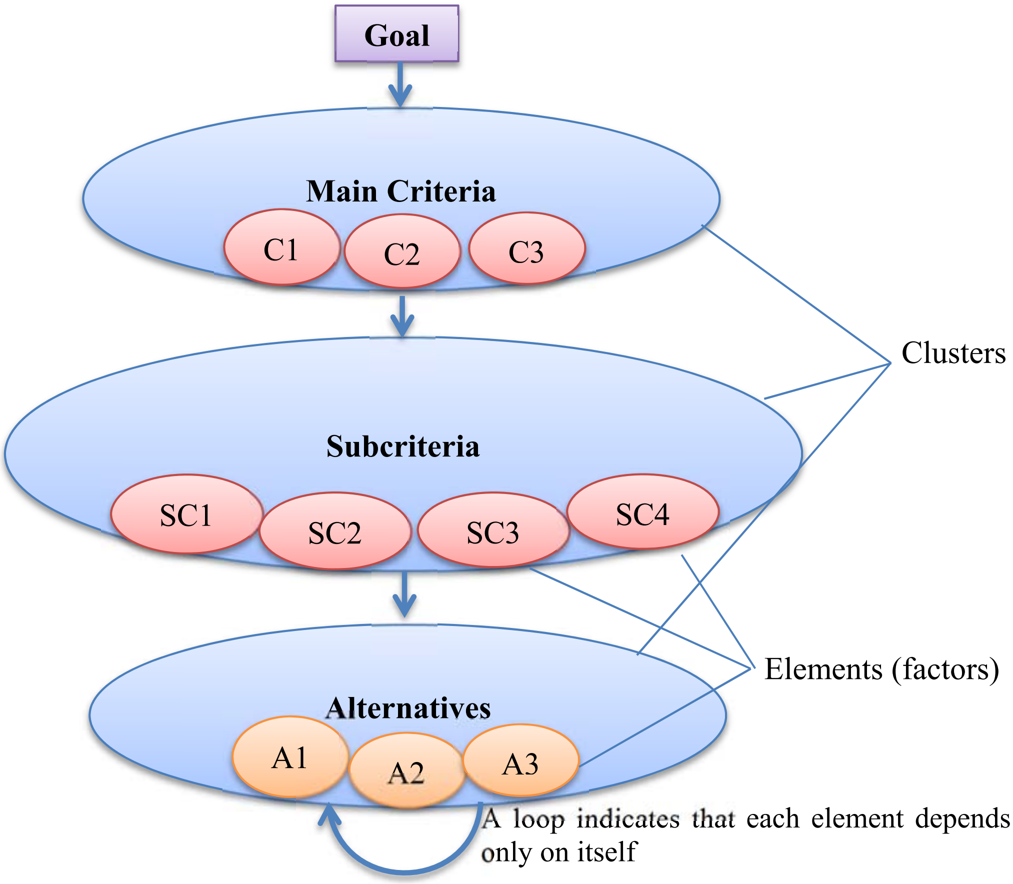


Figure 4.1: Hierarchy Structure (Saaty & Vargas, 2006)

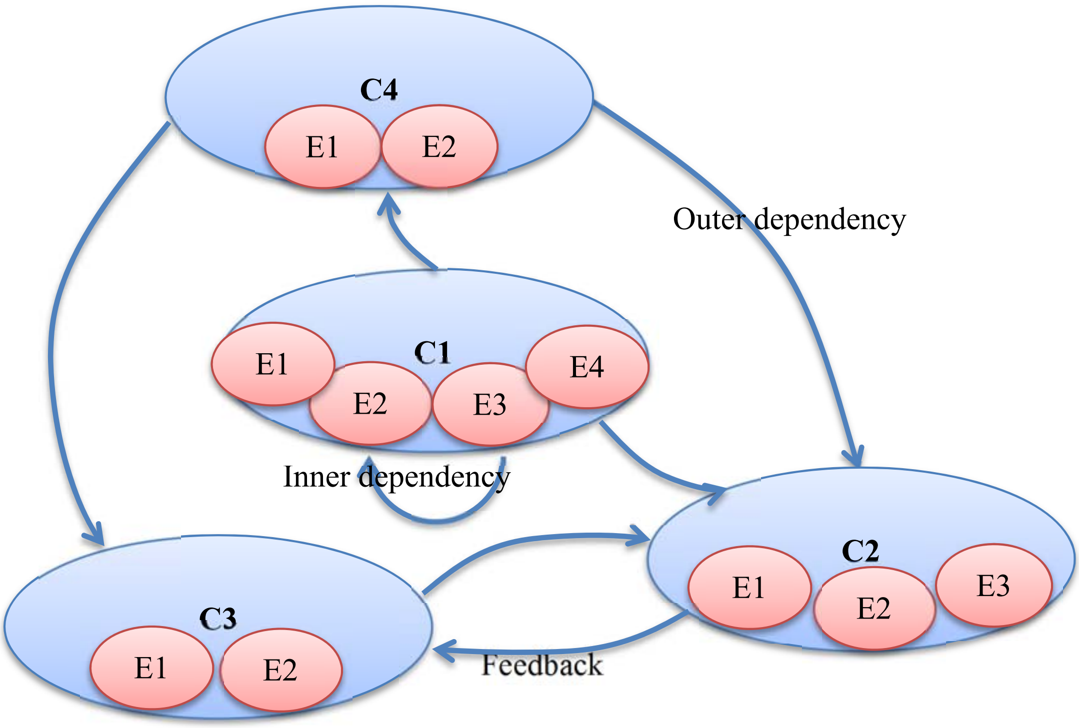


Figure 4.2: Network Structure (Saaty & Vargas, 2006)

4.3 ANP Methodology

Constructing appropriate network or hierarchy structure is vital for the solution of decision making problem. Saaty (1994) emphasized the importance of following concerns for decision making problem which are also used for the creation of compatible network or hierarchy structure.

- Having details about the decision problem itself,
- Being aware of the parties (people or actors) that are involved in,
- The objectives and policies of parties,
- The influences having an impact on outcomes,
- The time horizons, scenarios and constraints.

No matter which type of solution process is followed, a detailed analyzing of clusters and factors is inevitable for a proper identification of hierarchic or network structure including the main goal, criteria, subcriteria, alternatives and the interdependency links in the cases where ANP would be used. Having an appropriate network structure, Sarkis (1999b) summarized four main steps in ANP methodology as follows;

1. Performing pair-wise comparisons of elements in cluster and subcluster levels
2. Taking the result relative importance weights (eigenvectors) and placing in submatrices within the supermatrix
3. Adjusting the values in the supermatrix so that the column stochasticity will be achieved
4. Raising the supermatrix to very large power until the convergence is provided and the weights remain stable.

4.3.1 Pairwise Comparison, Fundamental Scale and Construction of Matrixes

Assessment of factors in the constructed structure is performed by professionals or decision makers whom generally have adequate experience and knowledge about the subjected decision making problem. However, as stated above, analytical network structure contains a number of clusters, factors and dependency links between them. This structure generally becomes so complicated for one to make judgments especially numerical assessment is asked based on the given qualitative expressions. Therefore, ANP uses reciprocal pairwise comparison system to achieve scientific comparisons rather than simply asking a person to score out the given objectives or criteria. Saaty (2008a) claimed that, by using the scale rather than randomly produced assessment numbers, more scientific and rational solutions would be achieved.

Saaty (1994) proposed the fundamental scale for converting qualitative judgments to the numerical expressions (Table 4.1). Qualitative descriptions for the assessment were associated with the numbers between 1 and 9.

Table 4.1: Pairwise Comparison Scale (Fundamental Scale) (Saaty, 1994)

Pairwise Comparison Scale		
Intensity of Importance	**Definition**	**Explanation**
1	Equal Importance	The contribution of two activities to the objective are equal
3	Moderate Importance	Experience and judgment slightly favor one activity over another
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another, its dominance demonstrated in practice
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it
Use reciprocals for inverse comparisons		

According to the factors in cluster or subcluster levels, square matrixes are constructed having all 1's on their diagonals. On the upper-right triangle part of the matrix, the numerical value obtained from pairwise comparison scale is placed meaning that $a_{i,j}$ element of the matrix is the scale value of the assessment that to what extend criterion i is more important than criterion j. Lower-left triangle of the matrix constitutes the reciprocals of upper right triangle meaning $a_{j,i} = 1/ a_{i,j}$. The complete matrix looks as given below (Saaty & Özdemir, 2003);

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix}.$$

Based on Miller's study, Saaty and Özdemir (2003) also suggested that the number of compared criteria should be between 5 and 9 since beyond these limitations the human capacity of "*processing information on simultaneously interacting elements with reliable accuracy and validity*" decreases (Miller, 1956).

In current practice, "group decision making" is frequently performed both in construction and other industries. In other words, more than one party concern about the decision making process and a group decision is made based on the individual judgment of those parties which holds the right of decision making. At this stage, collecting various ideas having an impact on the final decision and combining them in a proper way is essential. During this process, any contribution obtained from decision makers should be preserved and integrated into the decision process. Saaty (2008a) claims that the appropriate way of combining all various contributions of various decision makers could only be possible after the geometric mean of corresponding matrixes is calculated. Using geometric mean method, any extreme or irrelevant opinion of a contributor would be neutralized with answers of several relatively radical decision makers.

Referring the opinions of various decision makers causes inconsistency during decision making process to a certain extent. In fact, this is a group inconsistency which is practically inevitable and therefore accepted since obtaining the same assessment from different parties is not possible. On the hand, although fundamental scale helps to minimize the complexity of making pairwise comparisons, there is still a considerable chance of obtaining conflicting responses exist which cause the individual inconsistency. To illustrate this, a decision maker could say criteria A is three times more important than criteria B, criteria B is three times more important than criteria C and criteria C is three times more important than criteria A. This is an incorrect judgment which needs to be eliminated or ignored before continuing with the upcoming steps in decision making process. To cope with this problem, Saaty (1990) suggested a ratio and index called Consistency Ratio (CR) and Consistency Index (CI) and regards a matrix as consistent if CR value is below 0,1.

The Consistency Ratio (CR) is calculated by using the formula;

$$CR = \frac{CI}{RI}$$

where RI (Random Index) is a number changes according to the size of the matrix or number of compared criteria (Table 4.2).

Table 4.2: Random Index (RI) Table (Saaty, 2008b)

Order	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

and CI (Consistency Index) of a matrix is calculated by using the formula;

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

where n is defined as the count of assessed criteria and $\lambda_{max}$is defined as;

$$\lambda_{max} = \frac{\sum_{j=1}^{n} (a_{ij} w_j)}{w_i}$$

and where

a is the element placed in a particular row and column.

w is the weighted average of a particular row.

Below example shows the path that needs to be followed for CR calculation:

Say A is a pairwise comparison matrix;

$$A = \begin{bmatrix} 1 & 7 & 1/3 \\ 1/7 & 1 & 5 \\ 3 & 1/5 & 1 \end{bmatrix}$$

$$Column\ Sums \quad {}^{29}/_{7} \quad {}^{41}/_{5} \quad {}^{19}/_{3}$$

$Standardized\ Matrix$

$$A = \begin{bmatrix} 7/29 & 35/41 & 1/19 \\ 1/29 & 15/41 & 15/19 \\ 21/29 & 1/41 & 3/19 \end{bmatrix}$$

$Standardized\ Matrix$

$$A = \begin{bmatrix} 0.241 & 0.854 & 0.053 \\ 0.034 & 0.366 & 0.789 \\ 0.724 & 0.024 & 0.158 \end{bmatrix}$$

$Weights$

$$w = \begin{bmatrix} 0.241 + & 0.854 + & 0.053 = & 1.148/3 \\ 0.034 + & 0.366 + & 0.789 = & 1.189/3 \\ 0.724 + & 0.024 + & 0.158 = & 0.906/3 \end{bmatrix} \qquad w = \begin{bmatrix} 0.383 \\ 0.396 \\ 0.302 \end{bmatrix}$$

$A.w$

$$A.w = \begin{bmatrix} 1 & 7 & 1/3 \\ 1/7 & 1 & 5 \\ 3 & 1/5 & 1 \end{bmatrix} \begin{bmatrix} 0.383 \\ 0.396 \\ 0.302 \end{bmatrix} = \begin{bmatrix} 3.256 \\ 1.961 \\ 1.530 \end{bmatrix}$$

λ_{max}

$$\lambda_{max} = \frac{\frac{3.256}{0.383} + \frac{1.961}{0.396} + \frac{1.530}{0.302}}{3} = 6.17$$

CI

$$CI = \frac{6.17 - 3}{3 - 1} = 1.585$$

CR

$$CR = \frac{1.585}{0.52} = 3.048 > 0.1 \ (Matrix\ is\ not\ consistent!)$$

Obtaining a pairwise comparison matrix having the CR value of close to zero is something desired meaning the high consistency. However, inconsistency itself also shows the involvement of different opinions into the decision making process which in fact makes selecting the right alternative possible. Obtaining the pairwise comparison matrixes such that the calculated CR value would be around 0.1, would result in determining the most convenient option. Saaty (2008b) suggests the adjustment of CR such that *"it should not be as large as the judgment itself, nor so small that it would have no consequence"*.

4.3.2 Forming of Supermatrices

Supermatrix is a special matrix formed by relative importance weights (eigenvectors) obtained from pairwise comparisons described in previous part. ANP process involves forming of three types of supermatrices orderly: unweighted supermatrix, weighted supermatrix and limit supermatrix.

4.3.2.1 Unweighted Supermatrix and Connections in a Network

Unweighted supermatrix is the primarily constructed supermatrix in the process formed by placing the importance weights obtained from pairwise comparisons into the relevant columns and rows and, therefore, the relationships among decision making criteria are defined. In other words, the influence priority of a particular element placed on the left side of the matrix (criteria in vertical order on the left side of the matrix) over the one placed at the top (criteria in horizontal order at the top side of the matrix) is defined based on a particular control criterion. In supermatrix structure, while the importance weights are placed in the relevant locations of supermatrix considering the reciprocal relationships among decision making criteria (criteria having an impact on the other), remaining locations are filled with "zero" showing the irrelevancy. Saaty (1999a) used the notation in Figure 4.3 as the representative of supermatrix network. In the notation, a structure having N components (C_1 to C_N), and n elements in each component (E_{11} to E_{1n} or E_{N1} to E_{Nn}) is defined showing the importance weights as w_{11} to w_{NN}.

$$
W = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_N \\ e_{11}e_{12}\cdots e_{1n_1} & e_{21}e_{22}\cdots e_{2n_2} & & e_{N1}e_{N2}\cdots e_{Nn_N} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \vdots \\ C_N & \begin{array}{c} e_{N1} \\ e_{N2} \\ \vdots \\ e_{Nn_N} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \vdots\;\vdots\;\vdots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix} \end{array}
$$

Figure 4.3: Saaty's Representation of Supermatrix (1999a)

In the formed network, Saaty (1999a) identifies several types of components. The source component is defined in the cases where a type of component does affect one or several components but does not being affected by any of them. Sink component is defined as the component which does not affect any other but being affected by one or several of them. Lastly, the transient component is defined as a component which both affects and being affected by one or several others (Figure 4.4).

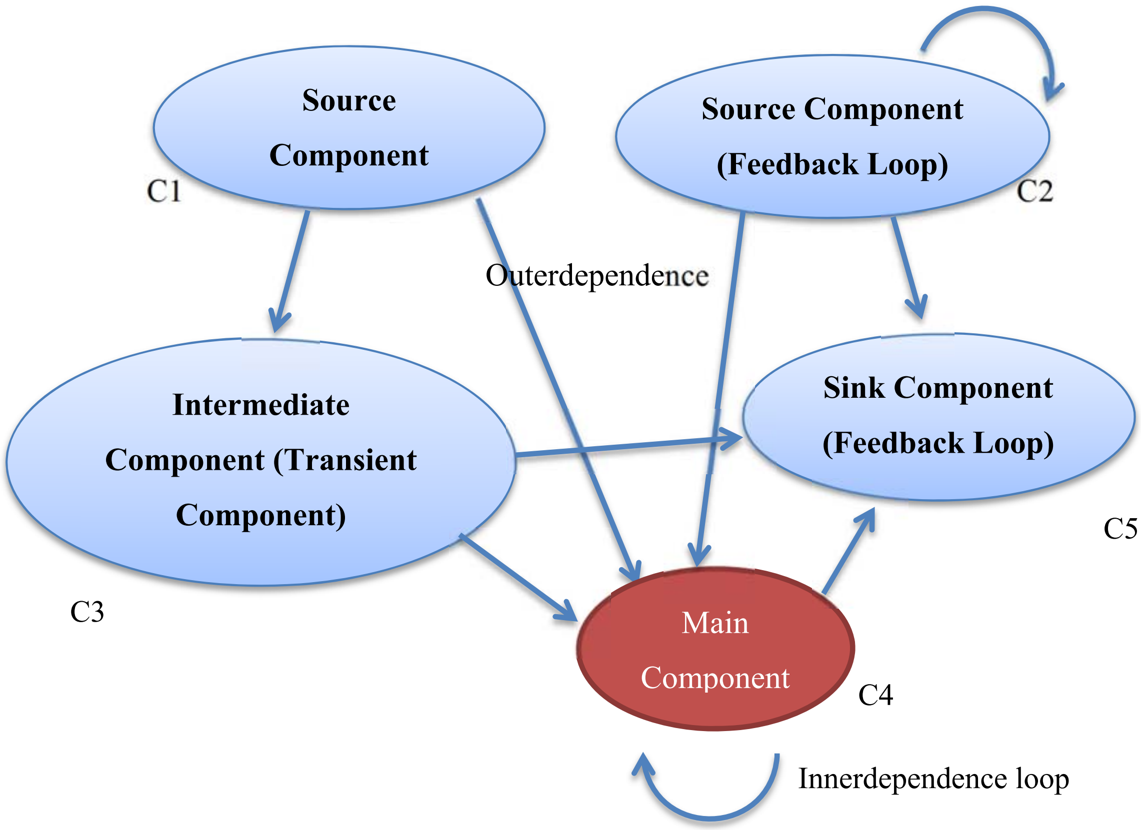


Figure 4.4: Connections in a Network (Saaty, 1999a)

Innerdependence loops as in C2 and C4 defines the feedback, meaning that inter-correlations among the factors in those particular components exist.

4.3.2.2 Weighted Supermatrix

Weighted supermatrix is obtained by multiplying each element in unweighted supermatrix with the eigenvector of the corresponding component. After this process, each column sums to unity and the obtained supermatrix becomes stochastic. In fact, this is required in order to develop meaningful limiting priorities which Saaty (1999a) described their dependency on a stochastic matrix's reducibility, primitivity and cyclicity. After then, as the exponent of matrix increases, the value of the elements in the same row of matrix approaches to each other and becomes equal to their limit value.

4.3.2.3 Limit Supermatrix and Global Priority Values

Limit supermatrix is obtained by raising the weighted supermatrix to a very large power so that one unique value is obtained at each row of the supermatrix. Piantanakulchai (2005) expressed this calculation with the formula;

$$\lim_{k\to\infty}(W)^{k}$$

Obtained unique values on each row give the global priority value of that particular criterion. Dağdeviren et al. (2006) claimed that the criterion having the highest priority value would be the best alternative for alternative selection problem and the most important factor in criteria weighting problem.

Piantanakulchai (2005) also stated that, in the cases where supermatrix has the effect of cyclicity, the number of N limiting might be two or more. In those cases, the average priority weights should be calculated by using Cesaro sum formula;

$$\lim_{k\to\infty}\left(\frac{1}{N}\right)\sum_{i=1}^{N} W_i^k$$

4.3.3 Control Hierarchies

In practical applications, decision makers use ANP for the variety of purposes. The literature contains numerous examples which show smart ANP applications carried by executives, managers, engineers and students from different industries. At this point, Saaty's definition of Control Hierarchies rises. Saaty (1999a) defined control hierarchy as *"the hierarchy of criteria and subcriteria for which priorities are derived in the usual way with respect to the goal of the system being considered"* and he proposed four control hierarchies as Benefits, Opportunities, Costs and Risks. This model is called as BOCR model. The model is constructed using relevant criteria and a decision making problem inserted in ANP process might include one or several of those hierarchies. Poonikom's example of university selection decisions (2004) clearly expresses a BCR which covers the control hierarchy of Benefits, Costs and Risks.

4.3.4 Sensitivity Analysis

A comprehensive and detailed network constructed for ANP generally proposes reasonable results in accordance with the decision makers' contributions. Still, it is quite natural that the owner or consultant may sometimes have different opinions at different times regarding the same criterion belonging to constructed model's network or different decision makers might have different opinions about the same criterion. For the purpose of detecting to what extent the order of alternatives and the final decision obtained as the outcome of ANP are sensitive against the change in decision makers' opinion, "sensitivity analysis" should be performed. The analysis could be performed both for the testing of ordered alternatives obtained as the outcome of ANP and for testing the model at the BOCR level. For the testing, the weight of the leading criteria or the merit belonging to BOCR is increased or decreased by keeping the remaining weights proportional and the result (the order of obtained alternatives or the overall ranks of merits belonging to BOCR) is investigated in order to discover the sensitive contributors. Saaty (1999a) summarized the process of sensitivity analysis as the process of answering the following questions: *"Can another outcome that is close also serve as the best outcome?"*, if yes, *"why and how?"*

4.4 Practical Use of ANP in Different Industries

The literature contains a number of examples describing the use of Analytical Network Process for the variety of purposes in different industries. In fact, during the discussion of literature review in previous sections, the use of ANP in the construction industry was exemplified with studies of Cheng and Li (2004) declaring the subcontractor selection practice and El-Abbassy et al. (2013) determining the most competitive contractor at the pre-bidding stage for highway projects. In the upcoming part, rather than giving various stereotyped examples of ANP which can be found in many articles, newly-raised examples of ANP belonging last couple years would be given which were used for different purposes both in construction and other industries.

Abdi (2012) used ANP in the food sector and he developed a conceptual framework for product family formation using different decision factors such as manufacturing requirements, market requirements, manufacturing cost and process reconfiguration. By mapping decision factors affecting product family formation, main criteria and elements are defined clearly together with the dependencies and connections between them and an Analytical Network Process model is proposed and examined based on a case study.

Stepchenko and Voronova (2015) used ANP methodology for performing the improvement of the risk function analysis of an insurance company. Taking advantage of including tangible and intangible strategic factors and elements into the decision making process, a comprehensive risk analysis was performed in accordance with the Solvency II regime requirements. Based on a case study of none-life insurance company, beyond proposing ANP methodology as being a part of the risk culture of an insurance company, the authors also suggested the usage of ANP in banking and investment areas since they use similar solvency requirements and challenges during performing their risk analysis.

Šimelytė et al. (2014) used ANP based on benefit-opportunity-cost-risk (BOCR) analysis in order to propose a foreign direct investment (FDI) policy. Using the methodology, rather than accepting FDI policies that just bring benefit to host countries, the new policies that also serving for achieving host countries strategic goals were discovered.

Zabihi et al. (2015) inserted ANP in Agriculture and used the methodology for sustainable land use planning and ecological land evaluation. Considering three discipline-criteria of socio-economic status, topography and hydro-climate, a network model is constructed using 14 different criteria based on the expert judgments and inserted in the process of sustainable citrus production. As the result of the study, the critical factors helping managers to obtain optimum crop yield and decrease the loss of citrus were clarified.

E. Çakmak and P.I. Çakmak (2014) used ANP for the analysis of dispute reasons in the construction industry. Based on a literature review, the main construction disputes were identified, classified into main categories and ANP approach is applied with the aim of determining the relative importance of relevant dispute causes.

Sharma and Singh (2014) adopted ANP for measuring the effectiveness of individual, organizational and technological knowledge sharing barriers (KSBs) in order to help managers to take decisions for improving knowledge sharing mechanism in a correct way in the engineering industries. In the scope of the study, a framework including determinants, dimensions and enablers were developed and three categories of KSBs were examined by using ANP methodology.

Cooper et al. (2012) created an ANP model for choosing the suitable third-party logistics provider with the aim of achieving improvements within the supply chain. The performance metrics (PM) were integrated together with their interrelations and ANP methodology were performed in order to obtain the weights of corresponding PMs. Beyond that, warning signals and trigger points within PM network were clarified and managerial insight into the relative impact of each metric was obtained.

Tseng and Chiu (2012) incorporated ANP methodology to the techniques of grey theory and entropy weight in order to assess the green innovation practices under uncertainty. By using the proposed model, the ranking of each alternative and sensitivity analysis were derived and calculated from incomplete information and dependence relations among them which were standing as the main purpose of performed study. The worlds largest printed out circuit board manufacturer have also validated the study and emphasized the practicability of proposed model.

Ghajar and Najafi (2012) utilized ANP framework to assess three existing harvesting methods as an international mechanism for local management within the scope of Sustainable Forest Management (SFM). The study was addressing the environmental, economic and social analysis of available alternatives and criteria for helping forest managers to prioritize their preferences. The purpose of the study was constructing a model for achieving more sustainable and leading forest utilization practices and the created model was validated by using a case study created for Caspian forests in northern Iran.

Nargesi et al. (2011) developed an ANP methodology for assessing the organizational readiness of Iranian firms to implement Customer Relationship Management (CRM) model. In the scope of the study, 14 readiness assessment criteria were determined based on 51 key papers published between 2001 and 2010 and a fuzzy ANP model was proposed taking the intercorrelations among proposed criteria into effect.

CHAPTER 5

UNCERTAINTY & FUZZY METHODOLOGY

Artificially produced problems that are studied in the literature generally have the characteristics of being more restricted and direct. That is mainly because they can be created and formulated up to the extent that one can imagine and they can be easily shaped by its creator through the way of its solution. However, the problems that are encountered in real world contain many unknowns and many blurred phases exist in their solution stage. Özdemir (2012) supports this view by emphasizing the failure of classical approaches to the solution of contemporary problems while they work quite successfully in basic and isolated environments. For decision making, the blurred phases defined in the problem structure shall be clarified as much as possible to achieve the best solution and this can be ensured only after the required information is obtained in a sort of way.

For solving a decision making problem, the required information might be obtained either in a structured way which can be expressed mathematically and directly inserted in the solution phase or unstructured way which need to be investigated or analyzed so the mathematical expression could be produced. At this point, Zadeh (1965) asserted his theory of "fuzzy logic" for obtaining the adequate expression in the environment that uncertainty prevails. Fuzzy logic basically makes uncertain expressions explicit by assigning them to the suitable class using a continuous scale where the grades of memberships are defined clearly. Zadeh (1965) defined those classes as "fuzzy set" which has *a continuum of grades of membership*.

Zadeh (1965) used the examples of the *class of beautiful women* and the *class of tall men* for explaining the logic behind the fuzzy approach. The examples could be increased such as the class of comfortable cars or luxurious houses. However, the main point here is that all the classes identified above include a certain amount of subjectivity or personal judgment. A tall man might be short or a luxurious house might be modest according to someone else's opinion. Therefore, to achieve exact mathematical expressions and get rid of ambiguous statements, fuzzy sets are used which proposes a framework in the cases where imprecision and sharp definitions are absent.

In fuzzy approach, the classes are formed such that, there exist intersections between them. That means, an element belonging a certain class might also be the member of another class. Klir and Yuan (1997) expressed this relationship such that, in fuzzy sets, the membership does not work as being a member or not, instead, the member of one group might be a member of another group to a certain degree.

Following example clearly describes the expression of Klir and Yuan (1997);

Assume grouping of cars according to their ages and let the age 5 to be the border between new and middle-aged and 15 between middle-aged and old. Classical set approach distributes the cars into the classes such that there would be no car belonging both classes (no intersection between classes). A 6 years old car belongs to the middle-aged class in classical set approach (Figure 5.1).

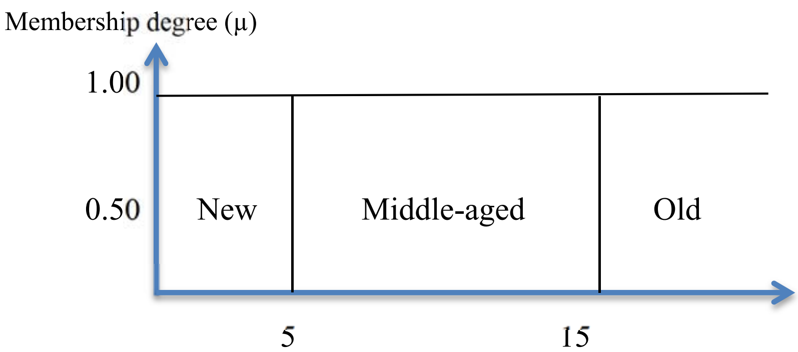


Figure 5.1: Classical Set Approach

Fuzzy set approach distributes the cars into the classes such that there would be a car belonging more than one class (intersection between classes) (Figure 5.2). A 6 years old car both belongs to new and middle-aged class to a certain degree.

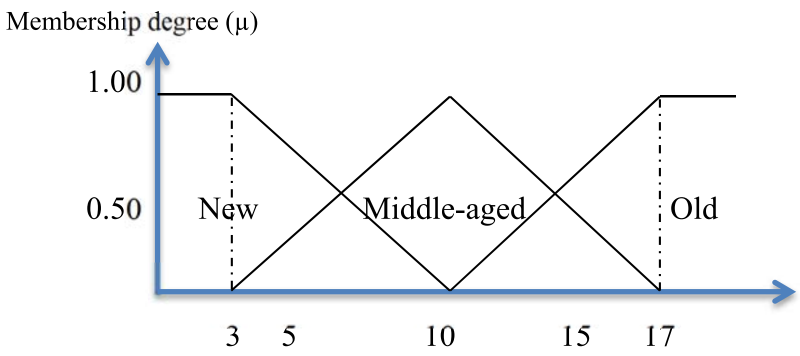


Figure 5.2: Fuzzy Set Approach

5.1 Fuzzy and Linguistic Expressions

In literature, researchers frequently encounter with problems which needed to be defined and modeled somehow so that a precise solution could be sought. Linguistic expressions are the main factors making the problem modeling blurry since it is not possible to use them directly as a mathematical expression. The ability to interpret linguistic inputs mathematically makes fuzzy logic an assertive method for those cases which ensures obtaining comprehensive solutions. Özdemir (2012) supports this idea by expressing fuzzy logic as an estimated reasoning technique which uses human based language for describing input-output relations of a system and she defines fuzzy logic as the system which directly coincides with the thinking ability of human that contains imprecise expressions.

In fuzzy approach, since mathematical expressions are directly derived from linguistic variables, obtaining the correct assessment from correct people becomes crucial for achieving the successful modeling. Therefore, in practice, candidate assessors shall be analyzed well before assessment process and they shall only be included after their specialty in the corresponding subject is ensured. In addition to that, rather than simply asking for the verbal evaluation, offering some verbal and hierarchical expressions such as "very good", "good", "very bad" in accordance with the problem definition would be appropriate in terms of keeping the response pool processable. In other words, using a scale the verbal expressions can easily be converted to the mathematical expressions.

5.2 Fuzzy Membership Functions

The information conserved in fuzzy sets is described by its membership function. In fuzzy approach, membership functions are constructed as either being continuous or discrete. Figure 5.3, illustrates a basic shape of the fuzzy membership function (Ross, 2010).

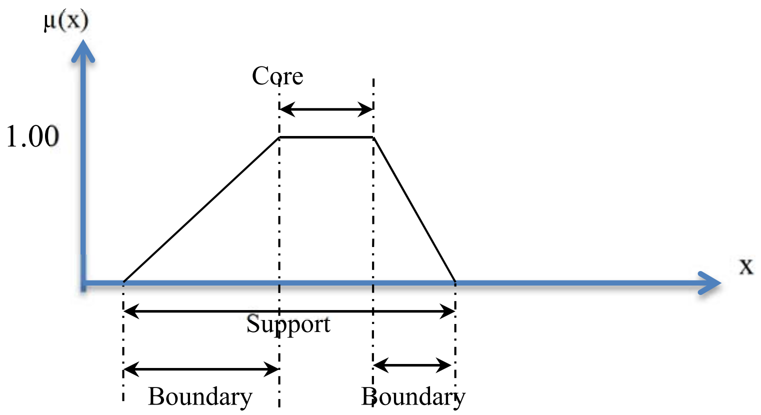


Figure 5.3: Core, Support and Boundaries of a Fuzzy Set

The *core* of a membership in a particular fuzzy set means there is a complete and full membership at that point or in that particular region. The complete membership of particular elements (x's) within the fuzzy membership function of A is showed such that $\mu A(x) = 1$.

The *support* of a membership in a particular fuzzy set shows the universe of variable x's where the membership exists. Therefore, the region where membership exists within the fuzzy membership function of A is called as “support” such that $\mu A(x) \geq 0$ within that particular frame.

The *boundaries* of a membership in a particular fuzzy set show the region of the universe where the membership is neither 0 nor 1, which describes the level of membership stands just between the zero and complete. Such regions within the fuzzy membership function of A is expressed such that $0 > \mu A(x) > 1$.

In the cases where at least one element of x within the specified frame has the membership value of 1 (unity), the set is named as the *normal* fuzzy set. Moreover, if there is only one element exists in a specified frame where the membership value is unity, it is referred as the *prototype* of the set or simply the *prototypical element*. Figure 5.4 explains the introduced descriptions.

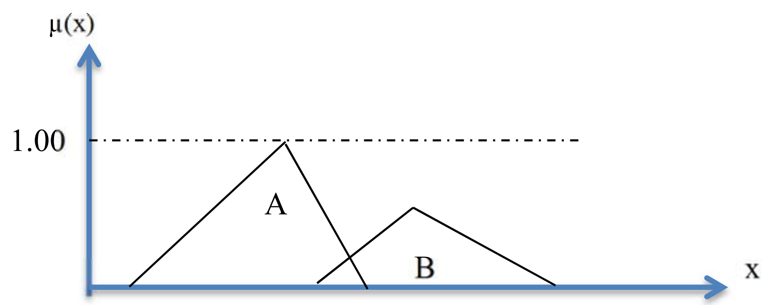


Figure 5.4: Normal (A) and Subnormal (B) Fuzzy Sets

In the cases where fuzzy membership values monotonically increase, monotonically decrease or monotonically increase and then decrease as the increasing values within the universe, the set is named as the *convex* fuzzy set. Figure 5.5 illustrates the convex and nonconvex normal fuzzy set.

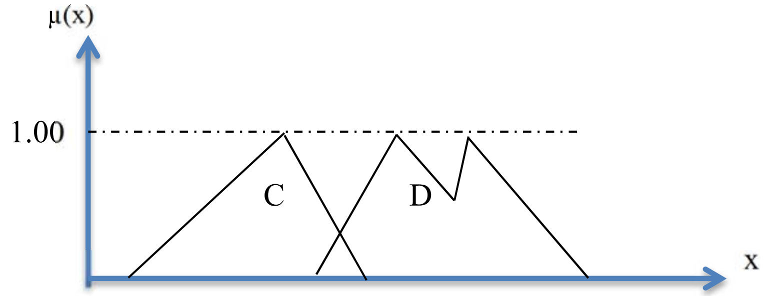


Figure 5.5: Convex, Normal Fuzzy Set (C) and Nonconvex, Normal Fuzzy Sets (D)

The *crossover points* of a membership function are defined for the elements of the universe where the semi-membership is obtained. Therefore, the membership values in those points become equal to 0.5 such that $\mu A(x) = 0.5$.

The *height* of a fuzzy set is defined the as the maximum value of membership within a specified universe such that $hgt(x) = \max\{\mu A(x)\}$ .That implies, if $hgt(x) = 1$ the fuzzy set is said to be normal. Klir and Yuan (1995) interpret the value of $hgt(x)$ as the validity or credibility of information expressed by the fuzzy set membership function of A.

The fuzzy set is *symmetrical* according to point "a" only if each membership value corresponding to values of "a-x" and "a+x" are equal for all the values lying in the specified universe. Therefore becoming symmetrical within the fuzzy set membership function of A shall be formulated as $\mu A(x + a) = \mu A(a - x)$

5.3 Types of Fuzzy Membership Functions

In literature, there are many types of fuzzy membership functions are used depending on the features of the system that would be inspected. Aytaç (2006) asserted some of those functions which are frequently used in practice namely; trapezoidal, triangular, Gaussian, curve shaped, sigmoidal and S-shaped.

5.3.1 Trapezoidal Fuzzy Membership Function

Trapezoidal fuzzy membership function is defined by four parameters as a_1, a_2, a_3, a_4 (Figure 5.6).

$$\mu A(x;\ a_1, a_2, a_3, a_4) = \begin{cases} a_1 \le x \le a_2 & then\ \ (x - a_1)/(a_2 - a_1) \\ a_2 \le x \le a_3 & then\ \ 1 \\ a_3 \le x \le a_4 & then\ \ (a_4 - x)/(a_4 - a_3) \\ a_4 < x\ or\ x < a_1 & then\ \ 0 \end{cases}$$

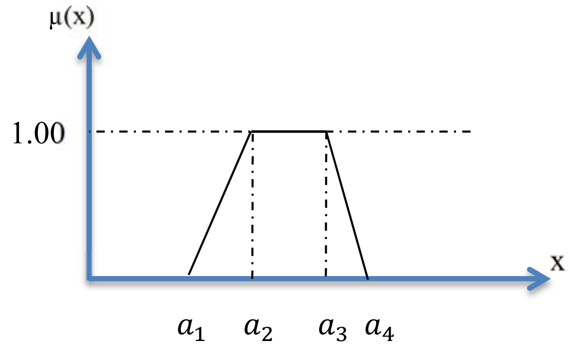


Figure 5.6: Trapezoidal Fuzzy Membership Function

5.3.2 Triangular Fuzzy Membership Function

The triangular fuzzy membership function is defined by three parameters as a_1, a_2, a_3. In fact, it is derived as a special form of trapezoidal fuzzy membership function (Figure 5.7).

$$\mu A(x;\ a_1, a_2, a_3) = \begin{cases} a_1 \le x \le a_2 & then \quad (x - a_1)/(a_2 - a_1) \\ a_2 \le x \le a_3 & then \quad (a_3 - x)/(a_3 - a_2) \\ a_3 < x & then \quad 0 \end{cases}$$

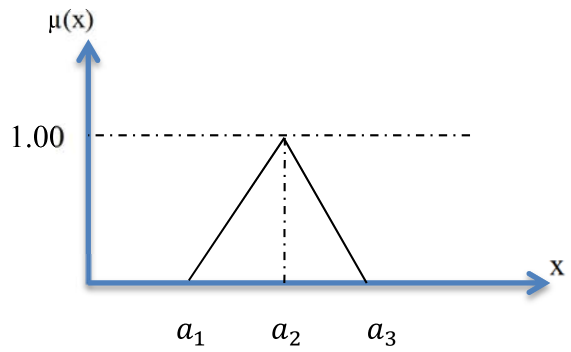


Figure 5.7: Triangular Fuzzy Membership Function

5.3.3 Gaussian Fuzzy Membership Function

Gaussian fuzzy membership function is defined by the parameters of m and σ. In the formulation, m stands for center of the membership function and σ stands for the width (Figure 5.8).

$$\mu A(x; m, \sigma) = exp\left\{\frac{-(x-m)^2}{2\sigma^2}\right\}$$

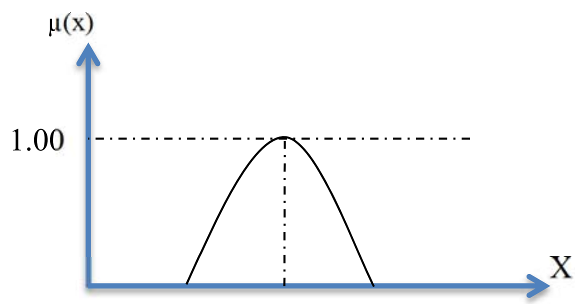


Figure 5.8: Gaussian Fuzzy Membership Function

5.3.4 Curve Shaped Fuzzy Membership Function

Curve shaped fuzzy membership function is defined by three parameters of a_1, a_2, a_3 and with the formulation of (Figure 5.9);

$$\mu A(x;\ a_1, a_2, a_3) = \left\{ \frac{1}{1 + \left| \frac{x - a_3}{a_1} \right|^{a_2}} \right\}$$

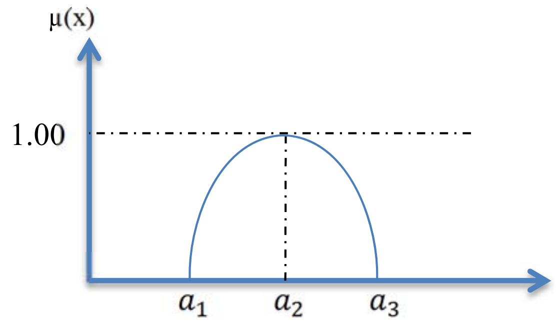


Figure 5.9: Curve Shaped Membership Function

5.3.5 Sigmoidal Fuzzy Membership Function

Sigmoidal fuzzy membership function is defined by two parameters of a_1, a_2 and with the formulation of (Figure 5.10);

$$\mu A(x;\ a_1, a_2) = \left\{\frac{1}{1 + e^{-a_1(x - a_2)}}\right\}$$

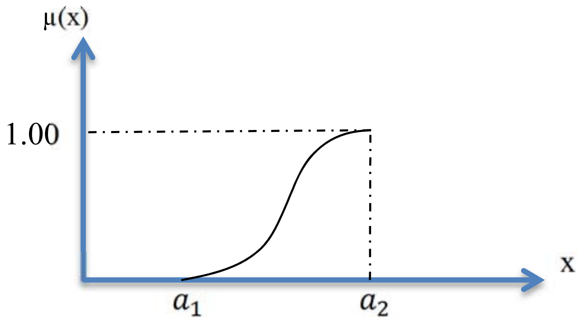


Figure 5.10: Sigmoidal Membership Function

5.3.6 S-Membership Function

S-membership function is defined by four parameters as a_1, a_2 and with the formulation of (Figure 5.11);

$$\mu A(x;\ a_1, a_2) = \begin{cases} x \le a_1 \quad then \ \ 0 \\ a_1 \le x \le [(a_1 + a_2)/2]\ then \quad 2\,[(x - a_1)/\,(a_2 - a_1)]^2 \\ [(a_1 + a_2)/2] \ \le x \le a_2 \ \ then \quad 1 - 2\,[(x - a_2)/\,(a_2 - a_1)]^2 \\ a_2 < x \quad then \quad 1 \end{cases}$$

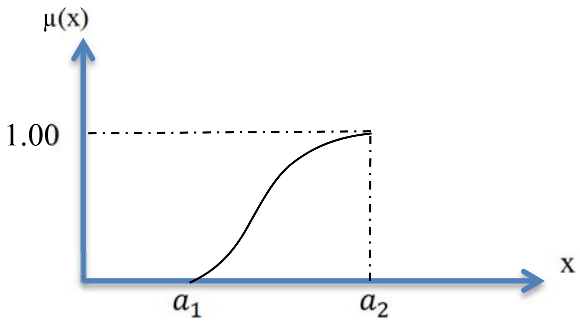


Figure 5.11: S- Membership Function

Depending on the problem definition, the different combination of introduced membership functions shall be allocated or a new function shall be created. Aytaç (2006) emphasized that self-intuition, logic and the experiment are the leading contributors for assigning the most suitable membership function to the fuzzy system. Apart from that, the approaches such as artificial neural networks, genetic algorithms and inference reasoning also contribute to the suitable membership function selection in some cases.

5.4 Typical Fuzzy System

Osofisan (2007) summarized a typical fuzzy logic model in four main components namely, *the fuzzifier, the inference engine, the defuzzifier,* and a *fuzzy rule base* (Figure 5.12).

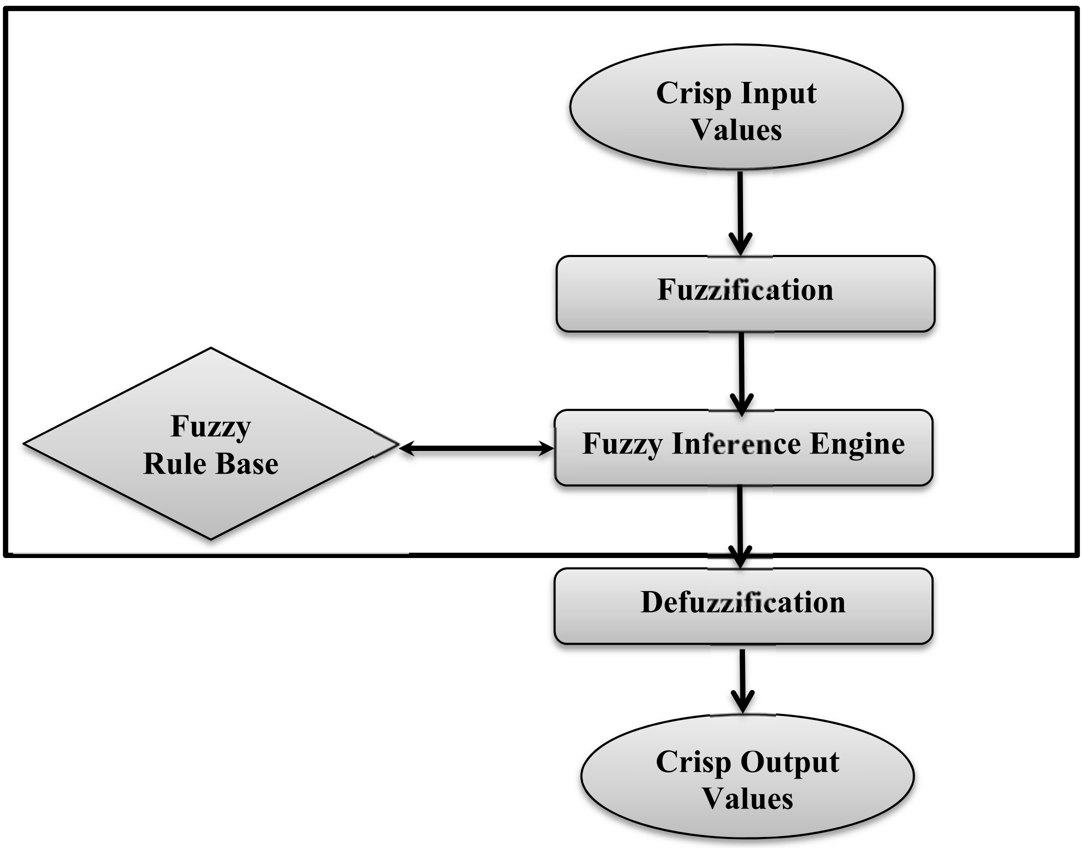


Figure 5.12: Structure of a Fuzzy Logic

Elmas (2003) stated that fuzzy logic systems contain the following characteristics:

- The scale factors of inputs and outputs are constant
- Fuzzy rule base is constant and there exists no interaction among defined rules. All the rules are equally accurate
- Membership functions are constant
- The number of rules changes with the number of input variables
- The method of combining outputs is constant
- The rule base structure is not hierarchical

Fuzzification:

Fuzzy logic model is stimulated with introducing the input values to the system as crisp numbers. At the following step, the input values are designated verbally according to relevant membership function defined in the fuzzy set. In other words, by using the membership function, the numerical crisp value is converted to a linguistic term which pre-described in fuzzy sets.

Fuzzy Rule Base:

Fuzzy Rule Base is constructed by experts' opinions or using unsupervised learning techniques based on information or data sets. (Reznik, 1997) In unsupervised learning technique, the system learns the relationship between examples and parameters by itself and the meaning of outputs are classified by the user at the end of learning phase (Öztemel, 2006).

Fuzzy rule base contains a database which contains *a knowledge of application domain* and *control goals* to be met (Osofisan, 2007) in conjunction with a rule base. While the fuzzy inference engine is running, the data required for the fuzzification and defuzzification are obtained from this unit. Therefore, a steady interconnection between the database and inference engine is crucial for the fuzzy logic system to proceed.

Rule base contains a set of fuzzy rules defining the relation between input and output variables. Those fuzzy rules mainly represent the conditional clauses such as IF-THEN-ELSE. (Aytaç, 2006) Based on the conditional statements identified for the input variables, the output values are produced as the function of various inputs.

Fuzzy Inference Engine:

Fuzzy Inference Engine processes the introduced data and makes inferences similar with the human inference behavior. In fact, the inferences are just the symbolic results shaped by the linguistic qualifiers and rules of model developer. Various inference methodologies exist before passing results through defuzzification process (Aytaç, 2006).

Aytaç (2006) summarized the methodologies as follows;

Max Dot: Each input value re-scale the fuzzy set depending on the membership degree in its membership function. The output value is the maximum value in the re-scaled fuzzy sets obtained after each input value has been run.

Min Max (Mamdani): Depending on the membership degree in its membership function, the part of the fuzzy set above the membership value is removed. The output value is the weighted mean of the remaining fuzzy sets.

Tsukamoto: The structure is formed setting the output membership function as an increasing function. The output value is the weighted mean of the sharp output values of each rule defined.

Takagi-Sugeno: The output value of each rule is found by the linear combination of input values. The sharp output value is the weighted mean of the sharp output values.

Defuzzification: Defuzzification is the process of converting fuzzy outputs obtained from fuzzy inference engine to the real numerical expressions. After this process, the outcomes become single scalar quantities which shall be appropriate for further analysis or direct use. For defuzzification, various processes are suggested and user shall choose the suitable methodology depending on the problem case.

Ross (2010) asserted the output of a fuzzy process can be the direct fuzzy membership function or the logical combination of two or more. In the cases that a general fuzzy output involves more than one output parts, each part of the output whether trapezoidal, triangular or any other, shapes the final output and the membership function is defined by;

$$C_k = \bigcup_{i=1}^{k} C_i = C$$

From above formula the figural expression of membership function combination would be illustrated as shown in Figure 5.13, Figure 5.14 and Figure 5.15.

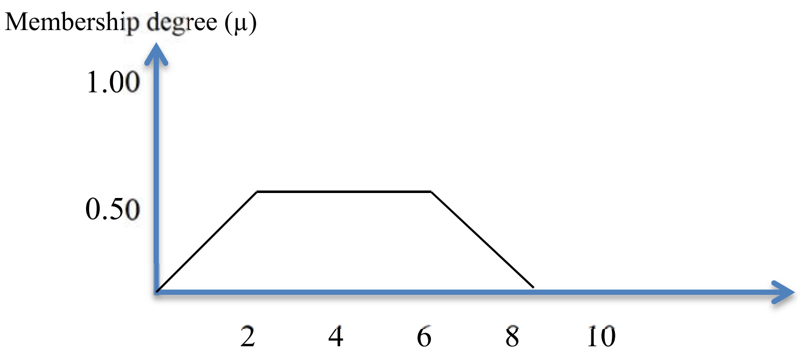


Figure 5.13: Trapezoidal Fuzzy Membership Function (C_1)

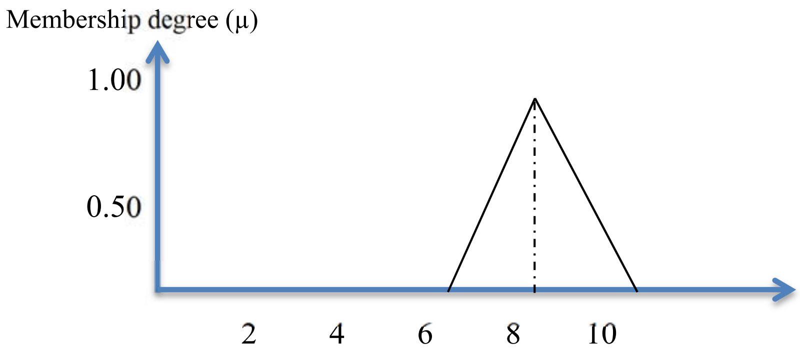


Figure 5.14: Triangular Fuzzy Membership Function (C_2)

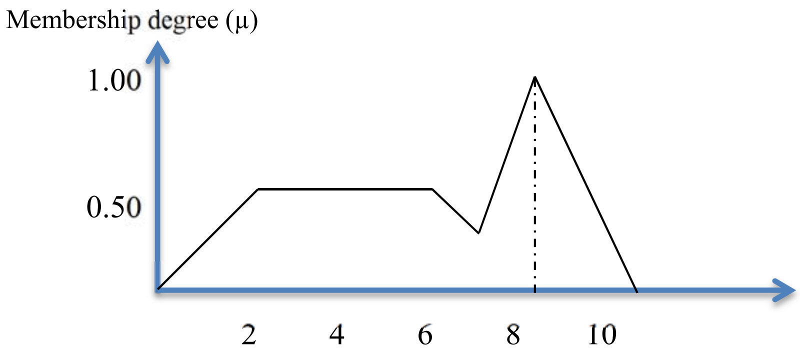


Figure 5.15: Combination of (C_1) and (C_2)

Ross (2010) identified the methods for defuzzification which are frequently used as follows;

1- Max Membership Principle (Height Method)

The scheme is limited to peaked output function and defined with the expression of;

$$\mu c(z') \geq \mu c(z) \qquad for\ all\ z\ \in Z,$$

where z' is the defuzzified value and is shown in Figure 5.16

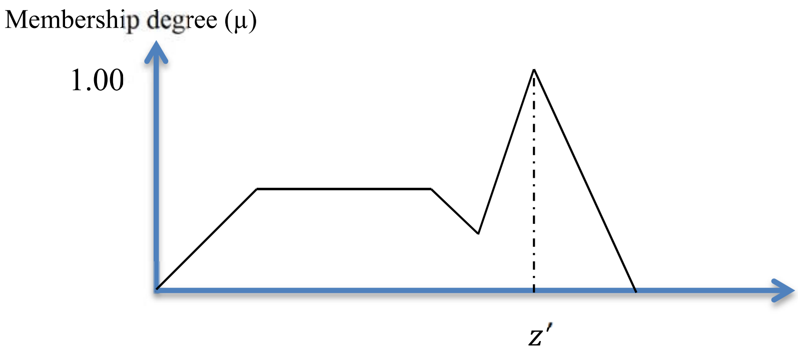


Figure 5.16: Max Membership Defuzzification Method

2- Centroid Method (Center of Area or Center of Gravity)

Centroid method uses the center of area or gravity of the final combined fuzzy membership function. Sugeno (1985) and Lee (1990) claim centroid method as the most prevalent and physically appealing among existing defuzzification methods. Centroid method is defined with algebraic expression;

$$z' = \frac{\int \mu c(z) \, . \, z dz}{\int \mu c(z) \, dz}$$

where $\int$ is algebraic integration and is shown in Figure 5.17

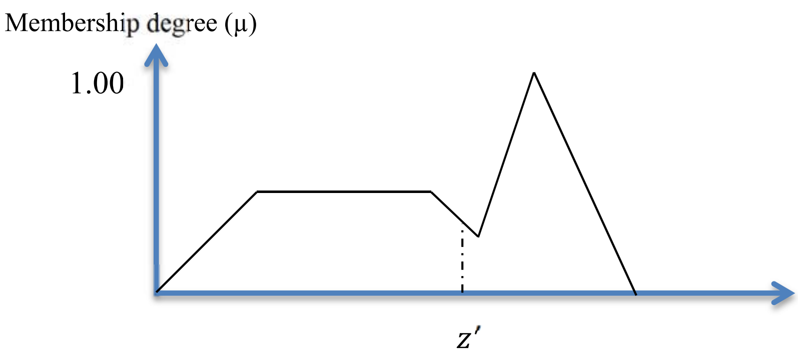


Figure 5.17: Centroid Defuzzification Method

3- Weighted Average Method

Ross (2010) asserted the weighted average method as the most frequently used in fuzzy applications because of its efficiency in being computational. However, the method's usage usually restricted to symmetrical output membership functions. The method is defined with the algebraic function of;

$$z' = \frac{\sum \mu c(z^*)\ .\ z^*}{\sum \mu c(z^*)}$$

where $\sum$ stands as the algebraic sum and z^* stands as the centroid of each symmetric membership function. The method is shown in Figure 5.18

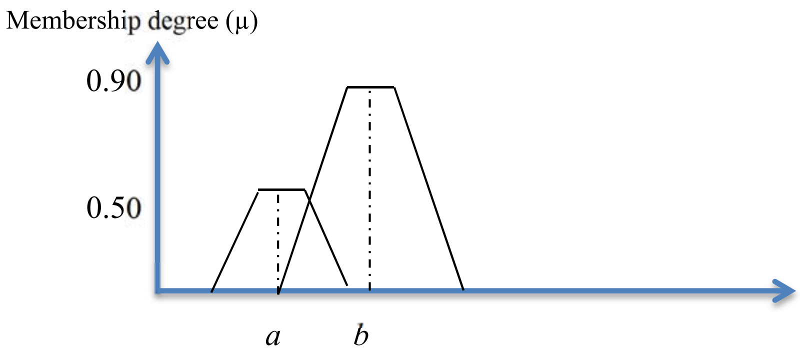


Figure 5.18: Weighted Average Method for Defuzzification

Assuring a and b are the centroids of corresponding membership functions, defuzzified value (z') value is calculated by;

$$z' = \frac{a\ (0.5) + b\ (0.9)}{(0.5) + (0.9)}$$

4- Mean Max Membership (middle-of-maxima)

Mean max membership method is, in fact, a specialized form of the first method (height method). In the cases that the number of maximum membership value exceeds one (the max membership might be more than one point or a plateau rather than one point) mean max membership method shall be used. Sugeno (1985) and Lee (1990) formulated this method with the algebraic expression of;

$$z' = \frac{a + b}{2}$$

Where a and b are defined in Figure 5.19

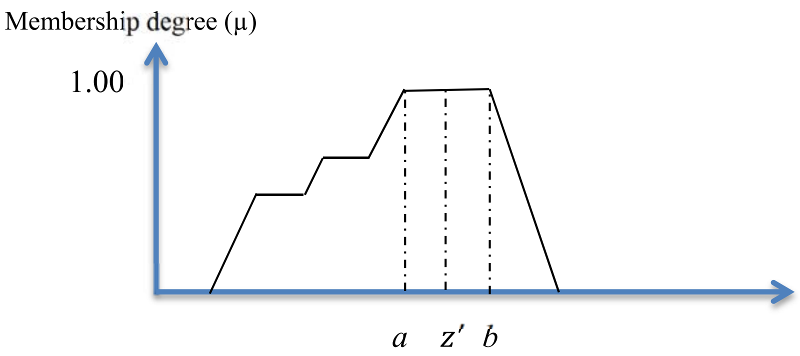


Figure 5.19: Mean Max Membership Defuzzification Method

5.5 Advantages of Using Fuzzy System

The observations about why fuzzy logic should be used are as follows;

- It is easy to understand: Fuzzy logic is a more intuitive approach containing simple mathematical concepts behind it.
- It is flexible: Fuzzy logic could be easily developed and made appropriate for any introduced system.

- It is tolerant of imprecise data: Considering the challenge about obtaining precise and adequate data, fuzzy logic understanding of working process without seeking for the precise information makes it quite advantageous.
- It can model nonlinear functions of arbitrary complexity: Any set of input-output data could be matched using a fuzzy system (Adaptive Neuro-Fuzzy Inference Systems-ANFIS).
- It can be built on top of the experience of experts: Fuzzy logic allows relying on pre-prepared models and experience of people who already understand the system.
- It can be blended with conventional control techniques: Fuzzy systems generally develop the conventional control methods and simplify their implementation rather than replacing them.
- It is based on natural language: Fuzzy logic is built on the structures of qualitative description belonging human communication of everyday language.

5.6 Fuzzy Examples in Construction Industry

The fuzzy methodology is a frequently used approach in construction industry especially for managerial issues such as the phases of bidding, tendering or contracting. In literature, many examples that are related to the fuzzy approach exist. The recent researches are illustrated in the upcoming parts.

Turkis et al. (2015) used the fuzzy approach in combination with AHP with the aim of proposing a fuzzy multi-attribute performance measurement (MAPM). In order to determine the best shopping center construction site in the city of Vilnius, the number of various qualitative and quantitative assessment criteria was determined and the qualitative attributes were dealt with fuzzy logic to remove ambiguities and vagueness. Fuzzy AHP was used for assigning weights of the attributes and Weighted Aggregated Sum Product Assignment method with Fuzzy values (WASPAS-F) was used to detect the most appropriate alternative.

Mousavi et al. (2015) created an artificial intelligence model by using neural networks and fuzzy logic approach with the aim of selecting the best project in the construction industry. In order to measure the overall performance of construction projects, a computationally AI model, namely locally linear neuro-fuzzy (LLNF) model was proposed and validated through a real case study. The outputs of the created model were also tested in terms of performance and accuracy using two widely-used regression methods and using the model for the future complex concrete problems were recommended.

Marzouk and Amin (2013) proposed a methodology using neural network technique and fuzzy logic for determining the materials that are most sensitive to price changes which directly affects the contract price. The study was constructed based on the material prices that occurred in the Egyptian Market in between the years 2000 to 2010 and in the scope of the study, the main cost items are classified into four components namely building materials, equipment, labor and administrative expenses. It is aimed to use the developed study for aiding the contractors in studying bids, during the tendering stage and procurement planning while the execution of the works continues. The second aim was to estimate the expected total cost of the upcoming projects for budget preparation by owners' representatives. The fuzzy model was formulated for calculating the degree of importance of each material in the item through three main criteria of the percent of elements' share in the total price of cost items, the difference in the study of the element's price index during study period and the difference percentage in the cost element's price.

Guan and Yang (2014) introduced a study for construction project cost control based on fuzzy control technology which includes cost fuzzy control system, fuzzy reasoning and fuzzy control process (rule). Unlike traditional cost control systems, fuzzy cost control system was found quite feasible and capable of conducting logical ratiocination based on different inputs and it was also capable of choosing and processing adequate schemes of management. The method was simple to apply, efficient for the scientific and computerized management of cost control and very useful for improving the level of project cost control.

Beyond above examples, Li et al. (2013) used fuzzy analytic hierarchy process and simulation for the risk management associated with modular construction by focusing on identifying risk factors and assessing the impacts of the identified risks on the project cost and duration. Lu et al. (2015) proposed a model with the aim of ensuring the safety of highways cross operation which uses the fuzzy methodology for quantifying the qualitative data. Finally, Jing and Shun-liang (2014) developed a fuzzy comprehensive evaluation dynamic model of bridge construction safety management status based on set pair analysis.

CHAPTER 6

OPTIMIZATION

Optimization is finding a solution having the most cost effective or highest achievable performance under given limitations by maximizing the desired factors and minimizing undesired ones. Therefore, optimization stands as an inevitable component of business life since it directly focuses on limited resources such as time and money which stands as cores in many industries.

This chapter briefly describes the optimization approach which is also used in the current study and introduces some basics.

6.1 Terms & Definitions

Optimization is about creating such a design that the objective of the user would be reached by choosing the correct inputs among the defined set of alternatives. Therefore, the performance of the final product could be improved. In the optimization of a design, the design objective could be basically minimizing the production cost or maximizing the production efficiency. The optimization algorithm works in such a way that the defined mathematical expression executes iteratively by comparing the various solutions produced until an optimum and satisfactory solution is obtained.

Optimization has become a major part of computer-aided design activities today and it is used in many fields including Mechanics, Economics, Civil Engineering, Electrical Engineering, Operations Research, Control Engineering, Petroleum

Engineering, Geophysics and Molecular Modeling (Iqbal, 2013). Designing a tool for calculating and validating loads on floor slabs and shores in the construction of multi-storey buildings (Buitrago et al., 2015), investigating the environmental performance of concrete structures varying design parameters and construction techniques to optimize its embodied energy (Miller et al., 2015) and optimal scheduling of resource constrained building construction projects for effective using of limited budget and time to avoid delay penalties (Sönmez & Bettemir, 2012) could be the couple examples belonging application fields of optimization approach from Construction Industry.

Deterministic Algorithms and *Stochastic Algorithms* are two distinct types of optimization algorithms which are widely used. In *Deterministic Algorithms*, a specific rule is used for moving one solution to other during iteration progress while in *Stochastic Algorithms* the probabilistic translation rules are valid. Although deterministic algorithms have been successfully applied many engineering problems, stochastic algorithms keep gaining popularity because certain properties that deterministic algorithms do not have.

The optimization problem begins with identifying the *design variables* which are varied during the optimization process. Those variables are executed using the mathematical expression defined in optimization problem and they stand as the input values of a certain solution alternative. The whole solution alternatives obtained from the execution process is called as *solution space* while the mathematical expression itself which executes the design variable for producing solution alternatives is called the *objective function*.

The engineering objectives usually include minimization and maximization type of problems. Therefore, the objective function of an optimization problem is organized such that minimizing of overall cost and overall time or maximizing efficiency, total life and durability. Although most of the objectives can be expressed in mathematical terms, the approximating mathematical expression should be used for some others such as reliability of contractor, the durability of the building or aestheticism of a structure.

The output of optimization process is called as *fitness value* or *values* depending on the number of functions are evaluated. The *constraints* stand for the functional relationships between the design variables and other design parameters for satisfying a certain physical phenomenon or resource restrictions. They can be defined either in mathematical expressions or not, however, they simply limit the performance of the objective function which causes elimination or arising of new solution alternatives.

Depending on the type of optimization problem, different solution techniques can be followed. Those techniques can be investigated in two main parts namely; *classical optimization techniques* and *heuristic optimization techniques*.

Classical optimization techniques search the optimal solution by using the gradient information of objective function(s). *Linear programming*, *non-linear programming, quadratic programming, real-valued programming, integer programming* and *Newton-Raphson programming* are some examples of classical optimization techniques which all include analytical methods and use differential calculus for determining the optimal solution. Those techniques are useful in finding the optimum solution, unconstrained maximum or minimum of continuous and differentiable functions. However, for discontinuous and non-differentiable functions, the classical methods have limited scope meaning that the proposed solution is either questionable or finding a solution takes a long time.

Heuristic optimization techniques are used for problems where using of classical optimization methods would be inefficient. They are designed based on the concepts found in nature and they became more feasible as a result of improving computational power. However, heuristic optimization approach does not guarantee the optimal solutions but it searches for the near-optimums (approximate solutions). *Memetic algorithm*, *differential evolution, evolutionary algorithms* and *dynamic relaxation* are some common heuristic optimization techniques. On the other hand, Meta-heuristic optimization techniques are used especially for incomplete or imperfect information or limited computation capacity. *Genetic algorithms, particle swarm optimization, artificial bee colony optimization, simulated annealing* and *tabu search* are the major meta-heuristic optimization techniques that profoundly used in literature.

6.2 Optimization Problems

Optimization problems can be investigated in two main parts namely *Single Optimization Problem* and *Multi-Objective Optimization Problem*.

6.2.1 Single Optimization

Single Optimization Problem is the problem in which there is only one single objective function exists and described as follows;

$min/\,max\ f(x)$

$subject\ to$

$$g_j(x) \geq 0$$

$$h_k(x) = 0$$

$x \in S$

where the scalar objective function $f(x)$ optimizes the variable set x in a vector space S, including the constraints of $g_j(x)$ and $h_k(x)$.

6.2.2 Multi-objective Optimization & Pareto Optimal Solutions

Multi-objective Optimization Problem is the problem in which there is more than one objective functions exist and described as follows;

$$min/\ max\ [f_1(x), f_2(x), \ldots \ldots, f_M(x)]$$

$$subject\ to$$

$$g_j(x) \geq 0$$

$$h_k(x) = 0$$

$$x \in S$$

where n>1 and the scalar objective functions of $f_1(x), f_2(x), \ldots \ldots, f_n(x)$ optimizes the variable set x in a vector space S, including the constraints of $g_j(x)$ and $h_k(x)$.

By nature of the multi-objective optimization problems, all generated solution sets are tested first with the aim of determining whether any predefined constraints are violated or not. After the constraint limitation is ensured, the performances of the solution sets are compared with each other to determine the dominance relations among them. The solution set is called dominated solution if at least one of the other solution set is better at all objectives than the current solution set. If not, the solution set is called as the non-dominated solution set.

Unlike single optimization, the optimal solution in multi-objective optimization is found in several steps. All non-dominated solutions are kept separately in the solution space and these solutions compose possible solution sets of the Pareto optimality curve drawn in M-dimensional space. Depending on the weights of the objectives included in the objective function or based on his self-intuition, the decision maker selects an appropriate solution set from Pareto curve. The solution set is called weak Pareto optima if at least one of the objectives belonging the solution set is equal to the compared Pareto optimal solution and dominated with regards to remaining objectives (Figure 6.1). On the other hand, the solution set is called strict Pareto optima if it dominates all Pareto solutions with regards to any objective(s) and dominated by the same solution in other objective(s) (Figure 6.2).

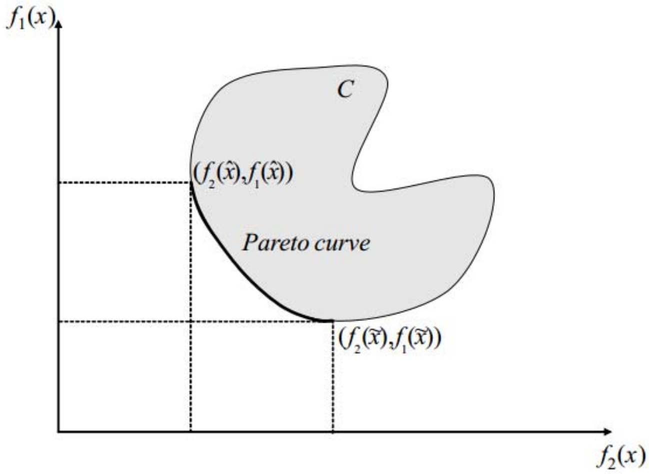


Figure 6.1: Example of Pareto Curve for the Objective Functions of $min\ [f_1(x), f_2(x)]$

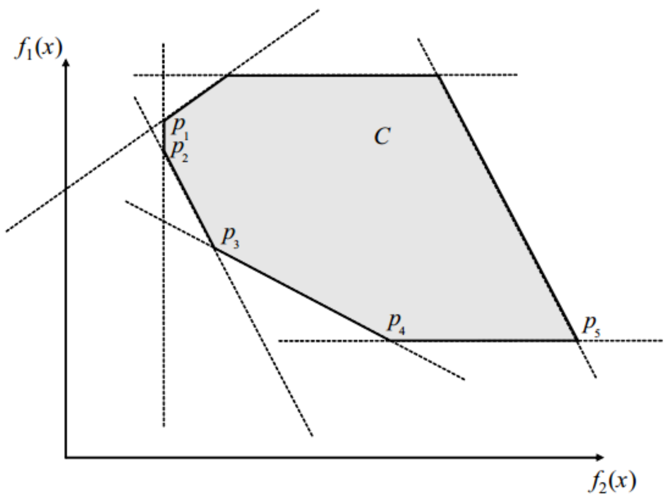


Figure 6.2: Example of Weak and Strict Pareto Optima for the Objective Functions of $min\ [f_1(x), f_2(x)]$

In many cases, Pareto curves cannot be computed efficiently which makes using of the approximation methods essential. Therefore, following approaches are frequently used for the formulation of the relationship between objectives in multi-objective optimization.

- Scalarization technique
- ∈-constraints method
- Goal programming
- Multi-level programming

6.2.3 Meta-heuristic Optimization

Glover (1986) describes the meaning of the word *heuristic* as to find or to discover by trial and error and the meaning of the word *meta* as beyond or higher level. Therefore, the term *meta-heuristic* goes one step further from simple heuristic and it is defined as *"master strategy that guides and modifies other heuristics to produce solutions beyond those that are normally generated in a quest for local optimality"* (Glover & Laguna, 1997).

As mentioned previously, meta-heuristic methods are used efficiently for difficult optimization problems where classical approaches remain incapable and the process is completed in a reasonable amount of time. However, there is no guarantee that the proposed solution(s) would be the optimal but near-optimal solutions are searched.

Blum and Roli (2003) identified two main components of meta-heuristic algorithms as *intensification* and *diversification*. *Diversification* also known as *exploration* means to produce number of solutions by exploring the research space in global scale whereas intensification also known as *exploitation* means to focus the search in narrower local region where good solutions are found. To achieve global optimal solution sets in comprehensive manner, a good combination of these two components is required. Achieving this combination, it would be ensured that the solution sets will converge to the optimum while the diversity of solution would be sought escape from local optima.

Within the scope of meta-heuristic optimization algorithm, several steps are followed. As a beginning, the algorithm is initialized by a random distribution of design variables. Although the type of distribution used changes depending on the algorithm used, uniform random distribution between upper and lower limits of design variables are frequently promoted for achieving the efficient solution and gaining the objective approach among possible local optimums. Then, the fitness function value is calculated and kept in the memory as position vector which includes the fitness value with its corresponding solution vector. Next, the position vector updates itself according to the algorithm inserted and keeps itself in the memory as local best position vector if it uses its or others' memories for its best fitness value which is called as local best fitness. After position vector is updated, the fitness value for each member calculated and compared with local best fitness values with the aim of updating local fitness best and local best position vector for population member. After sorting of local best fitness values and local best position vectors, the best local position vector is assigned as the global best position vector which has the best local best fitness value. The position vector updates itself until the introduced termination criterion such as the number of iteration or obtaining of the aimed solution value is met. Within the whole process, the way that position vector updates itself plays an important role in the optimization process since it is how various meta-heuristic approaches differs from each other.

In the scope of the current study, a heuristic optimization methodology is developed for completing the MDCM process. Based on the simple structure of the current multi-objective optimization problem, the heuristic algorithm is preferred in this study due to various reasons. First, heuristics are easy to use and provide quick responses. They simply focus on a certain aspect of the introduced problem and produce many results either being optimal or not. Although they produce solutions deviated from the defined purpose, they work in most of the circumstances as long as the required knowledge and experience is provided. Second, heuristics mostly do not require any planning which makes them quite useful to apply for early design processes. In the cases where a problem is faced during the design stage, this feature of heuristics makes the fixing process cheaper and easier. Last, although heuristics are mostly used for intuitive judgments, they might also be used for generating optimization solutions for limited information as long as the algorithm formed qualified to a certain degree (Nielsen, 1994).

CHAPTER 7

A MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR OPTIMAL ALLOCATION OF SUBCONTRACTORS IN CONSTRUCTION PROJECTS

This chapter describes the development process of "A Multi Criteria Decision Support System for Allocation of Subcontractors in Construction Projects" which constitutes four modules namely;

- Module-1 – Weighting of Selection Criteria
- Module-2 – Calculation of Credibility Indexes
- Module-3 – Defining of the Project
- Module-4 – Collecting the Bids & Tendering Process

7.1 Development of Selection Criteria

Detailed analysis of subcontractors shall only be possible when all the factors influencing the project success are determined. Only after, right questions could be directed to the subcontractors and right evaluations could be asked from experienced decision makers during assessment stage. Fortunately, project owner eliminates inappropriate candidate subcontractors and proceeds in the way of project success.

Selecting the lowest-bidder stands as a classical trend for subcontractor assessment process. The profit-oriented nature of the main contractors or owners makes "bid price" the leading assessment criteria among the others. In addition, similar to completion time, "bid price" as a measurable indicator shall become a prominent criterion compared with the number of subjective measuring criteria belonging quality consideration. In the cases where the project owner is a public organization, selecting the lowest-bidder is forced by various laws and regulations as long as the quality standards of the candidate subcontractor and declared project duration meet minimum or maximum tender requirements. In the cases where the project owner is private, although the assessment process loses its strictness compared with the case for the public owner and more rational evaluation of other criteria could be included in the assessment, "bid price" still steps forward among the others due to the aforementioned reasons.

Although the classical view of taking "bid price" as the lead criterion seems quite reasonable at the first glance from the cost-based perspective, the result may change when the entire process of a construction project is considered. In other words, the money gained from allocating the work to the lowest-bidder may not always compensate the quality and/or time being lost. For instance, beyond visible monetary results of quality concessions or elongated project time to the main contractor such as delay penalties or performance fines, invisible results may also harm to the main contractor since those faults would lead the main contractor to lose its popularity and credibility for the upcoming projects.

7.1.1 Background study

Enshassi et al. (2014) showed contractors' selection criteria using the opinions of Palestinian construction professionals (Table 7.1). In the scope of the study, through a comprehensive literature research, a questionnaire survey consisting 38 subcriteria under grouped of 10 main criteria which are believed to be determinant for subcontractor selection was created and performed for professionals. Expectedly, the results of the study showed financial consideration as the most dominant criteria with the average importance weight of 40.10%.

Table 7.1: The Weights of Main Criteria and Subcriteria Developed by Enshassi et al. (2014)

Main Criteria	Weight (%)	Subcriteria	Weight (%)
Financial Evaluation of the Bid	40.1	Lowest Bid	26.16
		Unbalanced Bid	5.26
		Arithmetic Mistakes	3.35
		Financial Reservation	2.43
		Balance Sheet for the Previous 3 Years	2.9
Completeness of Bid Document	9.64	Required Bond	4.28
		Taxes Clearance	1.51
		Financial Capability	1.82
		Shortage Contract Offer	2.03
Past Performances in Similar Projects	8.08	Perform Past Projects on Time	3.61
		Reasonability of Cost in Past Project	1.62
		Quality Level in Past Projects	2.85
Staff Skills and Experience	7.4	Existence of Staff Training Program	1.1
		Ratio of Trained Staff to Total Staff	1.22
		Project Managers' Experience	2.08
		Other Project Staff Experience	1.45
		Past Performance of the Project Staff	1.55
Contractor's Reputation/Image	6.86	Classification of the company	2.57
		Number of Years in the Business	1.21
		Contractor Capital	1.04
		Past Owner/Contractor Relationship	1.06
		Cooperative in Solving Problems	0.98
Quality of Work	6.7	Quality Records on Previous Projects	2.86
		Proposed Quality Control in Implementation	2.23
		Application of the ISO System	1.61

Table 7.1: The Weights of Main Criteria and Subcriteria Developed by Enshassi et al. (2014) (continued)

Main Criteria	Weight (%)	Subcriteria	Weight (%)
Contractor Site Management / Execution	6.12	Type of Proposed Control and Monitoring Procedures During Implementation	2.09
		Construction Progress Reporting Systems	1.57
		Provision of Trained/Skilled Staff for the Particular Project	2.46
Bid Understanding	5.62	Aware of bid document	2.36
		Explain ambiguous item	1.22
		Response ambiguous	0.95
		Solicit Classified Information	1.09
Plant and Equipment Resources	5.14	Condition of the Equipment	1.61
		Suitability of Equipment to the Project Size	1.55
		Efficiency of Proposed Technology Level to the Project Type	0.92
		Availability of Owned Construction Equipment	1.06
Health and Safety Performance	4.34	Proposed Health and Safety Program	2.18
		Health and Safety Records on Previous Projects	2.16

El-Abbasy et al. (2013) conducted a study for contractor selection model for highway projects (Table 7.2). In criteria determination phase, they have conducted an interview with experts and asked them to list the most important factors affecting the subcontractor eligibility. Comparing the obtained results with literature research, they came up with the criteria tree having 4 main criteria and 12 subcriteria in total which would presumably cover a wide range of selection aspects that should be taken into consideration during subcontractor assessment.

Table 7.2: The Weights of Main Criteria and Subcriteria Developed by El-Abbasy et al. (2013)

Main Criteria	Weight (%)	Subcriteria	Weight (%)
Project's Main Requirements	31.6	Project Bid Price	20.2
		Project Duration	4.9
		Risk Sharing with the Owner	6.5
Financial Capability	25.8	Financial Stability	19.4
		Working Capital	6.4
Past Performance	19.2	Percentage of Previous Works Completed on Time	4.8
		Past Relation with the Owner	6.9
		Response to the Claims	3.2
		Health and Safety Records	4.3
Experience	23.4	Experience with Similar Types of Projects	8.9
		Contractor's Staff Experience	5.8
		Equipment Availability	8.6

Arslan et al. (2007) performed a study in a mid-sized construction company based in New-York, USA between the years 2001 and 2003 for improving Web-Based Subcontractor Evaluation System (WEBSES) (Table 7.3). The company mainly focused on commercial projects and the yearly business volume was around $200,000,000.00. As the consequence of face-to-face interviews with a chief estimator and two other estimators in Estimating and Bidding Department, main criteria and subcriteria affecting the subcontractor performance were developed.

Table 7.3: Main Criteria and Subcriteria Developed by Arslan et al. (2007)

Main Criteria	Subcriteria
Cost	Financial Capacity
	Timely Payment to Laborers
	Completion of Job with the Budget
Quality	Quality of Production
	Standard of Workmanship
	Team Efficiency
	Quality of Material Used

Table 7.3: Main Criteria and Subcriteria Developed by Arslan et al. (2007) (continued)

Main Criteria	Subcriteria
Quality	Experience in Similar Works
	Experience in the Construction Industry
	Job Safety
	Personnel Training
	Number of Qualified Personnel
Time	Accessibility to the Firm
	Time Accuracy in Submitting Bids
	Completion of Job within the Time
	Adherence to Program
Adequacy	Proposal Accuracy
	Adequacy of Experienced Site Supervisor Staff
	Adequacy of Labor Resources
	Adequacy of Material Resources
	Adequacy of Equipment
	Care of Works & Workers
	Compliance with the Site Safety Requirements
	Compliance with Contract
	Compliance with Company Image

Hartmann et al. (2009) emphasized four main criteria as price, technical know-how, quality and cooperation during the assessment of subcontractors for explaining the importance of subcontractor selection criteria in Singapore (Table 7.4). The authors were used choice-based conjoint experiment for determining the relative importance weights of four criteria. At the end of the study, it was concluded that price consideration gets ahead over the other criteria and followed by quality, cooperation and technical know –how successively.

Khosrowshahi (2009) studied on a neural network model for contractors' prequalification for local authority projects. During the model construction, he identified 21 prequalification criteria based on an extensive literature research and asked 379 local authorities in England to rate the degree of importance of the presented elimination criteria using 1 to 5 Likert scale, in view of their past tendering records and experience. The questionnaire period was completed with the attendance of 42 participants and a table was obtained which reflects some of the most important factors for the subcontractor eligibility according to British local authority decision makers.

Table 7.4: Assessment Criteria Developed by Khosrowshahi et al. (2009)

Criteria
Financial Standing and Record
General Experience
Reputation for Completion on Time
Reputation for High Quality Service
Health and Safety Record
Post-business Relationship
Project Value
Efficient Organization
Personnel/team's expertise
Recent experience in similar projects
Depth of Technical Resources

Based on European Union Legislation, Cheng and Kang (2012) took two main considerations as construction cost and completion time into account and proposed a “Multi-Criteria Prospect Model” (Table 7.5). A review was performed on contractor selection criteria and the key determinants of contractor performance which resulted with a table containing 9 and 4 influencing factors for time discount and cost discount considerations respectively.

Table 7.5: Contractor Selection Influencing Factors Proposed by Cheng and Kang (2012)

Time-Discount Influencing Factors	Cost-Discount Influencing Factors
Staffing level	Magnitude of variations in past projects
Track record for completion on budget	Paid-in capital
Adequacy of plant and equipment	Track record for completion on budget
Track record for completion to acceptable quality	Track record for completion to acceptable quality
Financial management competency	
Technical expertise	
Track record for on-time completion	
Magnitude of claims and disputes in past projects	
Management abilities of key personnel	

Dulung and Pheng (2005) performed a study for identifying the factors influencing the selection of subcontractors in refurbishment works (Table 7.6). Based on the data obtained from academic literature and domain experts and by also investigating the current methods, a questionnaire including 5 point Likert scale rating questions was prepared and sent to 135 main contractors having experience in handling refurbishment projects. The questionnaires were delivered to the target participants using enclosed stamped envelope and after responding period of 4 weeks, 31% of attendance ratio (41 responses) was obtained which concluded with a selection criteria table of including 6 main and 28 subcriteria.

Table 7.6: Main Criteria and Subcriteria Proposed by Dulung and Pheng (2005)

Main Criteria	Subcriteria
Organization Characteristics	1. Responsiveness
	2. Company Reputation
	3. Company Age
Personnel Qualification	1. Technical Ability
	2. Relevant Experience
	3. Related Degree

Table 7.6: Main Criteria and Subcriteria Proposed by Dulung and Pheng (2005) (continued)

Main Criteria	Subcriteria
Financial Performance	1. Workload
	2. Bank reference
	3. Profitability history
Relevant Experience	1. Similar Type of Project
	2. Similar Size of Project
Past Performance	1. Number of references
	2. Showing close cooperation and coordination
	3. Completing past contract on time
	4. Always completing past contract
	5. Showing good knowledge of design and regulation
	6. Never engaged in illegal and fraudulent activities before
	7. Showing integrity and honesty
	8. Completing past contract on original budget
	9. Producing good quality on past works
	10. Employing high quality workmanship in past projects
	11. Employing highly skilled operations in past project
	12. No fatal accident on any site under its control in the last 3 years
	13. Showing stable financial performance
Culture	1. Trust
	2. Communication
	3. Similar Culture
	4. Relationship

7.1.2 The Main and Subcriteria in the Subcontractor Allocation System

The previous part includes a comprehensive review of the literature. Although the number of selection criteria and their definitions differ depending on the type of construction works (highway projects, refurbishment works etc.), type of organization that is worked with (public or private organizations) or the country where the research study is performed, all the interests are aroused on four main considerations: cost related issues, organizational characteristics and technical capability and experience.

In this study, “bid price” is evaluated as distinguished from the other elimination criteria and a new title “credibility” is created which in fact interprets all subcontractor selection criteria except “bid price”. Therefore, “bid price versus credibility trade off” would be performed.

Based on the data obtained from literature and remarks of three decision makers which actively involves in the subcontractor selection process from main contractor side and perform their activities in the private sector in Turkey, Table 7.7 is created for describing the “credibility” attributes of a subcontractor. During determining the below main and subcriteria, the characteristics of each credibility determinant is investigated based on its measurability, practicality or evaluation ability and the final contributors are identified accordingly. Within the process, the information obtained from the literature research is taken into account entirely and the scope assessment is kept as comprehensive as possible as possible by also considering the nature of “core and shell works of a superstructure project“.

Table 7.7: Main Criteria and Subcriteria for Determining “Credibility” Level of Subcontractor

Main Criteria	Subcriteria
Turnover	Financial Capacity of the Firm
	Current Workload
Organizational Structure	General Experience of the Firm in the Industry
	Health and Safety Performance
	Accessibility to the firm and Cooperation
	Post Business Relationship, Claims and/or Disputes
Technical Competence	Labor Resource of the Firm
	Material Resource of the Firm
	Equipment Resource of the Firm
Reputation - References	Reputation for Completing within Budget
	Reputation for Completing within time
	Reputation for High Quality Service
	References/Advices
Project-Specific	Experience in similar type of projects
	Experience in similar or larger size of projects

7.1.3 Description of Proposed Main Criteria and Subcriteria

7.1.3.1 Turnover

Turnover assesses the credibility performance of a firm considering the financial and workload emphasis.

- *Financial Capacity of the Firm* focuses solely on the financial perspective and tries to detect to what extent the firm has financial power in order to perform the duties undertaken by also taking the volumes of completed projects in the past into consideration. Financial power has a crucial impact on the continuity of a construction project since almost all of project scheduled activities including workmanship, machinery hiring or material purchasing costs considerable amounts depending on the project scale. In order to determine the financial strength of a company, this subcriterion asks the questions to the subcontractor such as;
  - *What is the amount of maximum bank reference that could be obtained for the project?*
  - *What is the value of the firm in the trade journal?*
  - *What is the endorsement amount belonging the last (last three, last five etc.) fiscal year?*
  - *What is the rate of the firm in balance-sheet?*
  - *What is the ratio of active assets over active debts?*
  - *What are the volume of the biggest (two, three etc.) project completed in terms of $ (TL, m2 etc.)?*

  or asks the main contractor;

  - *How do you evaluate the financial capacity of the firm based on the past project/s completed or heard from the construction industry?*

- *Current Workload* focuses on the quantity measure of construction related activities that the firm actively involves in currently. Depending on the type of construction activity (shell and core, finishing works etc.), this subcriterion asks the subcontractor;
    - *What is the total volume of ongoing projects in terms of $ (TL, m2 etc.)?*

7.1.3.2 Organizational Structure

Organizational Structure assesses the credibility performance of a firm considering the experience, health and safety performance, accessibility, post business relationship, collaborative attitude and the claim-dispute behavior.

- *General Experience of the Firm in the Industry* measures the experience of the firm considering for what time the firm proceeds in the construction industry. This subcriterion asks the questions to the subcontractor such as;
    - *How long have the firm proceeds in the construction industry in terms of year (month)?*
    - *What is the total volume of projects completed in terms of m2 until now?*

- *Health & Safety Performance* scores the performance of the firm based on its attitude towards the health and safety issues. This subcriterion asks the subcontractor;
    - *What is the performance of the firm based on the records of health and safety issues including both fatal and injury accidents based on the completed projects?*
    - *How many health and safety staff have been planned to allocate for the current project?*
    - *Is there any certificate or award showing the firm's attitude about health and safety performance? If yes, how many?*

or asks the main contractor;

- *How do you evaluate the health & safety performance of the firm based on the past project/s completed or heard from the construction industry?*

- *Accessibility to the Firm and Cooperation* mainly focuses the performance of the firm based on its accessibility and collaborative attitude. Accessibility of the firm identifies to what extent the firm has the organizational structure so that finding the responsible representative firm member is easy to reach in cases where needed. On the other hand, cooperation stands for the collaborative behavior of the firm especially when an adversity arises regarding the construction process. This subcriterion asks the main contractor;
    - *How do you evaluate the accessibility and collaborative attitude of the firm based on the past project/s completed or heard from the construction industry?*

- *Postbusiness Relationship, Claims and/or Disputes* describes the general attitude of the firm regarding business relationships based on the past projects involved in together and its behavior in the cases where claims and/or disputes are encountered. This subcriterion asks the main contractor;
    - *How do you evaluate the general attitude of the firm based solely on the past project/s involved in together?*
    - *How do you evaluate the attitude of the firm in the cases where claims and/or disputes are encountered based on the past project/s completed or heard from the construction industry?*

7.1.3.3 Technical Competence

Technical Competence assesses the credibility performance of a firm considering its technical capabilities.

- *Labor Resource of the Firm* scores the power of workmanship within the body the firm. This subcriterion asks the questions to the subcontractor such as;
  - *What is the total number of blue collar and/or white collars allocated for the current project?*
  - *What is the estimated efficiency of a (specified) blue or white collar? (Ex: 8 m2/ day for formwork worker, 12 mt/hour for pipe installer etc.)*

  or asks the main contractor;

  - *How do you evaluate the labor resource of the firm based on the past project/s completed or heard from the construction industry?*

- *Material Resource of the Firm* scores the power of material stock within the body the firm. This subcriterion asks the questions to the subcontractor such as;
  - *What is the stock amount of (specified) material/s allocated for the project?*

  or asks the main contractor;

  - *How do you evaluate the material resource of the firm based on the past project/s completed or heard from the construction industry?*

- *Equipment Resource of the Firm* scores the adequacy of equipment within the body the firm. This subcriterion asks the questions to the subcontractor such as;
  - *What kinds of equipment are allocated for the project and what are their corresponding amounts?*

  or asks to the main contractor;

- *How do you evaluate the equipment resource of the firm based on the past project/s completed or heard from the construction industry?*

7.1.3.4 Reputation & References

Reputation & References evaluates the credibility performance of a firm based on its reputation about completing the project within targeted time, budget and quality which takes the overall belief raised within the industry during judgment. It also assesses the quantity and the quality of the references provided by the subcontractor.

- *Reputation for Completing within Budget* measures the firm's performance of completing the project within aimed budget based on the general belief raised in the construction industry. This subcriterion asks the questions to the main contractor such as;
  - *How do you evaluate the performance of the firm about completing the project within targeted budget based on the general belief raised within the construction industry?*

- *Reputation for Completing within Time* measures the firm's performance of completing the project within aimed time based on the general belief raised in the construction industry. This subcriterion asks the questions to the main contractor such as;
  - *How do you evaluate the performance of the firm about completing the project within targeted time based on the general belief raised within the construction industry?*

- *Reputation for High Quality Service* measures the firm's performance of completing the project within desired quality and also providing the service through the warranty period. This subcriterion asks the questions to the main contractor such as;

- *How do you evaluate the performance of the firm in terms of completing the project within desired quality and also the service performance during the warranty period?*

- *References/Advices* measure the firm's performance by taking the quantity and quality of provided references into consideration which provided by subcontractor itself. It also considers the advices of the confidential third parties about the candidate subcontractors if available any. This subcriterion asks the questions to the subcontractors such as;
  - *What are the references of the firm?*

and/or asks to the main contractor;

  - *How do you evaluate the references provided by the subcontractor?*
  - *How do you evaluate the advices about the subcontractor if there exists any?*

7.1.3.5 Project-Specific Characteristics

Project-Specific Characteristics evaluates the credibility performance of a firm based on its experience with the similar type and similar or larger size of projects that have been involved in previously.

- *Experience in Similar Type of Projects* focuses on the firm's performance considering its capability of achieving the similar type of projects that have been completed in the past. This subcriterion asks the questions to the subcontractor contractor such as;
  - *What is the number of projects completed similar to the current project?*

and/or asks to the main contractor;

- *How do you evaluate the performance of the firm in terms of its achievements in a similar type of projects based on the past project/s completed or heard from the construction industry?*

- *Experience in Similar or Larger Size of Projects* focuses on the firm's performance considering its capability of achieving the similar or larger size of projects in terms of monetary value which have been completed in the past. This subcriterion asks the questions to the subcontractor contractor such as;
  - *What is the number of projects having similar or larger sizes with the current project in terms of monetary value?*

  and/or asks to the main contractor;

  - *How do you evaluate the performance of the firm in terms of its achievements in similar or larger size of projects in terms of monetary value based on the past project/s completed or heard from the construction industry?*

As stated in part 7.1.2, abovementioned main and subcriteria are specifically created for the assessment of subcontractors standing as candidates for core and shell works of a superstructure construction project. Although most of the criteria and described questions could be used for different type of construction projects since they principally aim to measure the reliability characteristics of candidate subcontractors such as the ones measuring subcontractors' financial statement or organizational structure, it would be better to reorganize the criteria and questions developed for measuring subcontractors' technical capabilities. For example; asking the efficiency of a formwork worker might be altered as the efficiency of crane operator if the project is constructing a wave breaker instead of constructing a superstructure.

On the other hand, the questions mentioned under each subcriterion might change depending on the type of construction project itself or the information that could be obtained from the subcontractor or the main contractor. Obviously, the more data obtained means the more rational assessment of the candidate subcontractors could be achieved. However, in some cases some of the presented questions in the previous part could be removed or altered either because of the incompetency of the main or subcontractor or because some questions do not make sense with the subjected construction project.

7.2 Weighting of Selection Criteria (Module-1)

In this part, the weighting of the selection criteria is described.

7.2.1 Defining Relations among Main and Subcriteria & ANP Influence Matrix

As mentioned previously, ANP approach considers the interdependencies between the main and subcriteria which directly affect the result of decision making process. Therefore, a network structure should be constructed which shows the dependency links between all elements and clusters.

In the scope of the current study, the network structure shown in Figure 7.1 is constructed which clearly describes the main criteria, the subcriteria under each main criteria and the dependency links between clusters. In the figure, the arrow heads show the clusters being influenced while arrow bottoms show the ones who influence. On the other hand, the double-headed arrows show bi-directional relationship between different clusters which is also called as “outer dependence” and the curved arrows show the “inner dependency” which describes the dependency within a cluster.

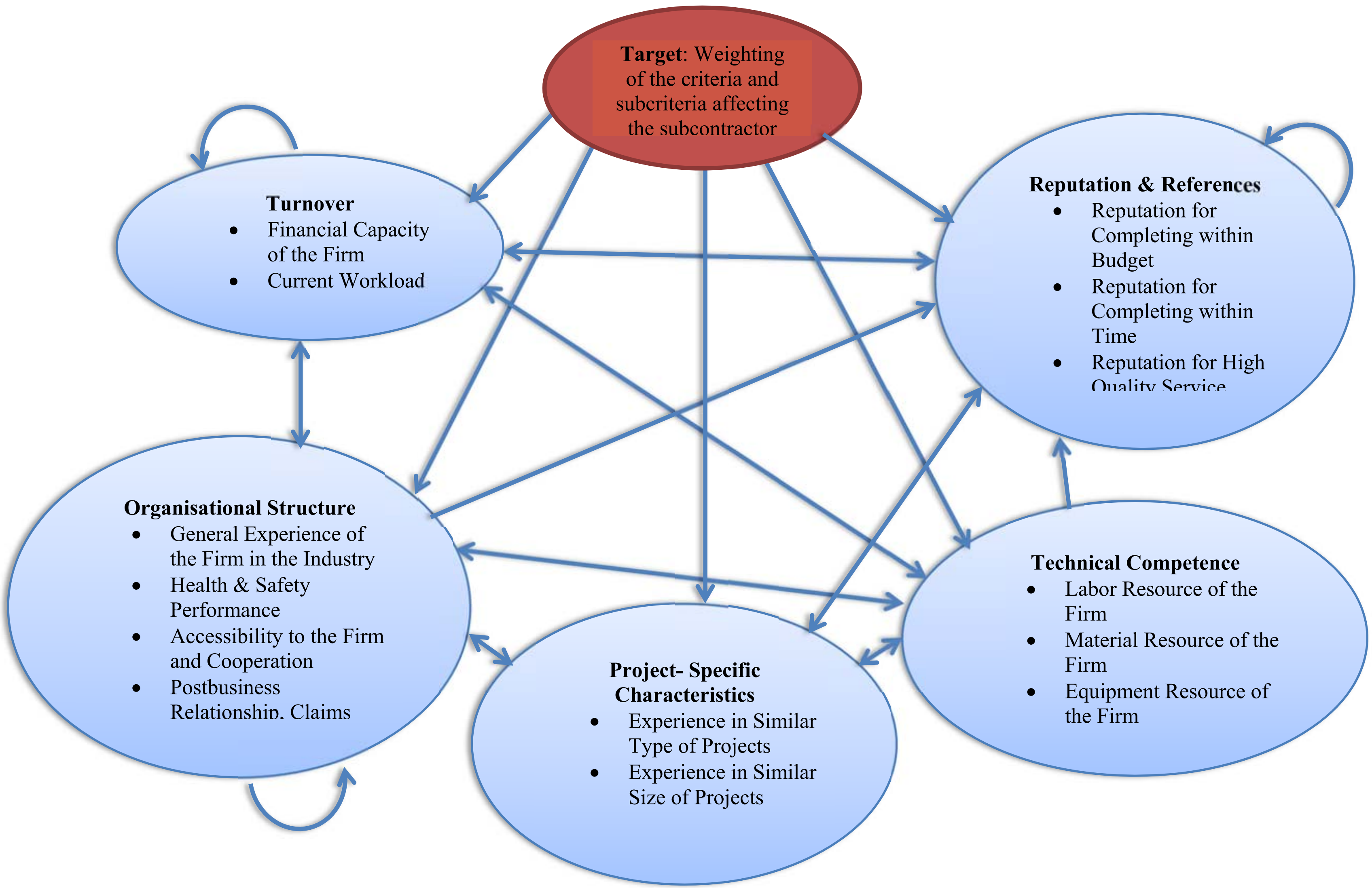


Figure 7.1: Analytical Network Structure

ANP Influence Matrix is formed before starting the ANP process in order to describe all of the relations among the main criteria and the subcriteria in a more systematic way. Therefore, the relationships between elements could be analyzed both in cluster and sub cluster levels.

In ANP Influence Matrix, the numbers of “0” (zero) and “1” (one) are used to describe the dependencies. The number “1” is used to describe if one element influences or being influenced by the other or a mutual influence exist between them while the number “0” is used if there is no such influence exists. The sample structure of ANP Influence Matrix is given in Figure 7.2.

		C_b			
		e_{b1}	e_{b2}	e_{b3}	e_{b4}
C_a	e_{a1}	$k_{a1,b1}$	$k_{a1,b2}$	$k_{a1,b3}$	$k_{a1,b4}$
	e_{a2}	$k_{a2,b1}$	$k_{a2,b2}$	$k_{a2,b3}$	$k_{a2,b4}$
	e_{a3}	$k_{a3,b1}$	$k_{a3,b2}$	$k_{a3,b3}$	$k_{a3,b4}$
	e_{a4}	$k_{a4,b1}$	$k_{a4,b2}$	$k_{a4,b3}$	$k_{a4,b4}$

Figure 7.2: The Structure of ANP Influence Matrix

where; $k_{aa,bb}$: influence of the elements k_{aa} on the elements k_{bb}

$k_{aa,bb} = 1$ if k_{aa} influences k_{bb}

$k_{aa,bb} = 0$ if k_{aa} does not influence k_{bb}

Therefore;

k_{aa} $\quad$ k_{bb} (No influence) $k_{aa,bb} = k_{bb,aa} = 0$

$k_{aa} \longleftarrow k_{bb}$ (k_{aa} influences on k_{bb}) $k_{aa,bb} = 1, k_{bb,aa} = 0$

$k_{aa} \longrightarrow k_{bb}$ (k_{bb} influences on k_{aa}) $k_{aa,bb} = 0, k_{bb,aa} = 1$

$k_{aa} \longleftrightarrow k_{bb}$ (Mutual influence) $k_{aa,bb} = k_{bb,aa} = 1$

In the scope of the current study, ANP Influence Matrices have been constructed in cluster and sub cluster levels as shown in Figure 7.3 and Figure 7.4.

ANP Influence Matrix (Main Criteria)	Turnover	Organizational Structure	Technical Competence	Reputation References	Project-Specific
Turnover	**1**	**1**	**1**	**1**	**0**
Organizational Structure	**1**	**1**	**1**	**1**	**1**
Technical Competence	**1**	**1**	**0**	**1**	**1**
Reputation - References	**1**	**0**	**0**	**1**	**1**
Project-Specific	**0**	**1**	**1**	**1**	**0**

Figure 7.3: ANP Influence Matrix in Cluster Level (Main Criteria)

Figure 7.3 describes which main criterion is affected by which other main criteria. To illustrate, the main criteria of *turnover* is affected by all remaining main criteria except by *project specific*.

ANP Influence Matrix (Subcriteria)		Turnover		Organisational Structure				Technical Competence			Reputation - References				Project-Specific	
		Financial Capacity of the Firm	Current Workload	General Experience of the Firm in the Industry	Health and Safety Performance	Accessibility to the firm and Cooperation	Postbusiness Relationship, Claims and/or Disputes	Labour Resource of the Firm	Material Resource of the Firm	Equipment Resource of the Firm	Reputation for Completing within Budget	Reputation for Completing within time	Reputation for High Quality Service	References/ Advices	Experience in similar type of projects	Experience in similar or larger size of projects
Turnover	Financial Capacity of the Firm	0	1	0	1	1	0	1	1	1	1	0	0	0	0	0
	Current Workload	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0
Organisational Structure	General Experience of the Firm in the Industry	1	1	0	1	0	0	0	0	0	0	0	0	1	1	1
	Health and Safety Performance	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
	Accessibility to the firm and Cooperation	0	1	0	0	0	1	1	0	0	0	0	0	1	0	0
	Postbusiness Relationship, Claims and/or Disputes	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Technical Competence	Labour Resource of the Firm	1	1	0	0	1	1	0	0	0	0	1	1	0	0	1
	Material Resource of the Firm	1	1	0	0	0	0	0	0	0	0	1	1	0	0	1
	Equipment Resource of the Firm	1	1	0	0	0	0	0	0	0	0	1	1	0	0	1
Reputation - References	Reputation for Completing within Budget	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
	Reputation for Completing within time	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
	Reputation for High Quality Service	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
	References/Advices	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Project-Specific	Experience in similar type of projects	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0
	Experience in similar or larger size of projects	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0

Figure 7.4: ANP Influence Matrix in Sub cluster Level (Subcriteria)

Figure 7.4 describes how each of the subcriteria is being influenced by other subcriteria either from the same or different subcluster/s. To illustrate, the subcriteria *Financial Capacity of the Firm* is being influenced by *Current Workload* from the same subcluster, *General Experience of the Firm in the Industry* from the cluster of Organizational Structure and all the elements (subcriteria) belonging the subclusters of *Technical Competence* and *Reputation & References.*

7.2.2 Weighting of Selection Criteria Using ANP

Having the ANP Influence Matrix, the weights of the selection criteria shall be determined. With the aim of determining the weights of main and subcriteria on the main goal of *credibility*, the questionnaire inserted in Module-1 is used for performing pairwise comparisons in three main categories as;

- Comparisons among clusters with respect to their impacts on other clusters.
- Comparison among elements of each cluster with respect to their impacts on the other elements within the same cluster.
- Comparison among elements of each cluster with respect to their impacts on the other elements outside the corresponding cluster.

Pairwise methodology in ANP process performs the pairwise comparison of all elements belonging the same cluster. Therefore, in the cases where a subcriterion or element is being influenced by the other subcriterion or elements belonging different cluster, pairwise comparison shall be made in each cluster and then shall be unified using normalization. As an example, since the subcriteria *Financial Capacity of the Firm* is being influenced by the elements belonging four different subclusters (*Turnover, Organizational Structure, Technical Competence, Reputation & References*), for the pairwise comparison, four different assessment group shall be constructed and unified using normalization.

Below example shows how the pairwise comparisons are performed using questionnaire;

With respect to ***Accessibility to the firm and Cooperation***

The importance or preference level of criterion

	Absolute	Very Strong	Strong	Moderate	Equal	Moderate	Strong	Very Strong	Absolute	
Financial Capacity of the Firm										*Current Workload*

Figure 7.5: Pairwise Comparison in the Questionnaire

The subcriterion *Accessibility to the Firm and Cooperation* is influenced by the subcriteria of *Financial Capacity of the Firm* and *Current Workload* from the same subcluster (Figure 7.5). In the question, the participant is asked to evaluate either *the financial capacity* or *the current workload* of the firm influence the *Accessibility to the Firm and Cooperation* more, and to what level? For the conformity of Saaty's pairwise comparison table given in part 4.3.1., the numerical values of 9, 7, 5, 3 and 1 are allocated for the definitions of "Absolute", "Very Strong", "Strong", "Moderate" and "Equal" correspondingly.

For combining the responses of participants, geometrical means of each element in the matrices are calculated. In order to conceive the consistency consideration, the CR values of each matrix belonging to the entire questionnaire shall be investigated and the matrices having the values above the allowed CR limit are eliminated. In fact, since the combined matrices are taken into consideration for constructing the future calculations in ANP process, the inconsistent answers of a particular respondent for a particular part of the questionnaire would not affect the result considerably. However, the created tool automatically calculates the CR values and in order to avoid the inconsistent answers, the user shall check the CR values of each matrix after each respondent and the matrices having unpermitted CR values shall be manually neutralized by setting all of the answers in the same assessment group as "Equal" which has the numerical equivalent of "1". This action is worked since the methodology of the geometrical mean (1 is the identity element) is used for combining the answers of all participants.

The steps for the ANP calculation can be illustrated as follows for one assessment part in the questionnaire and for two participants.

<u>Step 1: Constructing ANP Matrices</u>

Let's assume the first participant responded the corresponding part of the questionnaire as shown in Figure 7.6 below;

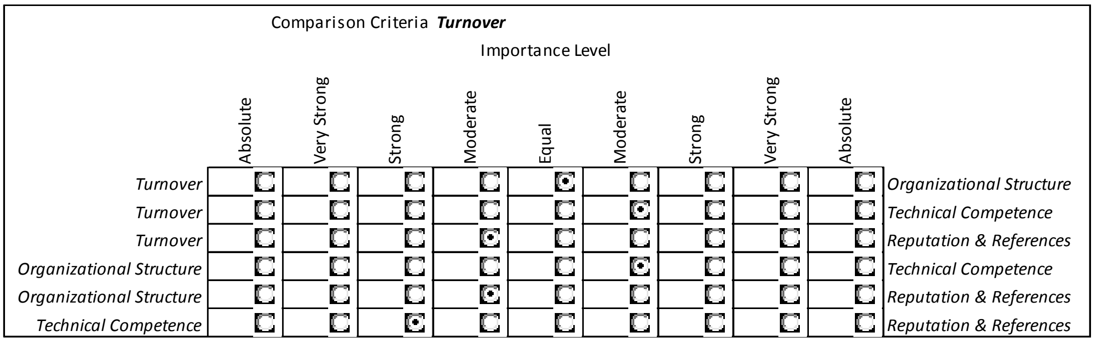


Figure 7.6: ANP Steps - Pairwise Comparison (Participant 1)

Then, the corresponding ANP matrix would be; (Figure 7.7)

ANP Matrix (Matrix 1)	Turnover	Organizational Structure	Technical Competence	Reputation & References
Turnover	1.00	1.00	0.33	3.00
Organizational Structure	1.00	1.00	0.33	3.00
Technical Competence	3.00	3.00	1.00	5.00
Reputation & References	0.33	0.33	0.20	1.00

Figure 7.7: ANP Steps – ANP Matrix (Participant 1)

Assuming that the second respondent responded the first part of the questionnaire as follows (Figure 7.8);

Comparison Criteria ***Turnover***

Importance Level

	Absolute	Very Strong	Strong	Moderate	Equal	Moderate	Strong	Very Strong	Absolute	
Turnover	○	○	○	○	○	●	○	○	○	*Organizational Structure*
Turnover	○	○	○	○	○	○	●	○	○	*Technical Competence*
Turnover	○	○	○	○	●	○	○	○	○	*Reputation & References*
Organizational Structure	○	○	○	○	○	●	○	○	○	*Technical Competence*
Organizational Structure	○	○	○	○	●	○	○	○	○	*Reputation & References*
Technical Competence	○	○	●	○	○	○	○	○	○	*Reputation & References*

Figure 7.8: ANP Steps – Pairwise Comparison (Participant 2)

Then, the second ANP matrix would be (Figure 7.9);

ANP Matrix (Matrix 1)	Turnover	Organizational Structure	Technical Competence	Reputation & References
Turnover	1.00	0.33	0.20	1.00
Organizational Structure	3.00	1.00	0.33	1.00
Technical Competence	5.00	3.00	1.00	5.00
Reputation & References	1.00	1.00	0.20	1.00

Figure 7.9: ANP Steps – ANP Matrix (Participant 2)

And the combined ANP matrix would be found by calculating the geometrical means of each element in the matrices (Figure 7.10);

Combined ANP Matrix (Matrix 1)	Turnover	Organizational Structure	Technical Competence	Reputation & References
Turnover	1.00	0.58	0.26	1.73
Organizational Structure	1.73	1.00	0.33	1.73
Technical Competence	3.87	3.00	1.00	5.00
Reputation & References	0.58	0.58	0.20	1.00

Sum	7.18	5.15	1.79	9.46

Figure 7.10: ANP Steps – Combined ANP Matrix

Step 2: Constructing Standardized Matrix and Weight Calculations

Standardized matrix is constructed by dividing each element in the combined ANP matrix by the corresponding column-sums (Figure 7.11).

Standardized Matrix (Matrix 1)	Turnover	Organizational Structure	Technical Competence	Reputation & References
Turnover	0.14	0.11	0.14	0.18
Organizational Structure	0.24	0.19	0.19	0.18
Technical Competence	0.54	0.58	0.56	0.53
Reputation & References	0.08	0.11	0.11	0.11

Figure 7.11: ANP Steps – Standardized Matrix

From the standardized matrix, the weights of each item can be found by calculating the arithmetic mean in each row (Figure 7.12);

Matrix 1	**Weight**
Turnover	**14.5%**
Organizational Structure	**20.1%**
Technical Competence	**55.2%**
Reputation & References	**10.2%**

Figure 7.12: ANP Steps – Weights

Step 3: CI & CR Calculations

CR Matrix is formed by multiplying each element of combine ANP matrix with the weights of the corresponding row. Row sums and sum-weight ratios are also given near the matrix (Figure 7.13).

CR Matrix (Matrix 1)	Turnover	Organizational Structure	Technical Competence	Reputation & References	SUM	SUM / Weight
Turnover	0.14	0.12	0.14	0.18	0.58	4.02
Organizational Structure	0.25	0.20	0.18	0.18	0.81	4.04
Technical Competence	0.56	0.60	0.55	0.51	2.23	4.04
Reputation & References	0.08	0.12	0.11	0.10	0.41	4.03

Figure 7.13: ANP Steps – CR Matrix

Knowing that;

n=4 stands for the number of items (number of rows or columns)

$\lambda\, max$ is calculated by calculating the arithmetic mean of sum-weight ratios;

$$\lambda\, max = \frac{4.02 + 4.04 + 4.04 + 4.03}{4} = 4.03$$

and,

$$CI = \frac{\lambda\, max - n}{n - 1} = \frac{4.03 - 4}{4 - 1} = 0.010$$

$$CR = \frac{CI}{Clr} = \frac{0.010}{0.9} = 0.011 < 0.1 \quad Matrix\ is\ consistent!$$

where Clr is “Random Index” defined in part 4.3.1.

Completing the survey for each participant and combining them using the geometrical mean as stated above, unweighted supermatrices are constructed from ANP Influence matrixes for both for Main Criteria and Subcriteria. Hypothetical examples of relevant supermatrices are shown in Figure 7.14 and Figure 7.15 below accordingly.

ANP Influence Matrix (Main Criteria)	Turnover	Organizational Structure	Technical Competence	Reputation - References	Project-Specific
Turnover	**0.25**	**0.25**	**0.3333333**	**0.2**	**0**
Organizational Structure	**0.25**	**0.25**	**0.3333333**	**0.2**	**0.3333333**
Technical Competence	**0.25**	**0.25**	**0**	**0.2**	**0.3333333**
Reputation - References	**0.25**	**0**	**0**	**0.2**	**0.3333333**
Project-Specific	**0**	**0.25**	**0.3333333**	**0.2**	**0**

Figure 7.14: ANP Unweighted -Weighted Supermatrix for Main Criteria

In order to allocate the cluster priorities, the supermatrix has to become a matrix stochastic by columns. As the following process of ANP methodology, each value of the supermatrix is divided by its corresponding column-sum, therefore, the supermatrix turned into a normalized matrix. The new form of the supermatrix is called as weighted supermatrix. As in Figure 7.14, the sum of each column for the supermatrix of Main Criteria is already "1" which makes it a Weighted Supermatrix. On the other hand, the illustrative example of a Weighted Supermatrix for Subcriteria is constructed as given in Figure 7.16.

ANP process continues with rising of weighted supermatrix to its successive powers. Since the obtained weighted supermatrix is stochastic by columns; it converges to the constant values when the supermatrix is exponentiated to a sufficiently large power. The form of supermatrix having the same values in each column is named as limit supermatrix as given in Figure 7.17. For calculating the limit supermatrix, two weighted supermatrix of main criteria and subcriteria are combined by multiplying each value of the weighted supermatrix of subcriteria with the corresponding value of the cluster obtained from the weighted supermatrix of main criteria. By making sure of the column stochasticity, the obtained combined matrix is raised to its sufficiently large power and the weights of each subcriterion are found. The value of each row shows the global priority of each element of the network. The exponentiation process is done by using Visual Basic for Applications (VBA) in excel and inserted as a function of the created tool.

ANP Influence Matrix (Subcriteria)		Turnover		Organisational Structure				Technical Competence			Reputation - References				Project-Specific	
		Financial Capacity of the Firm	Current Workload	General Experience of the Firm in the Industry	Health and Safety Performance	Accessibility to the firm and Cooperation	Postbusiness Relationship, Claims and/or Disputes	Labour Resource of the Firm	Material Resource of the Firm	Equipment Resource of the Firm	Reputation for Completing within Budget	Reputation for Completing within time	Reputation for High Quality Service	References/ Advices	Experience in similar type of projects	Experience in similar or larger size of projects
Turnover	Financial Capacity of the Firm	**0**	**1**	**0**	**1**	**0,5**	**0**	**0,5**	**0,5**	**0,5**	**1**	**0**	**0**	**0**	**0**	**0**
	Current Workload	**1**	**0**	**0**	**0**	**0,5**	**0**	**0,5**	**0,5**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**
Organisational Structure	General Experience of the Firm in the Industry	**1**	**0,333333**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,25**	**1**	**1**
	Health and Safety Performance	**0**	**0,333333**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,25**	**0**	**0**
	Accessibility to the firm and Cooperation	**0**	**0,333333**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0,25**	**0**	**0**
	Postbusiness Relationship, Claims and/or Disputes	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,25**	**0**	**0**
Technical Competence	Labour Resource of the Firm	**0,333333**	**0,333333**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0,333333**	**0,333333**	**0**	**0**	**0,333333**
	Material Resource of the Firm	**0,333333**	**0,333333**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,333333**	**0,333333**	**0**	**0**	**0,333333**
	Equipment Resource of the Firm	**0,333333**	**0,333333**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,333333**	**0,333333**	**0**	**0**	**0,333333**
Reputation - References	Reputation for Completing within Budget	**0,25**	**0,25**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,333333**	**0**	**0**
	Reputation for Completing within time	**0,25**	**0,25**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,333333**	**0**	**0**
	Reputation for High Quality Service	**0,25**	**0,25**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,333333**	**0**	**0**
	References/Advices	**0,25**	**0,25**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Project-Specific	Experience in similar type of projects	**0**	**0**	**0,5**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**
	Experience in similar or larger size of projects	**0**	**0**	**0,5**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0,5**	**0**	**0**	**0**
	Toplam	4	4	1	2	3	2	3	1	1	1	1	2	2	1	2

Figure 7.15: ANP Unweighted Supermatrix for Subcriteria

ANP Influence Matrix (Subcriteria)		Turnover		Organisational Structure				Technical Competence			Reputation - References				Project-Specific	
		Financial Capacity of the Firm	Current Workload	General Experience of the Firm in the Industry	Health and Safety Performance	Accessibility to the firm and Cooperation	Postbusiness Relationship, Claims and/or Disputes	Labour Resource of the Firm	Material Resource of the Firm	Equipment Resource of the Firm	Reputation for Completing within Budget	Reputation for Completing within time	Reputation for High Quality Service	References/ Advices	Experience in similar type of projects	Experience in similar or larger size of projects
Turnover	Financial Capacity of the Firm	**0**	**0,25**	**0**	**0,5**	**0,166667**	**0**	**0,166667**	**0,5**	**0,5**	**1**	**0**	**0**	**0**	**0**	**0**
	Current Workload	**0,25**	**0**	**0**	**0**	**0,166667**	**0**	**0,166667**	**0,5**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**
Organisational Structure	General Experience of the Firm in the Industry	**0,25**	**0,083333**	**0**	**0,5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,125**	**1**	**0,5**
	Health and Safety Performance	**0**	**0,083333**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,125**	**0**	**0**
	Accessibility to the firm and Cooperation	**0**	**0,083333**	**0**	**0**	**0**	**0,5**	**0,333333**	**0**	**0**	**0**	**0**	**0**	**0,125**	**0**	**0**
	Postbusiness Relationship, Claims and/or Disputes	**0**	**0**	**0**	**0**	**0,333333**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,125**	**0**	**0**
Technical Competence	Labour Resource of the Firm	**0,083333**	**0,083333**	**0**	**0**	**0,333333**	**0,5**	**0**	**0**	**0**	**0**	**0,333333**	**0,166667**	**0**	**0**	**0,166667**
	Material Resource of the Firm	**0,083333**	**0,083333**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,333333**	**0,166667**	**0**	**0**	**0,166667**
	Equipment Resource of the Firm	**0,083333**	**0,083333**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,333333**	**0,166667**	**0**	**0**	**0,166667**
Reputation - References	Reputation for Completing within Budget	**0,0625**	**0,0625**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,166667**	**0**	**0**
	Reputation for Completing within time	**0,0625**	**0,0625**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,166667**	**0**	**0**
	Reputation for High Quality Service	**0,0625**	**0,0625**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0,166667**	**0**	**0**
	References/Advices	**0,0625**	**0,0625**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Project-Specific	Experience in similar type of projects	**0**	**0**	**0,5**	**0**	**0**	**0**	**0,166667**	**0**	**0**	**0**	**0**	**0,25**	**0**	**0**	**0**
	Experience in similar or larger size of projects	**0**	**0**	**0,5**	**0**	**0**	**0**	**0,166667**	**0**	**0**	**0**	**0**	**0,25**	**0**	**0**	**0**
	Toplam	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 7.16: ANP Weighted Supermatrix for Subcriteria

0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057	0.1057
0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907	0.0907
0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485	0.2485
0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091	0.0091
0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385	0.0385
0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144	0.0144
0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667	0.0667
0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467
0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467
0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143
0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143
0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143	0.0143
0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123	0.0123
0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389
0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389	0.1389
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Figure 7.17: ANP Limit Supermatrix

Table 7.17 shows the level of importance of each Subcriteria which contributes the Subcontractors' credibility as the output of the created tool. According to the illustrative example given in Figure 7.17, the subcriteria *General Experience of the Firm in the Industry* has the highest importance with the percentage of 24,85% and followed by *Experience in similar type of projects* and *Experience in similar or larger size of projects* with the rates of 13,89% and 13,89% correspondingly. On the other hand, *Health and Safety Performance* has the lowest importance as a determinant factor of a Subcontractor's credibility. The weights of each subcriteria belonging the illustrative example are given in Table 7.8 below.

Table 7.8: Weights of Subcriteria

Financial Capacity of the Firm	**0.1057**
Current Workload	**0.0907**
General Experience of the Firm in the Industry	**0.2485**
Health and Safety Performance	**0.0091**
Accessibility to the firm and Cooperation	**0.0385**
Postbusiness Relationship. Claims and/or Disputes	**0.0144**
Labor Resource of the Firm	**0.0667**
Material Resource of the Firm	**0.0467**
Equipment Resource of the Firm	**0.0467**
Reputation for Completing within Budget	**0.0143**
Reputation for Completing within time	**0.0143**
Reputation for High Quality Service	**0.0143**
References/Advices	**0.0123**
Experience in similar type of projects	**0.1389**
Experience in similar or larger size of projects	**0.1389**

7.3 Calculation of Credibility Indexes (Module-2)

In this part, the credibility indexes of each subcontractor are calculated based on the information obtained from the Subcontractors and the evaluation of the Main

Contractor. “Subcontractor Evaluation” Module (Module-2) of the tool is created for this process within the scope of the current study.

7.3.1 Obtaining the Required Data for Credibility Indexes

The factors contributing the credibility index of a subcontractor was found in part 7.2.2 together with the corresponding level of importance. In order to calculate the credibility indexes, all 15 subcriteria contributing the credibility assessment shall be investigated in detailed. This process shall only be performed after the collection of the information required. Although, the limitation does not exist for accepting the evaluation of a criterion is satisfactory, if the questions are directed comprehensive enough, the more rational credibility indexes would be obtained.

With the purpose of obtaining satisfactory data, the questions might be asked either subcontractor, main contractor or both as explained in part 7.1.3. In this study, the relevant questions are directed to both the Subcontractor and the Main Contractor. Table 7.9 shows the map about which party is being questioned and how many questions are asked to each in order to obtain the required information about the Subcriteria determined.

Table 7.9: Number of Questions Directed to Main Contractor and Subcontractor

Main Criteria	Code	Subcriteria	# of Questions to Main Contractor	# of Questions to Subcontractor
Turnover	T1	Financial Capacity of the Firm	**1**	**4**
	T2	Current Workload		**1**
Organizational Structure	O1	General Experience of the Firm in the Industry		**2**
	O2	Health and Safety Performance	**1**	
	O3	Accessibility to the firm and Cooperation	**1**	
	O4	Postbusiness Relationship, Claims and/or Disputes	**2**	

Table 7.9 : Number of Questions Directed to Main Contractor and Subcontractor (continued)

Main Criteria	**Code**	**Subcriteria**	**# of Questions to Main Contractor**	**# of Questions to Subcontractor**
Technical Competence	TE1	Labor Resource of the Firm	**1**	**3**
	TE2	Material Resource of the Firm	**1**	**1**
	TE3	Equipment Resource of the Firm	**1**	
Reputation & References	RR1	Reputation for Completing within Budget	**1**	
	RR2	Reputation for Completing within time	**1**	
	RR3	Reputation for High Quality Service	**1**	
	RR4	References/Advices	**1**	
Project-Specific	PS1	Experience in similar type of projects	**1**	
	PS2	Experience in similar or larger size of projects	**1**	

7.3.1.1 Data Obtained from Subcontractor

The questions directed to Subcontractor are given in Table 7.10 below. The units are clarified in questions with the aim of preventing the participant from getting confused and only the numerical values were restricted as answers.

Table 7.10: The Questions Directed to Subcontractor

Main Criteria	Code	Subcriteria	Questions
Turnover	T1	Financial Capacity of the Firm	What is the amount of maximum bank reference that could be obtained for the project? (TL)
			What is the value of the firm in the trade journal? (TL)
			What is the endorsement amount belonging the last fiscal year?
			What is the volume of the biggest project completed? (m2)
	T2	Current Workload	What is the total volume of ongoing projects in terms of m2?
Organizational Structure	O1	General Experience of the Firm in the Industry	How long have the firm proceeds in construction industry in terms of year?
			What is the total volume of projects completed in terms of m2 until now?
Technical Competence	TE1	Labour Resource of the Firm	What is the number of blue collar and white collars allocated for the current project?
			What is the estimated efficiency of a formwork worker? (m2/day)
			What is the estimated efficiency of a steel worker? (kg/day)
	TE2	Material Resource of the Firm	What is the stock amount of formwork allocated for the project? (m2)

7.3.1.2 Data Obtained from Main Contractor

The questions directed to Main Contractor are given in Table 7.11 below. The questions are all assessment questions with the alternative answers of “very good”, “good”, “medium”, “poor”, “very poor” and “no idea”.

Table 7.11: The Questions Directed to Main Contractor

Main Criteria	Code	Subcriteria	Questions
Turnover	T1	Financial Capacity of the Firm	How do you evaluate the financial capacity of the firm based on the past project/s completed or heard from the construction industry?
Organizational Structure	O2	Health and Safety Performance	How do you evaluate the health & safety performance of the firm based on the past project/s completed or heard from the construction industry?
	O3	Accessibility to the firm and Cooperation	How do you evaluate the accessibility and collaborative attitude of the firm based on the past project/s completed or heard from the construction industry?
	O4	Postbusiness Relationship, Claims and/or Disputes	How do you evaluate the general attitude of the firm based solely on the past project/s involved in together?
			How do you evaluate the attitude of the firm in the cases where claims and/or disputes are encountered based on the past project/s completed or heard from the construction industry?
Technical Competence	TE1	Labor Resource of the Firm	How do you evaluate the labor resource of the firm based on the past project/s completed or heard from the construction industry?
	TE2	Material Resource of the Firm	How do you evaluate the material resource of the firm based on the past project/s completed or heard from the construction industry?
	TE3	Equipment Resource of the Firm	How do you evaluate the equipment resource of the firm based on the past project/s completed or heard from the construction industry?
Reputation & References	RR1	Reputation for Completing within Budget	How do you evaluate the performance of the firm about completing the project within targeted budget based on the general belief raised within the construction industry?
	RR2	Reputation for Completing within time	How do you evaluate the performance of the firm about completing the project within targeted time based on the general belief raised within the construction industry?

Table 7.11: The Questions Directed to Main Contractor (continued)

Main Criteria	Code	Subcriteria	Questions
Reputation & References	RR3	Reputation for High Quality Service	How do you evaluate the performance of the firm in terms of completing the project within desired quality and also the service performance during the warranty period?
	RR4	References/Advices	How do you evaluate the references provided by the subcontractor?
Project-Specific	PS1	Experience in similar type of projects	How do you evaluate the performance of the firm in terms of its achievements in the similar type of projects based on the past project/s completed or heard from the construction industry?
	PS2	Experience in similar or larger size of projects	How do you evaluate the performance of the firm in terms of its achievements in the similar or larger size of projects in terms of monetary value based on the past project/s completed or heard from the construction industry?

The obtained answers are quantified using Fuzzy Methodology as described in part 6. An et al. (2005) emphasized the frequency of using triangular and trapezoidal fuzzy number in the Construction Industry. In the scope of the current study, the triangular fuzzy numbers are used with the donation of $A = (a_1, a_2, a_3)$ where a_2 is the central value of $\mu(x) = 1$, a_1 is the left spread and a_3 is the right spread. The linguistic terms and triangular fuzzy numbers are illustrated in Figure 7.18.

Linguistic Term	Triangular Fuzzy Number
Very Good	(3,75; 5; 5)
Good	(2,5; 3,75; 5)
Medium	(1,25; 2,5; 3,75)
Poor	(0; 1,25; 2,5)
Very Poor	(0; 0; 1,25)

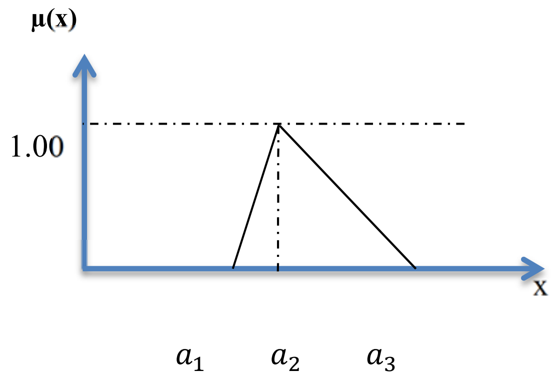


Figure 7.18: Linguistic Terms and Fuzzy Numbers

7.3.2 Combining of the Obtained Data & Credibility Indexes of the Subcontractors

As mentioned in part 7.3.1.1, only the numerical answers are accepted from the Subcontractors. For combining the different responses of the Subcontractors, the methodologies of *Geometrical Mean*, *Arithmetic Mean* and *Exponential Distribution* approaches are followed depending on the expected answers and the variances of the answers. For the rating of Subcontractors, the numbers between 1 and 5 are used for the minimum and the maximum grade correspondingly. Table 7.12 shows the methodologies used for combining the responses of Subcontractors.

Table 7.12: Combination Methodology of Subcontractors' Responses

Number	Questions	Combination Methodology
1	What is the amount of maximum bank reference that could be obtained for the project? (TL)	Geometric Mean
2	What is the value of the firm in the trade journal? (TL)	Geometric Mean
3	What is the endorsement amount belonging the last fiscal year?	Geometric Mean
4	What is the volume of the biggest project completed? (m2)	Geometric Mean
5	What is the total volume of ongoing projects in terms of m2?	Arithmetic Mean
6	How long have the firm proceeds in construction industry in terms of year?	Exponential Distribution
7	What is the total volume of projects completed in terms of m2 until now?	Geometric Mean
8	What is the number of blue and white collars allocated for the current project?	Arithmetic Mean
9	What is the estimated efficiency of a formwork worker?	Arithmetic Mean
10	What is the estimated efficiency of a steel worker?	Arithmetic Mean
11	What is the stock amount of formwork allocated for the project?	Arithmetic Mean

When questions 1,2,3,4 and 7 are investigated, it is seen that the responses would be around several thousand or even millions since the questions such as the bank references or volume of completed/ongoing projects are asked. Those are also the questions which would have the non-zero responses and one response might become 10 or even 100 times lower or higher than another one. Such a variation between the expected answers makes the using of geometric mean reasonably useful which would prevent biased ratings of Subcontractors in the cases where outliers exist. Therefore, the rating process would become less sensitive to outliers. To illustrate, in a case that the bank references of 1 million, 2 million, 5 million and 25 million are provided from candidate subcontractors of A, B, C and D, the subcontractors A and D would have 1 point and 5 points correspondingly. If arithmetic mean approach is used for the combination all responses, the subcontractors B and C would have the points between 1 and 2 although the subcontractor C is the second subcontractor keeping the highest bank reference. However, if geometric mean approach is used, the subcontractor C would get 3 points and the rating would become a lot fairer.

On the other hand, when the questions 8, 9, 10 and 11 are investigated, it is seen that the responses would be much lower numerically compared with the questions 1, 2, 3, 4, and 7. Moreover, since the questions such as the number of staff or their efficiencies are asked, the responses would expect to become more or less on the same plane. Therefore, arithmetic mean approach could be used which reflects the effect of difference better for especially the responses having small variances. That means, since outliers would not have expected to exist, fairer combining of different responses could be achieved. This approach is also used for question 5 although the expected quantity is quite high and the expected variance is quite low. This is mainly because there is probability of obtaining answers "zero" meaning that the subcontractor has no ongoing projects which makes using the geometric mean approach inappropriate.

For question 6, exponential distribution approach is followed. By setting the grade of 5 points for the companies of 50 years old or more, below exponential formula is used for rating of the subcontractors.

$$Score\ (question\ 6) = 5{,}25 * (1 - e^{-x/16{,}42293694})$$

Based on the known fact that, as the experience increases the speed of learning decreases, such a formulation is used meaning that as the year increases, the increase in the grade is decreases which provides the young subcontractors to have fairer grades.

For combining the different responses of the Main Contractors, the triangular fuzzy numbers which are constructed based on the responses of assessors for each question are combined using arithmetic mean methodology and the geometrical center of the final triangular fuzzy numbers is taken as the final result. In other words, as clearly stated in part 7.3.1.2, the left spreads, the right spreads and the central values are summed up and divided by the number of total participants to obtain final triangular fuzz numbers of each question. After this procedure, the geometrical center of the final triangular fuzzy numbers is calculated which corresponds to the final grade (1 to 5) of particular subcontractor from relevant selection criterion.

For the final credibility scores of subcontractors, the responses obtained from the Main Contractor, from the Subcontractor or from both are combined using arithmetic mean. Within this process, the shares of the Main Contractor evaluation and the Subcontractor's self-assessment are counted as the same. As an example, by looking at the Table 7.9, since the grade for Financial Capacity of the Firm (T1) obtained based on responses of 4 questions from the Subcontractor and 1 question from the Main Contractor, the final grade is found by summing up all the grades from the Main Contractor and the Subcontractor and dividing it by 5, which means 20% percent share for each response no matter obtained from the Main Contractor or the Subcontractor.

The created tool (Module-2) runs the abovementioned process and finds the credibility of each subcontractor which is shown in forthcoming case studies. Using the tool, ordering of the subcontractors based on the selected specific selection criteria is also possible.

7.4 Defining of the Project (Module -3)

Determining the credibility indexes of each subcontractor, the project needs to be identified by the Main Contractor. Obviously, any kind of information which would affect the bid prices given by the Subcontractor's shall be defined clearly and it shall be made sure that the requirements are completely being understood by the candidate

Subcontractors. Any kind of misunderstanding at this stage might result in rising of claims by the Subcontractors and inappropriate allocation of Subcontractors to the project's parts might be made. If that happens, the entire bid prices shall be re-collected according to the rearranged form of the project. Otherwise the subcontractor might go bankrupt for the low unit prices or high profit margin could be provided to a Subcontractor which would result in over budget.

In the scope of the current study, the "project development module" (Module-3) is developed within the created tool. The module, directs the Main Contractor for identifying the core and shell works of superstructure project in complete manner. It basically asks the following questions about the project which would be contracted.

- "How many main structures does the project include and what are their names?"
- What are the quantities belonging formwork, steel works and concrete works?
- What are the budgeted unit-prices belonging identified structural works?
- What are the scheduled completion times of each main structure?

In the first question, "Main structure" stands for the part of the project which would be contracted to one candidate Subcontractor. Therefore, if the project includes more than one structures/buildings which would be contracted to the one Subcontractor, it shall be counted as one main structure and cumulative structural quantities of the relevant buildings/structures shall be calculated and identified in the following parts. Inversely, if one main building/structure would be contracted with more than one subcontractor, corresponding main structures with the relative quantities shall be calculated and identified as several main structures.

Providing the required information by the Main Contractor, the project becomes suitable for taking bid prices from candidate Subcontractors. Before completing the identification of the project and closing Module-3, Main Contractor shall check the accuracy of defined information.

7.5 Collecting the Bids & Tendering Process (Module-4)

At this step, the subjects about importing the defined project, collecting the bids and constructing the tender matrix would be described which are all included in Module-4.

7.5.1 Importing the Defined Project

The tendering process starts with the importing of the defined project in the previous module by Main Contractor. Once the project imported, the module becomes ready for collecting the bids and importing command only activates with the password defined by the main contractor. The main purpose of that is preventing the candidate Subcontractors from altering the project data before giving their bids.

During project importing stage, some additional information is asked from Main Contractor as;

- What is the yearly interest rate (%)?
- What is the daily overhead cost (TL)?
- What is the percent of performance guarantee that would be asked from the Subcontractor (%)?
- What is the tolerance for the work completion (%)?

The yearly interest rate is used for Net Present Value (NPV) calculation which is frequently used in capital budgeting with the aim of examining the profitability of projected investment. By using the NPV approach in the scope of the current study, it is aimed to achieve the more rational approach especially for the subcontractors having close bid prices but different payment schedules. On the other hand, for the same purpose, the daily overhead cost is also asked and taken into consideration for the monthly cash flows and final NPV calculations.

Especially for the government tendering, adequacy of bank reference stands as an inevitable criterion that needs to be met by each candidate subcontractor no matter how its bid price is low or how credible the subcontractor is. Therefore, in Module-4, the percentage of the performance guarantee is asked to Main Contractor and the bank reference adequacy of a candidate subcontractor is calculated by adding the percentages of the performance guarantee and advance payment and multiplying this percentage by the bid price of the relevant subcontractor. If the maximum obtainable bank reference is lower than this amount, the bid price of the relevant subcontractor is highlighted in tender matrix meaning that there is bank reference inadequacy for the corresponding subcontractor.

Similar to bank reference, the owner or the main contractor generally asks for the work completion of candidate subcontractors in terms of monetary value. Although the tolerance percentage changes depending on the project owner or the project cost, if the candidate subcontractor cannot meet the minimum required amount, it is eliminated. The term of "tolerance percentage" stands for the amount that might be deducted from the project cost which is then compared with the work completion amounts of candidate subcontractors. To illustrate, if the tolerance amount is 30% in the project having the estimated cost of 1,000,000.00 $, the subcontractors having 700,000.00 $ of work completion amounts stand as eligible for the relevant part of the project.

When the abovementioned information is provided by the Main Contractor, the project becomes ready for importing.

7.5.2 Collecting of the Bids from Candidate Subcontractors

Once the project imported, candidate subcontractors enter the relevant information about themselves and the bidding stage starts. At this stage, the following questions are directed to the subcontractors before getting their bids which in fact stands as the responses for eligibility considerations described in the previous part.

- What is the maximum bank reference that can be obtained (TL)?
- What is the maximum work completion obtained (TL)?

Getting the answers to bank reference and work completion questions, Module-4 opens a new page where the candidate subcontractor can see the entire parts of the project together with the work items (formwork, steel works and concrete works), relevant quantities belonging to each work item and the estimated time of completion for each part of the project defined by the Main Contractor. At this point, it is expected from the subcontractor to give its bid prices for the relevant part or parts of the project considering the quantities belonging the identified work items and the estimated completion periods. For the part or parts being involved, the advance percentage that is claimed from the Main Contractor and the completion time is also asked, which would directly affect the NPV of the given bid.

When the candidate subcontractor has completed the bidding stage and completely filled required spaces for the project parts that he wants to be involved in, he clicks on the "send" button and the module automatically saves the information obtained from the relevant subcontractor and closes itself. The same procedure is also repeated by each candidate subcontractor and the module does not allow one subcontractor see any kind of information (even their names) about the other candidate which would cause to an unfair bidding process. However, in any case of bidding stage, the main contractor may reach the information about the candidate subcontractors and the corresponding bid prices using the password in the admin mode.

7.5.3 Bidding Results & Tender Matrix

When the bids are collected from all relevant subcontractors, the main contractor runs the Module-4 in admin mode. From the results page in admin mode, the main contractor can see the bid amounts and the corresponding completion time given by candidate subcontractors for each part of the project. The module also prepares a cash flow table assuming a linear monetary progress would be followed by the subcontractor. In the results page, the cumulative tender price and the corresponding

NPV of each subcontractor are given together with the aim of demonstrating the effect of overhead cost and yearly interest rate.

Module-4 also makes possible for the main contractor to see the entire bid prices obtained from different parts of the project as a matrix from which is called as “tender matrix”. In the tender matrix, the main contractor sees the project parts as column items and the name of the subcontractors as row items. For the purpose of emphasizing the bid prices which violates the restrictions defined by the main contractors, different font colors are used. Table 7.13 describes the meanings of font colors for the violations of timing out (requiring for more time than the main contractor’s estimation), inadequacy of bank reference and inadequacy of work completion;

Table 7.13: The Meaning of Colors in Tender Matrix

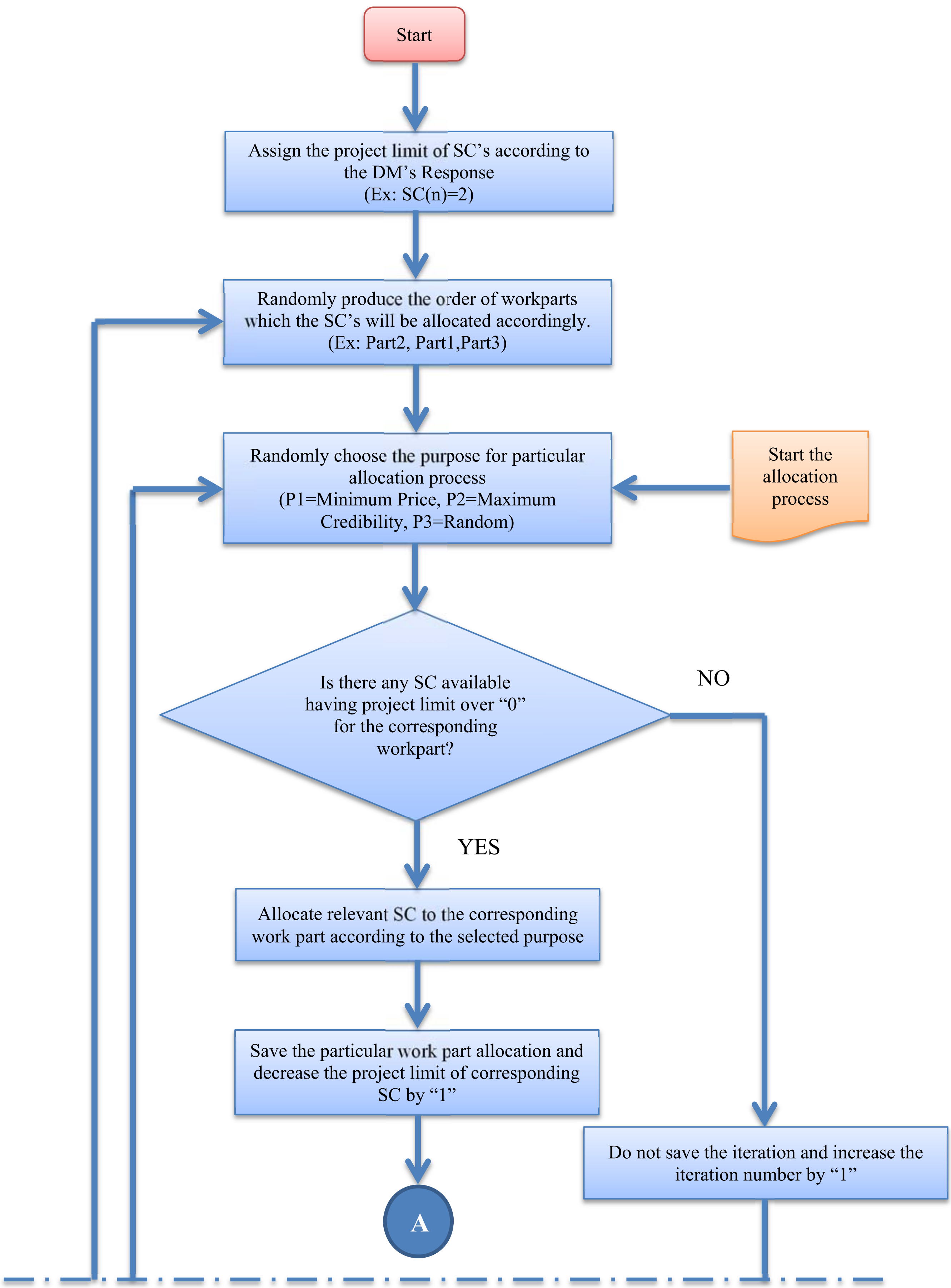
Color	Type of Violation
	Timing out
	Inadequacy of Bank Reference
	Inadequacy of Work Completion
	Timing out & Inadequacy of Bank Reference
	Timing out & Inadequacy of Work Completion
	Inadequacy of Bank Reference & Work Completion
	Timing out, Inadequacy of Bank Reference & Work Completion

7.6 Selecting the Best Subcontractors Using Heuristic Optimization

As the last step of the subcontractor selection within the scope of the study, the proposed module uses a heuristic optimization methodology inserted in VBA and produces price versus credibility scatter plot for the decision maker to choose the suitable set of subcontractor allocation. As stated in the previous part, when the tender matrix is formed the bid prices are painted with different colors having different meanings. At this stage, decision maker keeps the right of deleting some of the bid prices depending on his tolerance about the eligibility criteria of timing out, the inadequacy of bank reference and inadequacy of work completion. In that way, some of the proposals of different subcontractors can be ignored or some of the candidate subcontractors might directly eliminated from the tendering stage. This option gives decision makers to get rid of any candidate subcontractor that seems untrustworthy or eliminating of outlier proposals (either too high for the eligibility or too low for the realization). In addition to that, any subcontractor presuming unrealistic completion time, or having the inadequacy of bank reference or work completion might be eliminated at this stage.

After the elimination of undesired proposals, the tender matrix becomes ready for the optimization. By clicking on the relevant button, the tool asks for the maximum allowed number of part or parts that one subcontractor can be involved in and it produces the result showing all solutions and Pareto solutions which mention the solution sets having the minimum price for a particular credibility or maximum credibility for a particular price. At the first part of optimization code inserted in VBA, the logic described with a flow chart in Figure 7.19 is followed by performing 100, 500, 1000, 2000 or 5000 iterations depending on the Decision Maker's need.

Within the heuristic optimization process, the project limit of the candidate subcontractors "SC(n)" is arranged as the number given by decision maker which reflects the maximum number of work parts that can be obtained by a candidate subcontractor. Then, the work parts are ordered randomly and the allocation process starts according to the randomly chosen allocation purposes which are defined as "minimum price", "maximum credibility" and "random". The purpose of "random" is defined in order to expand the solution search space for avoiding convergence to the limited Pareto optimal solutions. Hence, finding of mid-points lying on the Pareto curve is provided. When the process starts with the first work part (according to the random work part sequencing), the code first checks whether is there any subcontractor exist having the project limit value of above "zero" or not. If exists, the subcontractor which fulfills the selected purpose the most is allocated for the corresponding work part and its project limit decreases by one. This process continues for all of the work parts through the random work part sequencing until each work part is matched with a subcontractor in the corresponding iteration. When the allocations are completed in that particular iteration, the cumulative cost and credibility value are calculated, the corresponding iteration is saved and the iteration numbers is increased by “one” for the next round. During the allocation process, if there is no subcontractor found for allocating to the corresponding work part (that means the project limit values (SC) of all subcontractors are “zero”), the iteration is not saved and the iteration number is increased by “one” again for the upcoming round. In each iteration, the work parts are ordered again in order to change the allocation path and enlarge the solution search set. The allocation process stops when the maximum iteration number (100, 500, 1000, 2000 or 5000) set by the decision maker is reached and “Cost vs. Credibility” scatter plot is drawn representing the all particular solutions found through the allocation process.


Start
Assign the project limit of SC's according to the DM's Response (Ex: SC(n)=2)
Randomly produce the order of workparts which the SC's will be allocated accordingly. (Ex: Part2, Part1,Part3)
Randomly choose the purpose for particular allocation process (P1=Minimum Price, P2=Maximum Credibility, P3=Random)
Start the allocation process
Is there any SC available having project limit over "0" for the corresponding workpart?
NO
YES
Allocate relevant SC to the corresponding work part according to the selected purpose
Save the particular work part allocation and decrease the project limit of corresponding SC by "1"
A
Do not save the iteration and increase the iteration number by "1"

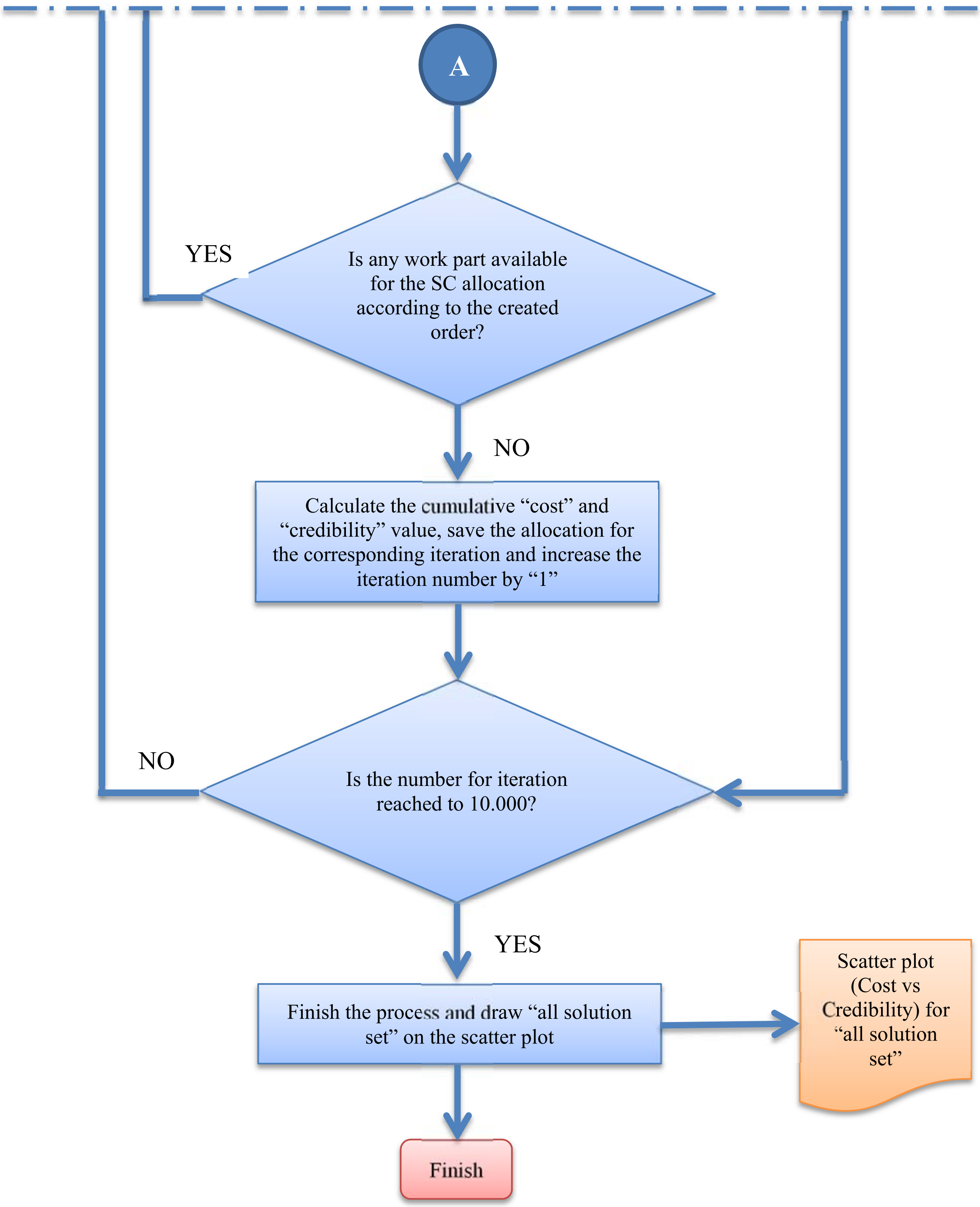
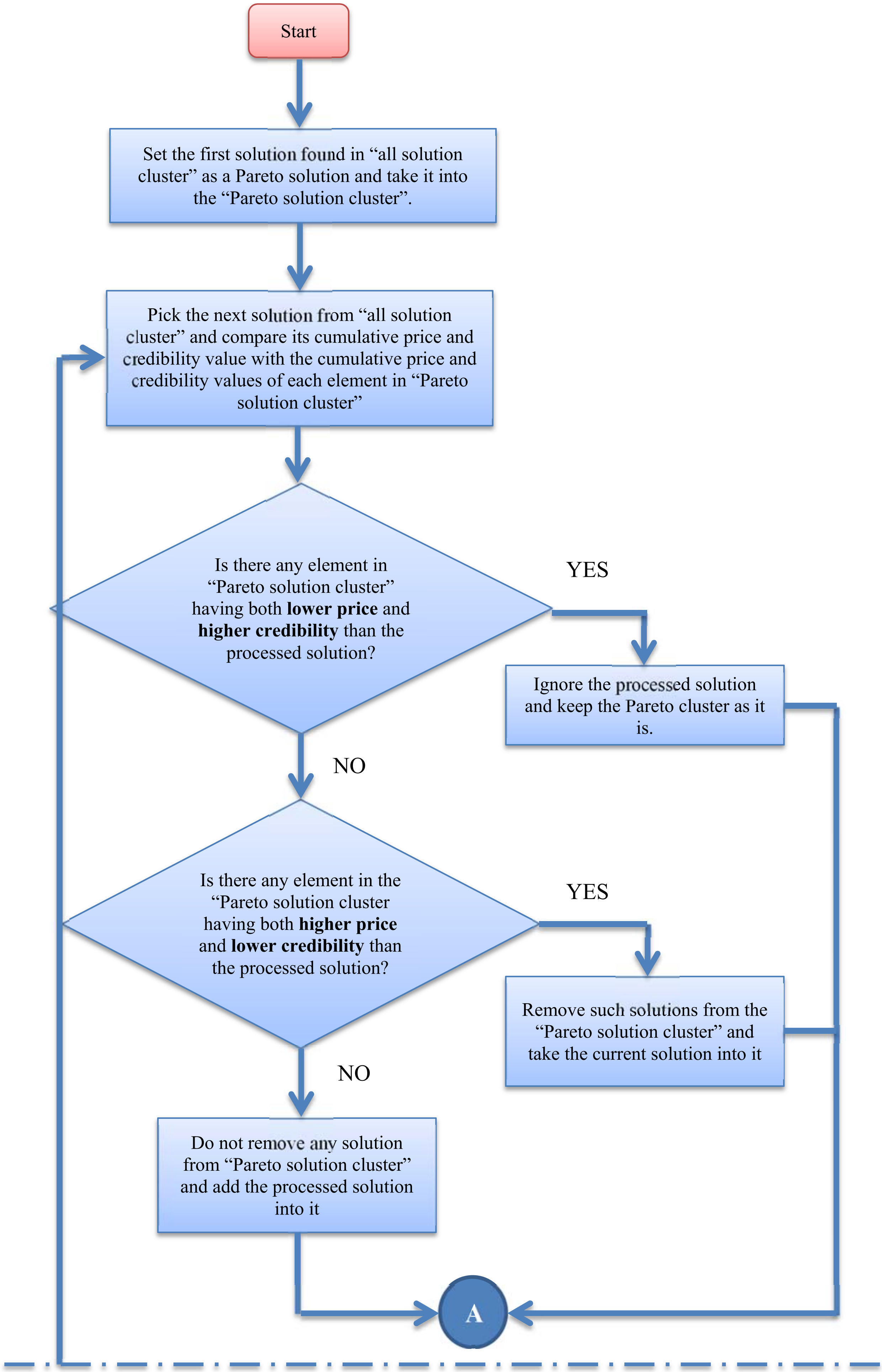


Figure 7.19: The Proposed Heuristic for Optimal Subcontractor Selection

Performing the desired number of iterations, using the random work part allocation for each iteration and allocating Subcontractors using the three different purposes are all contributes to arising of many allocation alternatives (solution sets). As the number of work parts and candidate Subcontractors increases, the solution set grows up more and fills up with many non-optimal allocation alternatives. In order to get rid of those non-optimal solutions, Pareto solutions are found by eliminating the solution sets having less credibility score for the same price or the solution sets having higher prices for the same credibility scores. Therefore, undesired solution sets are removed and the clearer information is presented to the decision maker to perform price-credibility trade off. For finding the Pareto solutions, the logic described in the flow chart in Figure 7.20 is followed in determining the Pareto Front solutions.

Within the process of finding Pareto solutions, two imaginary clusters are created named as “all solution cluster” and “Pareto solution cluster” and all the solution sets found in the previous step is placed in the “all solution cluster”. The first solution is taken to the “Pareto solution cluster” and the comparison among the available solution sets is started. The next solution set is taken from the “all solution cluster” and its cumulative cost and credibility values are compared with the corresponding values of the solution set in the “Pareto solution cluster”. The comparison process is performed such that; if is there any solution set exists in the “Pareto solution cluster” having both lower cost and higher credibility values compared with processed (current) solution set from “All solution cluster”, the processed solution is ignored and the “Pareto solution cluster” is remained the same. If is there any solution set exists in the “Pareto solution cluster” having both higher cost and lower credibility values compared with processed solution set from “All solution cluster”, such solutions are removed from “Pareto solution cluster” and the processed solution set is taken into it. If both two criteria described above are not valid, the processed solution is just added to the “Pareto solution cluster”. At the end of such comparison process, “Cost vs. Credibility” scatter plot is drawn representing the Pareto solutions found through the allocation process.


Start
Set the first solution found in "all solution cluster" as a Pareto solution and take it into the "Pareto solution cluster".
Pick the next solution from "all solution cluster" and compare its cumulative price and credibility value with the cumulative price and credibility values of each element in "Pareto solution cluster"
Is there any element in "Pareto solution cluster" having both **lower price** and **higher credibility** than the processed solution?
YES
Ignore the processed solution and keep the Pareto cluster as it is.
NO
Is there any element in the "Pareto solution cluster having both **higher price** and **lower credibility** than the processed solution?
YES
Remove such solutions from the "Pareto solution cluster" and take the current solution into it
NO
Do not remove any solution from "Pareto solution cluster" and add the processed solution into it
A

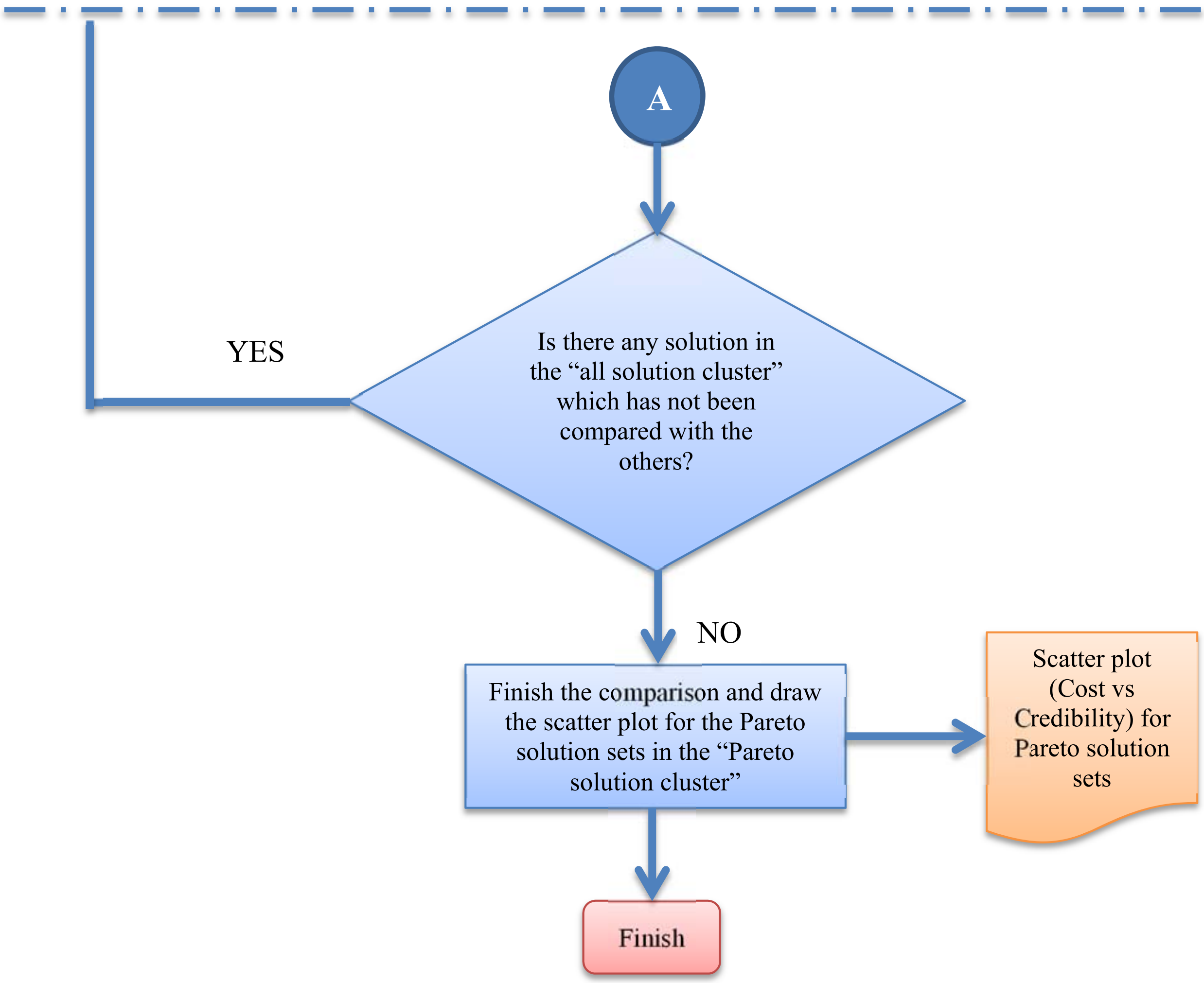


Figure 7.20: Flow Chart for Obtaining the Pareto Solution Sets

Using the scatter plot of Pareto solutions, the decision maker is expected to restrict the optimal solutions depending on the minimum credibility or maximum cost allowances which supposed to be defined by the project requirements. When the line of allowed solutions is achieved, any solution set point can be picked up by depending on cost/credibility priority of decision maker.

7.7 Case Studies

In the scope of this thesis, two governmental superstructure projects are used as the case studies which are both constructed in Ankara/ TURKEY. The employer of both projects is Housing Development Administration of Turkey (TOKI) and the main contractor is a private Turkish Company which takes place near the top in the Turkish Construction Industry. The name of the subcontractors and work parts remained hidden and all the bid amounts are multiplied by a number close to "1" by keeping the rate of bid amounts of each subcontractor undisturbed due to the privacy of the data.

As explained previously, the weights of subcontractor selection criteria are determined with the judgments of decision makers working for the main contractor and Module-1 is created for this process. Since the main contractor is the same for the both case studies in the current study, Module-1 is performed once and the same weights for the subcontractor selection criteria are used for both cases. The sample software screen of module-1 is shown in part 10.1 (Appendix-1).

In the scope of the study, Module-1 sent to a group of relevant nine people including one general director, one project manager, one project coordinator, one design coordinator and five technical office chiefs of the main contractor. In fact, all of the participants involved in the questionnaire actively perform in the subcontractor selection process and all of the participants are informed about how to use the tool before they started. Following the process described in part 7.2.2., the weights of subcontractor selection criteria are calculated as shown in Table 7.14 below.

Table 7.14: Weights of Subcriteria (Case Study I & II)

Subcriteria	Weight
Financial Capacity of the Firm	**0.1057**
Current Workload	**0.0907**
General Experience of the Firm in the Industry	**0.2485**
Health and Safety Performance	**0.0091**
Accessibility to the firm and Cooperation	**0.0385**
Postbusiness Relationship. Claims and/or Disputes	**0.0144**
Labor Resource of the Firm	**0.0667**
Material Resource of the Firm	**0.0467**
Equipment Resource of the Firm	**0.0467**
Reputation for Completing within Budget	**0.0143**
Reputation for Completing within time	**0.0143**
Reputation for High Quality Service	**0.0143**
References/Advices	**0.0123**
Experience in similar type of projects	**0.1389**
Experience in similar or larger size of projects	**0.1389**

7.7.1 Case Study I: Governmental Superstructure Project in ETİMESGUT / ANKARA

The first project is a governmental building complex including one large main building, four service buildings and one multi-storey car park in it. Since the quantities are very high for the main building, it is divided into three and therefore eight main work parts are obtained for the tendering stage. For the project, twenty-two core and shell subcontractors are invited and sixteen of them accepted to give their offers. Individual meetings are performed with each candidate subcontractor and the design projects are shared with the required conditions. During the meetings, the information required for the credibility evaluation is gathered from the subcontractors which are used in Module-2.

Based on the process explained in part 7.3, the credibility indexes of candidate subcontractors are calculated as follows.

Table 7.15: The Credibility Indexes of Subcontractors (Case Study I)

SUBCONTRACTOR	CREDIBILITY INDEX
Subcontractor 1	64.13%
Subcontractor 2	66.30%
Subcontractor 3	68.27%
Subcontractor 4	64.14%
Subcontractor 5	58.95%
Subcontractor 6	81.54%
Subcontractor 7	62.27%
Subcontractor 8	63.78%
Subcontractor 9	57.23%
Subcontractor 10	55.60%
Subcontractor 11	54.72%
Subcontractor 12	67.70%
Subcontractor 13	68.70%
Subcontractor 14	71.43%
Subcontractor 15	41.77%
Subcontractor 16	55.85%

As the next step, the project is developed by using the quantities given in Table 7.16. The module view of project development (module-3) for the first case study including the quantities, unit prices and the estimated durations is given in part 10.2 (Appendix-2).

Table 7.16: The Quantities Used in Module-3 (Case Study I)

Building Name	Formworks (m2)		
	Foundation	Column & Shearwall	Beam & Flooring
Building 1: KA-Middle	2,142.42	128,062.05	138,609.16
Building 2: KA-Side1	1,310.11	81,976.01	86,732.87
Building 3: KA-Side2	1,108.21	82,179.61	74,239.30
Building 4: KB-KC	5,110.91	64,684.77	87,427.65
Building 5: KD-KE	1,098.31	32,374.30	30,597.31
Building 6: KF-KG-KJ	1,211.49	35,080.32	39,885.39
Building 7: KH-KK-KI	1,007.43	36,574.05	39,718.17
Building 8: KL	642.13	34,294.37	69,390.89

Building Name	Steelworks (ton)			
	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring
Building 1: KA-Middle	1,809.71	57.17	3,463.10	4,331.13
Building 2: KA-Side1	925.10	31.93	2,186.18	2,540.15
Building 3: KA-Side2	845.92	26.70	2,213.55	2,287.73
Building 4: KB-KC	3,550.47	83.87	2,284.53	3,877.93
Building 5: KD-KE	604.89	24.48	875.97	850.32
Building 6: KF-KG-KJ	651.86	26.99	948.37	1,232.59
Building 7: KH-KK-KI	660.94	28.00	978.83	1,239.79
Building 8: KL	1,106.74	42.70	1,010.63	2,281.80

Building Name	Concreteworks (m3)			
	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring
Building 1: KA-Middle	4,021.57	22,963.69	23,883.46	29,869.87
Building 2: KA-Side1	2,248.24	11,875.39	15,077.09	17,518.31
Building 3: KA-Side2	1,879.83	10,734.09	15,265.85	15,777.47
Building 4: KB-KC	6,185.02	43,643.08	15,755.41	26,744.36
Building 5: KD-KE	1,900.30	7,944.90	6,041.14	5,864.27
Building 6: KF-KG-KJ	2,163.92	8,592.54	6,540.46	8,500.61
Building 7: KH-KK-KI	2,178.31	8,744.03	6,750.55	8,550.29
Building 8: KL	3,748.50	14,431.99	6,969.84	15,736.54

As the following step, the created project is defined into Module-4 by the Main Contractor. During this process, the yearly interest rate is introduced as 7.5% and the average overhead cost is defined as 25,000.00 TL per day. For the performance guarantee, 10% is defined and the tolerance for the work completion is determined as 75% identified as the project limitations. The candidate subcontractors are informed about the project limitations and Module-4 is sent to each of them in order together with the corresponding project drawings and technical specifications. When the bids are collected, the final tender matrix is constituted automatically by the decision maker as given in Table 7.17 below.

Table 7.17: The Tender Matrix in Module-4 (Case Study I)

TENDER MATRIX								
	Yapı 1: KA-Orta	Yapı 2: KA-Yan1	Yapı 3: KA-Yan2	Yapı 4: KB-KC	Yapı 5: KD-KE	Yapı 6: KF-KG-KJ	Yapı 7: KH-KK-KI	Yapı 8: KL
Subcontractor-1	15.435.863,43 ₺		8.853.536,40 ₺	14.367.414,42 ₺		5.997.342,08 ₺		8.080.465,09 ₺
Subcontractor-2		10.551.722,94 ₺					5.814.520,09 ₺	
Subcontractor-3		9.838.632,85 ₺			4.942.231,76 ₺		5.613.981,85 ₺	
Subcontractor-4	16.876.416,25 ₺						6.486.907,12 ₺	
Subcontractor-5				14.454.842,39 ₺	4.788.549,73 ₺			
Subcontractor-6		10.388.318,76 ₺						9.222.392,39 ₺
Subcontractor-7	18.023.703,62 ₺	11.151.784,94 ₺						8.820.569,18 ₺
Subcontractor-8			9.487.244,38 ₺					8.397.899,39 ₺
Subcontractor-9					4.678.119,27 ₺	5.215.750,78 ₺		
Subcontractor-10			10.449.539,39 ₺					
Subcontractor-11						5.565.402,80 ₺		
Subcontractor-12					4.723.621,31 ₺	5.300.342,54 ₺	5.608.826,33 ₺	9.009.530,35 ₺
Subcontractor-13				14.285.896,56 ₺				8.116.054,95 ₺
Subcontractor-14					4.553.056,54 ₺	5.021.228,47 ₺		6.399.497,54 ₺
Subcontractor-15					6.292.967,12 ₺			
Subcontractor-16					4.636.347,43 ₺		5.307.397,55 ₺	

In Case Study-I, the Main Contractor has no tolerance about the bank references while the work completion is and completion time is tolerable. In fact, the estimated project time is elongated since there is no subcontractor available for Building 4 fulfilling the condition about the time limitation. Therefore, the offers of;

- Subcontractor 7 in Building 1,
- Subcontractor 10 in Building 3,
- Subcontractor 12 in Buildings 5,6,7 and 8

and

- Subcontractor 13 in Building 8

are eliminated from the tendering process. After this process, the tender matrix is turned to the table shown in Table 7.18.

Table 7.18: The Tender Matrix in Module-4 After Elimination (Case Study I)

TENDER MATRIX								
	Yapı 1: KA-Orta	Yapı 2: KA-Yan1	Yapı 3: KA-Yan2	Yapı 4: KB-KC	Yapı 5: KD-KE	Yapı 6: KF-KG-KJ	Yapı 7: KH-KK-KI	Yapı 8: KL
Subcontractor-1	15.435.863,43 ₺		8.853.536,40 ₺	14.367.414,42 ₺		5.997.342,08 ₺		8.080.465,09 ₺
Subcontractor-2		10.551.722,94 ₺					5.814.520,09 ₺	
Subcontractor-3		9.838.632,85 ₺			4.942.231,76 ₺		5.613.981,85 ₺	
Subcontractor-4	16.876.416,25 ₺						6.486.907,12 ₺	
Subcontractor-5				14.454.842,39 ₺	4.788.549,73 ₺			
Subcontractor-6		10.388.318,76 ₺						9.222.392,39 ₺
Subcontractor-7		11.151.784,94 ₺						8.820.569,18 ₺
Subcontractor-8			9.487.244,38 ₺					8.397.899,39 ₺
Subcontractor-9					4.678.119,27 ₺	5.215.750,78 ₺		
Subcontractor-10								
Subcontractor-11						5.565.402,80 ₺		
Subcontractor-12								
Subcontractor-13				14.285.896,56 ₺				
Subcontractor-14					4.553.056,54 ₺	5.021.228,47 ₺		6.399.497,54 ₺
Subcontractor-15					6.292.967,12 ₺			
Subcontractor-16					4.636.347,43 ₺		5.307.397,55 ₺	

Obtaining the tender matrix, the table becomes ready for using as the input variable of the following optimization process. With the relative command, Module-4 runs as described in the flow chart in Figure 7.19, and all possible solutions for the subcontractor allocation is found as given in Figure 7.21. For the iteration number, 5000 is chosen in the heuristic, in order to evaluate as much allocation alternative as possible. Module-4 allows the decision maker to choose the numbers of 100, 500, 1000 and 2000 as an iteration number depending on the project complexity.

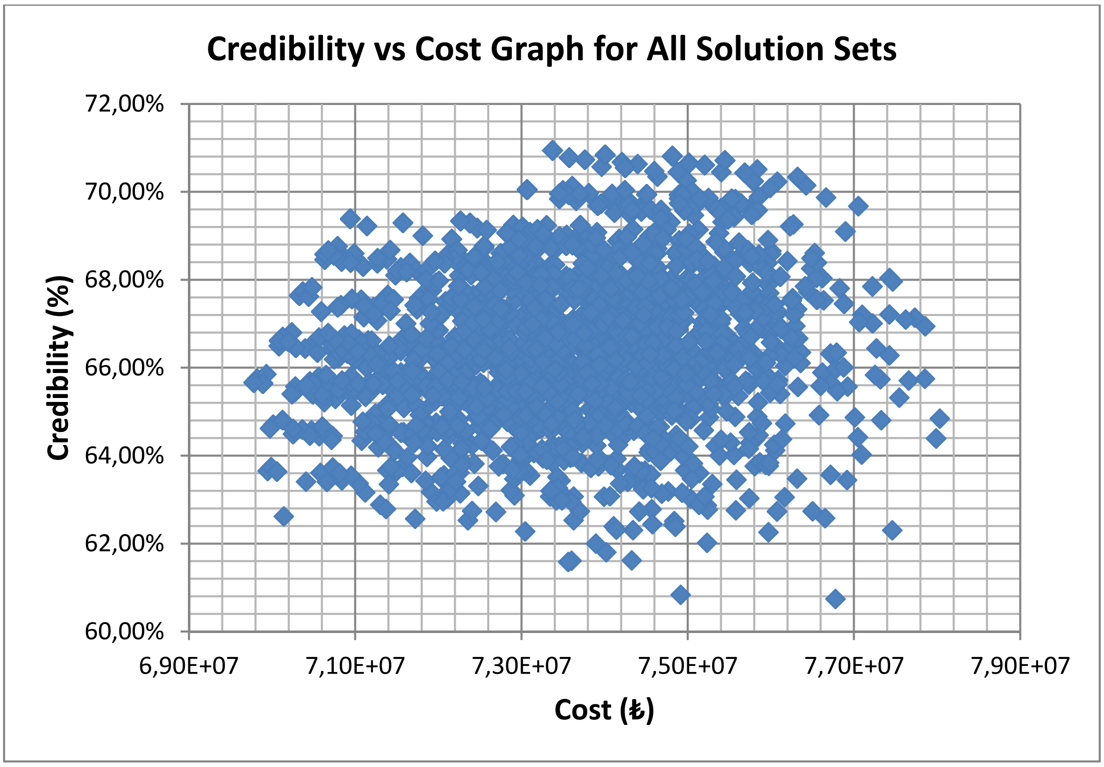


Figure 7.21: Credibility vs. Cost Graph for All Solution Sets (Case Study I)

Figure 7.21 shows all possible solution sets for 5000 iterations of the heuristic and it can be interpreted that the possible solutions lie between $69,000,000.00 & $79,000,000.00 in terms of overall cost and around 60% - 72% in terms of overall credibility. The graph gives an idea to the user about approximate cost of project portfolio and credibility however the most suitable point among all possible solution sets should be picked by the decision maker to determine the corresponding subcontractor allocation. Considering the elimination logic described in part 7.6, Module-4 finds the Pareto solutions as shown in Figure 7.22 below.

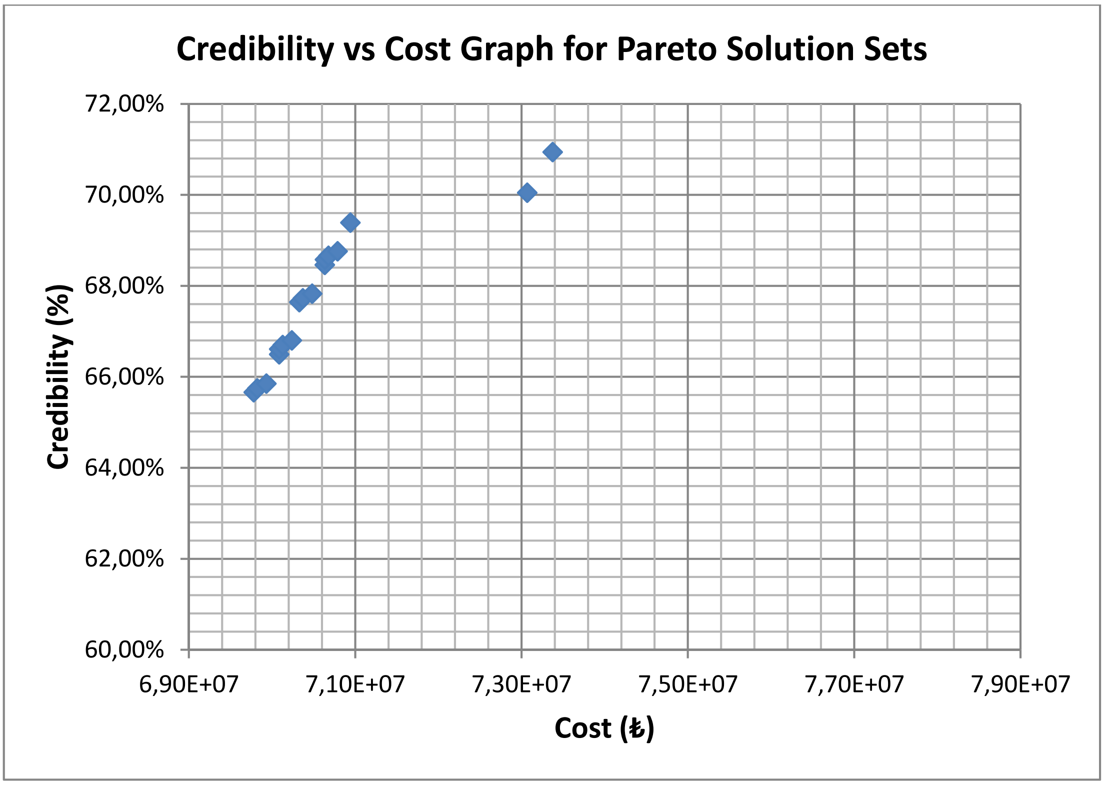


Figure 7.22: Credibility vs. Cost Graph for Pareto Solution Sets (Case Study I)

The module view shown in part 10.3 (Appendix-3) clearly describes that there are 17 solution sets exist as the part of Pareto solutions and minimum cost is 69,778,400.00 TL with the corresponding credibility value of 65.66%. In the case study, the targeted minimum credibility value is set as 60%, therefore the 17th Pareto solution set (the cheapest solution) is taken as the final solution set by decision maker which corresponds to the allocation of subcontractors 1,3,1,13,16,14,16,14 to the work parts one to eight orderly (Table 7.19).

Table 7.19: The Final Allocation of Subcontractors (Case Study I)

Work Part	Subcontractor #
Building 1: KA-Middle	Subcontractor 1
Building 2: KA-Side1	Subcontractor 3
Building 3: KA-Side2	Subcontractor 1
Building 4: KB-KC	Subcontractor 13
Building 5: KD-KE	Subcontractor 16
Building 6: KF-KG-KJ	Subcontractor 14
Building 7: KH-KK-KI	Subcontractor 16
Building 8: KL	Subcontractor 14

Cash Flow analysis produced by the module is shown in part 10.4 (Appendix-4). Using the table decision maker can see the breakdown of the monthly payment schedule for all eight work parts and the NPV values which reflects the net present value of the spent money throughout the project completion period.

7.7.2 Case Study II: Governmental Superstructure Project in YENIMAHALLE / ANKARA

The second project is a governmental building complex including one large library, one exhibition hall and one multi-storey car park between them. All buildings have four basement floors and the library and the exhibition hall buildings have thirteen and four floors above the ground. Total layout area of all three buildings is around 55,000.00 m2 while the perimeter of the building site of all three buildings is around 1.1 km. For each of the building a subcontractor is planned to be worked and therefore three work parts are obtained. For the tendering stage, eighteen core and shell subcontractors are invited and nine of them accepted to give their offers. Individual meetings are performed with each candidate subcontractor and the design projects are shared with the required conditions as performed in Case Study I.

The credibility indexes of candidate subcontractors are calculated as follows.

Table 7.20: The Credibility Indexes of Subcontractors (Case Study II)

SUBCONTRACTOR	CREDIBILITY INDEX
Subcontractor 1	86.11%
Subcontractor 2	85.02%
Subcontractor 3	77.87%
Subcontractor 4	72.23%
Subcontractor 5	59.89%
Subcontractor 6	70.24%
Subcontractor 7	75.41%
Subcontractor 8	69.42%
Subcontractor 9	68.78%

In the next step, the project is developed by using the quantities given in Table 7.21. The module view of project development (module-3) for the second case study including the quantities, unit prices and the estimated durations is given in Part 10.5 (Appendix-5).

Table 7.21: The Quantities Used in Module-3 (Case Study II)

Building Name	**Formworks (m2)**		
	Foundation	Column & Shearwall	Beam & Flooring
Library	770.00	180,000.00	54,530.00
Exhibition Hall	870.00	164,630.00	42,500.00
Multi-Storey Car Park	650.00	90,000.00	30,300.00

Building Name	**Steelworks (ton)**			
	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring
Library	3,450.00	300.00	2,775.00	7,237.00
Exhibition Hall	2,950.00	200.00	1,975.00	5,870.00
Multi-Storey Car Park	2,640.00	150.00	1,332.00	3,817.00

Building Name	**Concreteworks (m3)**			
	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring
Library	2,000.00	28,850.00	18,500.00	48,250.00
Exhibition Hall	1,900.00	25,000.00	15,000.00	36,700.00
Multi-Storey Car Park	1,650.00	19,360.00	10,300.00	27,600.00

As in the previous case study, the project is defined in Module-4 by the Main Contractor using the yearly interest rate of 7.5% and average daily overhead cost of 25,000.00 TL. 10% of the contract amount is asked for the performance guarantee and the tolerance for the work completion is determined as 50% in this case. The similar procedure is followed for informing the subcontractors about project limitations and the tender matrix is constructed as shown in Table 7.22 below.

Table 7.22: The Tender Matrix in Module-4 (Case Study II)

TENDER MATRIX

	Building 1: Library	**Building 2: Exhibition Hall**	**Building 3: Multi-Storey Car Park**
Subcontractor 1	23,711,790.00 ₺	18,279,200.00 ₺	10,150,734.50 ₺
Subcontractor 2		19,691,419.10 ₺	12,471,645.12 ₺
Subcontractor 3		19,396,784.05 ₺	13,054,682.31 ₺
Subcontractor 4		18,642,620.00 ₺	10,779,272.00 ₺
Subcontractor 5			11,303,814.00 ₺
Subcontractor 6		19,386,600.10 ₺	11,793,677.36 ₺
Subcontractor 7	21,649,180.00 ₺	18,317,800.00 ₺	10,686,460.00 ₺
Subcontractor 8		20,069,005.00 ₺	12,356,305.00 ₺
Subcontractor 9		15,127,436.90 ₺	11,695,132.75 ₺

In Case Study-II, the Main Contractor has no tolerance both for the bank reference and completion time while the work completion is tolerable. Therefore, the offers of;

- Subcontractor 3,4 & 6 in Building 2,
- Subcontractor 4 & 5 in Building 3,

are eliminated from the tendering process. After this process, the tender matrix is turned to the table shown in Table 7.23.

Table 7.23: The Tender Matrix in Module-4 after Elimination (Case Study II)

TENDER MATRIX			
	Building 1: Library	**Building 2: Exhibition Hall**	**Building 3: Multi-Storey Car Park**
Subcontractor 1	23,711,790.00 ₺	18,279,200.00 ₺	10,150,734.50 ₺
Subcontractor 2		19,691,419.10 ₺	12,471,645.12 ₺
Subcontractor 3			13,054,682.31 ₺
Subcontractor 4			
Subcontractor 5			
Subcontractor 6			11,793,677.36 ₺
Subcontractor 7	21,649,180.00 ₺	18,317,800.00 ₺	10,686,460.00 ₺
Subcontractor 8		20,069,005.00 ₺	12,356,305.00 ₺
Subcontractor 9		15,127,436.90 ₺	11,695,132.75 ₺

By preparing the tender matrix, the optimization is performed for 5000 iterations and all solution sets and Pareto solution sets are found as given Figure 7.23 and Figure 7.24 correspondingly.

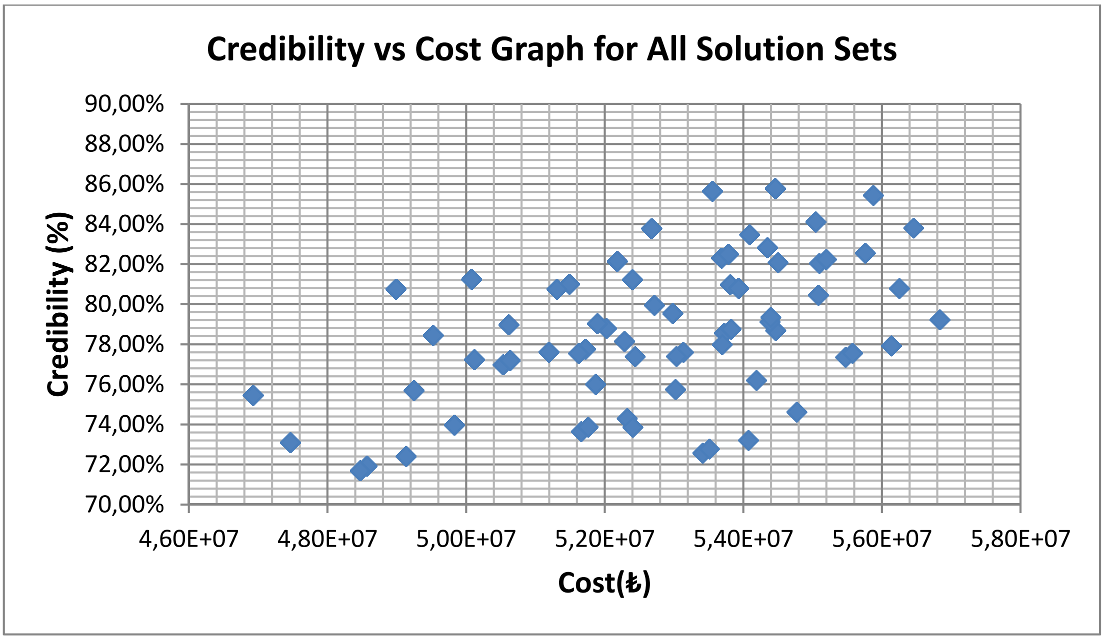


Figure 7.23 : Credibility vs Cost Graph for All Solution Sets (Case Study II)

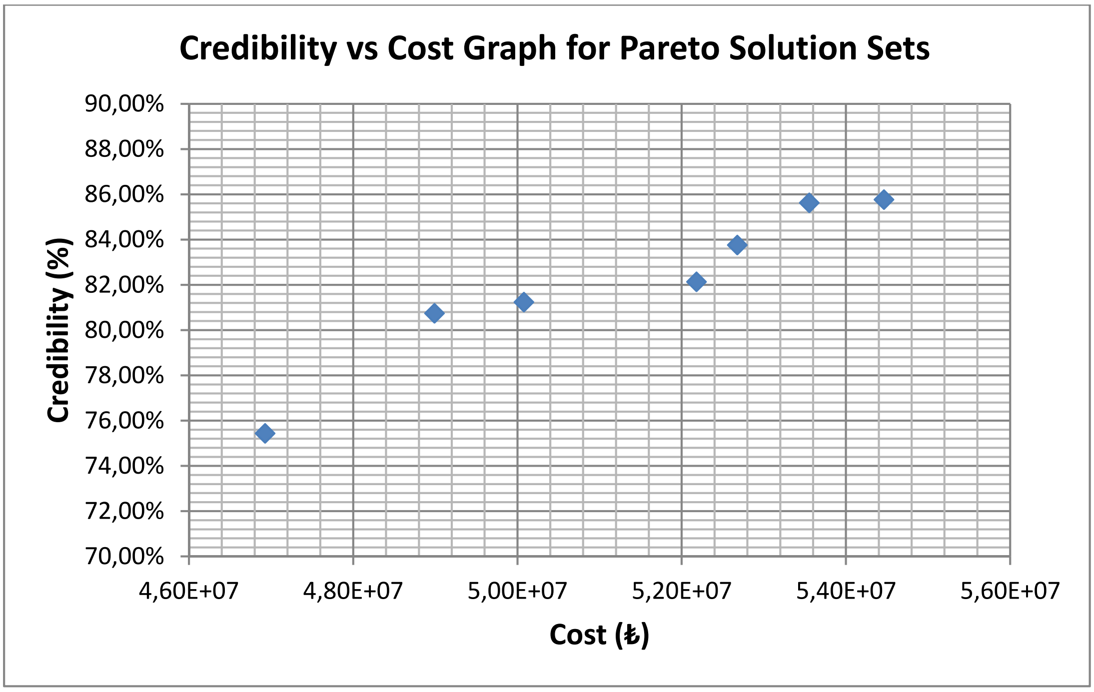


Figure 7.24 : Credibility vs Cost Graph for Pareto Solution Sets (Case Study II)

The module view shown in part 10.6 (Appendix-6) clearly describes that there are seven solution sets exist as the part of Pareto solutions and minimum cost is 46,927,351.00 TL with the corresponding credibility value of 75.45%. In this case study, the targeted minimum credibility value is set as 80%, therefore 5^{th} solution set (Pareto #5) is taken as the final solution set by decision maker which corresponds to the allocation of subcontractors 1,9,1 to the work parts of Library, Exhibition Hall and Multi-Storey Car Park (Table 7.24).

Table 7.24: The Final Allocation of Subcontractors (Case Study II)

Work Part	Subcontractor #
Building 1: Library	Subcontractor 1
Building 2: Exhibition Hall	Subcontractor 9
Building 3: Multi-Storey Car Park	Subcontractor 1

Cash Flow analysis produced by the module is shown in Table 7.25 which allows the decision maker to perform the budgeting and planning processes.

Table 7.25: Cash Flow of the Proposed Subcontractor Allocation (Case Study II)

	Cash Flow Analysis - Work Part 1									Credibility Index
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	
Quantity										
Subcontractor 1	2.994.268,50 ₺	7.137.772,80 ₺	11.281.277,10 ₺	15.424.781,40 ₺	19.568.285,70 ₺	23.711.790,00 ₺		23.711.790,00 ₺	23.328.931,40 ₺	86,11%
Subcontractor 2										85,02%
Subcontractor 3										77,87%
Subcontractor 4										72,23%
Subcontractor 5										59,89%
Subcontractor 6										70,24%
Subcontractor 7	3.429.836,00 ₺	6.466.393,33 ₺	9.502.950,67 ₺	12.539.508,00 ₺	15.576.065,33 ₺	18.612.622,67 ₺	21.649.180,00 ₺	21.649.180,00 ₺	21.257.182,06 ₺	75,41%
Subcontractor 8										69,42%
Subcontractor 9										68,78%

	Cash Flow Analysis - Work Part 2									Credibility Index
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	
Quantity										
Subcontractor 1	1.527.920,00 ₺	5.715.740,00 ₺	9.903.560,00 ₺	14.091.380,00 ₺	18.279.200,00 ₺			18.279.200,00 ₺	18.020.697,55 ₺	86,11%
Subcontractor 2	2.391.212,87 ₺	5.851.254,11 ₺	9.311.295,36 ₺	12.771.336,61 ₺	16.231.377,85 ₺	19.691.419,10 ₺		19.691.419,10 ₺	19.371.712,29 ₺	85,02%
Subcontractor 3	3.911.696,01 ₺	7.008.713,62 ₺	10.105.731,23 ₺	13.202.748,84 ₺	16.299.766,44 ₺	19.396.784,05 ₺		19.396.784,05 ₺	19.110.620,51 ₺	77,87%
Subcontractor 4	4.242.786,00 ₺	6.642.758,33 ₺	9.042.730,67 ₺	11.442.703,00 ₺	13.842.675,33 ₺	16.242.647,67 ₺	18.642.620,00 ₺	18.642.620,00 ₺	18.332.800,66 ₺	72,23%
Subcontractor 5										59,89%
Subcontractor 6	3.277.320,02 ₺	7.304.640,04 ₺	11.331.960,06 ₺	15.359.280,08 ₺	19.386.600,10 ₺			19.386.600,10 ₺	19.138.004,87 ₺	70,24%
Subcontractor 7	2.185.170,00 ₺	5.411.696,00 ₺	8.638.222,00 ₺	11.864.748,00 ₺	15.091.274,00 ₺	18.317.800,00 ₺		18.317.800,00 ₺	18.019.669,93 ₺	75,41%
Subcontractor 8	0,00 ₺	4.013.801,00 ₺	8.027.602,00 ₺	12.041.403,00 ₺	16.055.204,00 ₺	20.069.005,00 ₺		20.069.005,00 ₺	19.698.130,94 ₺	69,42%
Subcontractor 9	3.638.231,07 ₺	6.510.532,53 ₺	9.382.833,99 ₺	12.255.135,44 ₺	15.127.436,90 ₺			15.127.436,90 ₺	14.950.137,74 ₺	68,78%

	Cash Flow Analysis - Work Part 3									Credibility Index
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	
Quantity										
Subcontractor 1	0,00 ₺	5.075.367,25 ₺	10.150.734,50 ₺					10.150.734,50 ₺	10.056.358,24 ₺	86,11%
Subcontractor 2	1.533.246,77 ₺	5.179.379,55 ₺	8.825.512,34 ₺	12.471.645,12 ₺				12.471.645,12 ₺	12.336.326,17 ₺	85,02%
Subcontractor 3	1.005.468,23 ₺	4.017.771,75 ₺	7.030.075,27 ₺	10.042.378,79 ₺	13.054.682,31 ₺			13.054.682,31 ₺	12.868.741,22 ₺	77,87%
Subcontractor 4	1.279.390,80 ₺	4.446.017,87 ₺	7.612.644,93 ₺	10.779.272,00 ₺				10.779.272,00 ₺	10.661.748,95 ₺	72,23%
Subcontractor 5	4.526.907,00 ₺	6.785.876,00 ₺	9.044.845,00 ₺	11.303.814,00 ₺				11.303.814,00 ₺	11.219.976,87 ₺	59,89%
Subcontractor 6	954.367,74 ₺	4.567.470,94 ₺	8.180.574,15 ₺	11.793.677,36 ₺				11.793.677,36 ₺	11.659.584,24 ₺	70,24%
Subcontractor 7	843.646,00 ₺	4.124.584,00 ₺	7.405.522,00 ₺	10.686.460,00 ₺				10.686.460,00 ₺	10.564.694,53 ₺	75,41%
Subcontractor 8	0,00 ₺	4.118.768,33 ₺	8.237.536,67 ₺	12.356.305,00 ₺				12.356.305,00 ₺	12.203.445,13 ₺	69,42%
Subcontractor 9	1.889.026,55 ₺	5.157.728,62 ₺	8.426.430,68 ₺	11.695.132,75 ₺				11.695.132,75 ₺	11.573.821,39 ₺	68,78%

CHAPTER 8

CONCLUSION

This study focuses on the developing a rational and systematic approach for the optimal allocation of candidate subcontractors to the parts included in the construction project during the tendering stage. In contrast to the classical methods including subjective judgments of decision makers which are frequently used especially in private organizations, a useful tool is developed based on the methodologies of Analytical Hierarchy Process, Fuzzy Methodology and a Heuristic Optimization algorithm. Considering that each day spending for the tendering process will result in financial losses, the secondary aim is set up based on speeding up the tendering process and simplifying the roles of decision makers by highlighting the critical decision making factors.

Within the scope of the study, a four-module tool is developed that are capable of managing the tendering stage of a construction project including up to 15 parts and up to 35 candidate subcontractors. The tool is designed particularly for core and shell works of a superstructure project which constitutes one of the major components in the entire construction process in terms of cost and time. In the first module, the tool basically investigates the judges of decision makers and assigns the relative importance weights of predefined subcontractor credibility determinants. In the second module, based on the gathered information from the participant subcontractors and the ratings of decision makers, the tool calculates the credibility indexes of each candidate subcontractor. In the third module, the tool develops the project based on the information obtained from project owner or main contractor. In the last module, gathering the bids of each subcontractor, the tool creates the cash flows belonging each part of the project and tender matrix for the entire project portfolio. Additionally, by using a Heuristic Optimization Algorithm, the tool prepares a cost versus credibility scatter plot showing optimal solutions of subcontractor allocation sets which allow the decision maker to perform trade-off analysis between cost and credibility.

Although the tool might seem a little complex at first glance since it has four different modules in it, those modules literally represent the four main parts of the tendering stage which provide decision maker to use available information from past practices. Once the weights of credibility criteria of the subcontractors are determined in the first tender based on the judgments of decision makers within the company, the user can run the module by starting from module 2 for the next tenders. Similarly, if the tender proceeds among the subcontractors having credibility values from the past tenders, the module can be run from module 3. In fact, the tool constitutes a database including the judges of decision makers and profiles of subcontractors in it and gives the user the opportunity of investigating, correcting, adding or removing of any kind information that corrupts the decision making process.

The developed tool provides the cash flows for each part of the entire project which might stand as the "warning" for the cost control specialists from the tendering stage. Before final decision has made, the project owner or general contractor has the chance of changing the financial strategy based on the monthly reflections of given bids. Obtained cash flow reflection can also form the main support for the budget plan of the construction process.

The tool automatically warns the decision maker against the inadequacy of guarantee letter, work completion and completion time limitation. When the bids are gathered, the tool gives the tender prices of subcontractors in different colors identifying the violation of defined limitations in the tender matrix. At that stage, depending on the type of violation and the allowable tolerance, the decision maker may eliminate the subcontractor by erasing the tender, or he may allow him to keep involving in the tender process. Therefore, the tool provides decision maker to manage the tender limitations in a practical way.

The tool presents the cash flows and NPV values of the given bid prices by considering the completion time and requested advance percentages of each subcontractor for each part of the project. Therefore, the tool proposes the comparison of actual costs with the calculated credibility values at the final step which gives decision maker to have the opportunity of bargaining with some of the candidate subcontractors. On the graph of cost versus credibility, the decision maker would have the chance to bargain with the subcontractors involved in the optimal solution set. Thus, the cumulative tender price might be reduced or the cumulative credibility value of the project might be improved depending on the project needs.

While face to face negotiation is the leading procedure in the classical methods, the developed tool reveals the obstacles of subcontractors for face to face negotiation in the tendering process. By following the directions implemented in the tool, a member of the main contractor might be involved in the assessment process or a bid can be obtained easily from a subcontractor located in the far locations.

Last but not the least, the developed tool increases the winning change of small-sized subcontractors in the tendering stage. Since the developed tool simplifies the involvement and assessment process of participants, more subcontractors can be invited to tendering stage by main contractor or project owner which increases the invitation change of small sized companies. Additionally, non-biased assessment process would increase their chance since the evaluation is more rational and not based purely on the subjective judgments.

Although the tool attributes the process of subcontractor selection to the realistic and systematic basis, it still partially works depended on the personal judgments. By nature of decision making process, it is almost impossible to clean up the assessment process from subjectivity. However, within the scope of the study, the enormous effect of individual provisions is aimed to be minimized. For that purpose, a comprehensive contribution of main contractor members is advised since it provides the smoothening of heresies and contributes arising of corporate provisions.

In the study, a comprehensive literature study has been performed for identifying the factors contributing the subcontractors' credibility and the tool is constructed over them. Although the general views and project-specific needs are taken into consideration together with the expert judgments some additional criteria may arise for some kind of specific core and shell superstructure projects. The tool forces decision maker to use the predefined credibility determination criteria and the interference to the dependencies among the defined criteria is not possible. In addition to that, the questions directed to the main contractor or subcontractors for the rating of subcontractors are also remained fixed which over-all constitutes the subjective side of the current study that needs to be shaped somehow. A future study can be performed which allows the user to insert or remove any credibility determinant, change the dependencies among the credibility determinants or regulating the questions directed to main contractor and subcontractors during the rating stage.

Since the detailed analysis of cash flow is not possible with the obtained information at the tendering stage, the linear distribution of given bid over the estimated project completion duration of the corresponding subcontractor is used for the NPV calculations. Although such a distribution is not possible in reality, it forms a basis for the NPV calculations and it provides decision maker to gain insight into the actual cost of the project.

In the study, Visual Basic for Applications (VBA) is used as software for the development of the four-module tools including optimization process. The reason for developing four-module tool is described clearly in the previous parts. However, the developed tool forces user to keep all excel files in the same folder since there exist dependency links between them. On the other hand, for the achievement of such a process, decision maker needs to have the software of MS Office installed on his computer. A future study might be performed for developing a module for activating all described steps with an order with the improved visual quality which would eventually serve for the criterion of creating a tool standing more user-friendly.

For the optimization part of the study, a heuristic algorithm is used as an optimization methodology which has many similar applications in literature that correspond to the problem case in this study. However, using different optimization methodology might result with the different set of solution especially if the given bid prices of the subcontractors are close to each other. Therefore, a future study might be performed on improving the optimal set of solutions using different heuristic or meta-heuristic practices. The created models can be validated with the similar case studies. By proving the validity of the current study, similar tools might be developed for different work items in the construction project except for core and shell works.

REFERENCES

Abbasianjahromi, H., Rajaie, H., & Shakeri, E. (2011). A Framework for Subcontractor Selection in the Construction Industry. *Journal of Civil Engineering and Management, 19*(2), 158-168.

Abdelrahman, M., Zayed, T., & Elyamany, A. (2008). Best-Value Model Based on Project Specific Characteristics. *Journal of Construction Engineering and Management, 134*(3), 179-188.

Abdi, M. (2012). Product family formation and selection for reconfigurability using analytical network process. *International Journal of Production Research, 50*(17), 4908-4921.

Alarcon, L. F., & Mourgues, C. (2002). Performance Modeling for Contractor Selection. *J. Manage. Eng., 18*(2), 52-60.

Albino, V., & Garavelli, A. (1998). A neural network application to subcontractor rating in construction firms. *International Journal of Project Management, 16*(1), 9-14.

Al-Harbi, K. (2001). Application of the AHP in project management. *International Journal of Project Management, 19*(1), 19-27.

An, M., Baker, C., & Zeng, J. (2005). A fuzzy-logic-based approach to qualitative risk modeling in the construction process. *World Journal of Engineering, 2*(1), 1-12

Annealing for Resource-Constrained Project Scheduling Capabilities of Project Management Software for. *J. Manage. Eng*, pp.1–8.

Arditi, D., & Chotibhongs, R. (2005). Issues in Subcontracting Practice. *Journal of Construction Engineering and Management, 131*(8), 866-876.

Arditi, D., & Chotibhongs, R. (2015). Issues in Subcontracting Practice. *Journal of Construction Engineering and Management, 131*(8), 866-876.

Arslan, G., Kivrak, S., Birgonul, M., & Dikmen, I. (2007). Improving sub-contractor selection process in construction projects: Web-based sub-contractor evaluation system (WEBSES). *Automation in Construction, 17*(4), 480-488.

Atacak, İ, & Bay, Ö. (2004). Bulanık Mantık Denetimli Seri Aktif Güç Filtresi Kullanarak Harmonik Gerilimlerin Bastırılması. *Gazi Üniversitesi Mühendislik Ve Mimarlık Fakültesi Dergisi, 19*(2), 206-206.

Aytaç, E. (2006). *Kalite Kontrolde Bulanık Mantık Yaklaşımı ve bir Uygulama* (Master's Thesis). Retrieved from Library of Pamukkale University.

Baykal, N. (2003). Bulanık Mantık Denetleyiciler, Ankara: Seçkin Kitabevi (p. 230).

Behzadian, M., Kazemzadeh, R., Albadvi, A., & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research, 200*(1), 198-215.

Bendana, R., Cano, A., & Pilar de la Cruz, M. (2008). Contractor Selection: Fuzzy-control approach. *Can. J. Civ. Eng., 35*(5), 473-486.

Bianchi, L., Dorigo, M., Gambardella, L. M., & Gutjahr, W. J. (2008). A survey on metaheuristics for stochastic combinatorial optimization. *Natural Computing Nat Comput, 8*(2), 239-287.

Blum, C., & Roli, A. (2003). Metaheuristics in combinatorial optimization. *CSUR ACM Computing Surveys, 35*(3), 268-308.

Boucher, T.O. & McStravic E.L. (1991). Multi-attribute Evaluation Within a Present Value Framework and its Relation to the Analytic Hierarchy Process. The Engineering Economist, 37, 55-71.

Buitrago, M., Adam, J. M., Alvarado, Y. A., Moragues, J. J., Gasch, I., & Calderón, P. A. (2016). Designing construction processes in buildings by heuristic optimization. *Engineering Structures, 111*, 1-10.

Çakın, E. (2013) *Tedarikçi Seçim Kararinda Analitik Ağ Süreci (ANP) ve Electre Yöntemlerinin Kullanilmasi ve Bir Uygulama* (Master's Thesis). Retrieved from Council of Higher Education Thesis Center.

Cakmak, P., & Cakmak, E. (2013). An Analysis of Causes of Disputes in the Construction Industry Using Analytical Hierarchy Process (AHP). *Aei 2013, 109*, 183-187.

Cambron, K.E. & Evans G.W. (1991). Layout Design Using the Analytic Hierarchy Process. Computers & Industrial Engineering, 20, 221-229.

Chen, S., & Hwang, C. (1992). Multiple Attribute Decision Making — An Overview. In *Fuzzy multiple attribute decision making: Methods and applications* (1st ed., Vol. 375, pp. 16-41). Berlin: Springer-Verlag.

Cheng, E., Li, H. (2004). Contractor Selection Using the Analytical Network Process. *Construction Management and Economics., 22*(10), 1021-1032.

Cheng, M., & Kang, S. (2012). Integrated fuzzy preference relations with decision utilities for construction contractor selection. *Journal of the Chinese Institute of Engineers, 35*(8), 1051-1063.

Cooper, O., Tadikamalla, P., & Shang, J. (2012). Selection of a Third-Party Logistics Provider: Capturing the Interaction and Influence of Performance Metrics with the

Analytical Network Process. *Journal of Multi-Criteria Decision Analysis J. Multi-Crit. Decis. Anal., 19*, 115-128.

Dağdeviren, M., Dönmez, N., & Kurt, M. (2006, December 12). Bir İşletmede Tedarikçi Değerlendirme Süreci için Yeni Bir Model Tasarimi ve Uygulaması. *Gazi Üniversitesi Mühendislik ve Mimarlık Fakültesi Dergisi*, 247-255.

Documentation. (n.d.). Retrieved December 27, 2015, from http://www.mathworks.com/help/fuzzy/what-is-fuzzy-logic.html?requestedDomain=www.mathworks.com

Dulung, A., & Pheng, L. (2005). Factors Influencing the Selection of Subcontractors in Refurbishment Works. *Architectural Science Review, 48*(1), 93-103.

El-Abbasy, M., Zayed, T., Ahmed, M., Alzraiee, H., & Abouhamad, M. (2013). Contractor Selection Model for Highway Projects Using Integrated Simulation and Analytic Network Process. *Journal of Construction Engineering and Management, 139*(7), 755-767.

Elazouni, A. M., & Metwally, F. G. (2000). D-SUB: Decision Support System for Subcontracting Construction Works. *Journal of Construction Engineering and Management, 126*(3), 191-200.

Elazouni, A., & Metwally, F. (2000). D-SUB: Decision Support System for Subcontracting Construction Works. *Journal of Construction Engineering and Management, 126*(3), 191-200.

Enshassi, A., Mohamed, S., & Modough, Z. (2014). Contractors' Selection Criteria: Opinions of Palestinian Construction Professionals. *International Journal of Construction Management, 13*(1), 19-37.

Fong, P., & Choi, S. (2000). Final contractor selection using the analytical hierarchy process. *Construction Management and Economics, 18*(5), 547-557.

Ghajar, I., & Najafi, A. (2012). Evaluation of harvesting methods for Sustainable Forest Management (SFM) using the Analytical Network Process (ANP). *Forest Policy and Economics, 21*, 81-91.

Gholipour, R., Jandaghi, G., & Rajaei, R. (2014). Contractor selection in MCDM context using fuzzy AHP. *Iranian Journal of Management Studies (IJMS),* 151-173.

Glover F. and Laguna M., *Tabu Search*,Kluwer, Boston, (1997).

Glover, F. (1986). Future paths for integer programming and links to artificial intelligence. *Computers & Operations Research, 13*(5), 533-549.

Guan, X., & Yang, R. (2014). Research on Construction Project Cost Control Based on Fuzzy Control. *AMM Applied Mechanics and Materials, 543-547*, 4044-4047.

Hadipour, H., Azizmohammadi, R., Mahmoudabadi, A., & Khoshnoud, M. (2014). Application of ELECTRE Method for Sub-Contractor Selection using Interval-Valued Fuzzy Sets - Case Study. *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management Bali, Indonesia, January 7 – 9, 2014,* 713-722.

Hajkowicz, S., Mcdonald, G., & Smith, P. (2000a). An Evaluation of Multiple Objective Decision Support Weighting Techniques in Natural Resource Management. *Journal of Environmental Planning and Management, 43*, 505-518.

Hajkowicz, S.A., Young, M., Wheeler, S., MacDonald, D.H., Young, D., (2000a). Supporting decisions: understanding natural resource management assessment techniques. A Report to the Land and Water Resources Research and Development Corporation. CSIRO, South Australia.

Hartmann, A., Ling, F., & Tan, J. (2009). Relative Importance of Subcontractor Selection Criteria: Evidence from Singapore. *Journal of Construction Engineering and Management, 135*(9), 826-832.

Hinze, J., and Tracy, A. (1994). “The contractor-subcontractor relationship: The subcontractor’s view.” *J. Constr. Eng. Manage*., 120(2), 274–287.

Humphreys, P., Matthews, J., & Kumaraswamy, M. (2003). Pre-construction project partnering: From adversarial to collaborative relationships. *Supply Chain Management: An International Journal Supp Chain Mnagmnt, 8*(2), 166-178.

Iqbal, K. (2013). *Fundamental Engineering Optimization Methods* (1st ed.). Retrieved March 27, 2016, from http://bookboon.com

Khosrowshahi, F. (1999). Neural network model for contractors' prequalification for local authority projects. *Engineering, Construction and Architectural Management, 6*(3), 315-328.

Klir, G., Clair, U., & Yuan, B. (1997). *Fuzzy set theory: Foundations and applications* (Vol. 8). Upper Saddle River, NJ: Prentice Hall.

Ko, C., Cheng, M., & Wu, T. (2006). Evaluating sub-contractors performance using EFNIM. *Automation in Construction, 16*(4), 525-530.

Korhonen, P. (1988). A visual reference direction approach to solving discrete multiple criteria problems. *European Journal of Operational Research, 34*, 152-159.

Lee, C. (1990). Fuzzy logic in control systems: Fuzzy logic controller. Parts I & II. *IEEE Transactions on Systems, Man, and Cybernetics IEEE Trans. Syst., Man, Cybern., 20*, 404-435.

Li, H., Al-Hussein, M., Lei, Z., & Ajweh, Z. (2013). Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation. *Canadian Journal of Civil Engineering, 40*, 1184-1195.

Li, Y., Nie, X., & Chen, S. (2007). Fuzzy Approach to Prequalifying Construction Contractors. *Journal of Construction Engineering and Management, 133*(1), 40-49.

Lo, W., & Yan, M. (2009). Evaluating Qualification-Based Selection System: A Simulation Approach. *Journal of Construction Engineering and Management, 135*(6), 458-465.

Lotfi, V., Stewart, T., & Zionts, S. (1992). An aspiration-level interactive model for multiple criteria decision making. *Computers & Operations Research, 19*, 671-681.

Lu, Z., Yu, H., Gang, P., & Ni, X. (2015). The Application of Fuzzy AHP in Safety Evaluation of Highway Construction Crossover Operation. *AMM Applied Mechanics and Materials, 738-739*, 512-518.

Mahdi, I., Riley, M., Fereig, S., & Alex, A. (2002). A multi-criteria approach to contractor selection. *Engineering Construction and Architectural, 9*(1), 29-37.

Marzouk, M., & Amin, A. (2013). Predicting Construction Materials Prices Using Fuzzy Logic and Neural Networks. *Journal of Construction Engineering and Management, 139*(9), 1190-1198.

Metin M. (2012). *Enterprise Resource Planning Selection by Multi-Criteria Decision Making Methods for Defence Industry* (Master's Thesis). Retrieved from Council of Higher Education Thesis Center.

Miller, D., Doh, J., & Mulvey, M. (2015). Concrete slab comparison and embodied energy optimisation for alternate design and construction techniques. *Construction and Building Materials, 80*, 329-338.

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 343-352.

Minchin, R., & Smith, G. (2005). Quality-Based Contractor Rating Model for Qualification and Bidding Purposes. *Journal of Management in Engineering, 21*(1), 38-43.

Miri-Nargesi, S., Keramati, A., Haleh, H., & Ansarinejad, A. (2011). Assessing Organizational Readiness to Implement Customer Relationship Management Using Fuzzy Analytical Network Process: A Case Study. *International Journal of Academic Research, 3*(3), 409-418.

Mousavi, S., Vahdani, B., Hashemi, H., & Ebrahimnejad, S. (2015). An Artificial Intelligence Model-Based Locally Linear Neuro-Fuzzy for Construction Project Selection. *J. of Mult.-Valued Logic & Soft Computing, 25*, 589-604.

Nielsen, J. (1994). Usability inspection methods. *Conference Companion on Human Factors in Computing Systems - CHI '94*.

Nijkamp, P., Rietveld, P., & Voogd, H. (1990). *Multicriteria evaluation in physical planning*. Amsterdam: Elsevier.

OSOFISAN, P. (2007, October 1). Fuzzy Logic Control of the Syrup Mixing Process in Beverage Production from Leonardo Journal of Sciences. Retrieved December 23, 2015, from http://ljs.academicdirect.org/A11/get_htm.php?htm=093_108

Özdemir, B.E. (2012). *Bulanık Mantık Metodu İle İnşaat Sektöründe Strateji Belirleme* (Master's Thesis). Retrieved from Council of Higher Education Thesis Center. (Accession No. 316185)

Öztemel, E. (2003). *Yapay sinir ağları* (p. 232). İstanbul: Papatya.

Piantanakulchai, M. (2005). Analytic Network Process Model for Highway Corridor Planning. *ISAHP*, 10 page. Honolulu. Hawai. 8-10 July.

Poonikom, K., O'Brien, C. , and Chansa-ngavej, C. (2004). An application of the Analytic Network Process (ANP) for university selection decisions *ScienceAsia*, *30*, 317-326.

Putrus, P. (1990). Accounting for Intangibles in Integrated Manufacturing (nonfinancial justification based on the Analytical Hierarchy Process). Information Strategy, 6, 25-30.

Reznik, L. (1997). *Fuzzy controllers* (p. 240). Oxford: Newnes.

Ross, T. (1995). Properties of Membership Functions, Fuzzification, and Defuzzification. In *Fuzzy logic with engineering applications* (3rd ed., pp. 89-112). West Sussex: Wiley.

Russell, J., Skibniewski, M., & Cozier, D. (1990). Qualifier-2: Knowledge-Based System for Contractor Prequalification. *Journal of Construction Engineering and Management, 116*(1), 157-171.

Saaty, T. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48*, 9-26.

Saaty, T. (1994). How to Make a Decision: The Analytic Hierarchy Process. *Interfaces, 24*(6), 19-43.

Saaty, T. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences IJSSCI, 1*(1), 83-83.

Saaty, T. (2008b). The Analytic Network Process - Iranian Journal of Operations Research. Retrieved December 13, 2015, from http://www.iors.ir/journal/browse.php?a_id=27&slc_lang=fa&sid=1&ftxt=1

Saaty, T., & Ozdemir, M. (2003). Why the magic number seven plus or minus two. *Mathematical and Computer Modelling, 38*, 233-244.

Saaty, T., & Vargas, L. (2006). *Decision making with the analytic network process economic, political, social and technological applications with benefits, opportunities, costs and risks* (Vol. 95, pp. 1-26). New York: Springer.

Saaty, T.L. (1999a). Fundamentals of The Analytic Network Process. *ISAHP*, 14 page. Kobe. Japan. 12-14 August.

Saaty, T.L. (2008). The Analytic Hierarchy and Analytic Network Measurement Processes: Applications to Decisions under Risk. *European Journal of Pure and Applied Mathematics.* 1(1): 122-196.

Sarkis, J. (1999b). A methodological framework for evaluating environmentally conscious manufacturing programs. *Computers & Industrial Engineering, 36*(1), 793-810.

Sharma, B., & Singh, M. (2014). Modeling the Metrics of Individual, Organizational and Technological Knowledge Sharing Barriers:. *International Journal of Knowledge Management, 10*(1), 43-57.

Shash, A., & Abdul-Hadi, N. (1993). The effect of contractor size on mark-up size decision in Saudi Arabia. *Construction Management and Economics, 11*, 421-429.

Šimelytė, A., Peleckis, K., & Korsakienė, R. (2014). Analytical network process based on BOCR analysis as an approach for designing a foreign direct investment policy. *Journal of Business Economics and Management, 15*(5), 833-852.

Singh, D., Tiong, R. (2005). A fuzzy decision framework for contractor selection. *Journal of Construction Engineering and Management, 131*(1), 62-70.

Singh, D., Tiong, R. (2006). Contractor Selection Criteria: Investigation of opinions of Singapore construction practitioners. *Journal of Construction Engineering and Management, 132*(9), 998-1008.

Sonmez, R., & Bettemir, Ö H. (2012). A hybrid genetic algorithm for the discrete time–cost trade-off problem. *Expert Systems with Applications*, 39(13), 11428-11434.

Stepchenko, D., & Voronova, I. (2015). Assessment of Risk Function Using Analytical Network Process. *Engineering Economics EE, 26*(3), 264-271.

Sugeno, M. (1985). An introductory survey of fuzzy control. *Information Sciences, 36*, 59-83.

Triantaphyllou, E., Shu, B., Nieto Sanchez, S., & Ray, T. (1998). Multi-Criteria Decision Making: An Operations Research Approach. *Encyclopedia of Electrical and Electronics Engineering, 15*, 175-186.

Tseng, M., & Chiu, A. (2012). Grey-Entropy Analytical Network Process for Green Innovation Practices. *Procedia - Social and Behavioral Sciences, 57*, 10-21.

Tserng, H., & Lin, P. (2002). An accelerated subcontracting and procuring model for construction projects. *Automation in Construction, 11*(1), 105-125.

Turskis, Z., Zavadskas, E., Antucheviciene, J., & Kosareva, N. (2015). A Hybrid Model Based on Fuzzy AHP and Fuzzy WASPAS for Construction Site Selection. *International Journal of Computers Communications & Control INT J COMPUT COMMUN, 10*(6), 873-888.

Tzeng, G., & Huang, J. (2011). *Multiple attribute decision making methods and applications*. Boca Raton, FL: CRC Press.

Wabalickis, R.N. (1988). Justification of FMS With the Analytic Hierarchy Process. Journal of Manufacturing Systems, 17, 175-182.

Wang, L., & Raz T. (1991). Analytic Hierarchy Process Based on Data Flow Problem. Computers & Industrial Engineering, 20, 355-365.

What is optimization? definition and meaning. (n.d.). Retrieved January 31, 2016, from http://www.businessdictionary.com/definition/optimization.html

Yang, J., & Chen, S. (2014). The Evaluation Model of Bridge Construction Safety Management Variable Fuzzy Sets. *AMR Advanced Materials Research, 919-921*, 1494-1498.

Yang, X. (2011, April 26). Metaheuristic Optimization. Retrieved February 01, 2016, from http://www.scholarpedia.org/article/Metaheuristic_Optimization

Zabihi, H., Ahmad, A., Vogeler, I., Said, M., Golmohammadi, M., Golein, B., & Nilashi, M. (2015). Land suitability procedure for sustainable citrus planning using the application of the analytical network process approach and GIS. *Computers and Electronics in Agriculture, 117*, 114-126.

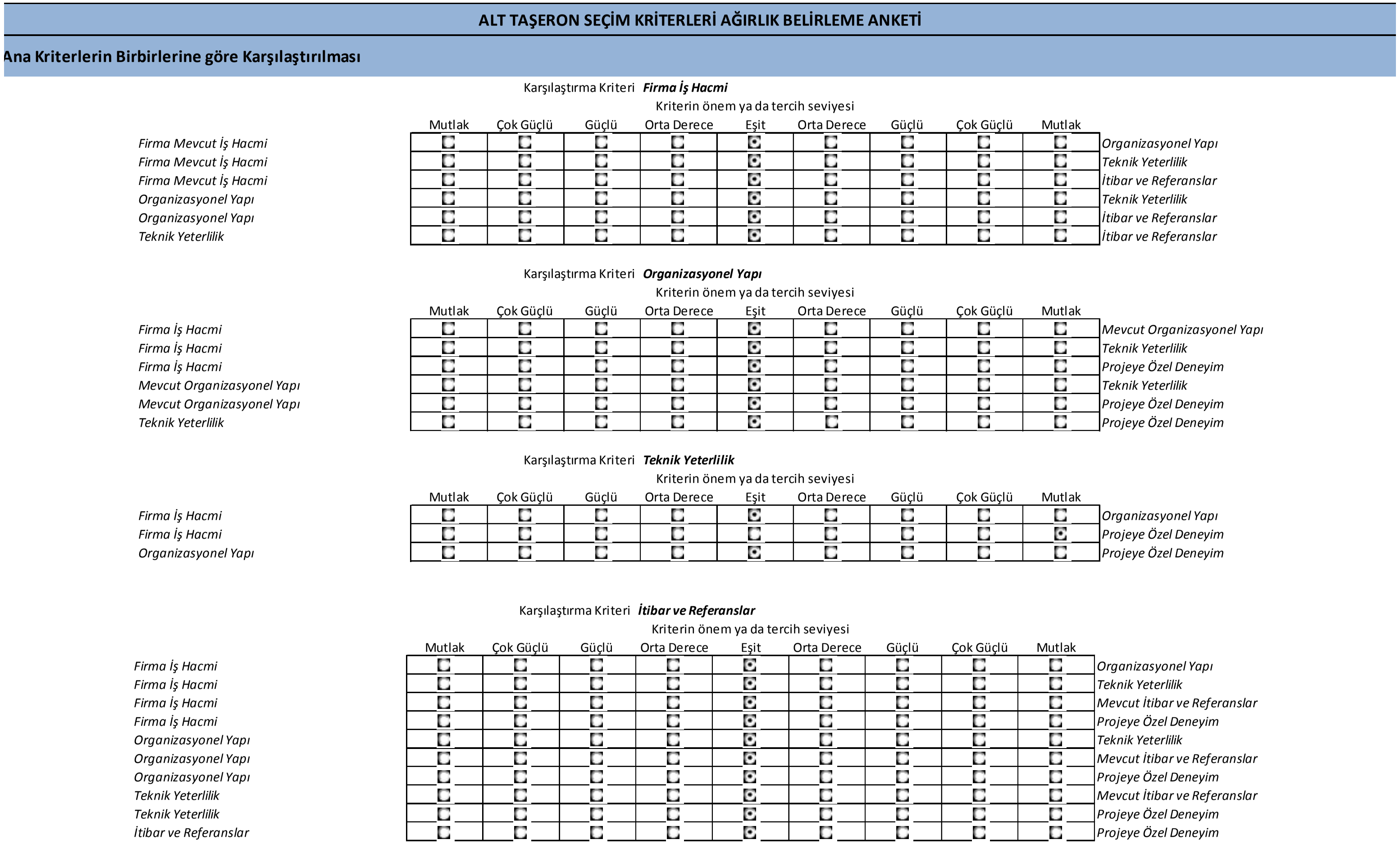
Zadeh, L. (1965). Fuzzy Sets. *Information and Control, 8*, 338-353.

Zavadskas, E., Turskis, Z., & Tamošaitiene, J. (2008). Contractor selection of construction in a competitive environment. *Journal of Business Economics and Management, 9*(3), 181-187.

Zeleny, M. (1982). *Multiple criteria decision making*. New York: McGraw-Hill.

APPENDICES

A. SAMPLE VIEW OF MODULE-1 – (QUESTIONNAIRE)



ALT TAŞERON SEÇİM KRİTERLERİ AĞIRLIK BELİRLEME ANKETİ

Ana Kriterlerin Birbirlerine göre Karşılaştırılması

Karşılaştırma Kriteri ***Firma İş Hacmi***

Kriterin önem ya da tercih seviyesi

	Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Firma Mevcut İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Organizasyonel Yapı*
Firma Mevcut İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Teknik Yeterlilik*
Firma Mevcut İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*İtibar ve Referanslar*
Organizasyonel Yapı	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Teknik Yeterlilik*
Organizasyonel Yapı	☐	☐	☐	☐	☑	☐	☐	☐	☐	*İtibar ve Referanslar*
Teknik Yeterlilik	☐	☐	☐	☐	☑	☐	☐	☐	☐	*İtibar ve Referanslar*

Karşılaştırma Kriteri ***Organizasyonel Yapı***

Kriterin önem ya da tercih seviyesi

	Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Firma İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Mevcut Organizasyonel Yapı*
Firma İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Teknik Yeterlilik*
Firma İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Projeye Özel Deneyim*
Mevcut Organizasyonel Yapı	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Teknik Yeterlilik*
Mevcut Organizasyonel Yapı	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Projeye Özel Deneyim*
Teknik Yeterlilik	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Projeye Özel Deneyim*

Karşılaştırma Kriteri ***Teknik Yeterlilik***

Kriterin önem ya da tercih seviyesi

	Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Firma İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Organizasyonel Yapı*
Firma İş Hacmi	☐	☐	☐	☐	☐	☐	☐	☐	☑	*Projeye Özel Deneyim*
Organizasyonel Yapı	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Projeye Özel Deneyim*

Karşılaştırma Kriteri ***İtibar ve Referanslar***

Kriterin önem ya da tercih seviyesi

	Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Firma İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Organizasyonel Yapı*
Firma İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Teknik Yeterlilik*
Firma İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Mevcut İtibar ve Referanslar*
Firma İş Hacmi	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Projeye Özel Deneyim*
Organizasyonel Yapı	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Teknik Yeterlilik*
Organizasyonel Yapı	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Mevcut İtibar ve Referanslar*
Organizasyonel Yapı	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Projeye Özel Deneyim*
Teknik Yeterlilik	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Mevcut İtibar ve Referanslar*
Teknik Yeterlilik	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Projeye Özel Deneyim*
İtibar ve Referanslar	☐	☐	☐	☐	☑	☐	☐	☐	☐	*Projeye Özel Deneyim*

Figure A: Sample View of Module-1

Karşılaştırma Kriteri ***Projeye Özel Deneyim***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
	Organizasyonel Yapı	○	○	○	○	●	○	○	○	○	*Teknik Yeterlilik*
	Organizasyonel Yapı	○	○	○	○	●	○	○	○	○	*İtibar ve Referanslar*
	Teknik Yeterlilik	○	○	○	○	●	○	○	○	○	*İtibar ve Referanslar*

Alt Kriterlerin Birbirine göre Kıyaslanması

Karşılaştırma Kriteri ***Finansal Kapasite***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Teknik Yeterlilik	*İş Gücü Kaynağı*	○	○	○	○	●	○	○	○	○	*Malzeme Kaynağı*
	Malzeme Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*
	İş Gücü Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*
İtibar ve Referanslar	*Bütçe Sınırları İçerisinde İş Bitirme (Ünü)*	○	○	○	○	●	○	○	○	○	*Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)*
	Bütçe Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Kaliteli İmalat (Ünü)*
	Bütçe Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Referanslar/Tavsiyeler*
	Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Kaliteli İmalat (Ünü)*
	Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Referanslar/Tavsiyeler*
	Kaliteli İmalat (Ünü)	○	○	○	○	●	○	○	○	○	*Referanslar/Tavsiyeler*

Karşılaştırma Kriteri ***Mevcut İş Yükü***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Organizasyonel Yapı	*Sektördeki Tecrübe*	○	○	○	○	●	○	○	○	○	*İş Güvenliği Performansı*
	Sektördeki Tecrübe	○	○	○	○	●	○	○	○	○	*Firma Erişiliebilirliği ve İşbirlikçi Tutum*
	İş Güvenliği Performansı	○	○	○	○	●	○	○	○	○	*Firma Erişiliebilirliği ve İşbirlikçi Tutum*
Teknik Yeterlilik	*İş Gücü Kaynağı*	○	○	○	○	●	○	○	○	○	*Malzeme Kaynağı*
	İş Gücü Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*
	Malzeme Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*
İtibar ve Referanslar	*Bütçe Sınırları İçerisinde İş Bitirme (Ünü)*	○	○	○	○	●	○	○	○	○	*Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)*
	Bütçe Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Kaliteli İmalat (Ünü)*
	Bütçe Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Referanslar/Tavsiyeler*
	Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Kaliteli İmalat (Ünü)*
	Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Referanslar/Tavsiyeler*
	Kaliteli İmalat (Ünü)	○	○	○	○	●	○	○	○	○	*Referanslar/Tavsiyeler*

Karşılaştırma Kriteri ***Sektördeki Tecrübe***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Projeye Özel Deneyim	*Benzer Türde Proje Tecrübesi (Niteliksel)*	○	○	○	○	●	○	○	○	○	*Benzer Büyüklükte Proje Tecrübesi (Nicelik)*

Figure A: Sample View of Module-1 (continued)

Karşılaştırma Kriteri ***Firma Erişiliebilirliği ve İşbirlikçi Tutum***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Firma İş Hacmi	*Finansal Kapasite*	○	○	○	○	●	○	○	○	○	*Mevcut İş Yükü*

Karşılaştırma Kriteri ***İş Gücü Kaynağı***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Firma İş Hacmi	*Finansal Kapasite*	○	○	○	○	●	○	○	○	○	*Mevcut İş Yükü*
Projeye Özel Deneyim	*Benzer Türde Proje Tecrübesi (Niteliksel)*	○	○	○	○	●	○	○	○	○	*Benzer Büyüklükte Proje Tecrübesi (Nicelik)*

Karşılaştırma Kriteri ***Malzeme Kaynağı***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Firma İş Hacmi	*Finansal Kapasite*	○	○	○	○	●	○	○	○	○	*Mevcut İş Yükü*

Karşılaştırma Kriteri ***Ekipman Kaynağı***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Firma İş Hacmi	*Finansal Kapasite*	○	○	○	○	●	○	○	○	○	*Mevcut İş Yükü*

Karşılaştırma Kriteri ***Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Projeye Özel Deneyim	*İş Gücü Kaynağı*	○	○	○	○	●	○	○	○	○	*Malzeme Kaynağı*
	İş Gücü Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*
	Malzeme Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*

Karşılaştırma Kriteri ***Kaliteli İmalat (Ünü)***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Teknik Yeterlilik	*İş Gücü Kaynağı*	○	○	○	○	●	○	○	○	○	*Malzeme Kaynağı*
	İş Gücü Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*
	Malzeme Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*

Karşılaştırma Kriteri ***Kaliteli İmalat (Ünü)***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Projeye Özel Deneyim	*Benzer Türde Proje Tecrübesi (Niteliksel)*	○	○	○	○	●	○	○	○	○	*Benzer Büyüklükte Proje Tecrübesi (Nicelik)*

Figure A: Sample View of Module-1 (continued)

Karşılaştırma Kriteri ***Referanslar/Tavsiyeler***

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Organizasyonel Yapı	*Sektördeki Tecrübe*	○	○	○	○	●	○	○	○	○	*İş Güvenliği Performansı*
	Sektördeki Tecrübe	○	○	○	○	●	○	○	○	○	*Firma Erişiliebilirliği ve İşbirlikçi Tutum*
	Sektördeki Tecrübe	○	○	○	○	●	○	○	○	○	*Geçmiş İlişkiler ve İhtilaf Tutumu*
	İş Güvenliği Performansı	○	○	○	○	●	○	○	○	○	*Firma Erişiliebilirliği ve İşbirlikçi Tutum*
	İş Güvenliği Performansı	○	○	○	○	●	○	○	○	○	*Geçmiş İlişkiler ve İhtilaf Tutumu*
	Firma Erişiliebilirliği ve İşbirlikçi Tutum	○	○	○	○	●	○	○	○	○	*Geçmiş İlişkiler ve İhtilaf Tutumu*
İtibar ve Referanslar	*Bütçe Sınırları İçerisinde İş Bitirme (Ünü)*	○	○	○	○	●	○	○	○	○	*Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)*
	Bütçe Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Kaliteli İmalat (Ünü)*
	Proje Süresi Sınırları İçerisinde İş Bitirme (Ünü)	○	○	○	○	●	○	○	○	○	*Kaliteli İmalat (Ünü)*

Karşılaştırma Kriteri **Benzer Büyüklükte Proje Tecrübesi (Nicelik)**

Kriterin önem ya da tercih seviyesi

		Mutlak	Çok Güçlü	Güçlü	Orta Derece	Eşit	Orta Derece	Güçlü	Çok Güçlü	Mutlak	
Teknik Yeterlilik	*İş Gücü Kaynağı*	○	○	○	○	●	○	○	○	○	*Malzeme Kaynağı*
	İş Gücü Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*
	Malzeme Kaynağı	○	○	○	○	●	○	○	○	○	*Ekipman Kaynağı*

Anketi Gönder

Figure A: Sample View of Module-1 (continued)

B.1 THE MODULE VIEW OF PROJECT DEVELOPMENT (CASE STUDY I)

Please insert the relevant data to the places colored in white.

Building 1: KA-Middle													
	Formworks = 268813,63 m2			Steelworks = 9661,11 ton				Concreteworks = 80738,59 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	2.142,42	128.062,05	138.609,16	1.809,71	57,17	3.463,10	4.331,13	4.021,57	22.963,69	23.883,46	29.869,87		4
Unit Price (TL)	32	32	32	420	420	420	420	8	8	8	8		
	Formworks Budget = 8602036,16 TL			Steelworks Budget = 4057666,2 TL				Concreteworks Budget = 645908,72 TL					
	Building 1: KA-Middle Overall Budget= 13305611,08 TL												

Building 2: KA-Side1													
	Formworks = 170018,99 m2			Steelworks = 5683,36 ton				Concreteworks = 46719,03 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	1.310,11	81.976,01	86.732,87	925,10	31,93	2.186,18	2.540,15	2.248,24	11.875,39	15.077,09	17.518,31		2
Unit Price (TL)	32	32	32	420	420	420	420	8	8	8	8		
	Formworks Budget = 5440607,68 TL			Steelworks Budget = 2387011,2 TL				Concreteworks Budget = 373752,24 TL					
	Building 2: KA-Side1 Overall Budget= 8201371,12 TL												

Figure B.1 : The Module View of Project Development (Case Study I)

	Building 3: KA-Side2												
	Formworks = 157527,12 m2			Steelworks = 5373,9 ton				Concreteworks = 43657,24 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	1108,21	82179,61	74239,3	845,92	26,7	2213,55	2287,73	1879,83	10734,09	15265,85	15777,47		2
Unit Price (TL)	32	32	32	420	420	420	420	8	8	8	8		
	Formworks Budget = 5040867,84 TL			Steelworks Budget = 2257038 TL				Concreteworks Budget = 349257,92 TL					
	Building 3: KA-Side2 Overall Budget= 7647163,76 TL												

	Building 4: KB-KC												
	Formworks = 157223,33 m2			Steelworks = 9796,8 ton				Concreteworks = 92327,87 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	5110,91	64684,77	87427,65	3550,47	83,87	2284,53	3877,93	6185,02	43643,08	15755,41	26744,36		6
Unit Price (TL)	32	32	32	420	420	420	420	8	8	8	8		
	Formworks Budget = 5031146,56 TL			Steelworks Budget = 4114656 TL				Concreteworks Budget = 738622,96 TL					
	Building 4: KB-KC Overall Budget= 9884425,52 TL												

Figure B.1: The Module View of Project Development (Case Study I) (continued)

	Building 5: KD-KE												
	Formworks = 64069,92 m2			Steelworks = 2355,66 ton				Concreteworks = 21750,61 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	1098,31	32374,3	30597,31	604,89	24,48	875,97	850,32	1900,3	7944,9	6041,14	5864,27		2
Unit Price (TL)	32	32	32	420	420	420	420	8	8	8	8		
	Formworks Budget = 2050237,44 TL			Steelworks Budget = 989377,2 TL				Concreteworks Budget = 174004,88 TL					
	Building 5: KD-KE Overall Budget= 3213619,52 TL												

	Building 6: KF-KG-KJ												
	Formworks = 76177,2 m2			Steelworks = 2859,81 ton				Concreteworks = 25797,53 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	1211,49	35080,32	39885,39	651,86	26,99	948,37	1232,59	2163,92	8592,54	6540,46	8500,61		2
Unit Price (TL)	32	32	32	420	420	420	420	8	8	8	8		
	Formworks Budget = 2437670,4 TL			Steelworks Budget = 1201120,2 TL				Concreteworks Budget = 206380,24 TL					
	Building 6: KF-KG-KJ Overall Budget= 3845170,84 TL												

Figure B.1: The Module View of Project Development (Case Study I) (continued)

	Building 7: KH-KK-KI												
	Formworks = 77299,65 m2			Steelworks = 2907,56 ton				Concreteworks = 26223,18 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	1007,43	36574,05	39718,17	660,94	28	978,83	1239,79	2178,31	8744,03	6750,55	8550,29		2
Unit Price (TL)	32	32	32	420	420	420	420	8	8	8	8		
	Formworks Budget = 2473588,8 TL			Steelworks Budget = 1221175,2 TL				Concreteworks Budget = 209785,44 TL					
	Building 7: KH-KK-KI Overall Budget= 3904549,44 TL												

	Building 8: KL												
	Formworks = 104327,39 m2			Steelworks = 4441,87 ton				Concreteworks = 40886,87 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	642,13	34294,37	69390,89	1106,74	42,7	1010,63	2281,8	3748,5	14431,99	6969,84	15736,54		4
Unit Price (TL)	32	32	32	420	420	420	420	8	8	8	8		
	Formworks Budget = 3338476,48 TL			Steelworks Budget = 1865585,4 TL				Concreteworks Budget = 327094,96 TL					
	Building 8: KL Overall Budget= 5531156,84 TL												

Figure B.1: The Module View of Project Development (Case Study I) (continued)

B.2. THE MODULE VIEW OF MODULE-4 FOR PARETO SOLUTIONS (CASE STUDY I)

İterasyon No	Toplam Maliyet /\	Güvenilirlik \/	Alt Yüklenici Ataması							
PARETO #10	69.778.400,00 ₺	65,66%	1	3	1	13	16	14	16	14
PARETO #3	69.820.172,00 ₺	65,75%	1	3	1	13	9	14	16	14
PARETO #8	69.930.603,00 ₺	65,85%	1	3	1	13	5	14	16	14
PARETO #13	70.084.285,00 ₺	66,50%	1	3	1	13	3	14	16	14
PARETO #14	70.084.984,00 ₺	66,62%	1	3	1	13	16	14	3	14
PARETO #12	70.126.756,00 ₺	66,70%	1	3	1	13	9	14	3	14
PARETO #9	70.237.187,00 ₺	66,80%	1	3	1	13	5	14	3	14
PARETO #6	70.328.086,00 ₺	67,64%	1	6	1	13	16	14	16	14
PARETO #7	70.369.858,00 ₺	67,73%	1	6	1	13	9	14	16	14
PARETO #16	70.480.289,00 ₺	67,83%	1	6	1	13	5	14	16	14
PARETO #5	70.633.971,00 ₺	68,46%	1	6	1	13	3	14	16	14
PARETO #4	70.634.670,00 ₺	68,58%	1	6	1	13	16	14	3	14
PARETO #15	70.676.442,00 ₺	68,66%	1	6	1	13	9	14	3	14
PARETO #1	70.786.873,00 ₺	68,76%	1	6	1	13	5	14	3	14
PARETO #2	70.940.555,00 ₺	69,39%	1	6	1	13	3	14	3	14
PARETO #17	73.067.690,00 ₺	70,05%	1	6	1	13	14	14	16	6
PARETO #11	73.374.274,00 ₺	70,94%	1	6	1	13	14	14	3	6

Grafik

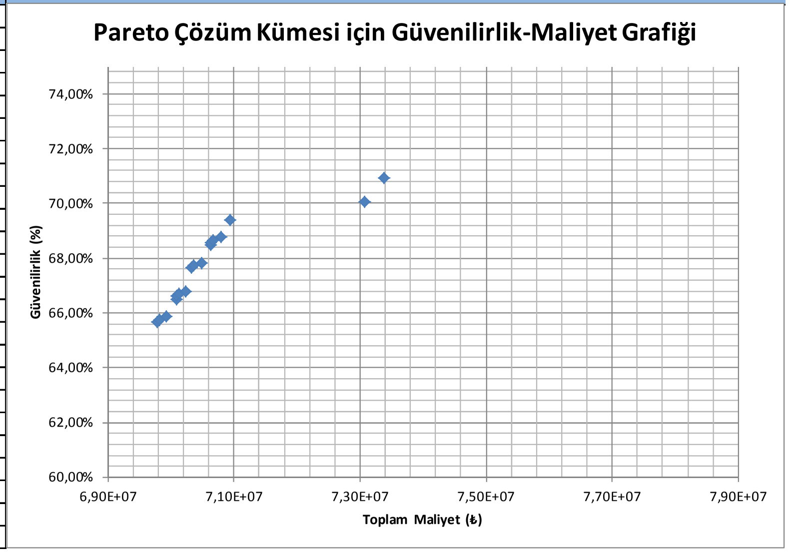


Figure B.2: The Module View of Module-4 for Pareto Solutions (Case Study I)

B.3. THE CASH FLOW DIAGRAMS FOR THE WORK PARTS 1 TO 8 (CASE STUDY I)

	Cash Flow Analysis - Work Part 1									
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	Credibility Index
Quantity										
Subcontractor 1	3.730.759,03 ₺	6.657.035,13 ₺	9.583.311,23 ₺	12.509.587,33 ₺	15.435.863,43 ₺			15.435.863,43 ₺	15.255.232,57 ₺	64,13%
Subcontractor 2										66,30%
Subcontractor 3										68,27%
Subcontractor 4	3.469.104,06 ₺	6.820.932,11 ₺	10.172.760,16 ₺	13.524.588,20 ₺	16.876.416,25 ₺			16.876.416,25 ₺	16.669.517,26 ₺	64,14%
Subcontractor 5										58,95%
Subcontractor 6										81,54%
Subcontractor 7										62,27%
Subcontractor 8										63,78%
Subcontractor 9										57,23%
Subcontractor 10										55,60%
Subcontractor 11										54,72%
Subcontractor 12										67,70%
Subcontractor 13										68,70%
Subcontractor 14										71,43%
Subcontractor 15										41,77%
Subcontractor 16										55,85%

	Cash Flow Analysis - Work Part 2									
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	Credibility Index
Quantity										
Subcontractor 1										64,13%
Subcontractor 2	2.262.930,74 ₺	6.407.326,84 ₺	10.551.722,94 ₺					10.551.722,94 ₺	10.474.658,05 ₺	66,30%
Subcontractor 3	1.250.794,93 ₺	5.544.713,89 ₺	9.838.632,85 ₺					9.838.632,85 ₺	9.758.787,59 ₺	68,27%
Subcontractor 4										64,14%
Subcontractor 5										58,95%
Subcontractor 6	2.222.079,69 ₺	6.305.199,23 ₺	10.388.318,76 ₺					10.388.318,76 ₺	10.312.393,31 ₺	81,54%
Subcontractor 7	1.930.356,99 ₺	6.541.070,96 ₺	11.151.784,94 ₺					11.151.784,94 ₺	11.066.048,89 ₺	62,27%
Subcontractor 8										63,78%
Subcontractor 9										57,23%
Subcontractor 10										55,60%
Subcontractor 11										54,72%
Subcontractor 12										67,70%
Subcontractor 13										68,70%
Subcontractor 14										71,43%
Subcontractor 15										41,77%
Subcontractor 16										55,85%

Figure B.3: The Cash Flow Diagrams for the Work Parts 1 to 8 (Case Study I)

	Cash Flow Analysis - Work Part 3									Credibility Index
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	
Quantity										
Subcontractor 1	2.206.060,92 ₺	5.529.798,66 ₺	8.853.536,40 ₺					8.853.536,40 ₺	8.791.731,62 ₺	64,13%
Subcontractor 2										66,30%
Subcontractor 3										68,27%
Subcontractor 4										64,14%
Subcontractor 5										58,95%
Subcontractor 6										81,54%
Subcontractor 7										62,27%
Subcontractor 8	2.795.535,53 ₺	6.141.389,96 ₺	9.487.244,38 ₺					9.487.244,38 ₺	9.425.028,35 ₺	63,78%
Subcontractor 9										57,23%
Subcontractor 10										55,60%
Subcontractor 11										54,72%
Subcontractor 12										67,70%
Subcontractor 13										68,70%
Subcontractor 14										71,43%
Subcontractor 15										41,77%
Subcontractor 16										55,85%

	Cash Flow Analysis - Work Part 4									Credibility Index
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	
Quantity										
Subcontractor 1	3.185.224,33 ₺	5.421.662,34 ₺	7.658.100,36 ₺	9.894.538,38 ₺	12.130.976,40 ₺	14.367.414,42 ₺		14.367.414,42 ₺	14.160.768,19 ₺	64,13%
Subcontractor 2										66,30%
Subcontractor 3										68,27%
Subcontractor 4										64,14%
Subcontractor 5	995.484,24 ₺	3.238.710,60 ₺	5.481.936,96 ₺	7.725.163,31 ₺	9.968.389,67 ₺	12.211.616,03 ₺	14.454.842,39 ₺	14.454.842,39 ₺	14.165.257,84 ₺	58,95%
Subcontractor 6										81,54%
Subcontractor 7										62,27%
Subcontractor 8										63,78%
Subcontractor 9										57,23%
Subcontractor 10										55,60%
Subcontractor 11										54,72%
Subcontractor 12										67,70%
Subcontractor 13	2.935.768,97 ₺	4.827.456,90 ₺	6.719.144,83 ₺	8.610.832,76 ₺	10.502.520,70 ₺	12.394.208,63 ₺	14.285.896,56 ₺	14.285.896,56 ₺	14.041.693,11 ₺	68,70%
Subcontractor 14										71,43%
Subcontractor 15										41,77%
Subcontractor 16										55,85%

Figure B.3: The Cash Flow Diagrams for the Work Parts 1 to 8 (Case Study I) (continued)

	Cash Flow Analysis - Work Part 5									
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	Credibility Index
Quantity										
Subcontractor 1										64,13%
Subcontractor 2										66,30%
Subcontractor 3	516.334,76 ₺	2.729.283,26 ₺	4.942.231,76 ₺					4.942.231,76 ₺	4.901.082,07 ₺	68,27%
Subcontractor 4										64,14%
Subcontractor 5	328.854,97 ₺	2.558.702,35 ₺	4.788.549,73 ₺					4.788.549,73 ₺	4.747.085,80 ₺	58,95%
Subcontractor 6										81,54%
Subcontractor 7										62,27%
Subcontractor 8										63,78%
Subcontractor 9	317.811,93 ₺	2.497.965,60 ₺	4.678.119,27 ₺					4.678.119,27 ₺	4.637.579,40 ₺	57,23%
Subcontractor 10										55,60%
Subcontractor 11										54,72%
Subcontractor 12										67,70%
Subcontractor 13										68,70%
Subcontractor 14	0,00 ₺	2.276.528,27 ₺	4.553.056,54 ₺					4.553.056,54 ₺	4.510.724,58 ₺	71,43%
Subcontractor 15	823.241,78 ₺	2.190.673,12 ₺	3.558.104,45 ₺	4.925.535,79 ₺	6.292.967,12 ₺			6.292.967,12 ₺	6.208.559,40 ₺	41,77%
Subcontractor 16	784.086,86 ₺	2.710.217,14 ₺	4.636.347,43 ₺					4.636.347,43 ₺	4.600.531,11 ₺	55,85%

	Cash Flow Analysis - Work Part 6									
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	Credibility Index
Quantity										
Subcontractor 1	1.349.202,62 ₺	3.673.272,35 ₺	5.997.342,08 ₺					5.997.342,08 ₺	5.954.126,09 ₺	64,13%
Subcontractor 2										66,30%
Subcontractor 3										68,27%
Subcontractor 4										64,14%
Subcontractor 5										58,95%
Subcontractor 6										81,54%
Subcontractor 7										62,27%
Subcontractor 8										63,78%
Subcontractor 9	371.575,08 ₺	2.793.662,93 ₺	5.215.750,78 ₺					5.215.750,78 ₺	5.170.712,15 ₺	57,23%
Subcontractor 10										55,60%
Subcontractor 11	406.540,28 ₺	2.985.971,54 ₺	5.565.402,80 ₺					5.565.402,80 ₺	5.517.438,37 ₺	54,72%
Subcontractor 12										67,70%
Subcontractor 13										68,70%
Subcontractor 14	176.061,42 ₺	2.598.644,95 ₺	5.021.228,47 ₺					5.021.228,47 ₺	4.976.180,62 ₺	71,43%
Subcontractor 15										41,77%
Subcontractor 16										55,85%

Figure B.3: The Cash Flow Diagrams for the Work Parts 1 to 8 (Case Study I) (continued)

	Cash Flow Analysis - Work Part 7									Credibility Index
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	
Quantity										
Subcontractor 1										64,13%
Subcontractor 2	1.078.630,02 ₺	3.446.575,06 ₺	5.814.520,09 ₺					5.814.520,09 ₺	5.770.488,24 ₺	66,30%
Subcontractor 3	617.097,28 ₺	3.115.539,56 ₺	5.613.981,85 ₺					5.613.981,85 ₺	5.567.523,41 ₺	68,27%
Subcontractor 4	1.059.226,78 ₺	2.868.453,56 ₺	4.677.680,34 ₺	6.486.907,12 ₺				6.486.907,12 ₺	6.419.761,28 ₺	64,14%
Subcontractor 5										58,95%
Subcontractor 6										81,54%
Subcontractor 7										62,27%
Subcontractor 8										63,78%
Subcontractor 9										57,23%
Subcontractor 10										55,60%
Subcontractor 11										54,72%
Subcontractor 12										67,70%
Subcontractor 13										68,70%
Subcontractor 14										71,43%
Subcontractor 15										41,77%
Subcontractor 16	951.849,39 ₺	3.129.623,47 ₺	5.307.397,55 ₺					5.307.397,55 ₺	5.266.901,92 ₺	55,85%

	Cash Flow Analysis - Work Part 8									Credibility Index
	Advance Amount (₺)	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Total Project Cost (₺)	NPV	
Quantity										
Subcontractor 1	1.524.139,53 ₺	3.163.220,92 ₺	4.802.302,31 ₺	6.441.383,70 ₺	8.080.465,09 ₺			8.080.465,09 ₺	7.979.289,17 ₺	64,13%
Subcontractor 2										66,30%
Subcontractor 3										68,27%
Subcontractor 4										64,14%
Subcontractor 5										58,95%
Subcontractor 6	1.555.598,10 ₺	3.472.296,67 ₺	5.388.995,24 ₺	7.305.693,82 ₺	9.222.392,39 ₺			9.222.392,39 ₺	9.104.079,93 ₺	81,54%
Subcontractor 7	873.085,38 ₺	2.859.956,33 ₺	4.846.827,28 ₺	6.833.698,23 ₺	8.820.569,18 ₺			8.820.569,18 ₺	8.697.925,18 ₺	62,27%
Subcontractor 8	1.889.264,79 ₺	3.516.423,44 ₺	5.143.582,09 ₺	6.770.740,74 ₺	8.397.899,39 ₺			8.397.899,39 ₺	8.297.459,43 ₺	63,78%
Subcontractor 9										57,23%
Subcontractor 10										55,60%
Subcontractor 11										54,72%
Subcontractor 12										67,70%
Subcontractor 13	1.023.210,99 ₺	2.796.421,98 ₺	4.569.632,97 ₺	6.342.843,96 ₺	8.116.054,95 ₺			8.116.054,95 ₺	8.006.599,58 ₺	68,70%
Subcontractor 14	244.974,88 ₺	3.322.236,21 ₺	6.399.497,54 ₺					6.399.497,54 ₺	6.342.275,98 ₺	71,43%
Subcontractor 15										41,77%
Subcontractor 16										55,85%

Figure B.3: The Cash Flow Diagrams for the Work Parts 1 to 8 (Case Study I) (continued)

C.1 THE MODULE VIEW OF PROJECT DEVELOPMENT (CASE STUDY II)

Building 1: Library

	Formworks = 235300 m2			Steelworks = 13762 ton				Concreteworks = 97600 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	770,00	180.000,00	54.530,00	3.450,00	300,00	2.775,00	7.237,00	2.000,00	28.850,00	18.500,00	48.250,00		6
Unit Price (TL)	36,15	36,15	36,15	430	430	430	430	10	10	10	10		
	Formworks Budget = 8506095 TL			Steelworks Budget = 5917660 TL				Concreteworks Budget = 976000 TL					
	Building 1: Library Overall Budget= 15399755 TL												

Building 2: Exhibition Hall

	Formworks = 208000 m2			Steelworks = 10995 ton				Concreteworks = 78600 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	870,00	164.630,00	42.500,00	2.950,00	200,00	1.975,00	5.870,00	1.900,00	25.000,00	15.000,00	36.700,00		5
Unit Price (TL)	36,15	36,15	36,15	430	430	430	430	10	10	10	10		
	Formworks Budget = 7519200 TL			Steelworks Budget = 4727850 TL				Concreteworks Budget = 786000 TL					
	Building 2: Exhibition Hall Overall Budget= 13033050 TL												

Building 3: Multi-Storey Car Park

	Formworks = 120950 m2			Steelworks = 7939 ton				Concreteworks = 58910 m3				Requests	
	Foundation	Column & Shearwall	Beam & Flooring	Foundation	Mesh Reinforcement	Column & Shearwall	Beam & Flooring	Lean Concrete	Foundation	Column & Shearwall	Beam & Flooring	Requested Advance (%)	Expected Completion Time (month)
Quantity	650	90000	30300	2640	150	1332	3817	1650	19360	10300	27600		3
Unit Price (TL)	36,15	36,15	36,15	430	430	430	430	10	10	10	10		
	Formworks Budget = 4372342,5 TL			Steelworks Budget = 3413770 TL				Concreteworks Budget = 589100 TL					
	Building 3: Multi-Storey Car Park Overall Budget= 8375212,5 TL												

Figure C.1: The Module View of Project Development (Case Study II)

C.2. THE MODULE VIEW OF MODULE-4 FOR PARETO SOLUTIONS (CASE STUDY II)

İterasyon No	Toplam Maliyet /\	Güvenilirlik \/	Alt Yüklenici Ataması		
PARETO #2	46.927.351,00 ₺	75,45%	7	9	1
PARETO #5	48.989.961,00 ₺	80,75%	1	9	1
PARETO #6	50.079.114,00 ₺	81,24%	7	1	1
PARETO #1	52.180.324,00 ₺	82,14%	1	7	1
PARETO #3	52.677.450,00 ₺	83,77%	1	1	7
PARETO #7	53.553.943,00 ₺	85,63%	1	2	1
PARETO #4	54.462.635,00 ₺	85,77%	1	1	2

Grafik

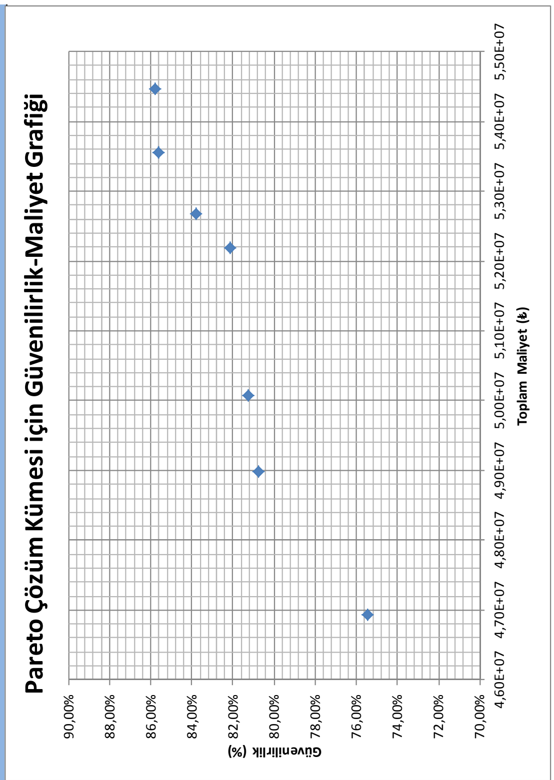


Figure C.2: The Module View of Module-4 for Pareto Solutions (Case Study II)