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SUPPLIER EVALUATION AND SELECTION FOR CONSTRUCTION PROJECTS.

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ACCEPTANCE AND APPROVAL PAGE

On 13/07/2020, **Ibrahim Mohamed AHMED** successfully defended the thesis entitled "**Supplier Evaluation and Selection of Construction Project**" which he prepared after fulfillling the requirements specified in the associated legislations, before the jury members whose signatures are listed below. This thesis is accepted as a **Master's Thesis** by Istanbul Commerce University. Graduate School of Natural and Applied Sciences **Industrial Engineering Department**.

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Istanbul Commerce University, Graduate School of Natural and Applied Sciences, accordance with the 1st article of the Board of Directors Decision dated 24.07.2020 and numbered 2020/288, "Ibrahim Mohamed AHMED" (TC: 99539970168) who has determined to fulfill the course load and thesis obligation was unanimously decided to graduated.

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DECLARATION OF COMPLIANCE WITH ACADEMIC AND ETHIC RULES

In this thesis I prepared in accordance with the rules of thesis writing, Istanbul Commerce University, Graduate School of Natural and Applied Science,

- I obtained all the information and documents in the thesis within the framework of academic rules,
- I present all visual, audio and written information and results in accordance with scientific moral rules,
- I refer to the related works in accordance with scientific norms in case of using others' works,
- I cited all the works I cited as a source,
- I did not make any distortions in the data used,
- and that I do not present any part of this thesis as another thesis study at this university or another university.

I declare.

24.07.2020

Ibrahim Mohamed AHMED

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ABSTRACT

M. Sc. Thesis

SUPPLIER EVALUATION AND SELECTION FOR CONSTRUCTION PROJECTS

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In recent years, supply chain management has taken attention to both business and academic areas. Notably, the selection of the best supplier is one of the most crucial problems in the supply chain. That is why studies on supplier selection problem increase day by day.

This study aims to determine the best supplier selection for a construction firm. Multi-criteria decision-making methods are the best approach for solving problems, including many selection criteria. For this reason, it is proposed a two-stage model in this thesis. In the first stage, Fuzzy AHP is used to find the weight of the criteria. Furthermore, the second stage TOPSIS and ELECTRE method are used to rank the supplier of cement. The presented model is applied to a construction company from Somali. The results support the decision process of managers.

Keywords: BAHS, Fuzzy AHP, Supplier selection, TOPSIS.

ÖZET

Yüksek Lisans Tezi

İNŞAAT PROJELERİ TEDARİKÇİ DEĞERLENDİRMESİ VE SEÇİMİ

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Son yıllarda, tedarik zinciri yönetimi hem iş hem de akademik alanlarda dikkat çekmektedir. Özellikle en iyi tedarikçinin seçimi tedarik zincirindeki en önemli problemlerden biridir. Bu nedenle, tedarikçi seçim problemi ile ilgili çalışmalar her geçen gün artmaktadır.

Bu çalışmanın amacı bir inşaat firması için en iyi tedarikçiyi tespit etmektir. Çok kriterli karar verme yöntemleri, bir çok seçim kriterini içeren problemler için en iyi seçenektir. Bunun için, bu makalede iki aşamalı bir model önerilmektedir. İlk aşamada, kriterlerin ağırlığını bulmak için Bulanık AHP kullanılır. İkinci aşama TOPSIS ve ELECTRE yöntemi, taşeronları kapsamak için kullanılır. Önerilen model Somali'den bir inşaat şirketine uygulanmıştır. Sonuçlar yöneticilerin karar alma sürecini desteklemektedir.

Anahtar Kelimeler: BAHS, Fuzzy AHP, tedarikçi seçimi, TOPSIS.

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Ibrahim Mohamed AHMED
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SYMBOLS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
CI	Consistency Index
CR	Consistency Ratio
ELECTRE	Elimination and Choice Translating Reality
FAHP	Fuzzy Analytical Hierarchy Process
MCDM	Multi-Criteria Decision Making
TOPSIS	Technique for Order by Similarity Ideal Solution

1. INTRODUCTION

1.1. Background

In recent years the construction industry has undergone tremendous development. The first shelters were built by hand and simple material as cities growth during the Brongez Ages, A class of skilled artisans emerged, including bricklayers and carpenters. Growth of population and urbanization created an increasing need for shelter developments, and the importance of materials and techniques was highly focused.

This increase in building demand and corresponding development in the contractual relationships of construction firms is growing. Construction Companies play an essential role in the economy, employment, and infrastructure. According to the (United States Bureau of economic analysis, 2018), Construction nominal gross output is $1,629.7 billion. Also, 1.5 million employees work in the sector of construction, according to the (United States Bureau of labor statistics, 2016).

There are many materials used for construction purposes; some are naturally occurring substances such as sand, rocks, and wood, while many are human-made products such as cement, glasses, and metal. Cement is among the most important construction materials (Schneider, 2011). It is used in construction as a binder or substance that hardens and adheres to other materials to bond them. Cement is rarely used alone but mixed with fine aggregate to produces mortar or with sand and gravel to produces concrete.

One of the major areas of wholesale distribution is the Construction material Industry which includes suppliers of materials used by construction companies. The selection of materials is one of the most important phases during the design phase of the construction, although construction projects depend heavily on the presence of appropriate materials and equipment to complete the project on time and a budget (Akintoye, 1995; Ibn-Homaid, 2002). The materials required for the construction projects at the required time, in the right quantity and the desired quality procurement is of great importance in the successful completion of the projects. Moreover, Time is one of the most important aspects of building parameters which had legal consequences, during the construction process the owner plan the start and end dates of the project. (Polat and Arditi, 2005) states that Among the most frequently encountered delays in the construction projects is the absence of the materials needed in the right amounts and on-time.

In the fast and variable buying environment, which is tough to get the product at the proper price and within the right quality in the market, the construction industries must know where to look for appropriate materials supplier. The search for a suitable supplier for a given material or service is a competitive issue in itself. Safa et al (2014) state that the cost of the material contributes to the total cost of the project, it is 50-60% of the total cost of the project, and its control affects 80% of the project schedule. It indicates that project success depends on the success of the right choice of a material supplier.

The evaluation and selection of suppliers are one of the most common problems that companies may face at the time of purchase. Also, it is defined as the comparison of suppliers using multiple criteria and selecting the most appropriate one. The selection of the best suitable supplier is based on assessing supplier capabilities (Shih et al. 2004). In most cases, the supplier evaluation and selection problem deals with more than one supplier, and multiple decision-makers, who have different viewpoints, select the supplier (Plebankiewicz and Kubek 2016). Before the 1960s, purchasing was considered something related to buying or selling, and supplier selection was focused on the short term until the late 1970s that purchasing was considered more than buying or selling function. Suppliers were often evaluated solely on price and were quickly dropped when out-bided by another supplier. At the beginning of quality improvement programs, buyers begin to understand the necessity of supplier selection based on factors other than price.

The current trend in the purchase of building materials continues to receive little attention on the basis of supplier evaluation, at the same time we witness, more construction companies increase the percentage of material they need to buy. Engineers often prefer to select their suppliers based on personal experiences instead of logical and systematic approaches. (Revelo 1999; Flanagan, 2009). High-quality materials are expected from every potential supplier. When a supplier has shown in the past the ability to produce a quality product, it is believed that he will continue to do so. (Monczka et al. 2011) was found that almost 50 percent of the quality issues stem from dealing with the wrong supplier and bad supply chain management.

Construction companies are mostly organizations established for-profit; therefore, they aim to reduce the total construction cost as much as possible and increase profit in the projects they undertake. The decision to select the suppliers is one of most tough decisions that companies made to achieve their goals. (Aretoulis et al. 2010) states that Supplier selection decision plays a key role in construction projects' progress or failure. Therefore the firms must be measured and evaluated the ability of the supplier in order to choose suppliers that consistently outperform the market.

1.2. Purpose of the Study

This study aims to provide a solution for supplier selection of cement in Alburuuj Construction Company. The problem of the cement supplier is a multi-criteria decision-making problem since it associated with multiple alternatives and criteria which includes numerical and non-numerical criteria in its structure. Three decision-makers from the company will evaluate the suppliers. For this study first, three Turkish cement manufacturers are identified. To evaluate the suppliers, five criteria, which are cost, quality, delivery, service, and supplier profile, are selected. The decision-makers were asked to compare criteria using the Likert scale. Then Fuzzy-AHP method is used to determine the weights of each criterion. TOPSIS method is used for the ranking supplier taken from the subjective judgments of the decision-makers using very-low to Excellent rating. Same as, ELECRE Method is used for ranking suppliers combined both subjective and objective judgments of the decision-makers two of the criteria, which is price and delivery" lead time," will use real data taken from the suppliers.

This study consists of six parts. In the first part, general information about the subject and the purpose of the study is explained. In the second part, a literature review related the supplier selection criteria and supplier selection process at the literature will analyze. In the third part, ANP, AHP, ELECTRE III, TOPSIS, and FUZZY AHP methods, which are among the multi-criteria decision-making methods that will be used within the scope of the thesis, is explained step by step. In the fourth chapter, case analysis study on the problem of selecting the cement supplier in a Somali construction company and explanation of the evaluation criteria used in the application is given to form hierarchical supplier selection problem structure. Also, data taking via-survey will present. In the fifth chapter, the problem is solved with the methods described in chapter 3 using the data collected from the via-survey. In the last section, the results and findings obtained from the methods were compared and interpreted.

2. LITERATURE REVIEW

In the literature, the problem of supplier selection in many sectors has been examined and seen that these studies are grouped under two main headings: criteria used in the selection of suppliers and methods used in supplier selection. When a company chooses the supplier who offers the lowest price it exposed to several risk. The evaluation and selection of suppliers are aimed to determine the suppliers that can supply the demands of an enterprise continuously at an appropriate price, in the desired quantities and good quality (Güner et al, 2005).

The main problems caused by poor supplier can be summarized as follows: failure to order on time, delivery at the wrong time, errors in quantity take-off, obtaining incorrect materials and lost or damaged materials (Flanagan, 2009). In today's competitive market, supplier evaluation and selection process are the best purchasing methods. One of the essential tasks of the purchasing function is the selection of the right suppliers and thereby, the acquisitions of required material (Zeydan et al. 2011). There are many types of research in the literature related to supplier evaluation and selection, which carried out in different sectors. Kahraman et al. (2003) proposed the Fuzzy AHP method for the solution of supplier selection problems. The proposed approach is shown as a case study on the supplier selection problem of a company in the white goods manufacturing sector; three alternative suppliers were evaluated according to 11 criteria by using the Fuzzy AHP method for ranking.

Chen et al. (2006) proposed the Fuzzy Topsis approach to evaluate and select suppliers in the supply chain method. They used their proposed approach to select the supplier of the materials to be used in the final products of a high-tech company. In the method, they worked with three decision-makers and evaluated five alternative suppliers according to 5 criteria.

Soner and Önüt (2006) solved the problem of supplier selection of a company that produces ventilation and air conditioning by using AHP and ELECTRE methods together. First, they determine the weights of 7 criteria that would use to evaluate the suppliers by using the AHP method, and then, using these weights, they ranked five alternative suppliers with the ELECTRE method. Shengbin and Chunsheng, (2009) developed a multi-purpose programming model by using quality, delivery, cost, and service criteria in supplier selection of a company that operates in the aviation industry.

Radziszewska (2010) solved the problem of subcontractor selection in the construction sector by using the ELECTRE III method. Selection criteria were cost distribution, adaptability to market changes, mutual relations, communication method, information sharing, solution conflicts, standards-codes of conduct, frequency of communication, reliability, and quality control service status. Guan et al (2013) examined the material Suppliers' selection process. He proposed the Fuzzy substance-element model and Fuzzy AHP methods for this process; the proposed approach is demonstrated on the problem of choosing a cement supplier for the National Highway project in the Republic of Congo. In the case study, three cement suppliers were evaluated according to 10 evaluation criteria. Alternatives are listed according to the results of the evaluation.

Rezaie and Ramiyani (2014) evaluated the performance of 27 Iranian cement firms in the Tehran stock exchange market for two years (2008 and 2009) separately. They gathered the financial ratio of the firm’s performance. Fuzzy AHP was used to determine the weight of criteria from a subjective judgment of decision-makers and VIKOR method used for ranking the firms. In another study, (Cengiz, 2017) researched supplier selection analysis for wall, cladding and roofing construction materials. The literature review and the expert panel were used to identify the criteria, the weights of each criterion are determined through an extensive questionnaire survey that was implemented to participants from construction companies, universities and government institutions. The Analytic Network Process (ANP) is utilized ranking the supplier.

Rouyendegh et al. (2018) used the TOPSIS method combined with an intuitionistic fuzzy set (IFS) to solve the problem of site selection in a wind energy plant at the TURKEY. For this purpose, four alternative locations that can build wind power plants had been identified.to evaluate alternatives ten criteria in four dimensions that are cost, location, wind potential, and social benefits are selected. The TOPSIS method is used to rank the alternatives, Although IFS has been used to represent acceptance, refusal and hesitations by addressing real-life uncertainty, inaccuracy, uncertainty and linguistic human decisions. The main purpose of the supplier selection is to meet the needs of the enterprises and to choose the suppliers with the most power at an affordable price.

2.1. Supplier Selection Criteria

In the literature, the criteria used the problem of supplier selection in many sectors has been examined. It has seen that most of the work is based on Dickson's 1966 extensive study of supplier selection criteria he surveyed with 170 purchasing managers and identified 23 criteria to be used in evaluating and selecting suppliers as a result of that study the criteria were ranked according to their importance among the 23 criteria defined quality is the most critical criterion. Quality criteria are followed by delivery and performance history. Table 2.1 shows the criteria defined by (Dickson, 1966).

Weber et al. (1991) reviewed the literature on supplier selection in their study; they tried to determine what academicians and purchasing managers pay attention to when supplier’s criteria. When they examined 77 studies on this subject within 1991-1996 they found that Quality, Delivery, and net price received the most attention the supplier’s production facilities, geographical location, financial positions, and capacities get intermediate attention. (Verma and Pullman, 1998) Found that while Engineers believe that quality is the most important criterion in the real-life selection of a supplier, they primarily choose suppliers on the basis of two parameters, which are price of the product and delivery speed.

Table.2.1. Dickson (1966) defined supplier selection criteria

Number	Criterion	The importance of a criterion
1	Quality	Very High Important
2	Delivery	
3	Performance history	
4	Warranties & claims policies	
5	Production facilities and capacity	Great Importance
6	Price	
7	Technical capability	
8	Financial position	
9	Procedural compliance	
10	Communication system	
11	Reputation and position in the industry	
12	Desire business	
13	Management and organization	
14	Operating controls	
15	Repair service	Medium Importance
16	Attitude	
17	Impression	
18	Packaging ability	
19	Labor relations record	
20	Geographical location	
21	Amount of past business	
22	Training aids	
23	Reciprocal arrangements	Low Importance

Thiruchelvam and Tookey, (2011) examined the selection of suppliers between 1966 and 2010 based on Dickson's criteria in their study. As a result of their study, 118 studies showed that the most used criteria are price also 111 times delivery and 108 times quality criteria were used. In addition to Dickson's criteria, reliability, flexibility, geographic location, technology, innovation, long-term relationships, process improvement, and product development criteria were also used.

Estehadian et al. (2013) used 23 criteria defined by Dickson 1996 for the selection of suppliers in Iranian construction companies**. (**Ho et al, 2007) used 29 of the criteria defined by Kannan and Tan in their selection of suppliers in the construction sectors in Taiwan and Vietnam. They used a t-test as a statistical test in their studies.

Schram and Morais, (2012) used nine criteria in their studies on supplier selection and evaluation in the construction sector. The criteria they used were the quality management system of the supplier, unit price, cost reduction policies, transportation fees, frequency of rejections, whether they returned to the request for assistance, supply time, flexibility in time and product flexibility. They listed five different alternatives using a SMARTER method with these criteria. (Patil and Adavi, 2012) defined 11 criteria in their study on the selection of suppliers in the construction sector: supply time, timely performance, flexibility, frequency of procurement, quality, transportation cost, pricing conditions, information coordination adequacy, design coordination competence, taxes and continuity of the supplier in the market.

2.2. Supplier Selection Process

The systematic evaluation and selection of a supplier is the best method agreed upon by most experts and organizations used by a variety of different approaches. The overall purpose of the supplier evaluation process is to reduce risk and maximize the overall value of the purchaser. An effective supplier selection process is essential in today's highly competitive environment, according to (Sevkli et al. 2010).

In the supplier assessment process, the entity has first to determine what to consider when selecting a supplier. In this way, evaluation and selection processes will be easy. There are two main categories of supplier evaluations, which are process-based evaluation and performance-based evaluations. The process-based assessment is an evaluation of the production process for the supplier. For long-term relationship suppliers, the company must perform an evaluation at the supplier's location to determine the level of competence in the supplier's operating system. The performance-based assessment is an evaluation of the real performance of the supplier, based on a range of criteria such as quality, price, and delivery. The evaluation based on performance is more common than the evaluation based on the process because objective data are readily available and easier to measure.

The supplier selection process has been so critical that multi-objective teams are frequently responsible for supplier visits and assessment. The evaluation and selection decision reduce or prevent problems. The decision to choose the best among suppliers, both quantitatively and qualitatively, covers a general process that needs to be seriously considered and carried out in terms of operational performance. Also, it adopts a systematic, structured approach by using a survey. An active survey should have other characteristics such as comprehensiveness, objectivity, accuracy, consistency, and mathematically straightforward. (Monczka, Trent and Handfield, 2002) presents a step-by-step process that evaluation of the supplier should be conducted. Figure 2.1 shows the steps to follow when developing such a system, and each step will explain in detail next.

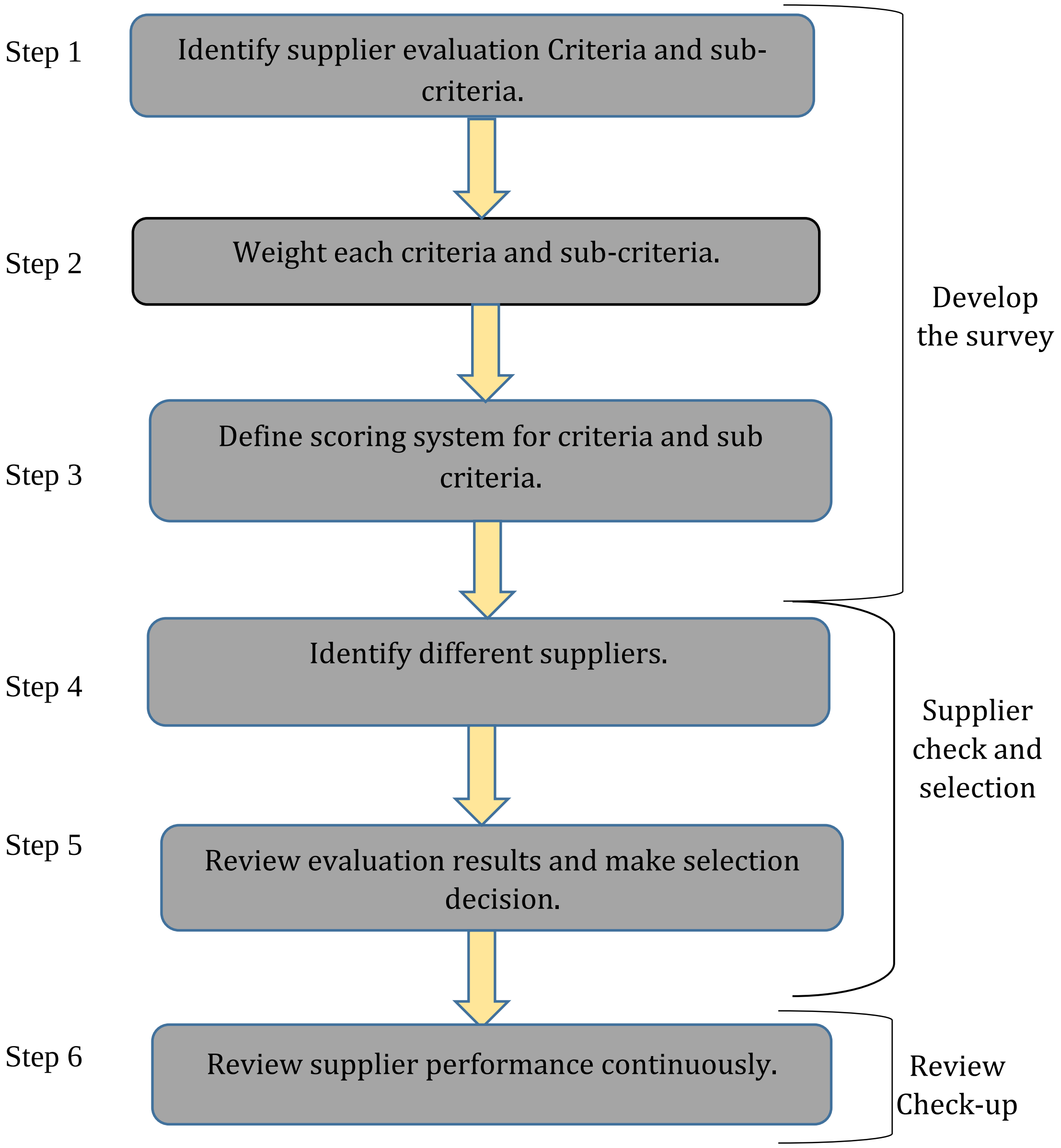

Figure 2.1. necessity supplier evaluation and selection survey development.

The details of six steps are;

Step 1. Identify supplier evaluation criteria and sub-criteria: The first step when developing the supplier survey is deciding the criteria to include also identify any sub-criteria if they exist in every broader main criterion. The basic standard is delivery, quality, and cost, which are often the most significant and important areas affecting the buyer. (Ho et al, 2010) Underline that the criteria to select the supplier should not depend merely on the price of the product or quality. Construction firms should take into consideration several compromise and conflicting criteria.

Step 2. Weight each criterion and sub-criteria: Performance criteria usually take a weight that reflects relative importance. The assigned weights of these criteria reflect the relative importance of each criterion. The purchaser must decide that the total weight of the sub-criteria should be equal to the total weight of the main criteria. The combined weights should be equal to 1.0. one way of managing this task can provide this flexibility by writing a variety of scales, adding components, or deleting when needed.

Step 3. Define a scoring system for criteria and sub-criteria: The defines each of the points in the performance area if the assessment uses a 9-point scale to evaluate the performance components, so the buyer must clearly define the difference between scores 9-7-5-3. One of the key points is to improve a scale that clearly defines what a specific score means.

Step 4. Identify Different Suppliers: In this stage the list of suppliers going through prequalification together with the targeted suppliers requiring further detailed are considered.

Step 5. Review evaluation results and make a selection: In this step, the purchaser evaluates different data collected from different suppliers evaluating and decide whether to choose or reject a supplier as a source. Evaluating suppliers before an actual buying requirement occurs can give the buyer greater advantages.

Step 6. Review supplier performance continuously: When a firm decides to pick a supplier, the supplier will instead meet the criteria of the customer.. The initial evaluation and selection of suppliers must keep steadily improving from the supplier.

3. MULTI-CRITERIA DECISION MAKING (MCDM)

3.1. Introduction

Multi-criteria decision making (MCDM) is one of the best Known branches of decision making is a method of choosing the best choice among multiple and simultaneous criteria. In decision problems, when many criteria need to be evaluated at the same time, these situations are examined under the heading of multi-criteria decision-making problems (Timor, 2011).

Vincke, (1992); Roy, (1996) describes multi-criteria decision making as a situation in which the decision-maker wishes to have defined a set of actions A and a family of criteria F. the determining a subset of actions deemed best for F(choice problem); splitting A into sub-set according to specific criteria (sorting problem), Rank A actions from the best to the worst (ranking problem) to define actions and their effects in a formalized and systematic way so that decision-makers can analyze those actions (issue description). In another definition of Multicriteria Decision Making is. While companies are choosing suppliers for their projects, they pay attention to many criteria such as price, quality, and delivery. Therefore, supplier selection is defined as a multi-criteria decision-making problem (Gökalp and Soylu, 2010).

In real-life problems, MCDM methods are commonly used and fit most of the problem structures. Problems are classified according to different points of view in the MCDM literature. For example, it is considered either continuous or discrete in one category, depending on the solution space of the alternatives. Multi-criteria decision-making involves identifying the most reasonable options among many different and interactive criteria (Nihan and Yücenur, 2011).

There are three basic steps in all decision-making strategies that are implemented in the same order in figure 3.1. the MCDM methods take part in the decision problem; we have a set of alternatives {A1, A2, … Am} and a set of criteria for decision denoted as { C1, C2, … Cn}. we also presume that for each DMU and criterion pair the decision-maker has already calculated a_{ij} it's relative performance values are (i=1,2,…

m and j=1,2,… m}.As a result, our problem is given a_{ij} and w_j are given to our question, and we plan to decide the rank of the DMUs while simultaneously considering all the criteria. The selection of suppliers should be regarded as an MCDM issue (Li et al. 2018).

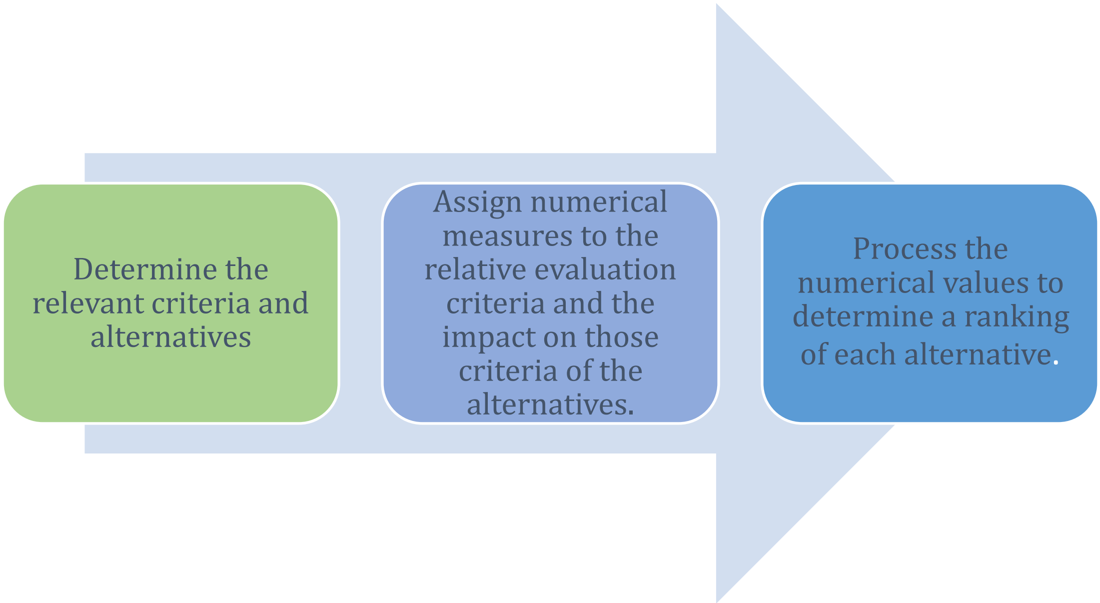

Figure 3.1. Steps of the decision-making process

The research results extracted from the web of science Databases shows the number of publications and quotations relevant to the MCDM subject figure 3.2 shows the results in terms of the published and citations articles. we can witness a sharp increase.

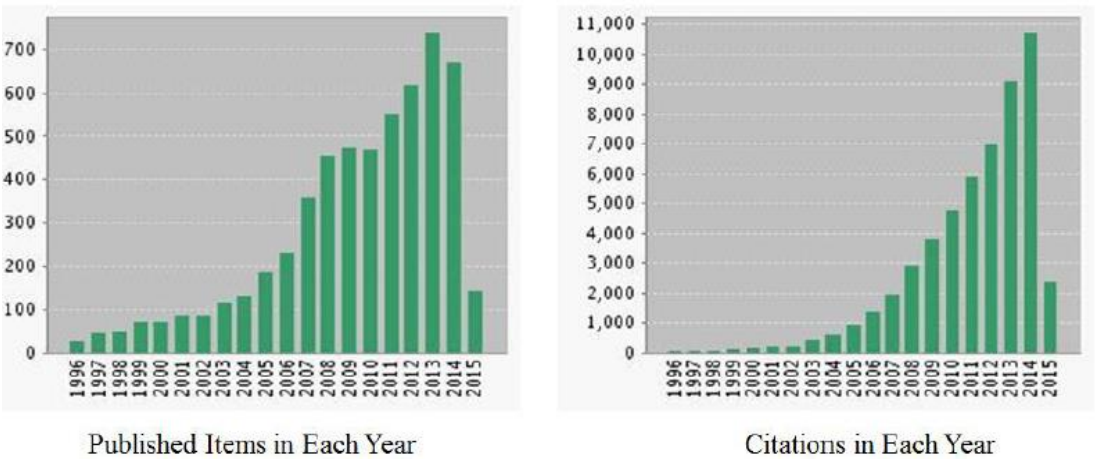

Figure.3.2. Web science citation report for MCDM (Web of Science, 2015).

3.2. Multi-Criteria Decision Making Methods

Multi-criteria decision making (MCDM) methods have been established to analyze and evaluate decision processes where multiple criteria are combined. The purpose of decision-makers is different for each problem, but the common thing is to find the best alternative and to rank all the alternatives from the best to the worst in the ranking problem. There are many multi-criteria decision-making methods used in solving supplier evaluation problems and facilitating the selection of the best supplier among alternatives.

In the literature, there are different types of Multi-Criteria decision making Methods used in different problems. (Ho et al, 2010) examined 78 articles about supplier selection published between 2000 and 2008. Data Envelopment Analysis was the most used method. When they examined the integrated methods, they found that AHP-GP (Goal Programming) combination was used the most. Chai et al. (2013) examined studies on supplier selection between 2008 and 2012. In that study, they examined 123 articles and defined 26 different decision-making methods. In the studies they examined, the most commonly used AHP method (24.39%) and the AHP method were LP (Linear Programming, 15.44%), TOPSIS (14.63%), ANP (12.20%), DEA (Data Envelopment Analysis, 10.57%) and purposeful optimization (10.57%).

MCDM methods are mathematical methods that can include multiple decision-makers in the decision-making process and evaluate many strategic and operational factors with their measurable and unmeasurable criteria (Önüt et al. 2016). The following pages will explain the steps taken to solve such problems while using multi-criteria decision-making methods. In the next sections, the AHP, ANP, ELECTRE, TOPSIS and Fuzzy AHP, which are multi-criteria decision-making methods, will be explained step by step.

3.2.1. Analytical hierarchy process (AHP)

The Analytical hierarchy process AHP was developed by Thomas L. Saaty 1980 is a structured method to solve complex problems with multiple criteria. It is built to deal with both the logical and the intuitive in order to choose the best from a variety of alternatives based on many criterias.

The most creative decision-making task is to decide what factors to include or not include in the structure of the hierarchy. All selection criteria judgments are always relative; therefore, absolute measures can not be integrated into the selection process for suppliers. (Sarkis and Talluri, 2002). In the process, if the data is sorted by decision-makers according to the size of the benefit, an output is made that will make the selection easier. As an effective method in choosing the best alternative among these data, it is the most widely used Multi-Criteria Decision Making (Saaty et al, 2008).

There are five necessary steps in the AHP method. These steps include constructing the problem structure, constructing comparison matrices, finding priority vectors, checking the consistency of judgments in comparison matrices, and calculating the order of alternatives. The necessary steps are summarized below (Palcic and Lalic, 2009).

Step 1: Forming the Mathematical Model and Solving the Problem

The first step of the AHP method is to establish the criteria that must be examined within the scope of the problem to be solved and the sub-criteria of these criteria if they exist. After determining the criteria and sub-criteria, alternatives are also identified. The decision hierarchy is formed. A useful hierarchy can be established when all decision-makers play a role in the selection of criteria. Thanks to this hierarchy created for the AHP method, decision-makers can visually see the problem to be solved. The hierarchy consists of three basic levels: the aim of the problem, criteria, and alternatives. According to the structure of the problem, the required level can be added to the hierarchy. With this hierarchy created for the AHP method, decision-makers can visually see the problem.

Step 2: Determination of Binary Comparison Matrix

After the decision hierarchy is formed, binary comparison matrices are created in order to calculate the importance of the criteria according to each other. Binary comparisons are made by decision-makers on the nine-point scale developed by Saaty. Table 3.1 has this scale and verbal equivalents.

Table 3.1. AHP measurement scales

Numerical Rating	The verbal judgment of Importance	Explanation
1	Equally Importance	Contribute equally to purpose
3	Moderately Importance	As a result of experience and evaluations, one criterion is preferred more than the other.
5	Strongly Importance	As a result of experience and evaluations, one criterion is much more preferred than the other.
7	Very Strongly Importance	One criterion is strongly preferred over the other.
9	Extremely Importance	One criterion is preferred to the highest possible degree over the other.
2-4-6-8	Intermediate values	When compromise is needed.

Step 3: Determination of Criterion Weights and Alternatives.

Priority vectors are generated after decision comparison matrices are formed by decision-makers, each element in the comparison matrices is divided by the sum of the columns, and then it determines the arithmetic mean of each section.

These values indicate the importance of each criterion. Priority vector is generated with these weights. The total value for each column in the generated normalized matrix must be 1. As the last step, the eigenvectors for the matrix are determined by calculating the averages of the criterion values in the line (Dağdeviren et al. 2009).
Step 4. Determination of Consistency Ratio

After calculating the priority vector, the consistency of each filled-in comparison matrix is examined. Consistency ratio (CR) must be calculated in all comparison matrices to measure whether decision-makers are consistent when filling comparison matrices. To ensure that the matrices are consistent, CR must be less than 0.1 if the value of C.R is greater than 0.1 in any matrix that is mean comparison matrix is inconsistent and needs to be recreated. To calculate the consistency index (CI), the below formula is used.

$$CI = \frac{(\lambda max - n)}{(n-1)} \quad (3.1)$$

CI = Consistency Index

λmax = the largest eigenvalue in the matrix

n = number of elements of each matrix

The consistency ratio (CR) is derived by dividing the consistency index by the matrix of the same scale corresponding to the random index (RI).

$$CR = \frac{CI}{RI} \quad (3.2)$$

RI = Average Random Consistency

Table3.2. Average random index of consistency

N	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

Step 5. The importance weights of the criteria relative to each other and the alternatives according to each criterion are found in the first three steps, and after the consistency ratio is less than 0.1, the matrix is formed in which the importance weights of the alternatives according to each criterion are shown. Rows are alternatives, and columns are criteria. With this matrix, the order of alternatives is obtained by multiplying the matrix with the importance weights of the criteria. The highest value alternative is to consider the best one.

3.2.2. Analytical network process (ANP)

The Analytical network process ANP was developed by Thomas L. Saaty 1970 as a decision making. The analytical network method (ANP) provides a general framework for decision-making without making claims about the independence of higher-level elements from lower-level elements, and the independence of the elements as a class hierarchy. (Saaty, 2004).

Like AHP, ANP also depends partly on the hierarchies of cluster variables and subfactors, The main advantage is to support the team execution assessment to recognize different relationships and valu. The interrelationships between the different selection criteria are explicitly integrated by means of pair-wise comparisons. (Glantsching, 1994).

Cluster is a set of related network or sub-network elements consist of components and ties which included in a decision network (Chai, 2013). An ANP method provides a general framework for decision making without assuming The separation of higher level elements from lower level elements and the separation of the elements inside a level.

Step 1: Define the goal or objective of the problem.

In this step, the criteria, sub-criteria, alternatives, and decision-makers of the problem are identified. The objectives of the decision-makers and the problem should be defined in detail to cover the results of the decision. Interlinked criteria will be in the same cluster; the same procedures are applied for alternatives. In addition, the interaction and clustering between clusters are determined, and a network structure is formed. In short, the decision problem is described in detail in this step.

Step 2: Identify the criteria and sub-criteria.

ANP consists of three types of dependence: internal dependence, external dependence, and feedback dependency. The cluster phases and link nodes of the system that are created for feedback are determined by taking into account the internal and external dependency effects. If a cluster affects or is connected to the nodes of another cluster, an arrow is drawn to the unaffected cluster to direct the affected cluster.

Step 3: Determine the inner dependencies between factors by pairwise comparison using the 1–9 scale to calculate priority vectors. Criteria and alternatives, interactive criteria, and binary comparisons with alternatives are made. The discrepancies are realized, and binary comparisons are similar to the AHP method. In the ANP method, binary comparisons are made, while the AHP method uses the 1-9 scale of Saaty.

Step 4: Determine the inner as well as external dependencies between sub-factors by pairwise comparison using the 1–9 scale to calculate priority vectors. For each comparison, the inconsistency index should be less than 0.1 to accept the decision.

Step 5: Form the unweight supermatrix by using priority vectors. In ANP, a stochastic supermatrix is formed through the series of matrix operations.

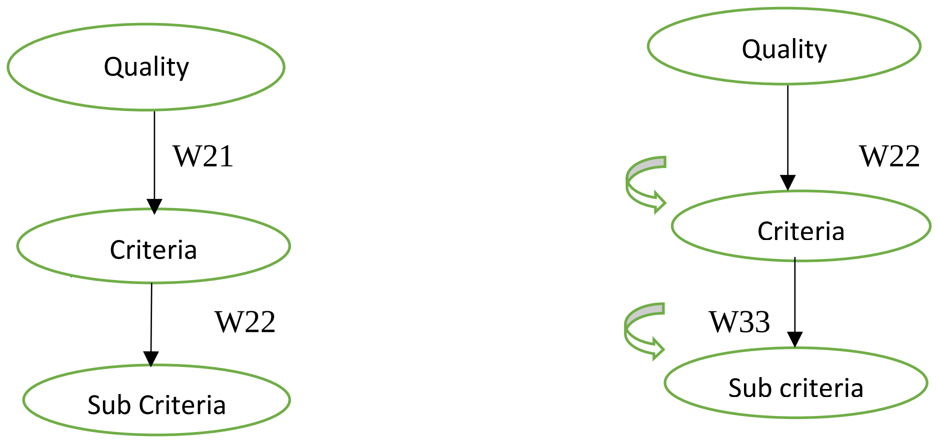

Figure.3.3. Comparisons of AHP and ANP

Step 6: By dividing each element by the sum of the corresponding column elements, form a weighted supermatrix so that the sum of each column is equal to one.

Step 7: Create a limit matrix by increasing the power of the weighted supermodel to arbitrary high power. Eigenvalues in a stochastic matrix are less than one the sum of each column in the limit matrix will be equal, and the sum of limiting priorities will be equal to the number of criteria. (Saaty, 2004). Eigenvalues in a stochastic matrix are less than one the sum of each column in the limit matrix will be equal, and the sum of limiting priorities will be equal to the number of criteria.

3.2.3. ELECTRE

ELECTRE (Elimination and Choice Translating Reality) is another multi-criteria decision-making technique it was developed in 1965 by Bernard Roy and his colleagues at the SEMA consulting firm (Tam et al, 2003).

The electre method provides a solution to the problem by establishing the superiority relationship between the alternatives to be selected. There are six versions of the electre method I, II, III, IV, V, VI. The difference between these versions is based on the different types of criteria in this method; the criteria are divided into two as real criteria and non-real criteria. The actual criteria are used in traditional preference models, while the false criteria include a two-stage limit value approach in traditional preference models.

There are two types of relationships between alternatives: if the performance of alternative A is better than that of alternative B, alternative A is superior to alternative B; If the performance of alternative A and B are equal, then alternatives A and B are identical. This method, all alternatives can be ranked from the best to the worst.

In fact, there is an intermediate region where there are no definite boundaries when choosing between alternatives. In this case, the problem is overcome by using a two-stage boundary value approach. In the two-stage boundary value approach, the limits (superiority and indifference limits) are determined to show the status of the alternatives with respect to each other. The area between these boundaries is called the weak superiority area. The details of the steps are summarized below (Gökhan and Görener, 2016).

Step 1. Determination of Decision Matrix (A)

The decision matrix shows the alternatives in the rows and the criteria in the columns. Here, the rankings are based on the alternatives that are required to be listed, and the columns are based on the evaluation criteria to be used in decision-making. Matrix A generated by the decision-maker is used as the initial matrix. The decision matrix is shown as follows:

$$A_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ . & & & . \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{3.3}$$

Step2. Normalizing of Standard Decision Matrix (R).

Using the elements of matrix A, the standard decision matrix is calculated using the following formula.

$$X_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} {r_{ij}}^{2}}} \tag{3.4}$$

For example, the element x of matrix X is determined by dividing the square root of the total of the squares of column elements of the matrix. The objective here is shown to relate the decision point to the relevant evaluation criterion and to weight it for other decision points. The matrix X is calculated as follows.

$$Xij = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{11} & \cdots & x_{2n} \\ . & & & . \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{3.5}$$

Step 3. The Weighted Normalizing Decision Matrix (Y).

The importance of the evaluation criteria for the decision-maker may be different. In order to solve these value differences by using the ELECTRE method, the Y matrix must be calculated. Decision maker for the continuation of the calculation determines the weights of the evaluation criteria (w_i).

$$y = xw \qquad \text{and} \qquad \sum_{i=1}^{n} w_i = 1 \tag{3.6}$$

After this step, the Y matrix is formed by multiplying the elements in each column of the X matrix by the corresponding $w_i$value. The Y matrix is shown below:

$$X_{ij} = \begin{bmatrix} w_1 x_{11} & w_1 x_{11} & \dots & w_1 x_{1n} \\ w_1 x_{21} & w_1 x_{22} & \dots & w_1 x_{2n} \\ . & & & . \\ w_1 x_{m1} & w_1 x_{m2} & \dots & w_1 x_{mn} \end{bmatrix} \tag{3.7}$$

Step 4: Determination of Concordance (c_{ki}) and Discordance (d_{ki}) Sets.

It is provided to determine the fit sets by using the Y matrix. Decision points are compared with each other in terms of evaluation criteria, and sets are determined by the following formula.

$$C_{kl} = \{ j, y_{kj} \geq y_{lj} \} \quad \text{for j=1, 2, 3……, n} \tag{3.8}$$

$$d_{kl} = \{ j, y_{kj} \leq y_{lj} \} \quad \text{for j=1, 2, 3……, n} \tag{3.9}$$

Thanks to the formula, it is possible to compare the magnitude of the weight of the row elements for multi-criteria decision problems used in the number of compliance sets, k and l must be $k \neq l$.

In the ELECTRE method, a set of non-conformances corresponds to each fit set (C). We can interpret this as the number of non-compliance sets, as well as the number of compliance sets.

Step5. Build the Concordance (C) and Discordance Matrices (D)

Compliance sets (ken) are used to create a compliance matrix (C). The elements of the matrix (C) are calculated by the formula shown below.

$$\mathrm{C_{pq}} = \sum_{\mathrm{j \in c_{kl}}} \mathrm{w_j} \tag{3.10}$$

The elements of the discordance matrix (D) are calculated by the following formula.

$$D_{pq} = \frac{(\sum_{j^o} / V_{pj^o} - V_{qj^o} /)}{(\sum_{j} / V_{pj^o} - V_{qj^o} /)} \tag{3.11}$$

For example, the Y matrix 1 and 2. The d_{12} (k = 1 and l = 2) element is obtained from the mutual comparison of the row elements Like (C) matrix, (D) matrix is (mxn) dimensional, and no value is given for k = 1. The matrix (D) is shown below:

$$D = \begin{bmatrix} - & d_{12} & d_{13} & \dots & d_{1m} \\ d_{21} & - & d_{23} & \dots & d_{2m} \\ . & & & & . \\ d_{m1} & d_{m2} & d_{m3} & \dots & - \end{bmatrix} \tag{3.12}$$

Step 6. Compliance of Superiority (F) and Mismatch Superiority (G) Matrices determination. The superiority matrix (F) is mxn. And by compa9oi9ring the compatibility threshold value of the matrix elements (c) with the elements of the compatibility matrix (c_{kl}), the compatibility advantage matrix (F) is obtained. The compliance threshold value (c) is obtained by the following formula:

$$\underline{C} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{i=1}^{m} c_{kl} \tag{3.13}$$

M is the number of decision points used in the formula. Here, the value $\underline{c}$ is equal to the $\frac{1}{m(m-1)}$ and the sum of the elements (C).

The elements of the matrix F (f_{kl}) take the values of 1 or 0 and do not have any value because they show the same decision points on the diagonal of the matrix if $c_{kl} \geq \underline{c} \Rightarrow f_{kl}$, if $c_{kl} < \underline{c} \Rightarrow f_{kl} = 0$.

The mismatch superiority matrix (G) is also dimensioned (mxn) and is constructed to resemble the (F) matrix. The discrepancy threshold value ($\underline{d}$) is calculated using the following formula.

$$\underline{d} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl} \tag{3.14}$$

In other words, the $\underline{d}$ value, $\frac{1}{m(m-1)}$ is the sum of the elements that make up the matrix (D).

The elements of the matrix G (g_{kl}) also take the value of 1 or 0 because They display the same decision points on a matrix diagonal.

If $d_{kl} \geq \underline{d} \;\Rightarrow\; g_{kl} = 1, if\; d_{kl} < \;\underline{d} \;\Rightarrow g_{kl} = 0.$

Step 7. Determine the Aggregate Dominance Matrix.

The elements (e_{kl}) of the Total Dominance Matrix (E) are as follows: corresponds to the multiplication of the elements(f_{kl}) and (g_{kl}) as indicated in the matrix. E is formed by taking the values of 1 or 0, while (C) and (D) depending on the matrix (mxn) is dimensional.

Step 8. Determining the Importance of Decision Points.

The columns and rows of the matrix (E) show the decision points. For example, if we calculate the matrix (E) as follows.

$$E = \begin{bmatrix} - & 0 & 0 \\ 1 & - & 0 \\ 1 & 1 & - \end{bmatrix} \tag{3.15}$$

e_{21}=1 e_{31}==1 e_{32}==1 takes values. This shows the absolute superiority value of the 2nd decision point in the matrix to the 1st decision point, the 3rd decision point to the

1st decision point, and the 3rd decision point to the 2nd decision point. Thus, if the decision points are defined by the symbols A_i(i = 1,2, ..., m). The order of importance of the decision points will be listed as A3, A2, and A1.

3.2.4. TOPSIS

The Technique for Order by Similarity Ideal Solution method abbreviated TOPSIS was developed by Yoon and Hwang in 1980 (Shyjith et al, 2008). TOPSIS is one of the most common methods used in decision-making processes in many sectors. This is a method used to select the best alternatives.

The TOPSIS method is a simple model that does not include complex mathematical data and sophisticated algorithms, as in other MCDM methods. It is used in many areas due to its application methods and easy to understand by users. TOPSIS makes it easier to understand outputs when asking users for a small number of input parameters.

Since our aim is to see the return of the application we make, the closeness to the ideal solution means maximizing the return, and the distance to the negative ideal solution means that the cost reaches the minimum. We are considering that two alternatives, like X and Y, are allowed. The fact that X is close to the ideal solution and away from the negative ideal solution causes X to be preferred over Y. For decision-makers, Y is far from the ideal solution, according to X, and is close to the negative ideal solution.

The decision matrix of the TOPSIS method is created first. Thanks to the generated decision matrix, a normalized decision matrix is obtained. This matrix is then weighted. Thus, we will list the alternatives according to their criteria. The TOPSIS method consists of 6 necessary steps, and these steps are summarized below (Supçiller and Çapraz, 2011).

Step 1: Formation of a decision matrix.
First, the decision matrix must be formed by the decision-maker. The decision matrix there are i, i = 1, 2,…, m for alternatives, and in the columns, j, j = 1, 2,…, n criteria.

The decision-maker creates the decision matrix, the decision points in the rows. The matrix of the decisions can be shown as follows.

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ . & & & . \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix} \quad (3.16)$$

Step 2: Create a normalized decision matrix.

In order to create a normalized matrix, normalization must be performed first. For this purpose, after the decision matrix is created, the values of each a_{ij}values (a_{11},a_{21}, $a_{31,}$…a_{n1}) are taken from the sum of these values. The resulting column totals are obtained and each a_{ij} value is divided by the square root of the column total to which the normalization process is performed. The procedure to be followed regarding this process is shown below.

$$R_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} {a_{ij}}^2}} \quad (3.17)$$

The normalized matrix can be obtained as follows;

$$N_{ij} = \begin{bmatrix} r_{11} & r_{11} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ . & . & & . \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \quad (3.18)$$

Step 3: Create a weighted normalized matrix.

After the normalized matrix, each value is weighted with a value such as w_{ij}. As the weighting is done according to the importance of the criteria, it reveals the subjective aspect of the TOPSIS method. The weights obtained are the only subjective parameter of the TOPSIS method. The weight of criteria was determined by the Fuzzy AHP method. The point to be considered at this stage w_i value sums equal to 1.

means $\sqrt{\sum_{i=1}^{m} w_i} = 1$

Thus, the n_{ij} values obtained with the normalized matrix are multiplied by the w_{ij} weights and the weighted normalized matrix (V matrix) is calculated.

$$V = \begin{bmatrix} w_1r_{11} & w_2r_{12} & \cdots & w_mr_{1m} \\ w_1r_{21} & w_2r_{22} & \cdots & w_mr_{2m} \\ . & & & . \\ w_1r_{n1} & w_2r_{n2} & \cdots & w_mr_{nm} \end{bmatrix} . \quad (3.19)$$

Step 4: Determine the best (A^+) and worst (A^*) ideal solutions.

After the weighted normalized matrix (V matrix) solutions In order to create the ideal solution set, the largest of the weighted criteria in the Y matrix (i.e., the smallest if the relevant criterion is minimized) is selected. The maximum values indicate ideal positive solution values, while the minimum values indicate ideal negative solution values. Generally the A^+ made up of all the best scores that the criteria produce and the A^- all the lowest possible results in the criteria (Krohling and Campanharo, 2011).

If the aim of the solution is minimization, the values are negative ideal solution values. If maximization, the obtained values will be the opposite. The way to determine the ideal and negative ideal solution values is shown below.

Positive Ideal solution values:

$$A^* = \{v_1{}^+, v_2{}^+, \ldots, v_n{}^+\} = \{(\max v_{ij} \mid \in I), (\min v_{ij} \mid J \in J^+)\} \quad (3.20)$$

Negative ideal solution value

$$A^* = \{v_1{}^-, v_2{}^-, \ldots, v_n{}^-\} = \{(\min v_{ij} \mid \in I), (\max v_{ij} \mid J \in J^-)\} \quad (3.21)$$

Step 5. Calculate the separation measure.

In the TOPSIS method, Euclidean distance is used when calculating distances between points; it is also called ideal and non-ideal distances Calculation. X and y coordinates, the distance between the two points in the coordinate plane to find the Euclidean distance calculation is used to calculate the following formula.

$$d_{ij} = \left[\sum_{k=1}^{p} (x_{ik} - x_{jk})^2\right]^{0.5} \tag{3.22}$$

Here, to determine the distances between the coordinates, the distance from the negative ideal solution to the ideal solution is tried to determine the nearest Euclidean distance. If the formula is generalized to determine the distance to ideal and non-ideal points, the following calculations can be applied.

Positive Ideal distance

$$\boldsymbol{s_i}^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j{}^+)^2} \tag{3.23}$$

Negative ideal distance

$$\boldsymbol{s_i}^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j{}^-)^2} \tag{3.24}$$

When making calculations, there will be $\boldsymbol{s_i}^+$ and $\boldsymbol{s_i}^-$ values as much as the number of decision points.

Step 6: Calculation proximity to the ideal solution.

The TOPSIS method uses distances from ideal and non-ideal points to determine the proximity to the ideal solution for each decision point. The value symbolized as

$C_i{}^+$ indicates the relative proximity to the ideal solution and the value $C_i{}^+$ takes a value within $0 \leq C_i{}^+ \leq 1$. Where $C_i{}^+ = 0$ indicates the absolute closeness of the relevant decision point to the negative ideal solution, $C_i{}^+ \leq 1$ indicates the absolute closeness of the relevant decision point to the ideal solution.

$$C_i = \frac{S_i{}^-}{S_i{}^- + S_i{}^+} \tag{3.25}$$

3.2.5. Fuzzy AHP method

The first Fuzzy AHP method was made by comparing the fuzzy rates defined the triangular membership functions by Laarhoven and Pedrycz (1983). There are many different Fuzzy AHP algorithms in the literature. In this thesis, Buckley's (1985) study, which developed models using trapezoidal fuzzy numbers is explained in detail and use to find the weight. The steps of the proposed Fuzzy AHP method are similar to those of the AHP method.

Step 1: The hierarchy of the problem is established as in the AHP approach.

Step 2: A binary comparison matrix is created. Decision-makers are asked to evaluate the criteria relative to each other and the alternatives for each criterion. Evaluation should be done according to the AHP evaluation scale given in Table 3.1. Decision-makers make binary comparisons. These comparisons are then blurred using the triangular fuzzy values shown in Table 3.3 (Anagnostopoulos et al, 2007). If there is more than one decision-maker, the geometric mean is used to combine the results.

Table.3.3. Linguistic variables for the importance weights of the criteria.

Linguistic Variables	Crisp AHP Scale	Fuzzy AHP Scale	
		TFNs	Reciprocal TFNs
Equally Importance	1	(1, 1, 1)	(1, 1, 1)
Moderately Importance	3	(2, 3, 4)	(1/4, 1/3, 1/2)
Strongly Importance	5	(4, 5, 6)	(1/6, 1/5, 1/4)
Very Strongly Importance	7	(6, 7, 8)	(1/8, 1/7, 1/6)
Extremely Importance	9	(8, 9, 9)	(1/9, 1/8, 1/8)
Intermediate values	2 4 6 8	(1, 2, 3) (3, 4, 5) (5, 6, 7) (7, 8, 9)	(1/3, 1/2, 1) (1/5, 1/4, 1/3) (1/7, 1/6, 1/5) (1/9, 1/8, 1/7)

Step 3: Once the comparison matrices are obtained in a blurred manner, the criteria have weightings relative to each other and alternatives to each criterion. Formula (4.4) is used first to find significance weights.

$$\tilde{r} = (\tilde{c}_{i1} \times \tilde{c}_{i2} \times \ldots . \times \tilde{c}_{in})^{\frac{1}{n}} \qquad (3.26)$$

In the formula, the values of the comparison matrices n represent the alternative number n. So, first of all, the geometric mean of each row of the binary comparison matrix is taken. Then the sum of the columns of each column of the $\tilde{r}$ gull obtained is calculated. The significance weights are then calculated using Formula (4.5).

$$\widetilde{W} = \left(\frac{r_l}{\sum r_u}, \frac{r_m}{\sum r_m}, \frac{r_u}{\sum r_l}\right) = (\mathrm{w_l}, \mathrm{w_m}, \mathrm{w_u}) \qquad (3.27)$$

In the formula, r_l represents the values of the fuzzy matrix r found in the previous formula, $\mathrm{r_m}$ and $\mathrm{r_u}$ respectively represent them and u values of the fuzzy matrix r. The significance weight (w) found by the above formula is in the form of a triangular fuzzy function. The actual weight values are obtained by the rinsing process and then normalization. The rinsing process is performed using a field center formula (Sun, 2010). It is given in Formula (3.28).

$$w_i = \frac{(l_1 + m_1 + u_1)}{3} \qquad (3.28)$$

The values found are divided by the column total. Thus, normalization of the values is provided. The values obtained after the normalization process are the significance of weight values.

Step 4: After calculating the significance weights, the consistency of the matrices is checked. C.R. value should be less than 0.1 as in the AHP method.

4. METHODOLOGY

4.1. Problem Definition

Alburuuj Construction Company was established in 2009 with the objective of providing construction services Alburuuj specializes in residential, commercial, and institutional building service. They carry out their projects both in Somalia and Djibouti. Alburuuj decided to buy cement from Turkish cement manufacturers. In this study, it will determine which "cement" supplier will be suitable for the company. The result supports the decision process of managers. The below Table.4.1 shows the details of the order from Alburuuj.

Table. 4.1. Shows order specification

ORDER SPECIFICATION						
Product	Type of Item	Color	Package	Quantity	Destination	Other Specification
Cement	Ordinary Portland Cement	Grey	50Kg	56tone	Mogadishu Port Somalia	Standard

Supplier selection is essential for construction companies as it provides outsourcing companies with many types of equipment. The materials like cement, doors, and tiles are all supplied from different suppliers. When choosing their suppliers, construction companies must be careful. Low-quality products can threaten the lives of people.

The supplier selection process is made for each project, depending on the expectation of the firm and the nature of the work. To evaluate supplier the criteria must be determine, firstly, the literature review, which is explained in Chapter 2, has been reviewed. Then, interviews were done with the purchasing department, who are responsible for the supplier selection. The criteria that evaluate the suppliers are selected, and the shortlist of suppliers is determined.

As a result of the interview with the decision-maker, five main criteria and three alternative suppliers were taken for the selection of the above order. The decision hierarchy is formed from the above information. It is shown in Figure.4.1.

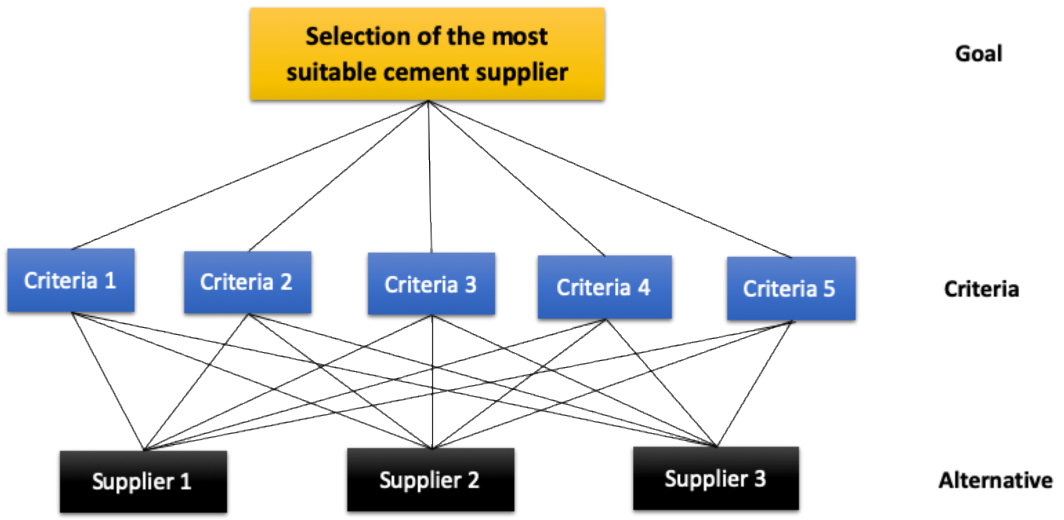

Figure.4.1. Decision hierarchy to use in supplier selection problem.

In the hierarchy shown in Figure 4.1, C1 represents quality, C2 cost, C3 delivery, C4 service, and C5 supplier profile A1, A2, A3, stands for alternative suppliers are shown.

Following the formation of the decision hierarchy, a questionnaire consisting of 3 sections has been prepared. In the preliminary, the purpose of the questionnaire is explained, which scale should be used in which matrix when filling the survey, and by which method the study data will be interpreted.

4.2. Decision Makers and List of Suppliers

1. Decision Makers: Construction companies have a purchasing department which is responsible for supplying processor, for example, they send someone to the abroad countries to buy an item; in reality they do not use or test the product.

That is why there is not just one decision-maker in this situation. Decision-making is made by the team of decision-makers, and the number of decision-makers is structured as three people who decide the purchasing product. These decision-makers are:

DM1: Purchasing Department

DM2: Purchasing Department

DM3: Construction Engineer

2. List of Suppliers: The whole suppliers that supplied the product appear on the list the names of suppliers are not listed due to confidentiality. So instead of that, A1, A2, and A3 have been used.

Supplier 1 is the cement industry leader. It is one of Turkey's largest suppliers, represents 15% of the capacity of the manufacturing of clinker in Turkey.

Supplier 2 is a comprehensive, easy-to-use, cement supplier framework that covers mid-size organizations.

Supplier 3 is public companies that supply and implement.

4.3. Determination of Supplier Selection Criteria

Numerous criteria can be found in the literature and various publications to evaluate suppliers. Criteria used in the examination of suppliers may differ according to the enterprises. The decision-maker has to present the criteria that will be taken into account in the selection process and in their rating scales.

Chou and Chang, (2008) underline the main task for the purchasing department is to determine the main important factors in their industry during the criteria formulation stage and translate these measurements with their own scales into supplier selection criteria.

Then, as a result of the interviews with the decision-makers, the criteria to be used in the selection of suppliers were determined. The five main criteria that are taken into account in the selection of suppliers are quality, cost, delivery, service and supplier profile. (Junior et al, 2014) used in in studies quality, price, delivery, and supplier profile criteria for the selection of metallic components supplier.

4.3.1. Quality

The quality criterion is one of the most important criteria that companies take into consideration when choosing their suppliers. The quality of packaging means that the product is delivered undamaged and packaged under the desired conditions. When evaluating the quality system, suppliers are in compliance with ISO 9001 and similar quality management system standards.

Companies should pay attention to the quality of the material as well as the cost of the material they are going to buy most experts defined quality simply as fitness for use.

4.3.2. Cost

Cost is a fundamental concept for businesses and is one of the major elements to consider when selecting a supplier. The total value in which the goods and services produced by enterprises are called cost.

The cost criterion was evaluated according to three points: which is product price, discount rate, and ease of payment. Businesses want to buy the materials they use to increase their profitability at the lowest possible price, so they try to find a low-cost source of supply and often choose low unit price suppliers to improve their businesses and make them profit sometimes cost alone can determine the supplier.

4.3.3. Delivery

Suppliers are obliged to deliver their products at the right time, in the right quantity, quickly and reliably. In practice, suppliers are evaluated according to two main points: which is the type of delivery they offer and lead time, which means the time between the start and finish of the production process.

The delivery of the desired raw materials or products to the company at a predetermined time is the subject of the delivery criteria on time. The ability of the supplier to comply with the delivery schedule is an essential criterion in the selection of suppliers and maintenance of relations with the entity. The supplier is obliged to deliver the purchased product reliably and quickly according to the demands of the customers and the enterprise.

4.3.4. Service

The service relationship between the enterprises and their suppliers is explained by three sub-criteria. While explaining the service criterion, suppliers' production flexibility, ease of communication, and attitude towards complaints were evaluated**.**

In the production flexibility criteria, the ability of the suppliers to produce different types of products and meet the demands of different models of products is expressed. Ease of communication is defined as being able to reach the business supplier when they call and get answers to their questions. The attitude criterion against complaints is considered as the success of suppliers to provide solutions to any problems.

4.3.5. Supplier profile.

The supplier profile is just what the name implies. It is a document explaining what the supplier is and what is doing. Within the scope of the supplier's profile, suppliers are evaluated according to three main points, which are brief information about the company, financial structure, and the company's position in the market.

When looking at the brief information about the company, a list of suppliers referred to as the Supplier Profile list It displays necessary supplier information such as name, status, parent profile name, categories to which the supplier is associated with all the suppliers at one glance.

The financial structure of the suppliers they are decided according to their financial statement for the last two years. When evaluating the company's position in the market, it is seen how many years the supplier companies have been active in the sector how many enterprises are working with suppliers. The products received from the suppliers are not more or less than the number requested by the company.

4.4. Data Gathering Via Survey

The questionnaire was filled in by three decision-makers that mention previous pages working at the companies purchasing department, which is responsible for the supplier selection process.

In the first part of the survey, decision-makers were asked to evaluate alternatives according to each criteria. The assessment was set to be based on the Very Good - Very Bad scale given with the questionnaire. Table 4.2 shows the specific answers of each decision-maker. In the tables, DM1, DM2, and DM3 represent each decision-maker answer.

Table 4.2. Evaluation results of alternatives according to criteria.

Decision Makers	Criteria / Alternatives	C1	C2	C3	C4	C5
DM1	A1	6	6	5	5	6
	A2	4	5	4	3	5
	A3	4	4	5	3	5
DM2	A1	5	6	5	4	7
	A2	4	6	6	3	5
	A3	3	5	5	4	4
DM3	A1	6	6	5	5	6
	A2	5	5	5	4	4
	A3	4	4	4	4	4

In the second part of the questionnaire, real data of two criteria were taken from the suppliers, which are; the total price of the product (in TL or foreign currency) and supply time for each alternative (day). This information was obtained from the purchasing department presented by the suppliers. This part of the questionnaire was completed only once. The data received is shown in Table 4.3.

Table 4.3: Actual data alternatives.

Criteria / Alternative	Total price of the product (foreign currency $)*50kg	Lead time (Days)
A1	3920	20
A2	2800	30
A3	2240	37

In the third part of the survey, in order to find the weights of the criteria, decision-makers were asked to make comparisons matrices. They compared the criteria using 9 point Likert scale of "equally important, Moderately Importance, Strongly Importance, Very Strongly Importance, Extremely Importance and Intermediate values" The comparison matrices filled by decision-makers scale is shown in Table 4.4.

Table 4.4. Binary comparison matrix comparing criteria.

		C1	C2	C3	C4	C5
DM1	C1	1	1/2	3	4	1/2
	C2	2	1	4	5	4
	C3	1/3	1/4	1	3	5
	C4	¼	1/5	1/3	1	1/4
	C5	2	1/4	1/5	4	1
DM2	C1	1	2	3	5	4
	C2	1/2	1	2	4	3
	C3	1/3	1/2	1	6	4
	C4	1/5	1/4	1/6	1	1/3
	C5	1/4	1/3	1/4	3	1
DM3	C1	1	4	3	5	6
	C2	1/4	1	1/3	5	4
	C3	1/3	3	1	6	5
	C4	1/5	1/5	1/6	1	1/2
	C5	1/6	1/1	1/5	2	1

5. APPLICATION AND SOLUTIONS

5.1. Determination of Criteria Weights by Fuzzy AHP Method

FAHP method was used to determine the weights of the criteria In order to determine the weights of all criteria, a team of 3 decision-makers from the purchasing department and construction engineer of the company was consulted. Decision-makers were asked to evaluate the criteria by asking paired comparison metrics. At this stage, the 1-9 scale of Saaty was used. Since there are three decision-makers, a geometric mean is used to get one value. Buckley (1985) is used to determine the weight. The procedure described in Chapter 3 is followed step by step.

Step1: For the solution with the Fuzzy AHP method, firstly, the hierarchy of the problem is established.

Step 2: firstly, the data obtained from the survey were blurred. Blurring was performed using Table 3.3, as described in Fuzzy AHP. The blurred states of binary comparison matrices are shown in Table5.1 below.

Table 5.1. Fuzzy binary comparison matrix comparing criteria.

DM1	**C1**	**C2**	**C3**	**C4**	**C5**
C1	(1, 1, 1)	(0.333, 0.5, 1)	(2, 3, 4)	(3, 4, 5)	(0.333, 0.5, 1)
C2	(1, 2, 3)	(1, 1, 1)	(3, 4, 5)	(4, 5, 6)	(3, 4, 5)
C3	(0.20, 0.333, 0.5)	(0.20, 0.25, 0.333)	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)
C4	(0.20, 0.25, 0.333)	(0.166, 0.20, 0.25)	(0.20, 0.333, 0.5)	(1, 1, 1)	(0.20, 0.25, 0.333)
C5	(1, 2, 3)	(0.20, 0.25, 0.333)	(0.166, 0.20, 0.25)	(3, 4, 5)	(1, 1, 1)
DM2	**C1**	**C2**	**C3**	**C4**	**C5**
C1	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(4, 5, 6)	(3, 4, 5)
C2	(0.333, 0.5, 1)	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	(2, 3, 4)
C3	(0.20, 0.333, 0.5)	(0.333, 0.5, 1)	(1, 1, 1)	(5, 6, 7)	(3, 4, 5)
C4	(0.166, 0.20, 0.25)	(0.20, 0.25, 0.333)	(0.142, 0.166, 0.20)	(1, 1, 1)	(0.20, 0.333, 0.5)
C5	(0.20, 0.25, 0.333)	(0.20, 0.333, 0.5)	(0.20, 0.25, 0.333)	(2, 3, 4)	(1, 1, 1)

DM3	C1	C2	C3	C4	C5
C1	(1, 1, 1)	(3, 4, 5)	(2, 3, 4)	(4, 5, 6)	(5, 6, 7)
C2	(0.20, 0.25, 0.333)	(1, 1, 1)	(0.20, 0.333, 0.5)	(4, 5, 6)	(3, 4, 5)
C3	(0.25, 0.333, 0.5)	(2, 3, 4)	(1, 1, 1)	(5, 6, 7)	(4, 5, 6)
C4	(0.166, 0.20, 0.25)	(0.166, 0.20, 0.25)	(0.142, 0.166, 0.20)	(1, 1, 1)	(0.333, 0.5, 1)
C5	(0.142, 0.166, 0.20)	(0.20, 0.25, 0.333)	(0.166, 0.20, 0.25)	(1, 2, 3)	(1, 1, 1)

The geometric mean of binary comparison matrices blurred because there is more than one decision-maker. The fuzzy evaluation matrix in Table 5.2 was obtained by taking the geometric mean of the binary comparisons of the five main criteria.

Table 5.2. Binary comparison matrix of main criteria.

	C1	C2	C3	C4	C5
C1	(1, 1, 1,)	(1, 1.58, 2.46)	(2, 3, 4)	(3.63, 4.64, 5.64)	(1.70, 2.28, 3.27)
C2	(0.40, 0.63, 1)	(1, 1, 1)	(0.84, 1.38, 1.95)	(3.63, 4.64, 5.64)	(2.62, 3.63, 4.64)
C3	(0.21, 0.333, 0.5)	(0.51, 0.72, 1.10)	(1, 1, 1,)	(3.68, 4.76, 5.80)	(3.63, 4.64, 5.64)
C4	(0.176, 0.215, 0.275)	(0.17, 0.21, 0.27)	(0.16, 0.21, 0.27)	(1, 1, 1)	(0.23, 0.34, 0.55)
C5	(0.30, 0.43, 0.56)	(0.2, 0.27, 0.38)	(0.17, 0.21, 0.27)	(1.81, 2.88, 3.91)	(1, 1, 1)

Step 3: Once the comparison matrices are obtained in a blurred manner. In order to calculate the values of the criteria, firstly, the triangular fuzzy number values of each criterion must be obtained. For each criterion, there is an $l < m < u$ relationship between the triangular number values, which means the lowest probability (l), the absolute value (m), and the highest probability (u).

According to criteria 1; Calculation of l, m and u values are as follows

$l_{c1} = 1 \times 1 \times 2 \times 3.63 \times 1.70 = 12.342 = Ans^{0.2} = 1.653$

$m_{c1} = 1 \times 1.58 \times 3 \times 4.64 \times 2.28 = 50.145 = Ans^{0.2} = 2.187$

$u_{c1} = 1 \times 2.46 \times 4 \times 5.64 \times 3.27 = 181.477 = Ans^{0.2} = 2.829$

The calculations of the other criteria are made by the same procedure, and the values obtained as a result of the transactions are shown in Table 5.3.

Table 5.3: Fuzzy number values of main criteria.

	C1	**C2**	**C3**	**C4**	**C5**
l	1.653	1.261	1.074	0.256	0.511
m	2.187	1.710	1.395	0.317	0.587
u	2.829	2.195	1.782	0.405	0.652

In the calculation of the total sum of fuzzy numbers, the sum of the triangular fuzzy number values of all the criteria is taken.

L = $l_{c1} + l_{c2} + l_{c3} + l_{c4} + l_{c5} = 4.755$

M = $m_{c1} + m_{c2} + m_{c3} + m_{c4} + m_{c5} = 6.196$

U = $u_{c1} + u_{c2} + u_{c3} + u_{c4} + u_{c5} = 7.863o$

The equation that describes chapter 3 is used in the calculation of the inverse of the total ($\frac{1}{u}, \frac{1}{m}, \frac{1}{l}$). like this ($\frac{1}{7.863}$, $\frac{1}{6.196}$, $\frac{1}{4.755}$). The result obtained by calculating is (0.210; 0.161; 0.127) value was found in the vector.

C_1= (1.653; 2.187; 2.829) × (0.210; 0.161; 0.127) = (0.210; 0.352; 0.594)

C_2= (1.261; 1.710; 2.195) × (0.210; 0.161; 0.127) = (0.160; 0.275; 0.461)

C_3= (1.074; 1.395; 1.782) × (0.210; 0.161; 0.127) = (0.136; 0.225; 0.374)

C_4= (0.256; 0.317; 0.405) × (0.210; 0.161; 0.127) = (0.032; 0.051; 0.085)

C_5= (0.511; 0.587; 0.652) × (0.210; 0.161; 0.127) = (0.064; 0.094; 0.137)

Then, the Fuzzy weight of the criteria were calculated. Using formula (3.) l, m and u values then divided the number of consist n.

C_1= (0.210, 0.352, 0.594) = 0.385

C_2= (0.160, 0.275, 0.461) = 0.298

C_3= (0.136, 0.225, 0.374) = 0.245

C_4= (0.032, 0.051, 0.085) = 0.056

C_5= (0.064, 0.094, 0.137) = 0.098

The resulting weight vector is W' = (0.385, 0.298, 0.245, 0.056, 0.098). Found W′ weight vector value is divided by the sum of the normalized matrix of the criteria. The sum of the probability values obtained with the normalized matrix must be equal to 1. As a result of this process, the W matrix is obtained. Table 5.4 shows the exact weight values of the criteria.

Table 5.4. Weights of the criteria.

Criteria	**Weight**
Quality	0.355
Cost	0.275
Delivery	0.226
Service	0.053
Supplier Profile	0.091

The most important criteria among the chosen criteria are quality, followed by cost, delivery, supplier profile, and service, respectively. It indicates that the quality of the products is more important than all the other criteria.

Step 4: After the significance weights were calculated, the consistency of the data was tested with the Consistency Ratio C.R. values and the fuzzy significance weight values of the relevant table under each table and the actual weight values obtained as a result of rinsing process as a separate matrix.

Table 5.5. The group paired comparison matrix in which the criteria are compared.

	C1	**C2**	**C3**	**C4**	**C5**
C1	1	1.58	3	4.64	2.28
C2	0.63	1	1.38	4.64	3.63
C3	0.333	0.72	1	4.76	4.64
C4	0.215	0.21	0.21	1	0.34
C5	0.43	0.27	0.21	2.88	1
C.R	0.06				

Consistency ratios (C.R.) of comparison matrices is 0.06, which is lower than 0.1. It shows that the validity of the comparison matrices is good.

5.2. Solution by TOPSIS Method

When the weights of the criteria were determined by the FAHP method, the TOPSIS method was used to select the best supplier of the cement Manufacturers. When applying the TOPSIS method, decision-makers were asked to make a comparison according to Table 4.2. About the three cement suppliers determined to criteria since we have more than one decision-maker Geometric means used to create the TOPSIS decision matrix.

Table.5.6. Formation of decision matrix.

	C1	C2	C3	C4	C5
A1	5.67	6	5	4.67	6.33
A2	4.33	5.33	5	3.33	4.67
A3	3.67	4.33	4.67	3.67	4.33

Step 2. A vector for matrix (R) normalization formula is used. The squares of each a_{ij} value after the decision matrix is created. The column totals obtained from the sum of these values were calculated and each a_{ij} the value was divided by the square root of the column total to which it belongs, and normalization was performed. When performing the normalization process, formula (3.14) is used.

Table.5.7. Normalized decision matrix.

	C1	C2	C3	C4	C5
A1	0.707	0.659	0.594	0.687	0.705
A2	0.539	0.583	0.585	0.488	0.518
A3	0.455	0.472	0.551	0.537	0.483

Step 3. After finding the normalized decision matrix, Weighted Standard Decision Matrix (V) was formed. The criterion weights obtained from the FAHP method were used to calculate the V matrix. Found Weighted was given in Table 5.8.

Table 5.8: Weighted decision matrix.

	C1	C2	C3	C4	C5
A1	0.251	0.181	0.133	0.035	0.063
A2	0.191	0.161	0.13	0.025	0.047
A3	0.162	0.130	0.124	0.027	0.043

Step 4. After finding the weighted Standard Decision Matrix, ideal A^{+} and negative ideal A^{-} solutions were formed by using Formula (3.20) and Formula (3.21).

The solutions created are shown in Table 5.9. Then, the ideal positive and negative separation criteria were calculated by using Formula (3.18) and Formula (3.19). The calculated separation criteria are shown in Table 5.6.

Table 5.9: Ideal (A +) and negative ideal (A-) solution sets.

S^{+}	0.251378	0.130905	0.13344	0.035452	0.063989
S^{-}	0.162708	0.181395	0.124633	0.025279	0.043771

Step 5, 6. After calculating the ideal and negative separation criteria, these values were replaced by Formula (3.20) and the relative proximity of the alternatives to the ideal solution C_i was calculated. According to the Topics method, the alternatives are listed starting from the largest C_i value. Table 5.10 shows the C_i values of the alternatives and their place in the ranking.

Table.5.10. The distances of suppliers from fuzzy positive and negative ideal solutions and the closeness coefficient.

	S^{+}	S^{-}	C_i	Rank
A1	0.0504	0.0919	0.6458	1
A2	0.0694	0.0368	0.3465	3
A3	0.0916	0.0505	0.3553	2

According to Table 11 C_i values, A1 “Supplier” which takes the highest value is treated as the best alternative, and A2 “Supplier” which takes the lowest value is determined as the worst alternative.

5.3. Solution By ELECTRE Method

In the solution made by the ELECTRE III method, the data collected in the first two parts of the survey and criterion weights calculated by the Fuzzy AHP method were used. In the scope of this method, we combine the subjective judgment of decision-makers and objective data taken from suppliers.

Step 1, 2. The ELECTRE method is formed, just like the TOPSIS method in steps 1 and 2. The standard matrix and normalized decision matrix values were created. In this method, the second and third criteria, which are Cost (C2) and Delivery “lead time” (C3) actual data taken from suppliers is used. While other criteria decision-makers’ comparison matrix, according to Table 5.2. is used. The decision matrix of the whole criteria is shown in Table 5.11, as determined. After the decision matrix is formed the normalized decision matrix required for the 2nd step of the Electre method process is given in Table 5.12 below.

Table 5.11. Group evaluation matrix.

	C1	**C2**	**C3**	**C4**	**C5**
A1	5.64	3920	23	4.64	6.31
A2	4.30	2800	30	3.30	4.64
A3	3.63	2240	24	3.63	4.30

Table 5.12. Normalization of the decision matrix.

	C1	**C2**	**C3**	**C4**	**C5**
A1	0.7077	0.0602	0.00097	0.6869	0.7061
A2	0.5400	0.0843	0.00074	0.4886	0.5189
A3	0.4555	0.1054	0.00093	0.5378	0.4817

Step 3. In this step, the Weighted Decision Matrix was created. The normalization decision matrix in Table 5.12 is multiplied by the criterion weights obtained from the FAHP method in table 5.4.

Table 5.13. Weighted decision matrix.

	C1	**C2**	**C3**	**C4**	**C5**
A1	0.25123	0.01656	0.00022	0.0364	0.06426
A2	0.19172	0.02319	0.00017	0.0259	0.04722
A3	0.1617	0.02899	0.00021	0.0285	0.04383

Step 4. For each alternative comparison matrix cluster (C) and mismatch (D) clusters are created using formula 3.8 and formula 3.9.

Here, the supplier selection is made, where the criteria value 1, 3, 4, 5, which are used in the evaluation of suppliers, are expected to be large and 2, criteria will be small.

Table 5.14. Concordance and discordance sets.

C (1,2)	(1,3,4,5)	**D (1,2)**	(2)
C (1,3)	(1,3,4,5)	**D (1,3)**	(2)
C (2,1)	(2)	**D (2,1)**	(1,3,4,5)
C (2,3)	(1,5)	**D (2,3)**	(2,3,4)
C (3,1)	(2)	**D (3,1)**	(1,3,4,5)
C (3,2)	(2,3,4)	**D (3,2)**	(1,5)

Step 5. As shown in Formula 3.10 and Formula 3.11, Concordance (c_{ki}) and Discordance were calculated by using harmony and incompatibility sets.

Other compliance clusters are calculated with "Formula 3.10" and shown in the table below.

According to this, C (1,2) = (1,3,4,5) harmony sets.

$C_{12} = \sum W_j = W_1 + W_3 + W_4 + W_5$ = 0.355+0.226+0.053+0.091= 0.725 found.

The other incompatibility indexes are calculated using Formula 3.11 and shown in the table below.

D (1,2) = (2) for the set of incompatibilities.

The other incompatibility indexes are calculated using "Formula 3.11" and shown in the table below.

Table 5.15. Concordance and discordance comparisons.

C (1,2)	0.725	**D** (1,2)	0.11
C (1,3)	0.725	**D** (1,3)	0.13
C (2,1)	0.275	**D** (2,1)	1.00
C (2,3)	0.446	**D** (2,3)	1.00
C (3,1)	0.275	**D** (3,1)	1.00
C (3,2)	0.554	**D** (3,2)	0.19
Total C	3.00	Total D	3.44
C (Average)	0.50	D (Average)	0.57

Step 6. To find the Concordance (C) and Discordance matrices, the average of C and D is first taken.

If c (1,2) is greater than or equal to the average of c, e (1,2) = 1 is Yes, If not, 0 is written.

If the values of d (1,2) are less than the average of d, f (1,2) = 1 is Yes, If not, 0 is written.

Accordingly, the matrix C and D is as the below table 5.16.

Table 5.16. Concordance and discordance indexes.

$C_{(p,q)}$	$C_{(p,q)} \geq C_{ave}$	$D_{(p,q)}$	$D_{(p,q)} \leq D_{ave}$	$A_p \rightarrow A_q$
C (1,2)	YES	**D** (1,2)	YES	1→ 2
C (1,3)	YES	**D** (1,3)	YES	1→ 3
C (2,1)	NO	**D** (2,1)	NO	NO
C (2,3)	NO	**D** (2,3)	NO	NO
C (3,1)	NO	**D** (3,1)	NO	NO
C (3,2)	YES	**D** (3,2)	YES	3→ 2

Step 7. As shown in figure 5.1, ‘Alternative ‘A1’ has no incoming arrows that indicate it is the best choice among the suppliers, and ‘Alternative ‘A2’ is the worst choice.

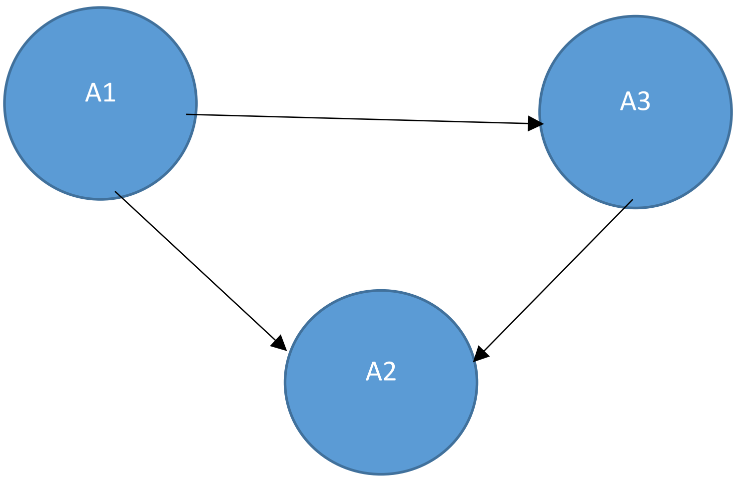

Figure 5.1. Core Solution for supplier selection

6. RESULT AND DISCUSSION

The selection of supplier process is one of the most critical problems in supply chain management. In the construction sector, the correct selection of suppliers affects the success of construction projects. Their completion at the expected quality level and within the calculated budget depends, to a large extent, on the correct procurement of the materials required for the project. Therefore, the supplier selection process is essential for companies and requires tremendous work.

In the decision-making process, first of all, there must be a purpose, alternatives, and criteria suitable for the purpose set. The alternative should be more than one, which should increase the likelihood of the decision-maker to evaluate the options. Otherwise, if there is only one alternative, the decision-making event will not take place, as there is no other choice for the decision-maker. The criteria to be considered when evaluating the alternatives is one of the most critical issues and must be determined in accordance with the company's goals.

This study is proposed a two-stage multi-criteria decision-making model in order to determine the best cement supplier, a series of procedures have been carried out for the selection of cement suppliers, which is an essential cost element for Alburuuj Construction Company operating in Somalia and Djibouti. In this case, multiple criteria decision making is used, and alternatives are evaluated according to the specified criteria to make the correct decision.

First, the purchasing department of the Company, which is responsible for supplying nominates three Turkish cement manufacturers, the names of the suppliers were not shared to prevent unfair competition. In order to evaluate these alternatives, the decision-makers consist of three, two from the purchasing department, and one who is a civil engineer at the company were determined criteria considered necessary for the company. In the evaluation phase, the decision-makers were asked to evaluate supplier according to each criteria. In the second part, decision-makers were asked to make pair-wise comparisons matrices of evaluation criteria according to the relative importance scale given in the survey.

Within the scope of this thesis, five multi-criteria decision-making methods are explained first. Which are AHP, ANP, ELECTRE III, TOPSIS, and Fuzzy AHP, three of these methods are used for the solution of this study. Each method is described step by step before proceeding with case analysis.

In this study, The Fuzzy AHP method is used to determine the weight of criteria while the TOPSIS and ELECTRE methods are used to select the best supplier among the suppliers. In the first stage of the study, the Fuzzy AHP method determines the weights of the criteria as a result of comparisons, the consistency of the matrices filled by decision-makers was tested. Consistency ratios (C.R.) of all comparison matrices are 0.06 lower than 0.1, which indicates the validity of the comparison. The most important criteria among the chosen criteria are quality, followed by cost, delivery, supplier profile, and service, respectively. It indicates that the quality of the products was more important than the other criteria.

The first solution was made by the TOPSIS method after the criteria weights were determined by the FAHP method. The decision matrix was formed used geometric mean since there is more than one decision-maker. The values obtained by normalizing the decision matrix are multiplied by criterion weights. The cost criteria in the evaluation are negative since we prefer low cost while calculating the maximum or minimum values of the criteria. The distances of the alternative suppliers to the positive ideal solution and the negative ideal solution were measured, and the suppliers were ranked according to their relative proximity to the ideal solution. As a result, the cement supplier representing A1 is the best in the ranking and should be the first choice over the other suppliers while the A2 supplier is the lowest in the ranking.

The second solution was made by the ELECTRE method. In this method, the same as the previous one, the criteria weights obtained by the FAHP method and the evaluation matrix data in which the suppliers are evaluated according to the criteria were used. Exceptional in the evaluation matrix, actual data from the supplier at the criteria of the total cost (C2) and Delivery "lead time" (C3) are used. Other criteria are based on evaluations made by the decision-makers on a very bad-very good scale. Since the real data of alternatives are used in this method, it gives more satisfactory results compared to the order obtained from the TOPSIS method. In this solution, A1 alternatives are the best, and A2 alternative was the worst.

The problem of cement supplier selection, weighted by the Fuzzy AHP method, and ranking the alternatives by TOPSIS and ELECTRE method. The most suitable supplier is “Alternative-A1”, and “Alternative-A2” was chosen the worst supplier in both methods solution. As more than one department in the company participated the assessment, the result is considered justified.

This study provides the purchasing department with a tool that facilitates the decision-making for an extremely critical process, such as the selection of steel, which directly affects the performance of the construction projects. In future studies, different multi-criteria decision-making methods can be applied while used both subjective and objective judgment of the decision-makers to obtain more accurate results.

REFERENCES

Akintoye, A., 1995. Just-in-Time Application and Implementation for Building Material Management, Construction Management and Economics, 13(2), 105–13.

Anagnostopoulos, C., Tsekouras, G. E., Gavalas D., Dafhi E., 2007. Classification of Web Documents Using Fuzzy Logic Categorical Data Clustering. IFIP International Federation for Information Processing 247, 93–100.

Aretoulis, G.N., Kalfakakou, G.P., Fevronia, Z., 2010. Construction Material Supplier Selection under Multiple Criteria, Operational Research 10(2), 209–30.

Benton, W.C. Jr., McHenry, L.F., 2009. Construction Purchasing & Supply Chain Management. McGraw-Hill Companies. 257p, New York.

Buckley, J.J., 1985. Fuzzy Hierarchical Analysis, Fuzzy Sets and Systems 17(3), 233–47.

Cengiz, A. E., Aytekin, O., Ozdemir, I., Kusan, H., Cabuka, A., 2017. A Multi-Criteria Decision Model for Construction Material Supplier Selection. Procedia Engineering 196(June), 294–301.

Chai, J., Liu, J.N.K., Ngai, E.W.T., 2013. Application of Decision-making tTechniques in Supplier Selection: A Systematic Review of Literature, Expert Systems with Applications, 40, 3872–3885.

Chen, X., Xue, F.Z., Zhang, Y., 2006. Research on Building Engineering Materials Supplier Selection Based on ANP Method. Key Engineering Materials 474–476, 2089–94.

Chou, S.Y., Chang, Y.H., 2008. A Decision Support System for Supplier Selection Based on a Strategy-Aligned Fuzzy SMART Approach. Expert Systems with Applications 34(4), 2241–53.

Dağdeviren, M., Serkan, Y., Kilinç, N., 2009. Weapon Selection Using the AHP and TOPSIS Methods under Fuzzy Environment. Expert Systems with Applications 36(4), 8143–51.

Dickson, G.W., 1966. An analysis of vendor selection systems and decisions, Journal of Purchasing 2/1, 5-17.

Donyavi, S., Flanagan, R., 2009. The Impact of Effective Material Management on Construction Site Performance for Small and Medium-Sized Construction Enterprises. School of Construction Management and Engineering, University of Reading.

Eshtehardian, E., Ghodousi, P., Bejanpour, A., 2013. Using ANP and AHP for the Supplier Selection in the Construction and Civil Engineering Companies; Case Study of Iranian Company, KSCE Journal of Civil Engineering 17(2), 262-270.

Guan, J., Zhang, Z., Wu, Y., 2013. Using the Fuzzy Matter-element Model and Triangular Fuzzy AHP Method to Select the International Construction Project Material Suppliers, Applied Mechanics, and Materials, 357-360, 2277-2281.

Gökalp, B., Soylu, B., 2010. Tedarikçinin Süreçlerini İyileştirme Amaçlı Tedarikçi Seçim Problemi., Endüstri Mühendisliği Dergisi YA/EM 2010 Özel Sayısı, 23(1), 4-15.

Gökhan Y, M., Görener A., 2016. Decision Making for Company Acquisition by ELECTRE Method. International Journal of Supply Chain Management 5(1), 75–83.

Guner, M., Yücel, O., 2005. Environmental Protection and Waste Management in the Textile and Apparel Sectors. Journal of Applied Sciences, 5, 1843-1849.

Ho, W., Xiaowei X., Dey P., 2010. Multi-Criteria Decision Making Approaches for Supplier Evaluation and Selection: A Literature Review. European Journal of Operational Research 202(1), 16–24.

Ho, C., Nguyen, P.M., Shu, M.H., 2007. Supplier Evaluation and Selection Criteria in the Construction Industry of Taiwan and Vietnam, Information and Management Sciences, 18(4), 403-426.

Ibn-Humaid, N.T., 2002. A Comparative Evaluation of Construction and Manufacturing Materials Management. International Journal of Project Management 20(4), 263–70.

Junior, F.R.L., Osiro, L., Carpinetti, L.C.R., 2014. A Comparison between Fuzzy AHP and Fuzzy TOPSIS Methods to Supplier Selection. Applied Soft Computing Journal 21, 194–209.

Kahraman, C., Cebeci, U., Ulukan, Z., 2003. Multi-criteria supplier selection using fuzzy AHP, Logistics Information Management, 16(6), 382-394.

Krishnendu, M.J., 2017. Supplier Selection: An MCDA-Based Approach Studies in Systems, Decision, and Control. The Springer Nature, 144p, New Delhi.

Krohling, R.A., Campanharo, V.C., 2011. Fuzzy TOPSIS for Group Decision Making: A Case Study for Accidents with Oil Spill in the Sea. Expert Systems with Applications 38(4), 4190–97.

Laarhoven, P.J.M., Pedrycz, W., 1983. A fuzzy extension of Saaty’s priority theory, Fuzzy Set Systems 11, 229–241.

Marlene, J.S. 2003. A Case Study Approach To The Suppliers Selection Processes, University Of Puerto Rico, Industrial Engineering Department, M.Sc. Thesis, 128p, Mayaguez.

Monczka, R.M., Trent, R.J., Handfield, R.B., 2002. Purchasing and Supply Chain Management, South-Western College, 800p, Cincinnati.

Monczka, R., Handfield, R.B., Giunipero, L.C., Patterson, J.L., (Ed.4). 2008. Purchasing and Supply Chain Management, South-Western College / West, 841p, Mason.

Nihan, Ç.D., Yücenur, G.N., 2011. The Cruise Port Place Selection Problem with Extended VIKOR and ANP Methodologies under Fuzzy Environment. Proceedings of the World Congress on Engineering, WCE 2011 2, July 2011, 1128–33.

Önüt, S., Kara S.S., Işik E., 2009. Long Term Supplier Selection Using a Combined Fuzzy MCDM Approach: A Case Study for a Telecommunication Company. Expert Systems with Applications 36(2) 3887–95.

Patil, S., Adavi, P.R., 2012. A Survey Study of Supplier Selection Issues in Construction Supply Chain. International Journal of Engineering Research and Application 2(5), 1806–1809.

Paleie, I., Lalic, B., 2009. Analytical Hierarchy Process as a Tool for Selecting and Evaluating Projects. International Journal of Simulation Modelling 8(1), 16–26.

Pagell, M., Fugate, B., Flynn, B., 2015. Journal of SS & ISI Journal Citation Report Ranking: 10/192 (Management) Online ISSN: 1745-493X.

Polat, G., Arditi, D., 2005. The JIT Materials Management System in Developing Countries. Construction Management and Economics 23(7), 697–712.

Plebankiewicz, E., Kubek, D., 2015. Multi-criteria Selection of the Building Material Supplier Using AHP and Fuzzy AHP. Journal of Construction Engineering and Management 142(1), 04015057.

RADZİSZEWSKA-ZİELİNA, E., 2010. Methods for Selecting The Best Partner Construction Enterprise in Terms of Partnering Relations, Journal of Civil Engineering and Management 16(4), 510-520.

Rezaie, K., Ramiyani S.S., Nazari-Shirkouhi S., Badizadeh A., 2014. Evaluating Performance of Iranian Cement Firms Using an Integrated Fuzzy AHP-VIKOR Method. Applied Mathematical Modelling 38(21–22), 5033–46.

Rouyendegh, B.D., Yildizbasi, A., Arikan Ümmühan, Z.B., 2018. Using Intuitionistic Fuzzy TOPSIS in Site Selection of Wind Power Plants in Turkey. Advances in Fuzzy Systems 2018.

Roy, B., 1996. Multicriteria Methodology for Decision Aiding. Springer Science + Business Media or Springer. 293p, Columbus.

Saaty, T.L., Vargas, L.G., 2008. Hierarchical Analysis of Behavior in Competition: Prediction in Chess. Behavioral Science, 25(3), 180–91.

Saaty, T.L., 2004. Decision Making the Analytic Hierarchy and Network Processes AHP/ANP. Journal of Systems Science and Systems Engineering 13(1), 1–35.

Safa, M., Shahi, A.H., Hipel, K., 2014. Supplier Selection Process in an Integrated Construction Materials Management Model. Automation in Construction 48, 64–73.

Sang-Chul, K., Kim, Y-w., 2014. Computerized Integrated Project Management System for a Material Pull Strategy. Journal of Civil Engineering and Management 20(6), 849–63.

Sarkis, J., Talluri S., 2002. A Model for Strategic Supplier Selection. Journal of Supply Chain Management 38(4), 18–28.

Sevkli, M., 2010. An Application of the Fuzzy ELECTRE Method for Supplier Selection. International Journal of Production Research 48(12), 3393–3405.

Soner, S., Önüt, S., 2006. Multi-Criteria Supplier Selection: An Electre-AHP Application, Sigma Journal of Engineering and Natural Sciences, 2016(4).

Supçiller, A., Çapraz O., 2011. AHP-TOPSIS Yöntemine Dayalı Tedarikçi Seçimi Uygulamasi. Ekonometri ve İstatistik e-Dergisi 13(13), 1–22.

Schneider, M., Romer, M., Tschudin, M., Bolio, H., 2011. Sustainable Cement Production-Present and Future. Cement and Concrete Research 41(7), 642–50.

Shengbin, Z., Chunsheng, S., 2009. Supplier Selection Mode of Aerospace Batch Production Based on Multiple Objective Programming. International Conference on Multimedia Information Networking and Security, IEEE.

Shih, H. Sh., Wang, C.H., Lee, E. S., 2004. A Multiattribute GDSS for Aiding Problem-Solving." Mathematical and Computer Modelling 39(11–12), 1397–1412.

Shyjith, K., Ilangkumaran, M., Kumanan, S., 2008. Multi-Criteria Decision-Making Approach to Evaluate Optimum Maintenance Strategy in the Textile Industry. Journal of Quality in Maintenance Engineering 14(4), 375–86.

Schramm, F., Morais, D.C., 2013. A Bilateral and Multi-Issue Negotiation Framework to Support a Supply Chain of Construction Industry. Pesquisa Operacional 33(3), 491–512.

Tam, M., Tummala, M.R., 2001. An Application of the AHP in Vendor Selection of a Telecommunications System. Omega 29(2): 171–82.

Triantaphyllou, E., Parlos, P.M., 2000. Multi-Criteria Decision Making Methods: A Comparative Study. Springer, 320p, Baton Rouge.

Thiruchelvam, S., Tookey J. E., 2011. Evolving Trends of Supplier Selection Criteria and Methods. International Journal of Automotive and Mechanical Engineering 4(1), 437–54.

Verma, R., Pullman M. E., 1998. The Scholarly Commons an Analysis of the Supplier Selection Process. Omega 26(6), 739–50.

Vincke, P., 1992. Multicriteria Decision-Aid. John Wiley & Sons, Inc. 174p, Hoboken.

Weber, A.C., Current, J.R., Benton, W.C. 1991. Vendor selection criteria and methods, European Journal of Operational Research 50, 2-18, North-Holland.

Zeydan, M., Çolpan C., Çobanoġlu C., 2011. A Combined Methodology for Supplier Selection and Performance Evaluation. Expert Systems with Applications 38(3), 2741–51.

Zhongyou, X., 2012. Study on the Application of TOPSIS Method to the Introduction of Foreign Players in CBA Games. Physics Procedia 33, 2034–2039.

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