T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES

MULTIPLE CRITERIA DECISION MAKING (MCDM) IN SUPPLIER SELECTION

Seda ŞEN

THESIS

FOR THE DEGREE OF MASTER OF SCIENCE
IN
INDUSTRIAL ENGINEERING

SUPERVISOR
Asst. Prof. Dr. Bahar SENNAROĞLU

ISTANBUL 2009

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ACCEPTANCE AND APPROVAL DOCUMENT

"MULTIPLE CRITERIA DECISION MAKING (MCDM) IN SUPPLIER SELECTION"

The jury established by the Executive Board of the *INSTITUTE FOR GRADUATE STUDIES IN PURE AND APPLIED SCIENCES* on .... (Resolution no: ....) has accepted Miss Seda ŞEN's thesis titled **"MULTIPLE CRITERIA DECISION MAKING (MCDM) IN SUPPLIER SELECTION"** as Master of Science thesis in Industrial Engineering.

Advisor :(Asst. Prof. Dr. Bahar SENNAROĞLU)(Marmara University)
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2. Member of the jury:(Prof. Dr. Ercan ÖZTEMEL)(Marmara University)
3. Member of the jury:(Asst. Prof. Dr. Ufuk KULA)(Sakarya University)

Date : ....

APPROVAL

Miss Seda ŞEN has satisfactorily completed the requirements for the degree of Master of Science in Industrial Engineering at Marmara University. The Executive Commitee approves that she be granted the degree of Master of Science on .... (Resolution no: ....)

DIRECTOR OF THE INSTITUTE
Prof. Dr. Sevil ÜNAL

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ÖZET

TEDARİKÇİ SEÇİMİNDE ÇOK KRİTERLİ KARAR VERME

Günümüzün küreselleşen sanayi ve ticari iş çevrelerinde, bütün organizasyonların amacı; müşteri isteklerini müşteri beklentileri sürekli ve hızla artarken karşılayabilmek ve rekabetçi kalabilmektir. Bu amaçlarını gerçekleştirmek için, firmalar birçok kısıtı aynı anda göz önünde bulundurmalıdırlar. Firmalar istenen ürün ve/veya hizmetleri müşterilerine daha ucuz, daha hızlı ve daha kaliteli sunabilmek için bir yarış içerisindedirler. Ancak bunu tek başlarına gerçekleştiremeyecekleri aşikârdır. Bu noktada başarılı olmak için; tedarikçiler, perakendeciler, toptancılar, dağıtım merkezleri ve müşterileri kapsayan tedarik zincirleri sürecin bir parçası olmakta ve tedarik zinciri yönetim sistemince de desteklenmektedirler.

Tedarik zinciri yönetimi zorlu ortam ve rekabet koşullarına karşı ayakta kalabilmek için tedarik zincirlerinin tüm üyelerine ortak fayda oluşturmayı önerir. Bu sebeple, başarılı bir tedarik zincirine ulaşmada etkili bir satın alma fonksiyonu çok önemlidir. Satın alma maliyetlerini düşürmek ve rekabet gücünü geliştirmek için doğru tedarikçilerin seçimi ve değerlendirilmesi şarttır. Bu yüzden, rekabet gücünü korumak ve sürdürülebilir gelişmeyi sağlamak için tedarikçi seçimi süreci gereklidir.

Bu çalışmanın amacı, tedarikçi seçimi için uygun çok kriterli karar verme metotlarını belirlemektir. Ancak hali hazırda farklı kullanım alanları olan birçok metot vardır ve bu metotların buna göre seçilmeleri gerekmektedir. Çalışmanın uygulama bölümünde düşük voltajlı şalt aletleri imalatçısı olan firmanın verileri analiz edilerek, en iyi tedarikçiyi belirlemek amacıyla uygun çok kriterli karar verme metotlarından AHP, TOPSIS ve ELECTRE uygulanmıştır. Tedarikçilerin karşılaştırılmasından sonra, ileride kurulacak olan tedarik zinciri sisteminde işbirliği içinde çalışılacak en iyi alternatif seçilmiştir.

Temmuz, 2009 **Seda ŞEN**

ABSTRACT

MULTIPLE CRITERIA DECISION MAKING (MCDM) IN SUPPLIER SELECTION

In today's global industrial and commercial environment all businesses aim to stay competitive and meet customer requirements while customers' expectations are increasing continuously and rapidly. In order to achieve these aims, companies should take into consideration a lot of constraints at the same time and use some techniques. Companies are in a competition to present the desired products and/or services to their customers cheaper, faster and more of high quality. So, it is obviously seen that all of them can not be done by alone. At that point, Supply Chains; including suppliers, retailers, warehouses, distribution centers and customers, become a part of these processes in order to be successful and Supply Chains has to be supported by Supply Chain Management.

Supply Chain Management proposes forming mutual benefits for all members of the Supply Chains to survive to the tough conditions of the environment and the competition. For this reason, an effective purchasing function is very important for attaining a successful supply chain. To reduce the purchasing costs and improve competitiveness, evaluating and selecting the right suppliers is considerably essential. So, supplier selection process is very necessary to keep the competitiveness and sustainable development.

The aim of this study is to determine the appropriate multiple criteria decision making (MCDM) methodologies for the supplier selection. However, there are many different methodologies with different uses and they should be selected accordingly. In the implementation section of the study a low voltage contactor switch devices manufacturing firm's data were analyzed and appropriate multiple criteria decision making methods such as AHP, TOPSIS and ELECTRE were implemented with the aim of determining the best supplier. After the comparisons of the suppliers, the best supplier was selected to work collaboratively in a supply chain in the future.

July, 2009 **Seda ŞEN**

LIST OF ABBREVIATIONS

ABC	: Activity-Based Costing
AHP	: Analytic Hierarchy Process
AI	: Artificial Intelligence
ANP	: Analytic Network Process
CA	: Cluster Analysis
CBR	: Case-Based Reasoning
CI	: Consistency Index
CR	: Consistency Ratio
DEA	: Data Envelopment Analysis
DMU	: Decision Making Units
ELECTRE	: Elimination and Choice Translating Reality English
FST	: Fuzzy Sets Theory
JIT	: Just in Time
ILP	: Integer Linear Programming
LP	: Linear Programming
MAUT	: Multi – Attribute Utility Theory
MCDM	: Multiple Criteria Decision Making
PCA	: Principal Component Analysis
R&D	: Research and Development
RI	: Random Index
SC	: Supply Chain
SCM	: Supply Chain Management
TCO	: Total Cost of Ownership
TOPSIS	: Technique for Order Preference by Similarity to Ideal Solution
TQM	: Total Quality Management

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CHAPTER I: INTRODUCTION

Nowadays, instead of companies supply chains are competing in international markets. Supply chain provides to minimize cost of firms and by the way to take advantages in competitiveness. Therefore, supply chain is one of the most important relationship types between firms and ancillary industries.

As a general definition, a supply chain is a series of activities which lies to corporate functions from ordering and supplying of raw materials to manufacturing products and the distribution & transmission to customers. Supply chain management uses advanced technology, information management and operations research mathematics for the purpose of planning and controlling of the extended factors component which will satisfy customers by representing a product or a service. Even though supply chain management technology is so complicated, the most important concepts and the working techniques of supply chain management are pretty clear. [1]

Supplier selection is an important purchasing activity for many firms. Today's consumers demand cheaper, high quality products, on-time delivery and excellent after-sale services. Hence, companies are under intense pressure to cut product and material costs while maintaining a high level of quality and after-sale services. Achieving this starts with supplier selection. Supplier selection and evaluation is the process of finding the suppliers being able to provide the buyer with the right quality products and/or services at the right price, at the right quantities and at the right time [2, 3]. Evaluation and selection of suppliers is a typical multiple criteria decision making (MCDM) problem involving multiple criteria that can be both qualitative and quantitative. Therefore, an efficient supplier selection process needs to be in place and of paramount importance for successful supply chain management. It begins with the realization of the need for a new supplier; determination and formulation of decision criteria; pre-qualification; final supplier selection; and the monitoring of the suppliers selected [4]. The main purpose of this study is to provide an extensive literature review and critique of the studies related to various aspects of supplier selection processes.

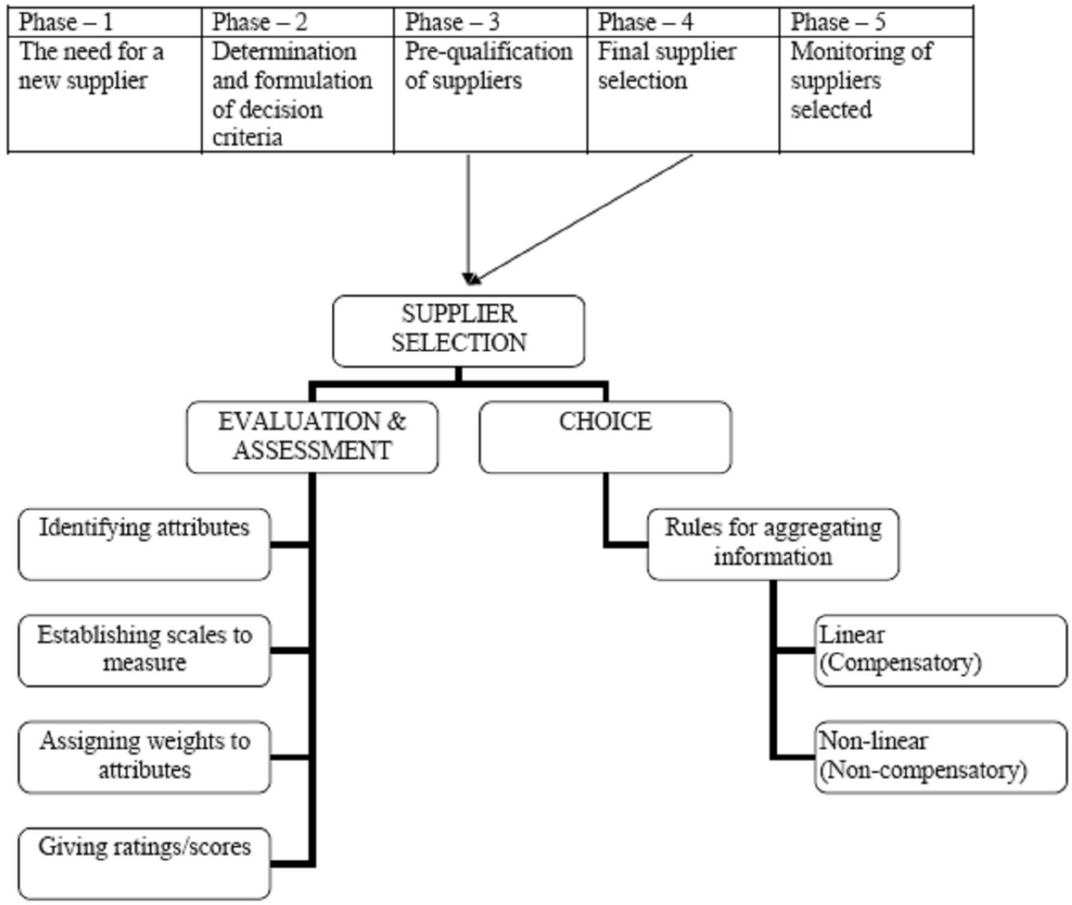

Figure I-1 Phases of Supplier Selection Process and Tasks in Supplier Selection (Sonmez, 2006) [4]

Today's organizations have to work with a lot of suppliers to sustain their activities. It is a hard decision problem to choose suppliers from a group of candidates. For this reason; firm managers need accurate, reliable data and forecasts to make decisions. In very common meaning, a decision problem can be defined as a selection of the most appropriate alternative according to at least one objective or criterion from a set of alternatives. So the elements of a decision problem are decision maker, alternatives, criteria, results, environment and the priorities of the decision maker. [5, 6]

In this study, supplier selection subject which is entirely strategic decisions will be investigated. Supplier selection is a decision problem which can be solved by usage of one of the appropriate MCDM techniques, needs to provide more than one constraints at the same time [7]. For suppliers' information, some data will be taken from a manufacturing firm in Adapazari. With the guidance of these suppliers' information, some strategies will be developed and some solution suggestions will be represented to the firm. That is why; some studies and methods will be investigated for various approaches of decision problems in the literature survey primarily. Afterwards, the proper methods for the firm will be determined and then firm's supplier selection problem will be remedied.

CHAPTER II: LITERATURE REVIEW

II.1 DEFINITION OF SUPPLY CHAIN MANAGEMENT

There are numerous definitions of Supply Chain Management (SCM) in the literature. As defined by Ganeshan and Harrison, A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers. Supply chains exist in both service and manufacturing organizations, although the complexity of the chain may vary greatly from industry to industry and firm to firm. [8]

A Supply Chain is a network of organizations that are involved in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer. Supply chain management (SCM) is an integrated and process-oriented approach to the design, management, and control of the supply chain (SC); its aim is to produce value for the customer by improving customer services and lowering costs. [9]

Supply Chain Management (SCM) has received recently considerable attention in both academia and industry. The major aims of SCM are to reduce SC risk, reduce production costs, maximize revenue, improve customer service, optimize inventory levels, business processes, and cycle times, and resulting in increased competitiveness, customer satisfaction and profitability. [10]

Recently, SCM is becoming a hot issue in international academic circle. Here goes the definition of supply chain and supply chain management given by American Supply Chain Association. The supply chain— a term now commonly used internationally—encompasses every effort involved in producing and delivering a final product or service, from the supplier's suppliers to the customer's customers. The core of SCM is a decision-making problem. Suppliers are very important in the supply chain because their performances not only influence the benefits of the core enterprise in the supply chain but also determine whether win-win can be achieved or not. Therefore, supplier selection is both a key problem and a tough one. We believe that by using a class of technique we may solve the key and tough problems of supplier selection in SCM. [11]

From an industrial point of view, SCM involves a variety of management and technical issues, starting from the distributed design of products and processes, the decentralized but efficiently coordinated production of goods through suppliers contracting and outsourcing, the coordination of third-party logistics and multi-location inventories. [12]

II.2 SUPPLIER SELECTION

When we consider the truth of competition between companies from now on is in Supply Chains, it is obvious that power of the companies not only depend on their own performance. Performances of all the units in supply chains affect the company's success. Selection and evaluation of the suppliers which have a crucial significance in supply chains, is one of the important topics at this juncture. The importance which is given to the supplier selection provides to develop the long-term relationships with suppliers which are not only depended on the price of supplied product. These long-term relationships influence the company's competitiveness power in a positive way.

Supplier selection, the process of finding the right suppliers who are able to provide the buyer with the right quality products and/or services at the right price, at the right time and in the right quantities, is one of the most critical activities for establishing an effective supply chain. On the other hand, it is a hard problem since supplier selection is typically a multi criteria group decision-making problem involving several conflicting criteria on which decision maker's knowledge is usually vague and imprecise. [10]

Supplier selection is one of the most important elements of supply chain management. This function involves evaluation of many factors such as, cost of parts/materials, size of order, quality, and delivery performance. Therefore, this problem is categorized as multi-criteria decision making problems. [13]

Supplier selection in industry is a cross-functional, group decision-making problem, frequently solved by a non-programmed decision-making process, and involving long-term commitment for a company. A decision group includes many decision makers/experts such as the research and development (R&D), engineering, quality assurance, and financial personnel. In reality, the importance (or reliability) of individual decision makers may not be equal or uniform. The final outcome of the group decision-making process may be significantly influenced by the degree of importance of such individual decision makers. The growing importance of cross-functional team involvement in supplier selection and evaluation significantly influences overall buying firm performance. Therefore, an effective method of aggregating the various influences of individual opinions, evaluations, and ratings from multiple decision makers must be identified and applied to supplier selection problems. [14]

Any decision process can be divided into two distinct phases. Having determined the assessing criteria for measuring the performance of various alternatives of the problem, the first phase is the evaluation phase that comprises the steps under which various alternatives of the problem are evaluated through the pre-determined criteria. Based on the literature, this step is mostly dependent on experts and their expertise to quantitatively and/or qualitatively evaluate each alternative under each criterion. The result of this phase is usually a matrix, called decision matrix, comprised of the alternatives as its rows and the criteria as its columns. Its cells are the performances of alternatives under each criterion. Having determined the decision matrix for a problem, the second phase of the decision problem can be initialized consisting of the ranking and selecting steps. Based on the decision matrix, gained through the first phase, the various alternatives is ranked and based on this ranking the best/worst alternative is selected. Doing so, different decision-making methods have been proposed which are comprised of the MCDM literature. MCDM is one of the most widely used decision methodologies in the sciences, business, government and engineering worlds. MCDM methods can help to improve the quality of decisions by making the decision-making process more explicit, rational, and efficient. Nowadays, outsourcing is a popular business strategy and requires close attention to the outsourcing contract selection process. The outsourcing contract price is no longer the only aspect to be taken into account regarding decisions on outsourcing selection. That is, different aspects have to be considered by the decision maker, such as cost of the contract and performance of the service. In general, delivery time is a formal commitment written in the outsourcing contract. Normally a different delivery time implies a specific condition of resources, personal skills and service availability and may result in a different cost. The outsourcing contract is assumed to have basic variables related to multiple objectives. These multiple objectives may be represented through the performance objectives of a production strategy plan, such as quality, speed, dependability, flexibility, and cost. Other approaches for multiple objectives may be obtained from multidimensional quality views. [15]

Selection of appropriate suppliers in supply chain management strategy is a challenging issue because it requires battery of evaluation criteria/attributes, which are characterized with complexity, elusiveness, and uncertainty in nature. [16]

Procurement and supply management are the most significant parts in engineering, procurement, and construction contracts. When a supplier selection decision needs to be made, the buyer generally establishes a set of criteria, evaluated by the experts about the prospective suppliers. These evaluations can then be used to compare and rank the potential sources. The basic criteria typically utilized for this purpose are pricing structure, delivery (lead-time and reliability), product quality, and service (i.e., personnel, facilities, research and development, capability, etc.). These evaluation criteria are usually conflicting with one another, which complicates the decision making algorithm more. In addition, the relative importance of each criterion varies from one purchase to the next. This situation can be further sophisticated by the fact that some of the criteria are quantitative (such as: price, quality, etc.) and some are qualitative in nature (such as: service, etc.), making the evaluations more diverse. [17]

The decision for choosing a vendor is highly complex and purchaser’s most demanding responsibility. Firstly, such a decision involves more than one selection criterion to evaluate the vendors based upon. Secondly, the involving criteria in the supplier evaluation process may frequently contradict with each other (lowest price against poor quality). Thirdly, the complication surrounding the supplier evaluation and selection decision usually arises from internal and external constraints imposed on the buying process, influencing the evaluation and selection process of suppliers. Finally, as organizational requirements and market conditions change, the importance of the analysis of tradeoffs among the evaluating criteria may be increased. [18, 19]

When the studies are analyzed which are about supplier selection, various studies can be seen which are using different criteria and methods. If we look into the light of supplier selection criteria; Dickson [20] identified 23 criteria such as quality, price, delivery and performance turned to the past that have been considered by purchasing managers in various supplier selection problems. De Boer et al. [21] identified four stages for supplier selection including definition of the problem, formulation of criteria, qualification, and final selection, respectively. They reviewed and classified MCDM approaches for supplier selection. Lehman and O'Shaughnessy [22]; have used price, delivery, warranties and obligations, financial state, technical support, response to customer demands, references, position in the sector, technical capacity and impression criteria. Verma and Pulman [23]; consider quality, cost, on time delivery, delivery time and flexibility in the supplier selection phase. Ellram [24], besides quantitative factors in supplier selection, emphasize the long-term and qualitative factors are also important; and he brings together these factors in four groups as financial units, organization culture, technology and other factors. Tam and Tummala [25] in their studies; have used cost, operational quality, technical quality criteria. Boer and the others [26], consider the financial circumstance of the supplier, distance between the company and the supplier, supplier's price adequacy and quality. Weber et al. [27] found that 47 out of 76 articles which they reviewed, addressed more than one criterion for supplier selection decision making such as price, delivery, quality, etc. Hence supplier selection problem is a MCDM problem and it is necessary to make a trade off between conflicting quantitative and qualitative criteria to select the best suppliers. Min and Gale [28], state the criteria like price, delivery, quality, e-commerce capability and green manufacturing in their studies that mention about the importance of e-commerce function in purchasing. Bharadwai [29] indicates the most important criteria as delivery, price, quality and service level in his observation of decision making criteria intended for supplier selection. Jayaraman and the others [30] have mentioned cycle time, quality, production capacity and warehousing sufficiency. Perreault and Russ [31]; consider price, quality, delivery, geographical location and bilateral alliances criteria. Bhutta and Hug [32]; concentrate on manufacturing costs, quality, technology and service criteria. Ding and the others [33]; give importance to delivery time and purchasing costs. While Barla [34] pays attention to reliability, competence, quality, geographical conditions, financial state, service and price properties, Ting [35]; says the criteria which are like cost, just in time delivery, service after sales and flexibility as significant.

While Soner and Onut [36] are using cost, distance, technology usage, speed and quality criteria, Oz and Baykoc [37] have been built the sub criteria in the frame of some main criteria such as price, quality and delivery. Gencer and Gurpinar [38] have used business structure of the supplier, production capability of the supplier and the quality system of the supplier criteria as the main criteria. Dagdeviren and Eraslan [39] have studied on quality, price, supply performance, flexibility, technology, and distance criteria. While Faez and the others [40] are considering cost, delivery and quality criteria and Ayag and the others [41] are using criteria such as resources, production variety, problem solving ability, manufacturing technology and management, quality policy, implementation control, technical capacity and product development. On the other hand, Sevkli and the others [42] have regarded performance, human resources, quality systems, manufacturing, company attributes and information technologies criteria. In another recent study, Chan and the others [43] indicate quality, cost, geographical location, financial state, performance and risk factors as the selection criteria. According to studies which are made until today, supplier selection criteria can be sum up like as the following table.

Table II-1 Supplier Selection Criteria (Gorener, 2009) [44]

Price	Technology	Production Capacity
Quality	Geographical Location	Warehousing Sufficiency
Delivery	Service	Experience
Past Performance	Flexibility	Product Appearance
Warranties & Obligations	Just in Time Delivery	Cycle Time
Financial State	Delivery Time	E-Commerce Capability
Technical Support	Bilateral Alliances	Green Production
Response to Customer Demand	Management-Organization	Product Development
References	Technical Capacity	Product Variety
Risk Factor	Supplier Profile	Implementation Control
Speed	Resources	Problem Solving Ability
Quality System	Human Resources	Manufacturing
Information Technologies	Packaging Capability	Communication
Position in the Sector	Impression	Number of Technical Staff

Several methodologies have been proposed for the supplier selection problem. The systematic analysis for supplier selection includes linear weighting models, mathematical programming (MP) models, statistical models, artificial intelligence based models and cost based models. Most of these methods do not seem to address the complex and unstructured nature and context of many present day purchasing decisions. In many existing decision models in the literature, only quantitative criteria have been considered for supplier selection. Several influence factors are often not taken into account in the decision-making process, such as incomplete information, additional qualitative criteria and imprecision preferences. Therefore, fuzzy sets theory (FST) has been applied to supplier selection recently. [10]

Choosing the best alternative is quite though job for decision makers. Decision makers have to find the most suitable alternative through the whole alternatives which is achieving the various objectives, in contrary sometimes is discordant. For this reason, a lot of decision makers carry out MCDM methods when they encounter this kind of problems. The objective of the MCDM methodology, is gathering up the various size of data which can compare different alternatives.

In this study, supplier selection subject which is entirely strategic decisions will be investigated. Supplier selection is a decision problem which can be solved by usage of one of the appropriate MCDM techniques, needs to provide more than one constraints at the same time. For suppliers' information, some data will be taken from a manufacturing firm in Adapazari which is one of the leading low voltage contactor switch devices manufacturer. The products are designing in R&D departments and the entire phases from producing to final controls and to tip experiments are performing by the firm. There are various kinds of materials which are used in production of these contactor switch devices. Producing all the materials is a pretty hard and time-consuming job. That's why the firm works with a lot of suppliers for different kinds of materials. For this study, some of the materials have been observed and the firms which are supplying these materials have been investigated. In the study, there are seven criteria which are used to choose the appropriate supplier from the alternatives. They are quality, cost, delivery time and transportation, minimum order quantity, production capacity, technology & flexibility, holding stock, and payment term.

II.3 PHASES OF SUPPLIER SELECTION

De Boer et al. report that some decision making steps make up the supplier selection process, as it is seen in Table II-2 after formulating the problem and performance criteria, prequalification of potential suppliers and final choice phases are successively detailed. De Boer et al. determine every phase of the supplier selection process for every purchasing situation. [21]

Table II-2 The supplier selection framework (De Boer, 1998) [26]

	New Task	Modified Rebuy (leverage items)	Straight Rebuy (routine items)	Straight Rebuy (strategic/bottleneck)
Problem Definition	Use a supplier or not? Varying importance One-off decision	Use more, fewer or other suppliers? Moderate/high importance Repeating decision	Replacing the current supplier? Low/moderate importance Repeating decision	How to deal with the supplier? High Importance Repeating evaluation
Formulation of Criteria	No historical data on suppliers available No previously used criteria available Varying importance	Historical data on suppliers available Previously used criteria available	Historical data on suppliers available Previously used criteria available	Historical data on suppliers available, yet very few actual selections Previously used criteria available
Qualification	Small initial set of suppliers Sorting rather than ranking No historical records available	Large initial set of suppliers Sorting as well as ranking Historical data available	Large initial set of suppliers Sorting rather than ranking Historical data available	Very small set of suppliers Sorting rather than ranking Historical data available
Choice	Small initial set of suppliers Ranking rather than sorting Many criteria Much interaction No historical records available Varying importance Model used once	Small to moderate set of initial suppliers Ranking rather than sorting Also: how to allocate volume? Fewer criteria Less interaction Historical data available Model used again	Small to moderate set of initial suppliers Ranking rather than sorting Fewer criteria Less interaction Historical data available Model used again Single sourcing rather than multiple sourcing	Very small set of suppliers (often only one) Historical data available Evaluation rather selection Sole sourcing

II.3.1 Problem Definition

All companies are for purchasing, making sales and getting profit regardless to its size. Purchasing is the all necessary activities for providing ownership of the assets and utilization authority from the others. In other words, purchasing is to supply raw materials, materials, tools and equipments, which are necessary, for continuity of the activities in the company. However, by the development of techniques in purchasing activities, purchasing has become a management function not only as a supplying function. But purchasing can not only be contented with this function; it has included functions such as research, development, planning and control and it should include. That is why; purchasing is one of the essential functions of the companies. Due to upgrade the variety and type of companies' product or material range, companies should evaluate and improve the current suppliers and search for the new ones all the time. To keep the competitive edge in global market conditions different purchasing situations lead to different decisions such as establishing close connections with suppliers who are leading to partnership, privileged suppliers, long – term agreement etc. As a result, the purchasing process should start with finding out exactly what is wanted to be achieved by selecting a supplier for making the right choice.

II.3.2 Formulation of the Decision Criteria

Because of the partnerships of the companies with their suppliers, these companies should define important criteria in supplier selection decision; because they actually have to evaluate different alternatives of suppliers according to various criteria in the supplier selection process.

In traditional form, firms have been selected their suppliers especially according to unit cost performance criteria. But the supplier selection problem became a multiple criteria decision with the competitive conditions. Making the right decisions to select the right suppliers can be affected by some conflicting criteria. Because multiple criteria decisions involve multi – faceted thinking and also trade – offs. As it is known, there are some studies which depend on MCDM in supplier selection. For example; Dickson's 23 criteria are widely used in supplier selection. These supplier selection evaluation criteria are seen in Table II-3. His study depended on implementing questionnaire to more than 200 purchasing staff. Dickson's 23 criteria still cover the majority of the criteria presented in the literature until today.

Furthermore, the evolution of the industrial environment modified the degrees of the relative importance of these criteria. From 1966 till now, profound changes have taken place in political, economic, social and technological environments of business, including purchasing. Consequently, the supplier selection issues have also evolved. [45]

Net price, delivery and quality are rated as having "extreme" or "considerable" importance by Dickson. This implies that these three criteria have invariably been the most important ones in supplier selection decisions, and that there may be more agreement on recognition of their importance. [45]

After the supplier selection evaluation of Dickson, Weber et al. reviewed 74 articles between 1966 and 1991 and Dickson's important 23 criteria. Furthermore, Zhang et al. also reviewed 49 articles about supplier selection criteria between 1992 and 2003 and he has compared with Weber et al. [46]

Table II-3 Dickson's Supplier Selection Criteria (Dickson, 1966)*, [20]

Rank	Factor	Mean rating	Evaluation
1	Quality	3.508	Extreme Importance
2	Delivery	3.417	
3	Performance History	2.998	
4	Warranties and Claim Policies	2.849	
5	Production Facilities and Capacity	2.775	Considerable Importance
6	Price	2.758	
7	Technical Capability	2.545	
8	Financial Position	2.514	
9	Procedural Compliance	2.488	
10	Communication System	2.426	
11	Reputation and Position in Industry	2.412	
12	Desire for Business	2.256	
13	Management and Organization	2.216	
14	Operating controls	2.211	
15	Repair service	2.187	Average Importance
16	Attitude	2.120	
17	Impression	2.054	
18	Packaging ability	2.009	
19	Labor relations record	2.003	
20	Geographical location	1.872	
21	Amount of past business	1.597	
22	Training aids	1.537	
23	Reciprocal arrangements	0.610	Slight Importance

*See Dickson (1966), 0=no importance, 4=extreme importance

Some observations may be made from Table II-4. It indicates that net price, quality and delivery have invariably been the most important ones in supplier selection decisions, and that there may be more recognition and of their importance. They also occupied the top three positions in Weber et al.'s study with relatively smaller frequencies.

Table II-4 Criteria discussed in annotated bibliography (Zhang et al., 2003), [46]

Dickson (1966)		Criteria	Zhang et al. (2003)			Weber et al. (1991)	
Rank	Rating a		Rank b	No	%	No	%
6	1	Net price	1	39	87	61	80
1	1A	Quality	2	37	82	40	53
2	1	Delivery	3	33	73	44	58
5	1	Production Facilities and Capacity	4	20	44	23	30
7	1	Technical Capability	5	15	33	15	20
8	1	Financial Position	6	13	29	7	9
20	2	Geographical Location	7	5	11	16	21
13	2	Management and Operation	7	5	11	10	13
3	1	Performance History	7	5	11	7	9
14	2	Operating Controls	7	5	11	3	4
10	2	Communication System	7	5	11	2	3
11	2	Reputation and Position in Industry	12	3	7	8	11
15	2	Repair Service	13	2	4	7	9
18	2	Packaging Ability	13	2	4	3	4
22	2	Training Aids	13	2	4	2	3
9	2	Procedural Compliance	13	2	4	2	3
19	2	Labor Relations Record	13	2	4	2	3
4	1	Warranties & Claim Policies	13	2	4	0	0
16	2	Attitude	19	1	2	6	8
23	3	Reciprocal Arrangements	19	1	2	2	3
17	2	Impression	21	0	0	2	3
12	2	Desire for Business	21	0	0	1	1
21	2	Amount of Past Business	21	0	0	1	1

Rating a : 1A=Extreme importance, 1=Considerable importance,
2=Average importance, 3=Slight importance
Rank b: based primarily frequency in Zhang et al.'s study.

Production facilities and capacity takes the 4th position in both Weber et al.'s study and Zhang et al.'s study. Below that, there are differences in positions of the remaining 19 criteria, which may indicate changes in attentions of researchers and practitioners over the years. For example, financial position was discussed in only 9% of the articles in Weber *et al.*'s study, but 29% in Zhang et al.'s study. The reason may be that in today's business environment, firms and their suppliers may form a more close relationship to enhance the whole supply chain's profit. Thus, supplier's financial position and stability may become more important. Another example is geographical location which was discussed in 11% of the articles in Zhang et al.'s study but 21% in Weber et al.'s study. The main reason is that with the economic globalization, suppliers are selected from the whole world, especially in the developing countries for their low cost. And with the development of global logistics, geographical location is no longer a major criterion for supplier selection. Yet another criterion which is of large difference between Weber et al.'s study and ours is communication system, 3% versus 11%. Information share is nowadays critical to the success of both parties in a supply chain. Thus building an effective communication system is important. Most other criteria are mentioned in less than 4% of the articles in both studies. Of the 45 articles, 27 or 60% were published in the last five years. It seems that supplier selection issues got more attention in the competitive environment. It can also be seen that net price, quality and delivery have received the greatest amount of attention in the last five years. [46]

Since 1994, more criteria that did not appear in Dickson's 23 criteria are presented in the supplier selection articles. The definitions of Dickson's 23 criteria have been expanded and some new criteria are developed with the growth of new business needs. Of the top three criteria (net price, quality and delivery), the meaning of net price is extended most. In Dickson's study, net price was defined as price offered by each vendor including discounts and freight charges. In the development of this criterion, cost seems to be substituting net price. These include, for example, fixed cost; design cost and supplier cost; inventory holding cost and fixed ordering cost; quality cost, technology cost and after-sales service cost. In recent years, total cost of ownership (TCO) has become increasingly important. TCO is a methodology and philosophy, which looks beyond the price of a purchase to include many other purchase-related costs. In the supplier selection process, only considering net price is no longer enough. In TCO model, some of the factors (such as product cost, quality cost, service cost, etc.) considered are qualitative and the manager could easily evaluate them. For quality, Dickson defined it as the ability to meet quality specifications consistently. In the new development, some specifies are added, for example, ISO9001 system; inspection, experimentation and quality staff. Dickson defined delivery as the ability to meet specified delivery schedules. Its meaning is extended into criteria such as freight terms; lead time; delivery capacity; shipment quality; cycle time and just in time (JIT) delivery capability. Dickson's definition is still the dominant one. [46]

In addition to proliferation of the three core criteria, some new criteria are generated with the advance of management philosophy. The first one is the product design and development. Examples in the literature include design capability; product development and product improvement; commitment to continuous improvement in product and process. Another one is flexibility, including production flexibility and responsiveness to customers. Examples include responsiveness to customer needs; response to changes and process flexibility; flexibility in changing the order; flexibility; flexibility of response to customer's requirements; quota flexibility reverse capacity or the ability to respond to unexpected demand. The third one is relationship between the buying firms and the suppliers. Highly quality of relationship with suppliers was regarded when they investigated Chinese purchasing managers' preferences and trade-offs in supplier selection and performance evaluation. The role of past and current relationship with supplier, along with willingness to integrate supply chain management and willingness to share confidential information was investigated in comparing attitudes of US and European managers toward supplier selection and assessment. [46]

The three newly developed criteria, product design and development, flexibility, and relationship were mostly presented from the end of 1990s. Since then, supply chain management (SCM) has become a prominent concern of both large and small companies as they strive for better quality and higher customer satisfaction. The two are closely related. In SCM environment, competition is no longer company to company, but supply chain to supply chain. It needs the chain members to collaborate seamlessly to gain competitive advantages. Relationship and the related thinking such as information sharing must be a critical criterion for buying firms to select their suppliers. Buying firms should build long-term relationship with their main suppliers instead of the former arms-length relationship. The ultimate aim of the supply chain is to satisfy customer needs. With the political, economic, social, and technological changing, consumers become more fickle, more demanding, and have more customized requirements. Small lot size and frequent deliveries thus replace the former economic scale production. Flexibility in production and responsiveness to customers is thus of great importance to supplier selection. To accelerate the product development cycle, suppliers often participate in the process of design and development of final product. The suppliers' ability of product design and development thus become an important selection criterion. Another trend is global sourcing. Buying firms search their suppliers all over the world for cost reduction. In this circumstance, criteria such as political stability, foreign exchange rate and tariff and customer duties should be considered. Also, environment issues start to be considered in supplier selection process in recent years. [46]

According to the level of buyer-supplier integration, the company's competitive situation and its corporate strategies, define the important criteria for supplier selection. As the levels of buyer-supplier relationship affects the number of the criteria considered, some important buyer-supplier integration strategies and their criteria are discussed as follows:

Level 1: At this level no integration can be assumed. Price and quality are important criteria for supplier selection at this level.

Level 2: At this level logistical integration exists between buyer and supplier and the supplier has an important role in the buyer's competitiveness. Therefore, great importance is given to the suppliers' logistical performance. Hence in these circumstances, besides the quality and price, the operational logistics elements such as reliability, flexibility, supply lots, lead time and so on should be considered in the supplier selection process.

Level 3: At this level operational integration of buyer and supplier is desired. Usually for full implementation of JIT/TQM (total quality management) this level of integration is selected. Therefore not only the output characteristics of the supplier should be considered, but the way in which these services are provided should also be taken into account. For example, a supplier with a highly flexible production line is preferred to a supplier which keeps a warehouse full of finished products to support JIT services. At this level of integration the suppliers' process capability such as set up time, lot size, lead time, etc. should be considered in the assessment process. From a quality point of view, if two suppliers have the same defects rate, the supplier who achieved this level of quality by the less inspection is preferred. In other words, the supplier's process capability indexes are important.

Level 4: The integration for this situation is deeper than the previous levels. The corporate management decides to integrate process and products with their supplier. In this situation besides the criteria of the preceding levels, the supplier's human resource from several points of view such as design involvement, management ability, culture, etc. should be involved in the evaluation process.

Level 5: Business Partnership is desired at this level of integration. In these circumstances, the strategic directions of the suppliers become very important, such that the best supplier from the technological and human resource point of view might be inadequate if the supplier does not consider the direction of the clients business. After a definition of supplier selection criteria, based on the corporate integration strategy, the hierarchy structure of the problem can be built. [47]

The majority of buyers can not take more than 8 or 9 factors into account in their decision – making process, so researchers tend to develop smaller, more customized sets of attributes as the final aim of their research work. The relative importance of these selection criteria has been estimated in various procurement situations. To be more precise, the predictive capacity of supplier selection models and the relative importance attributed to the assessment criteria varies considerably according to the nature of the choice that has to be made. [48]

According to company's expectations and requirements; various supplier selection criteria can be used in supplier selection processes. Therefore; price, quality, delivery and flexibility are not to be traded – off against one to another but need to be simultaneously prioritized. Nevertheless; these priorities among supplier selection criteria can be probably affected by the actual conditions of industrial environment.

II.3.3 Pre-Qualification of Suitable Suppliers

In collaborative supply chain environments, it is very hard to decide selecting the appropriate suppliers among the high number of alternatives. So, there should be some methods to reduce the set of all suppliers into a small range and define the acceptable and inefficient ones. The purpose of this phase is to determine these decisions according to some rules.

One of the important problems related with the strategy of supplier selection is whether making the activities with only one supplier or a couple of suppliers. Deming advocates that having a long term relationship with only one supplier can be more effective in terms of quality development and cost reduction. Deming states that weak supplier performance arises from the weak communication and lack of coordination. Outsourcing strategy with only one supplier provides to set up powerful relations with the supplier. Although one supplier strategy has negative effect in terms of bargain and performance, it can be effective in some cases. Deming determines that coordination and control of activities with a couple suppliers can be more expensive. But Porter has been advised working with a couple of suppliers to achieve the high performance, quality and provide the low cost assurance. Furthermore, Porter determines that this situation will increase the power of bargain of the company while making contracts.

There are several methods to determine the supplier according to their qualifications, competencies and also their priorities. If an elimination method is used, marks of suppliers (with respect to a criterion) are defined according to company's satisfaction and whose marks are lower than the minimal threshold are eliminated. In this method, the judgment is considerably clear because of intolerable possible results which can not pass the minimal threshold value under any criteria or objectives of the company.

In one of these pre-selection rules, the most important criterion is identified as a first level, lexicographically. In this method; a single objective or criterion is rated as most important, and alternatives are ranked according to how well they satisfy this objective. If an alternative is clearly superior in this criterion to other alternatives it is selected. Otherwise the second most important criterion is used to rank the top alternatives from the first ranking. This process continues, constantly reducing the number of alternatives ranked and ranking by less important criteria, until a single project is clearly superior for the attribute being used to rank the alternatives.

The most common pre-selection method is the data envelopment analysis (DEA). DEA, occasionally called frontier analysis and it is used to empirically measure productive efficiency of decision making units (or DMU). DEA is a linear programming methodology which is based on the efficiency analysis of alternative suppliers. The suppliers are evaluated on benefit criteria (outputs) and cost criteria (inputs). Supplier efficiency is defined as the ratio of the weighted sum of its outputs (i.e. the performance of the supplier) to the weighted sum of its inputs (i.e. the costs of using the supplier). [49]

A classification algorithm, cluster analysis (CA) allows classifying suppliers described by a set of numerical attribute scores in groups of comparable suppliers. In this way, the difference between suppliers' performance within a cluster are minimal whereas it is maximal between different clusters. CA offers greatest potential for pre-qualifying all suppliers. That is, CA reduces the probability of rejecting a ‘good’ supplier too early in the process via subjective reduction of the often large original set. CA would enlarge the scope for rationalization of the selection process by identifying the criteria involved. [45]

II.3.4 Final Selection

As an important part of the purchasing process, most of the studies on supplier selection topic have focused on determining the best mixture of suppliers to provide all the needed stuff. That is why; the final supplier(s) are specified at this phase and the orders are assigned among these suppliers while taking into account the system’s constraints and a multitude of supplier evaluation criteria. So; huge concentration has been taken pains to provide an efficient supplier selection models.

The main purpose of this study is determining the best supplier to provide an overall efficiency in the supply chain.

II.4 SUPPLIER SELECTION METHODS

There are various kinds of supplier selection methods available in the literature. Zhang et al. separated supplier selection methods into 4 categories: linear weighting models, mathematical programming models, statistical approach, and other methods. [46]

II.4.1 Linear Weighting Models

In linear weighting models weights are given to the criteria, the biggest weight indicating the highest importance. Ratings on the criteria are multiplied by their weights and summed in order to obtain a single figure for each supplier. The supplier with the highest overall rating can then be selected [45]. There are several methods in linear weighting models such as analytic hierarchy process (AHP), analytic network process (ANP), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), ELECTRE (Elimination and Choice Translating Reality English), multi – attribute utility theory (MAUT), and fuzzy sets theory (FST).

II.4.1.1 The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) provides a way to rank the alternatives of a problem by deriving priorities. The AHP gives a proven, effective means to deal with complex decision making and can assist with identifying and weighting selection criteria, analyzing the data collected for the criteria and expediting the decision-making process.

The AHP has been shown to be a robust method of eliciting and using multi criteria preference relationships in a range of applications. It is designed for situations in which ideas, feelings, and emotions are quantified based on subjective judgment to provide a numeric scale for prioritizing decision alternatives. The AHP is based on a matrix of pair wise comparisons between criteria, and it can be used to evaluate the relative performance of decision alternatives (for example products and services) with respect to the relevant criteria. The AHP was seen to be a suitable tool for the purpose here, as it is a robust method that is particularly suited to decisions made with limited information. [50]

The AHP is a powerful and understandable methodology that allows groups or individuals to combine qualitative and quantitative factors in decision making process. The AHP is a multi criteria decision making method for complicated and unstructured problems and also it is an approach that uses a hierarchical model having levels of goal, criteria, possible sub-criteria, and alternatives.

The AHP, can be stated, a decision – making and estimation method which gives the percentage distribution of decision points according to factors affecting decision, that is used if there is a defined decision hierarchy. On a decision hierarchy, AHP depends on one – to – one comparison, both on the factors that are affecting decision and importance value with using a predefined comparison scale. Eventually, importance diversities turn into percentage distribution on decision points.

The AHP is a methodology to rank alternative courses of action based on the decision maker's judgments concerning the importance of the criteria and the extent to which they are met by each alternative. Because of this reason, AHP is properly suited for the supplier selection problem.

To solve a decision problem with AHP, there are some steps which are defined below. All along the line, there will be related instructions with the formulation.

Step 1: Decision – Making Problem Is Defined

Definition of the decision making problem, is formed from two phases. At first phase, decision points are established. In other words, an answer is looked for "The decision will evaluate by how many results?" question. At second phase, factors which are affecting decision points are established. In this study, the numbers of decision points are symbolized with m and the numbers of factors that are affecting these points are symbolized with n; especially, correctly determining the numbers of factors which will affect the result is very important to perform consistent and rational pair wise comparisons.

Step 2: Comparison Matrix between Factors Is Formed

Comparison matrix between factors is a nxn dimensional square matrix. The matrix components on the diagonal of this matrix take 1 value. Comparison matrix is shown below.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

When $i = j$, components on the diagonal of the comparison matrix take 1 value; because related factor has been comparing with itself in this situation. Comparing factors is done according to their importance value to each other by one – to – one and reciprocally. One – to – one and reciprocally comparison of the factors importance scale, which is on Table II-5, is used.

Table II-5 Importance Scale

Values (a_{ij})	Definition
1	*i* and *j* are equally important
3	*i* is moderately more important than *j*
5	*i* is strongly more important than *j*
7	*i* is very strongly more important than *j*
9	*i* is extremely more important than *j*
2,4,6,8	Intermediate values (Used when a compromise is needed.)

For example; *i* seems more important than *j* by decision maker, first row third column component of the comparison matrix ($i = 1, j = 3$) takes 3 value in this situation. Otherwise, namely the comparison of first factor to third factor; if the more important option is used for third factor, first row third column component of the matrix ($i = 3, j = 1$) will take 1/3 value at this time. In the same comparison, comparison of first and third factors; if the factors have equal importance, first row third column component will take 1 value.

Comparisons are done for the values which are above of all the 1 – valued diagonal of comparison matrix. Naturally, using (2.1) formula will be enough for the components which are below of the diagonal.

$$a_{ji} = \frac{1}{a_{ij}} \tag{2.1}$$

If the example, which is above, is taken into consideration; when first row third column component of the comparison matrix ($i = 1, j = 3$) takes 3 value, third row first column component of the comparison matrix ($i = 3, j = 1$) takes 1/3 value according to 2.1 formula.

Step 3: Percentage Importance Distribution of the Criteria Are Determined

Comparison matrix shows importance levels of factors to each other within a certain logic framework. However, the weights of these factors in total, in other words to determine the percentage importance distribution, column vectors, which constitute the comparison matrix are used and column vector B which has n units with n components is constituted.

This vector is pointed at below:

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ . \\ . \\ . \\ b_{n1} \end{bmatrix}$$

The calculation of column vectors B, (2.2) formula is used.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2.2}$$

When the steps, which are told above, are repeated for the other evaluation criteria, column vector B is acquired as the number of criteria. When n units of column vector B are gathered in a matrix format, matrix C that is shown below will be created.

$$C = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ c_{n1} & c_{n2} & \dots & c_{nn} \end{bmatrix}$$

Using matrix C; percentage importance distributions, which show the criteria importance value according to each other, can be gotten. Therefore, arithmetic average of row components, which is comprised matrix C, is taken and then column vector W which is called priority vector is attained.

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{2.3}$$

Vector W is shown below.

$$W = \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix}$$

Step 4: Consistency in Factor Comparisons Is Calculated

Even if AHP has a considerably consistent systematic, naturally the realism of the results will depend on consistency of decision maker's pair wise comparison between criteria. AHP suggests a process to measure the consistency of these comparisons. Eventually, with acquired Consistency Ratio (CR), there has been an opportunity to test the consistency of priority vector and also consistency of pair wise comparisons between criteria. Essence of the CR calculation is based on comparison of number of criteria and a coefficient, which is called Principal Value (λ), by AHP. Principally, from the multiplication of comparison matrix A and priority vector W, column vector D is acquired for the calculation of λ.

$$D = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix}$$

Just like defined in (2.4) formula, division of the corresponding elements of column vector *D*, which is found above, with column vector *W* constitutes the Principal Value (*E*) for every evaluation criteria. The arithmetic average of these values ((2.5) formula) gives the principal value (λ) according to comparison.

$$E_i = \frac{d_i}{w_i} \qquad (i = 1,2,\ldots,n) \tag{2.4}$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \tag{2.5}$$

After λ is calculated, Consistency Index (CI) can be computed according to (2.6) formula.

$$CI = \frac{\lambda - n}{n-1} \tag{2.6}$$

At the last stage, CI divided by Random Index (RI) which is shown as standard correction value ((2.7) formula) in Table II-6 and then Consistency Ratio (CR) is obtained. From Table II-6 the value that is corresponding to number of criteria is chosen. For example; RI value of 3 criteria comparisons will be 0.58 from Table II-6.

Table II-6 RI Values

Number of Criteria	**RI**	**Number of Criteria**	**RI**
1	0	8	1,41
2	0	9	1,45
3	0,58	10	1,49
4	0,90	11	1,51
5	1,12	12	1,48
6	1,24	13	1,56

$$CR = \frac{CI}{RI} \tag{2.7}$$

When the calculated CR value is less than 0.10, comparisons that made by decision maker are consistent. If the CR value is more than 0.10, either there could be a calculation error or there is an inconsistency in the comparisons of decision maker.

Step 5: For Every Criterion, Percentage Importance Distributions Are Found At *m* Decision Point

This stage is just like that told above, but this time, for every criterion percentage importance distributions of decision points are determined. In other words, one – to – one comparison and matrix operations are repeated as the number of criteria (n times). However, the dimension of comparison matrices *G*, which will be used at decision points for every criterion, will be *mXm*. After every comparison operations; column vector *S*, which has *mX1* dimensions and shows the percentage distribution according to decision points of evaluated criterion, is acquired. These column vectors are stated below.

$$S_i = \begin{bmatrix} s_{11} \\ s_{21} \\ . \\ . \\ . \\ s_{m1} \end{bmatrix}$$

Step 6: Finding the Result Distribution at Decision Points

In this stage principally, *mXn* dimensioned decision matrix *K*, which is consisted of *mX1* dimensioned column vector *S*, is attained. Decision matrix is defined below:

$$K = \begin{bmatrix} s_{11} & s_{12} & \dots & s_{1n} \\ s_{21} & s_{22} & \dots & s_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ s_{m1} & s_{m2} & \dots & s_{mn} \end{bmatrix}$$

In conclusion; when decision matrix multiplies by column vector W (priority vector), column vector L that has m elements is achieved. Column vector L gives the percentage distribution of decision points. In other words, the sum of vector's elements is 1. This distribution also shows the importance order of decision points.

$$L = \begin{bmatrix} s_{11} & s_{12} & \dots & s_{1n} \\ s_{21} & s_{22} & \dots & s_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ s_{m1} & s_{m2} & \dots & s_{mn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} = \begin{bmatrix} l_{11} \\ l_{21} \\ . \\ . \\ . \\ l_{m1} \end{bmatrix}$$

II.4.1.2 The Analytic Network Process (ANP)

The Analytic Network Process (ANP) is the most comprehensive framework for the analysis of societal, governmental and corporate decisions that is available today to the decision-maker. It is a process that allows one to include all the factors and criteria, tangible and intangible that has bearing on making a best decision. The ANP allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects of interplay in human society, especially when risk and uncertainty are involved.

The ANP is a methodology that allows groups or individuals to deal with the interconnections (dependence and feedback) between factors of complex structure in decision making process. The ANP is a multi criteria decision making method for complicated and unstructured problems and also it is an approach that uses a network model having clusters of elements (criteria and alternatives).

The ANP, developed by Thomas L. Saaty, provides a way to input judgments and measurements to derive ratio scale priorities for the distribution of influence among the factors and groups of factors in the decision. Because the process is based on deriving ratio scale measurements, it can be used to allocate resources according to their ratio-scale priorities. The well-known decision theory, the Analytic Hierarchy Process (AHP) is a special case of the ANP. Both the AHP and the ANP derive ratio scale priorities for elements and clusters of elements by making paired comparisons of elements on a common property or criterion. Although many decision problems are best studied through the ANP, one may wish to compare the results obtained with it to those obtained using the AHP or any other decision approach with respect to the time it took to obtain the results, the effort involved in making the judgments, and the relevance and accuracy of the results.

The AHP structures a decision problem into levels forming a hierarchy, while the ANP is using a network approach. Then use a system of pair wise comparisons to measure the weights of the items in the hierarchy, and finally to rank the alternatives in the decision. In the AHP, each element in the hierarchy is considered to be independent of all the others. But in many real-world cases, there is interdependence among the items and the alternatives. The ANP does not require independence among elements, so it can be used as an effective tool in these cases. For example, ANP allows for decision elements to control or be controlled by the varying levels, decision criteria or alternatives.

The ANP models have two parts: the first is a control hierarchy or network of objectives and criteria that control the interactions in the system under study; the second are the many sub-networks of influences among the elements and clusters of the problem, one for each control criterion. The ANP has been applied to a large variety of decisions: marketing, medical, political, social, forecasting, prediction and many others. Its accuracy of prediction is impressive in applications that have been made to economic trends, sports and other events for which the outcome later became known. [51]

In the ANP methodology, some analyzes are done by using non – weighted super matrix, weighted super matrix and limit super matrix. Non – weighted super matrix is the matrix that gives the relative importance vector of every component as a result of pair wise comparisons. Weighted super matrix is the matrix where values of multiplication of the values which come from non weighted super matrix with the weight of the set where the related component takes part. After taking the limit of the weighted super matrix, where the converged values of relative importance values are acquired, is the limit matrix. Results of the decision problems are obtained from this matrix. In the ANP methodology, evaluation related to the criteria by experienced and expert people in the studied topic, sufficiency of consistency index and especially correct expressions of all the components and relations that affect a problem are very important for increasing the reliability of the results. The ANP particularly has been used to determine the best alternative in the decision problems which have finite alternatives. [44]

Steps of the ANP can be sum up by this way:

Step 1: Definition of the Decision Problem and Modeling the Problem

In the first step decision problem is defined. Goal, criteria, sub criteria and alternatives are stated clearly.

Step 2: Determination of the Relations

Interactions between criteria are determined. Inner and outer dependencies and also feedbacks between the criteria are associated.

Step 3: Pair Wise Comparisons between the Criteria are done and the calculation of the Priority Vectors

The group from decision makers achieves the comparisons by using defined scale values. Pair wise comparisons are done in a matrix framework and local priority vector is determined by the Eigen vector from the solution of $A.w= \lambda_{max}.w$ equation. In here; A is the pair wise comparison matrix, w is the eigenvector, λ_{max} is the greatest Eigen value of a comparison matrix. Saaty proposes the normalizing algorithm fort he approximately solution of w.

Step 4: Consistency Analyzes of the Comparison Matrices

After the comparison matrices are built, for each matrix consistency ratio (CR) should be calculated to state the comparisons are consistent or not. CR is acquired by the division of consistency index (CI) to random consistency index (RI). If the CR value is lower than 0.10, consistency of pair wise comparisons can be said. If the values are higher than 0.10, there is an inconsistency. In this case, decision maker group should review the comparisons again.

Step 5: Constitution of the Super Matrix

To acquire the global priorities in a system that has dependent affects, local priority vectors are written into the columns of the matrix which is called as super matrix. Super matrix is a sectional matrix and every matrix section in here shows the relation between two factors in the system. Proportional long term affects of the criteria to each other are determined by taking the power of the super matrix. To provide the equality of importance weights at one point, $(2n+1)^{th}$ power of super matrix is taken. n is a randomly selected big number in here and the obtained new matrix is named as limit super matrix.

Step 6: Selection of the Best Alternative

With the obtained limit super matrix, importance weights will be determined according to the alternatives and/or compared criteria. In the selection problem, the alternative which has the highest importance weight will be the best alternative; in weighting problem, the criterion which has the highest importance weight is the most important criteria that affect the decision process. The ANP methodology has found an implementation field where the complicated decision problems are existed in various areas. That is why; it is used in supplier selection processes easily. [44]

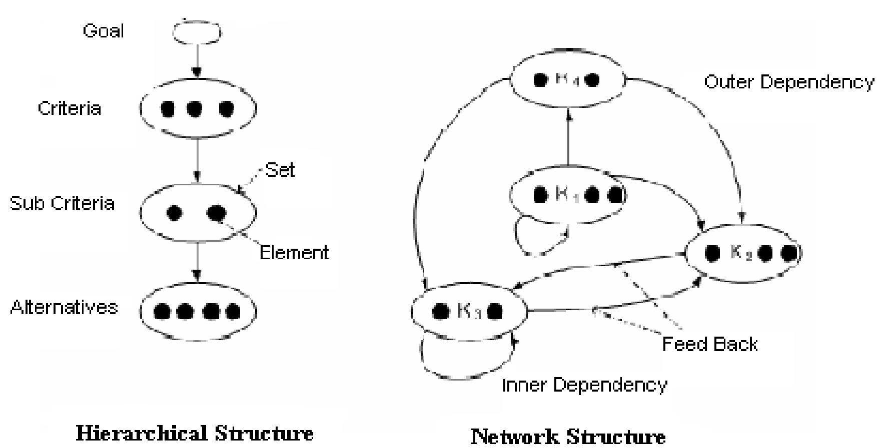

Figure II-1 Comparison of AHP vs. ANP (Gorener, 2009) [44]

II.4.1.3 TOPSIS

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was originally proposed by Hwang and Yoon in 1980 and uses the basic approaches of ELECTRE method. TOPSIS is a multiple criteria decision making (MCDM) method to identify solutions from a finite set of alternatives. TOPSIS depends on decision points' nearness to ideal solution main principal and solution process shorter than ELECTRE method. This method considers three types of attributes or criteria;

- Qualitative benefit attributes/criteria
- Quantitative benefit attributes
- Cost attributes or criteria

A basic assumption of TOPSIS is that each attribute has a tendency towards monotonically increasing or decreasing utility. In this sense, it is easy to define two artificial points in the n-dimensional space: the ideal and the negative ideal solution. The ideal solution has the best values for all considered attributes whereas the negative ideal solution has all the worst attribute values. With the assumption that the closeness between two points can be measured by the Euclidean distance, solutions from TOPSIS are defined to be those which simultaneously are farthest from the negative ideal point as well as closest to the ideal point. TOPSIS considers the distances to both the ideal and the negative ideal solutions simultaneously by defining ''relative closeness to ideal solution'', C_i^* (i.e. the relative distance between a certain alternative and ideal and negative ideal solutions) according to the relation:

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^+}$$

where S_i^- is the separation from the negative ideal solution measured by the n-dimensional Euclidean distance between the ith alternative and the negative ideal solution and S_i^+ is the separation from the ideal solution measured by the n-dimensional Euclidean distance between the i^{th} alternative and the ideal solution. [55]

The steps of TOPSIS method are:

Step 1: Calculate the normalized decision matrix $R = \left[r_{ij} \right]_{mxn}$. The normalized value r_{ij} is calculated as

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1, 2, ..., m; \; j = 1, 2, ..., n \tag{2.8}$$

The normalization is done for convenience of comparison by converting different units of attributes to a unified unit.

Step 2: Calculate the weighted normalized decision matrix $V = \left[v_{ij} \right]_{mxn}$. The weighted normalized value v_{ij} is calculated as

$$v_{ij} = (w_j)(r_{ij}) \qquad i = 1, 2, ..., m; \; j = 1, 2, ..., n \tag{2.9}$$

where w_j is the weight of the j^{th} attribute and $\sum_{j=1}^{n} w_j = 1$.

Step 3: Determine the positive ideal solution (PIS) A^+ and negative ideal solution (NIS) A^-.

$$\begin{aligned} A^+ &= \left\{ \left(\max_i v_{ij} \mid j \in J \right), \left(\min_i v_{ij} \mid j \in J' \right), i = 1, 2, ..., m \right\} = \left\{ v_1^+, v_2^+, ..., v_n^+ \right\} \\ A^- &= \left\{ \left(\min_i v_{ij} \mid j \in J \right), \left(\max_i v_{ij} \mid j \in J' \right), i = 1, 2, ..., m \right\} = \left\{ v_1^-, v_2^-, ..., v_n^- \right\} \end{aligned} \tag{2.10}$$

where J is a set of benefit attributes and J' is a set of cost attributes.

Step 4: Calculate the separation measures, using the n-dimensional Euclidean distance.

The separation of each alternative from the positive ideal solution

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \qquad i = 1, 2, ..., m \tag{2.11}$$

The separation of each alternative from the negative ideal solution

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \qquad i = 1, 2, ..., m \qquad (2.12)$$

Step 5: Calculate the relative closeness to the ideal solution.

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \qquad i= 1, 2, \ldots, m; \;\; 0 \le C_i \le 1 \qquad (2.13)$$

In here; C_i^* takes a value between $0 \le C_i^* \le 1$ intervals and $C_i^* = 1$ shows the absolute closeness of related decision point to the ideal solution, $C_i^* = 0$ shows the absolute closeness of related decision point to the negative ideal solution.

Step 6: Rank the alternatives with respect to C_i in the descending order.

The preferred alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution, where a higher C_i would mean higher preference.

II.4.1.4 ELECTRE

ELECTRE (Elimination and Choice Translating Reality English) is a Multiple Criteria Decision Making Method which was conceived by Bernard Roy in response to deficiencies of existing decision making solution methods and it is answered a real-world problem brought to Bernard by SEMA (Société d'Economie et de Mathématiques Appliquées) consultants. SEMA had developed a technique, called MARSAN, designed to help firms selecting new activities. In order to help firms selecting new activities, the activities were evaluated on a series of 48 dimensions (the word "criterion" was not used then). They included "quantitative" as well as "qualitative" dimensions. Qualitative dimensions were translated on a numeric scale more or less arbitrarily. A weighted sum of all these numbers was computed to measure the attractiveness of these new activities. It soon appeared that the use of a weighted sum allowed compensation effects that were not desirable:

small advantages on several dimensions could compensate for major weaknesses on some others, which was not felt desirable. Moreover, the numerical recoding of qualitative dimensions was playing an important part in the final result. [52]

By the way, Roy came up with a method that would at the same time deal with qualitative dimensions without the need for recoding them and that would not tolerate compensation effects that were felt undesirable. This was the birth of ELECTRE I. Basically, in ELECTRE I, alternatives are compared by pair using the following reasoning. Alternative *a* will be declared at least as good as alternative *b* if:

- The proposition is supported by a "sufficient majority" of dimensions (concordance condition),
- Among the dimensions opposing the proposition, there is none on which the opposition is "too strong" (non-discordance condition).

Such an "at least as good as" relation (quickly called an *outranking* relation) can be built on the basis of purely ordinal considerations. The non-discordance condition prevents undesirable compensation effects from occurring. The application of the concordance condition leads to assigning weights to each dimension. In order to decide if a majority is sufficiently important, the sum of the weights is compared to a threshold called the concordance threshold (note that these weights are quite different from the weights used in a weighted sum; they are never multiplied with scores and are therefore independent from the scale used to measure scores). Similarly the strength of the opposition of dimensions is computed using a veto threshold. A specific feature of this relation is that it does not have to be transitive (even in its asymmetric part, because of Condorcet-like effects) or complete (some alternatives may remain incomparable). Therefore, deriving a prescription on this basis is not an easy task and calls for the application of specific techniques, called exploitation techniques. They differ on the type of recommendation that is looked for. ELECTRE I has been designed in a choice problem formulation, i.e., aims at recommending a subset of alternatives (as small as possible) that is likely to contain the best alternatives. Technically, Roy suggested using the kernel of the outranking graph, after reduction of eventual circuits. ELECTRE II is a variant of ELECTRE I that is designed to rank order alternatives. It uses two outranking relations instead of one. The ranking is not necessarily complete: it preserves incomparability between alternatives that appear difficult to compare. ELECTRE III is a far-reaching generalization of ELECTRE II that uses a fuzzy outranking relation instead of two crisp ones. Furthermore, it refines the preference modeling on each dimension with the introduction of thresholds preventing small differences between scores from being interpreted as a definite advantage. Such thresholds were introduced in a new version of ELECTRE I, called ELECTRE IS. ELECTRE IV is a variant of ELECTRE III designed to deal with situations in which weights are difficult to elicit given the diversity of opinions. ELECTE TRI is the most recent method. It is designed to deal with a sorting problem formulation in which each alternative is assigned to a category pre-defined by norms which, e.g., separate “good” and “bad” credit files. [52] ELECTRE method provides a different approach. This method concentrates the analysis on the dominance relations among the alternatives. That is why; this method is based on the study of outranking relations, exploiting notions of concordance. These outranking relations are built in such a way that it is possible to compare alternatives. The information required by ELECTRE consists of information among the criteria and information within each criterion. [53]

ELECTRE is more than just a solution method; it is a philosophy of decision. ELECTRE has evolved through a number of versions (I through IV); all are based on the same fundamental concepts but are operationally somewhat different. It is important to note that ELECTRE is not being presented as the "best" decision aid. It is one proven approach. Simpson has compared both SMART and ELECTRE and she concludes that, "There are obvious differences between the methods, but it is not obvious that one method is stronger than the other". [54]

All these methods were developed at the occasion of real-world studies. ELECTRE methods were applied to a large variety of problems in a large number of countries. ELECTRE depends on dual priority comparisons for every evaluation criteria between alternative decision points. ELECTRE goes to the solution in 8 steps.

Steps of ELECTRE are defined below:

Step 1: Decision Matrix (A) is constituted

There are decision points which are wanted to be arranged at the rows of decision matrix and evaluation criteria which will be used in decision making at the columns of the matrix. Matrix A is the beginning matrix which is formed by decision maker. Decision matrix is shown like below:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}$$

In the matrix A_{ij}, m gives the number of decision points and n gives the number of factors.

Step 2: The Standard Decision Matrix (X) is constituted

Standard Decision Matrix is calculated with the benefit from elements of matrix A by the formulation which is below.

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \qquad (2.14)$$

For example; to compute the element x_{11} of matrix, a_{11} element of matrix A is divided by square root of sum squares of elements of column 1. While a decision point is connecting with the related evaluation criterion, in here the aim is weighting according to other evaluation criteria. End of the calculations matrix X is acquired as below:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$

Step 3: Weighted Standard Decision Matrix (*Y*) is constituted

Importance of the evaluation criteria can be different according to decision maker. To reflect these importance differences to the ELECTRE solution matrix *Y* is computed. First of all, decision maker should determine the weights (w_i) of evaluation criteria ($\sum_{i=1}^{n} w_i = 1$).

Later on, elements of matrix *X* in each column are multiplied by related (w_i) value and the matrix *Y* is constituted. Matrix *Y* is shown below:

$$Y_{ij} = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \dots & w_n x_{1n} \\ w_1 x_{21} & w_2 x_{22} & \dots & w_n x_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ w_1 x_{m1} & w_2 x_{m2} & \dots & w_n x_{mn} \end{bmatrix}$$

Step 4: Determination of the Concordance (C_{ij}) and Discordance (D_{ij}) Sets

For determining the concordance sets, matrix *Y* is used, decision points are compared to each other in terms of evaluation criteria and matrices are defined with the help which is shown in formula:

$$C_{ij} = \{k, y_{ik} \geq y_{jk}\} \tag{2.15}$$

Basically, the formula depends on comparison of sizes of row elements to each other. In a multiple decision problem, the number of concordance sets is ($m.m - m$); because, to constitute the concordance set, *i* and *j* indices should be $i \neq j$. Number of the elements in a concordance set can be as the number of evaluation criteria (n) at maximum.

For instance; for $i = 1$ and $j = 2$ for the concordance set C_{12}, first and second raw elements of matrix Y are compared correspondingly each other and if there are 4 evaluation criteria, concordance set C_{12} will have 4 elements at most. In the given example; at first and second row comparison,

$y_{11} > y_{21}$

$y_{12} < y_{22}$

$y_{13} < y_{23}$

$y_{14} = y_{24}$

if the results is met which are seen above, $k = 1$ and $k = 4$ values will fit in (2.2) formula and the concordance set C_{12} will be formed as $C_{12} = \{1,4\}$.

In ELECTRE method, a discordance set (D_{ij}) corresponds to every concordance set (C_{ij}). In other words, there are number of discordance sets as the number of concordance sets. Elements of discordance sets are consisted of k values which do not belong to the related concordance set. In given example; if $C_{12} = \{1,4\}$ is, then $D_{12} = \{2,3\}$ will be.

In ELECTRE method; while concordance sets are forming, meaning of the evaluation factors should be taken into consideration. For example; if the related evaluation factor is profit, formula (2.2) will be used for the concordance set. However, if the evaluation criterion is cost, required condition will be $y_{ik} < y_{jk}$ for the concordance set in this case.

Step 5: Concordance (C) and Discordance Matrices (D) are constituted

For constituting the Concordance Matrix (C), concordance sets are used. Matrix C has mxm dimensions and does not take any value for $k = l$. Elements of the matrix C compute by the help of the relation which is shown below formula.

$$c_{kl} = \sum_{j \in C_{kl}} w_j \qquad (2.16)$$

For example; if $C_{12} = \{1,4\}$ is, value of the element c_{12} in matrix C will be $c_{12} = w_1 + w_4$. Matrix C is pointed out below:

$$C = \begin{bmatrix} - & c_{12} & c_{13} & \dots & c_{1m} \\ c_{21} & - & c_{23} & \dots & c_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ c_{m1} & c_{m2} & c_{m3} & \dots & - \end{bmatrix}$$

Elements of Discordance matrix (D) are computed by the help of below formula:

$$d_{kl} = \frac{\max\limits_{j \in D_{kl}} \left| y_{kj} - y_{lj} \right|}{\max\limits_{j} \left| y_{kj} - y_{lj} \right|} \tag{2.17}$$

For instance; from the comparison of first and second row elements of matrix Y, element d_{12} ($i = 1$ and $j = 2$) is acquired. For d_{12}, from the numerator part of the formula (2.4) $k = 2$ and $k = 3$ values, which are formed the discordance set, are taken into consideration and from the absolute difference $\left| y_{12} - y_{22} \right|$ and $\left| y_{13} - y_{23} \right|$ greater one is chosen. For the denominator part of the formula, absolute differences of all the elements in first and second rows of matrix Y are found and the greatest one is chosen.

Such as matrix C, matrix D has also mxm dimensions and does not take any value for $i = j$. Matrix D is pointed out below:

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

Step 6: Concordance Strength (F) and Discordance Strength (G) Matrices are constituted

Concordance Strength Matrix (F) has mxm dimensions and elements of this matrix are acquired from the comparison of concordance threshold value ($\underline{c}$) with the elements of concordance matrix (c_{ij}). Concordance threshold value ($\underline{c}$) is obtained with the help of below formula:

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl} \qquad (2.18)$$

m that is in the formula shows the number of decision points. With a clearer manner, $\underline{c}$ value is equal to multiplication of $\frac{1}{m(m-1)}$ and sum of elements that are consisted matrix C.

Elements of matrix F (f_{ij}), either take 1 or 0 value; and furthermore there are no value because of showing the same decision points on the diagonal of the matrix. If $c_{ij} \geq \underline{c}$, then $f_{ij} = 1$; if $c_{ij} < \underline{c}$, then $f_{ij} = 0$.

Discordance Strength Matrix (G) also has mxm dimensions and it is constituted in a similar way to matrix F. Discordance threshold value ($\underline{d}$) is acquired with the help of below formula:

$$\underline{d} = \frac{1}{m(m-1)} \sum_{i=1}^{m} \sum_{j=1}^{m} d_{ij} \qquad (2.19)$$

In other words $\underline{d}$ value is equal to multiplication of $\frac{1}{m(m-1)}$ and sum of elements that are consisted matrix D.

Elements of matrix G (g_{kl}), either take 1 or 0 value; and furthermore there are no value because of showing the same decision points on the diagonal of the matrix. If $d_{ij} \geq \underline{d}$, then $g_{ij} = 1$; if $d_{ij} < \underline{d}$, then $g_{ij} = 0$.

Step 7: Total Domination Matrix (E) is constituted

Elements of the Total Domination Matrix (e_{ij}) is equal to reciprocally multiplication of f_{ij} and g_{ij} elements like as it is shown in the following formula. Herein, matrix E has mxm dimensions correlated to matrices C and D, and again it is constituted either 1 or 0 values.

Step 8: Determining the Importance Order of Decision Points

Rows and columns of matrix E shows the decision points. For example; if matrix E is computed as below,

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

then it takes $e_{21} = 1$, $e_{31} = 1$ and $e_{32} = 1$ values. This shows that the second decision point's absolute strength to first decision point, third decision point's absolute strength to first decision point and also third decision point's absolute strength to second decision point. In this situation; if the decision points are indicated by the A_i ($i = 1,2,...,m$) symbol, importance order of the decision points will occur such as A_3, A_2 and A_1.

II.4.1.5 Multi Attribute Utility Theory

Multi-attribute utility theory (MAUT) has been used in international supplier selection considering one decision maker in a single sourcing environment by Min however the probabilistic nature of supplier performance still remained unanswered. [56]

As indicated in the previous section, supplier selection is a complex decision-making problem. The complexity stems from the probability nature of the problem, a multitude of quantitative and qualitative factors influencing supplier choices as well as the intrinsic difficulty of making numerous tradeoffs among these factors. One analytical approach often suggested for solving such complex problems is MAUT.

Keeney and Raiffa employed the utility concept in complex decision problems involving multiple attributes and multiple conflicting objectives, and provided a systematical approach of multiple attributes utility analysis. Multiple attributes utility analysis is targeted in solving problems of trading off the achievement of some objectives against other objectives to obtain the maximum overall utility. A decision-maker is assumed to be facing the above-mentioned problem, and he/she has to choose a solution from some solution alternatives.

Multiple attributes utility analysis is used to assess the decision-maker's preference structure and model it mathematically with a multiple attributes utility function. This multiple attributes utility function is then applied to help the decision maker reach an optimal decision. [57]

MAUT enables the decision maker to structure a complex problem in the form of a simple hierarchy and to subjectively evaluate a large number of quantitative and qualitative factors in the presence of uncertainty. Utility is a measure of desirability or satisfaction and provides a uniform scale to compare and/or combine quantitative and qualitative factors. A utility function is a device which quantifies the preferences of a decision maker by assigning a numerical index to varying levels of satisfaction of a criterion. The major strength of MAUT is its ability to deal with both deterministic and stochastic decision environments. The systematic nature of MAUT in tackling complex problems with conflicting criteria makes it especially suitable for selecting the most appropriate supplier. [57]

Under multi-attribute utility theory, a decision maker formulates his or her preferences in terms of a scalar function, called a utility function, over the domain of attribute values. This function defines the decision maker's preferred attribute values and the tradeoffs between different attributes. Uncertainty is modeled probabilistically as a distribution over the possible attribute values for a given action on the part of a decision maker. For a properly-constructed utility function, the most preferred action of the decision maker corresponds to the action that maximizes expected utility. In the context of a design decision, actions represent the different design alternatives from which a designer can choose. Attributes are aspects of the design about which a designer cares such as cost, reliability, or speed and their exact values for a given design alternative might not be known with certainty. Under utility theory, designers model these uncertainties probabilistically and aggregate the possible outcomes by taking an expectation over the uncertain domain. Mathematically, one can state a design decision according to multi-attribute decision theory as:

$$d^* = \arg\max_{d_i \in D} E_x \left[U\left(x_1(d_i), x_2(d_i), \ldots x_N(d_i)\right) \middle| d_i \right] \quad (2.20)$$

where d_i is a particular design alternative, D is the notional set of all design alternatives, d^* is the most preferred design alternative, $x_j(d_i)$ is one of the N (uncertain) attributes corresponding to the specified design alternative, $U(.)$ maps attribute values to a scalar value and $E_X [.|d_i]$ is the expectation taken over attribute values given a particular design alternative. Note that there is no imprecision in this formulation; uncertainty about the attributes of a given decision alternative is represented using a precise probability distribution. [58]

II.4.1.6 Fuzzy Sets Theory

Fuzzy Set Theory was formalized by Professor Lofti Zadeh at the University of California in 1965. What Zadeh proposed is very much a paradigm shift that first gained acceptance in the Far East and its successful application has ensured its adoption around the world.

Fuzzy sets are sets whose elements have degrees of membership. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition — an element either belongs or does not belong to the set. By contrast, fuzzy set theory permits the gradual assessment of the membership of elements in a set; this is described with the aid of a membership function valued in the real unit interval [0, 1]. Fuzzy sets generalize classical sets, since the indicator functions of classical sets are special cases of the membership functions of fuzzy sets, if the latter only take values 0 or 1. Classical bivalent sets are in fuzzy set theory usually called *crisp* sets.

A number of authors suggests to use fuzzy sets theory (FST) to model uncertainty and imprecision in supplier choice situations. In short, FST offers a mathematically precise way of modeling vague preferences for example when it comes to setting weights of performance scores on criteria. Simply stated, FST makes it possible to mathematically describe a statement like: criterion X should have a weight of around 0.8. FST can be combined with other techniques to improve the quality of the final tools. [21]

II.4.2 Mathematical Programming Models

Any organization, from a single person to a multinational company through small companies, factories, etc., make always decisions (investment, resources acquisition, production planning, etc.) and mathematical programming allows the decision maker to formulate the decision problems in terms of a mathematical objective function. Decisions are made by choosing numerical values of some free variables called decision variables or control variables (production level for a given period, stock level, investment budget level, etc.) in order to optimize (minimize or maximize) some objectives (maximize profit, minimize cost, minimize risk, etc.) when respecting some constraints due to necessarily limitation of available resources (budget limitation, lake of qualified manpower, etc.) and some technical specifications. For that reason; on the one hand, it may be argued that mathematical programming models are more objective than rating models because they force the decision maker to explicitly state the objective function. On the other hand, mathematical programming models often only consider the more quantitative criteria. The problems are well formulated when all the parameters are specified by the so-called mathematical programming (also known as optimization) problem in the literature.

II.4.2.1 Linear Programming

A linear programming (LP) problem may be defined as the problem of maximizing or minimizing a linear function subject to linear constraints. The constraints may be equalities or inequalities.

Linear programming, sometimes known as linear optimization, is the problem of maximizing or minimizing a linear function over a convex polyhedron specified by linear and non-negativity constraints. Simplistically, linear programming is the optimization of an outcome based on some set of constraints using a linear mathematical model.

Linear programming theory falls within convex optimization theory and is also considered to be an important part of operations research. Linear programming is extensively used in business and economics, but may also be used to solve certain engineering problems.

Wood and Dantzig state that linear programming can be solved using the simplex method which runs along polytope edges of the visualization solid to find the best answer. Khachian (1979) found a $O(x^5)$ polynomial time algorithm. A much more efficient polynomial time algorithm was found by Karmarkar (1984). This method goes through the middle of the solid (making it a so-called interior point method), and then transforms and warps. Arguably, interior point methods were known as early as the 1960s in the form of the barrier function methods, but the media hype accompanying Karmarkar's announcement led to these methods receiving a great deal of attention. [59]

Linear programming is an important field of optimization for several reasons. Many practical problems in operations research can be expressed as linear programming problems. Certain special cases of linear programming, such as network flow problems and multi commodity flow problems are considered important enough to have generated much research on specialized algorithms for their solution. A number of algorithms for other types of optimization problems work by solving LP problems as sub-problems. Historically, ideas from linear programming have inspired many of the central concepts of optimization theory, such as duality, decomposition, and the importance of convexity and its generalizations. Likewise, linear programming is heavily used in microeconomics and business management, such as planning, production, transportation, technology and other issues.

Standard form is the usual and most intuitive form of describing a linear programming problem. It consists of the following three parts:

1. A linear function to be maximized

   e.g. maximize $c_1x_1 + c_2x_2$

2. Problem constraints of the following form

   e.g.

$$a_{11}x_1 + a_{12}x_2 \le b_1$$
$$a_{21}x_1 + a_{22}x_2 \le b_2$$
$$a_{31}x_1 + a_{32}x_2 \le b_3$$

3. Non-negative variables

e.g. $x_1 \geq 0$

$x_2 \geq 0$

The problem is usually expressed in matrix form, and then becomes:

Maximize $c^T x$

Subject to $Ax \leq b, x \geq 0$

Other forms, such as minimization problems, problems with constraints on alternative forms, as well as problems involving negative variables can always be rewritten into an equivalent problem in standard form.

Geometrically, the linear constraints define a convex polyhedron, which is called the feasible region. Since the objective function is also linear, hence a convex function, all local optima are automatically global optima. The linearity of the objective function also implies that an optimal solution can only occur at a boundary point of the feasible region, unless the objective function is constant, when any point is a global minimum.

There are two situations in which no optimal solution can be found. First, if the constraints contradict each other (for instance, $x \geq 2$ and $x \leq 1$) then the feasible region is empty and there can be no optimal solution, since there are no solutions at all. In this case, the LP is said to be infeasible.

Alternatively, the polyhedron can be unbounded in the direction of the objective function (for example: maximize $x_1 + 3\,x_2$ subject to $x_1 \geq 0$, $x_2 \geq 0$, $x_1 + x_2 \geq 10$), in which case there is no optimal solution since solutions with arbitrarily high values of the objective function can be constructed.

Barring these two pathological conditions (which are often ruled out by resource constraints integral to the problem being represented, as above), the optimum is always attained at a vertex of the polyhedron. However, the optimum is not necessarily unique: it is possible to have a set of optimal solutions covering an edge or face of the polyhedron, or even the entire polyhedron.

The simplex algorithm solves LP problems by constructing an admissible solution at a vertex of the polytope, and then walking along edges of the polytope to vertices with successively higher values of the objective function until the optimum is reached. Although this algorithm is quite efficient in practice, and is guaranteed to find the global optimum, it has poor worst-case behavior: it is possible to construct a linear programming problem for which the simplex method takes a number of steps exponential in the problem size. In fact for some time it was not known whether the linear programming problem was NP-complete or polynomial-time solvable.

The first worst-case polynomial-time algorithm for the linear programming problem was proposed by Leonid Khachiyan in 1979. It was based on the ellipsoid method in nonlinear optimization by Naum Shor , which is the generalization of the ellipsoid method in convex optimization by Arkadi Nemirovski , a 2003 John von Neumann Theory Prize The John von Neumann Theory Prize of the Institute for Operations Research and Management Science (INFORMS, previously TIMS-ORSA) is awarded annually to an individual (or sometimes group) who have made fundamental and sustained contributions to theory in winner, and D. Yudin . However, the practical performance of Khachiyan's algorithm is disappointing: generally, the simplex method is more efficient. Its main importance is that it encouraged the research of interior point method s. In contrasts with the simplex algorithm, which only considers point on the boundary of the polytope defined by the constraints, interior point methods move through the interior of the polytope. In 1984, N. Karmarkar proposed the projective method. This is the first algorithm performing well both in theory and in practice: Its worst-case complexity is polynomial and experiments on practical problems show that it is reasonably efficient compared to the simplex algorithm. Since then, many interior point methods have been proposed and analyzed. A popular interior point method is the Mehrotra predictor-corrector method, which performs very well in practice even though little is known about it theoretically.

The current opinion is that the efficiency of good implementations of simplex-based methods and interior point methods is similar for routine applications of linear programming.

LP solvers are in widespread use for optimization of various problems in industry, such as optimization of flow in transportation networks, many of which can be transformed into linear programming problems only with some difficulty. [60]

II.4.2.2 Goal Programming

Goal programming is a branch of multiple objective programming, which in turn is a branch of multi-criteria decision analysis, also known as multiple-criteria decision making. It can be thought of as an extension or generalization of linear programming to handle multiple, normally conflicting objective measures. Each of these measures is given a goal or target value to be achieved. Unwanted deviations from this set of target values are then minimized in an achievement function. This can be a vector or a weighted sum dependent on the goal programming variant used. As satisfaction of the target is deemed to satisfy the decision maker(s), an underlying satisfying philosophy is assumed.

II.4.2.3 Multi Objective Programming

Optimization of a single objective oversimplifies the pertinent objective function in some potential mathematical programming application situations. Arguments can also be made following Simon that optimization is not as appropriate as satisfying. These two statements introduce the general topic of multiple objective programming. Multi objective programming formally permits formulations where:

a) Solutions are generated which are as consistent as possible with target levels of goals;

b) Solutions are identified which represent maximum utility across multiple objectives; or

c) Solution sets are developed which contain all non dominated solutions.

Multiple objectives can involve such considerations as leisure, decreasing marginal utility of income, risk avoidance, preferences for hired labor, and satisfaction of desirable, but not obligatory, constraints.

A discussion of this area requires some definitions. An objective is a measure that one is concerned about when making a choice among the decision variables (something to be maximized, minimized or satisfied like leisure, risk, profits, etc.). A goal implies that a particular goal target value has been chosen for an objective.

Multi objective programming will be used to refer to any mathematical program involving more than one objective regardless of whether there are goal target levels involved.

Multi objective programming involves recognition that the decision maker is responding to multiple objectives. Generally, objectives are conflicting, so that not all objectives can simultaneously arrive at their optimal levels. An assumed utility function is used to choose appropriate solutions. Several fundamentally different utility function forms have been used in multi objective models. These may be divided into three classes: lexicographic, multi attribute utility and unknown utility.

II.4.2.4 Integer Programming

Integer programming is similar as linear programming. Integer programming is a general term that refers to any mathematical optimization or feasibility program in which some or all of the variables are restricted to be integral. If the unknown variables are all required to be integers, then the problem is called an integer linear programming (ILP) problem. In contrast to linear programming, which can be solved efficiently in the worst case, integer programming problems are in many practical situations (those with bounded variables) NP-hard. 0-1 integer programming or binary integer programming (BIP) is the special case of integer programming where variables are required to be 0 or 1 (rather than arbitrary integers). This problem is also classified as NP-hard.

II.4.2.5 Mixed Integer Programming

If only some of the unknown variables are required to be integers, then the problem is called a mixed integer programming problem. These are generally also NP-hard.

II.4.2.6 Nonlinear Programming

Nonlinear programming is the process of solving a system of equalities and inequalities, collectively termed constraints, over a set of unknown real variables, along with an objective function to be maximized or minimized, where some of the constraints or the objective functions are nonlinear.

A typical non convex problem is that of optimizing transportation costs by selection from a set of transportation methods, one or more of which exhibit economies of scale, with various connectivity and capacity constraints. An example would be petroleum product transport given a selection or combination of pipeline, rail tanker, road tanker, river barge, or coastal tank ship. Owing to economic batch size the cost functions may have discontinuities in addition to smooth changes.

II.4.2.7 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a relatively new data oriented approach for evaluating the performance of a set of peer entities called Decision Making Units (DMU) which convert multiple inputs into multiple outputs. The definition of a DMU is generic and flexible. Recent years have seen a great variety of applications of DEA for use in evaluating the performances of many different kinds of entities engaged in many different activities in many different contexts in many different countries. These DEA applications have used DMU of various forms to evaluate the performance of entities, such as hospitals, US Air Force wings, universities, cities, courts, business firms, and others, including the performance of countries, regions, etc. Because it requires very few assumptions, DEA has also opened up possibilities for use in cases which have been resistant to other approaches because of the complex (often unknown) nature of the relations between the multiple inputs and multiple outputs involved in DMU.

DEA has also been used to supply new insights into activities (and entities) that have previously been evaluated by other methods. For instance, studies of benchmarking practices with DEA have identified numerous sources of inefficiency in some of the most profitable firms - firms that had served as benchmarks by reference to this (profitability) criterion – and this has provided a vehicle for identifying better benchmarks in many applied studies. Because of these possibilities, DEA studies of the efficiency of different legal organization forms such as stock vs. mutual insurance companies have shown that previous studies have fallen short in their attempts to evaluate the potentials of these different forms of organizations. Similarly, a use of DEA has suggested reconsideration of previous studies of the efficiency with which pre- and post-merger activities have been conducted in banks that were studied by DEA.

DEA is a mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates of relations - such as the production functions and/or efficient production possibility surfaces – that are cornerstones of modern economics

Formally, DEA is a methodology directed to frontiers rather than central tendencies instead of trying to fit a regression plane through the center of linear surface to rest on top of the observations. Because of this perspective, DEA proves particularly adept at uncovering relationships that remain hidden from other methodologies. For instance, consider what one wants to mean by “efficiency”, or more generally, what one wants to mean by saying that one DMU is more efficient than another DMU. This is accomplished in a straightforward manner by DEA without requiring explicitly formulated assumptions and variations with various types of models such as in linear and nonlinear regression models. [61]

II.4.2.8 Heuristics

A heuristic method is particularly used to rapidly come to a solution that is hoped to be close to the best possible answer or optimal solution, but not guarantee that the best will be found. Therefore they may be considered as approximately and not accurate algorithms. Heuristics are rules of thumb, educated guesses, intuitive judgments or simply common sense. These algorithms usually find a solution close to the best one and they find it fast and easily. Sometimes these algorithms can be accurate, that is they actually find best solution, but the algorithm is still called heuristic until this best solution is proven to be the best.

II.4.3 Statistical Models

Statistical models deal with the stochastic uncertainty related to the supplier selection. Although stochastic uncertainty is present in most types of purchasing situations, e.g. by not knowing exactly how the internal demand for the items or services purchased will develop, only very few supplier selection models really handle this problem. [21]

II.4.3.1 Principal Component Analysis

Principal component analysis (PCA) is appropriate when you have obtained measures on a number of observed variables and wish to develop a smaller number of artificial variables (called principal components) that will account for most of the variance in the observed variables. The principal components may then be used as predictor or criterion variables in subsequent analyses.

PCA is a variable reduction procedure. It is useful when you have obtained data on a number of variables (possibly a large number of variables), and believe that there is some redundancy in those variables. In this case, redundancy means that some of the variables are correlated with one another, possibly because they are measuring the same construct. Because of this redundancy, you believe that it should be possible to reduce the observed variables into a smaller number of principal components (artificial variables) that will account for most of the variance in the observed variables.

Because it is a variable reduction procedure, PCA is similar in many respects to exploratory factor analysis. In fact, the steps followed when conducting a principal component analysis are virtually identical to those followed when conducting an exploratory factor analysis. However, there are significant conceptual differences between the two procedures, and it is important that you do not mistakenly claim that you are performing factor analysis when you are actually performing principal component analysis.

The principal component analysis method is a multi objective approach to supplier selection that attempts to provide a useful decision support system for a purchasing manager faced with multiple suppliers and trade-offs such as price, delivery, reliability, and product quality. This multivariate statistical method is a data reduction technique used to identify a small set of variable that account for a large portion of the total variance in the original variance. This method is also a popular ranking method in multidimensional analysis. The principal component analysis methodology has the advantage to be fairly simple to exploit, since it has been accessible for decades. This method has proved to be capable of handling multiple conflicting attributes inherent in supplier selection while simultaneously trading-off key supplier selection criteria. [62]

II.4.3.2 Conjoint Analysis

Many consumers are unable to accurately determine the relative importance that they place on product attributes when they are asked to do so obviously. For example, when asked which attributes are the more important ones, the response may be that they all are important. Furthermore, individual attributes in isolation are perceived differently than in the combinations found in a product. It is difficult for a survey respondent to take a list of attributes and to construct mentally the preferred combinations of them. The task is easier if the respondent is presented with combinations of attributes that can be visualized as different product offerings. However, such a survey becomes impractical when there are several attributes that result in a very large number of possible combinations.

Fortunately, conjoint analysis can facilitate the process. Conjoint analysis is a tool that allows a subset of the possible combinations of product features to be used to determine the relative importance of each feature in the purchasing decision. Conjoint analysis is based on the fact that the relative values of attributes considered jointly can better be measured than when considered in isolation.

In a conjoint analysis, the respondent may be asked to arrange a list of combinations of product attributes in decreasing order of preference. Once this ranking is obtained, a computer is used to find the utilities of different values of each attribute that would result in the respondent's order of preference. This method is efficient in the sense that the survey does not need to be conducted using every possible combination of attributes. The utilities can be determined using a subset of possible attribute combinations. From these results one can predict the desirability of the combinations that were not tested. [63]

II.4.3.3 Discrete Choice Models

Discrete choice models are statistical procedures that describe choices made by people among a finite set of alternatives. The models have been used to examine, e.g., the choice of which car to buy, where to go to college, which mode of transport (car, bus, rail) to take to work, among numerous other applications. Discrete choice models are also used to examine choices by organizations, such as firms or government agencies.

Discrete choice models statistically relate the choice made by each person to the attributes of the person and the attributes of the alternatives available to the person. For example, the choice of which car a person buys is statistically related to the person's income and age as well as to price, fuel efficiency, size, and other attributes of each available car. The models estimate the probability that a person chooses a particular alternative. The models are often used to forecast how people's choices will change under changes in demographics and/or attributes of the alternatives.

II.4.4 Artificial Intelligence Based Models

Artificial Intelligence (AI) based models are based on computer-aided systems that in one way or another can be trained by a purchasing expert or historic data. Subsequently, non-experts who face similar but new decision situations can consult the system. Although only few examples of AI methods applied to the supplier evaluation problem can be found in the literature to date it is important to investigate these methods for their potentialities. Because of newness of some methods, such as Internet-based technology, only few examples with a demonstrative character are already available. [21]

II.4.4.1 Expert Systems

An expert system is a computer program that contains some of the subject-specific knowledge of one or more human experts. Knowledge base is the component of an expert system that contains the system's knowledge. Expert systems are also known as Knowledge-based systems. The most common form of expert systems is a program made up of a set of rules that analyze information (usually supplied by the user of the system) about a specific class of problems, as well as providing mathematical analysis of the problem(s), and, depending upon their design, recommend a course of user action in order to implement corrections. It is a system that utilizes what appear to be reasoning capabilities to reach conclusions.

II.4.4.2 Artificial Neural Networks

An artificial neural network, usually called neural network, is a mathematical model or computational model that tries to simulate the structure and/or functional aspects of biological neural networks. In most cases an artificial neural network is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. A neural network, also known as a parallel distributed processing network, is a computing paradigm that is loosely modeled after cortical structures of the brain. It consists of interconnected processing elements called nodes or neurons that work together to produce an output function. The output of a neural network relies on the cooperation of the individual neurons within the network to operate. Processing of information by neural networks is characteristically done in parallel rather than in series (or sequentially) as in earlier binary computers or Von Neumann machines. Since it relies on its member neurons collectively to perform its function, a unique property of a neural network is that it can still perform its overall function even if some of the neurons are not functioning.

Neural network theory is sometimes used to refer to a branch of computational science that uses neural networks as models to simulate or analyze complex phenomena and/or study the principles of operation of neural networks analytically. It addresses problems similar to artificial intelligence (AI) except that AI uses traditional computational algorithms to solve problems whereas neural networks use networks of agents (software or hardware entities linked together) as the computational architecture to solve problems. Neural networks are trainable systems that can “learn” to solve complex problems from a set of exemplars and generalize the “acquired knowledge” to solve unforeseen problems as in stock market and environmental prediction. I.e., they are self-adaptive systems.

The user of a system only has to provide the neural network with the characteristics of the current situation (e.g. the performance of the supplier on the criteria). The neural network subsequently makes the actual trade-off for the user, based on what it has learned from the expert or cases in the past. At the same time, this strength can be seen as a weakness because it also implies that the user of the neural Network will not be able to explain the trade-off to others, for example to suppliers that will not receive business. This makes neural networks primarily suitable for situations where external justification is less important or as a shadow method in combination with a traditional method. [21]

II.4.4.3 Cased Based Reasoning

Case-based reasoning (CBR) solves new problems by adapting previously successful solutions to similar problems. An auto mechanic who fixes an engine by recalling another car that exhibited similar symptoms is using case-based reasoning. A lawyer who advocates a particular outcome in a trial based on legal precedents or a judge who creates case law is using case-based reasoning. So, too, an engineer copying working elements of nature; is treating nature as a database of solutions to problems. Case-based reasoning is a prominent kind of analogy making.

Case-based reasoning (CBR) technology is very new and only a few CBR systems have been developed for the use in purchasing decision-making, but some characteristics of CBR systems such as the capability to use information from previous negotiations and the easy training of the system, make them interesting in connection with supplier choice. [21]

II.4.5 Cost Based Models

II.4.5.1 Activity Based Costing (ABC)

Activity-Based Costing (ABC) is a costing model that identifies activities in an organization and assigns the cost of each activity resource to all products and services according to the actual consumption by each: it assigns more indirect costs (overhead) into direct costs. In this way an organization can establish the true cost of its individual products and services for the purposes of identifying and eliminating those which are unprofitable and lowering the prices of those which are overpriced.

In a business organization, the ABC methodology assigns an organization's resource costs through activities to the products and services provided to its customers. It is generally used as a tool for understanding product and customer cost and profitability. As such, ABC has predominantly been used to support strategic decisions such as pricing, outsourcing and identification and measurement of process improvement initiatives. [64]

II.4.5.2 Total Cost of Ownership (TCO)

Total Cost of Ownership (TCO) focuses on the true costs associated with the entire purchasing cycle, thus TCO considers all costs associated with the acquisition, usage, maintenance, and follow-up of purchased goods or service, not just the purchasing price. [64]

TCO attempts to quantify all of the costs related to the purchase of a given quantity of products or services from a given supplier. Optimum use of all discounts available can lead to substantial savings. In addition to the price component, other cost factors also play an important role, including the costs associated with quality shortcomings, a supplier’s unreliable delivery service, transport costs, ordering costs, reception costs, and inspection costs. This method uses activity- based costing which is a management accounting technique that attempts to assign costs to cost generating activities within a business. This technique uses activity analysis, which defines the various activities performed by an organization. The first step of the total cost of ownership method is to define all the activities related to external purchasing. These are specific to every enterprise and should be expressed through the activity analysis. Subsequently, costs must be assigned to the different activities. The next step is to define factors which raise the cost of a given activity (cost drivers). Finally, one must identify which activities are generated in the purchasing organization by each individual supplier. This approach enables substantial cost savings to be achieved and, at the same time, allows various purchasing policies to be compared with one another. [62]

II.4.5.3 Cost Ratio Method

The cost-ratio method relates all identifiable purchasing costs to the monetary value of the goods received from suppliers. The higher the ratio of costs to value, the lower the rating applied to the vendor. The choices of costs to be incorporated in the evaluation depend on the products involved.

The costs associated with quality include the costs of visits to a supplier's plants and sample approval, inspection costs of incoming shipments, and the costs associated with defective products such as unusual inspection procedures, rejected parts and manufacturing losses due to defective goods. Quality costs can be determined and documented by the quality control department, with the help of other departments such as production and receiving. The usual costs associated with delivery include communications, settlements and emergency transport costs (for example air shipments). The same tabulation procedure is followed as for the quality costs. The cost-ratio method establishes a "norm" of supplier services and evaluates suppliers above and below the norm in relation to price. The subjective elements common to other methods are thus reduced.

The cost ratio method is based on cost analysis that considers cost ratios for product quality, delivery, customer service and price. The cost ratio measures the cost of each factor as a percentage of total purchase for the supplier. Due to the flexibility of this method, any company in any market can adopt it. The drawback of the method is its complexity and requirement for a developed cost accounting system. [62]

CHAPTER III : APPLICATION

III.1 METHODOLOGY

Supplier selection process has an increasing importance in today's competitive business world. So, finding better supplier selection methods is quite crucial to has a competitive edge in this environment. For this reason, supplier selection topics studied in the literature for many times with many methods and models to help decision makers.

Heretofore; the mentioned subjects in this study show that the supplier selection process is a considerably tough topic to cope with its conflicting objectives such as cost, quality, delivery time, and etc. That is why; it is a multiple criteria decision making process, because if everything is not taken into consideration, the process can be more complicated and harder.

In this thesis, various supplier selection methods in the literature were studied and analyzed. Then the appropriate ones were chosen to implement in a manufacturing firm. With the guidance of the suppliers' information, some strategies were developed and some solution suggestions were represented to the firm. For this study, suitable suggestions for firm's requirements and conditions were selected from entire alternatives.

The firm is a low voltage switch devices manufacturer. Their main product is contactor switches. For the production of them, the firm is purchasing various kinds of materials and raw materials. Switches, gauges, transformers, electric circuit breakers, electronic circuits generally come from the Far East. So, the most important raw materials after them, which are from domestic markets, are cap screws. There are a lot of supplier firms that supply cap screws; but the manufacturer firm works with only 3 suppliers at maximum and keeps 1 supplier as an auxiliary supplier according to the firm's policy. Furthermore, the manufacturer firm determines 2 of these suppliers as main suppliers.

The manufacturer firm follows the monthly technical publications, fairs, friendly firms and internet to determine new suppliers. Afterwards, the cost proposals are taken and samples are requested. If the samples satisfy the manufacturer firm's requests, manufacturer firm starts to work with these suppliers. However, the manufacturer always keeps an alternative supplier handy for just in case. Then trial order is placed. Trial order is very important because the point is not one time satisfaction, it is finding good suppliers and working with them in a stable way. In contracts, the manufacturer firm usually wants price guarantee for a 6-month period and sometimes they can assign a limit as ±10%. If the firm's satisfaction is sustainable, the contracts will renew in second 6-month period.

For cap screws, 10000 holding stocks are desired. In the supervisions, these stocks are checked and there are also controls for quality which make an audit for checking correct measurement in calipers and checking if qualified employers are working or not.

According to the data which the firm has shared, some methods were eliminated because of their inconvenience. Artificial intelligence based methods were eliminated because they need historical data. Cost based methods are eliminated because of the privacy policy of the selected firm; they did not share detailed cost data. Mathematical programming models aim to select more than one choice under some restrictions such as quality. But it is aimed to select the best supplier to work cooperative base as a supply chain. Mathematical programming models are used for multiple sourcing strategies. So they are eliminated. Remained methods are linear weighting methods. In this thesis, 3 of these methods (AHP, TOPSIS and ELECTRE) were implemented.

In the literature review section, phases of supplier selection are explained and there was pre-qualification of suitable suppliers phase. Theoretically decision makers eliminate suppliers in this phase by using some selection methods. But in this study, there are only 4 different suppliers which are supplying the same materials in the supplier list of the firm. So a pre-qualification phase was not needed.

III.2 IMPLEMENTATION

III.2.1 Problem Definition

As it is mentioned, supply chain management (SCM) has an increasing importance in today's competitive business world and companies need to have strong relationships and integrations with their suppliers for a successful SCM system. So, having strong relationships with suppliers is also an important aspect for decreasing the costs of the company, increasing the customer satisfaction and the indirect result such as remaining competitive. [45]

In this study, there are 4 different suppliers of a company for one kind of material. The aim is to find the best supplier for the integration reasons by different supplier selection methods.

III.2.2 Formulation of the Decision Criteria

As a result of interviews with staff and getting information from them, the supplier evaluation criteria were decided. According to this analysis; quality, cost, delivery time & transportation, minimum order quantity, production capacity, technology & flexibility, holding stock and payment term are defined as the criteria. The criteria and the sub criteria are seen in the following table.

Table III-1 Supplier Selection Criteria and the Sub Criteria for the Firm

Criteria (According to their importance)	Sub Criteria
Quality	Quality inspection methods Percentage of refused products High quality employee Product performance
Cost	Discount dependent on purchasing quantity Outsourcing costs Holding costs
Delivery Time & Transportation	Delivery speed Just in time delivery Transportation costs Flexibility on delivery time
Minimum Order Quantity	Holding stock on desired quantity Supplier’s adaptation to requested quantity
Production Capacity, Technology & Flexibility	Utilization of the capacity Product variety that can be produced by the supplier Operation amendment tendency Able to respond to changes of quantity
Holding Stock	Special stock holding for the firm, separately
Payment Term	On time payment Abide by payment conditions Type of payment

According to these criteria and their sub criteria, staff gave points to that 4 suppliers and agreed to the points are shown in the following 4 tables.

Table III-2 Points of Supplier A

Criteria (According to their importance)	**Sub Criteria**	**Sub Criteria Points**	**Total Points**
Quality	Quality inspection methods	25	90
	Percentage of refused products	25	
	High quality employee	10	
	Product performance	30	
Cost	Discount dependent on purchasing quantity	40	80
	Lateness cost	25	
	Holding cost	15	
Delivery Time & Transportation	Delivery speed	15	80
	Just in time delivery	15	
	Transportation costs	20	
	Flexibility on delivery time	30	
Minimum Order Quantity	Holding stock on desired quantity	30	70
	Supplier's adaptation to requested quantity	40	
Production Capacity, Technology & Flexibility	Utilization of the capacity	15	80
	Product variety that can be produced by the supplier	25	
	Operation amendment tendency	20	
	Able to respond to changes of quantity	20	
Holding Stock	Special stock holding for the firm, separately	70	70
Payment Term	On time payment	30	80
	Abide by payment conditions	30	
	Type of payment	20	

Table III-3 Points of Supplier B

Criteria (According to their importance)	Sub Criteria	Sub Criteria Points	Total Points
Quality	Quality inspection methods	20	80
	Percentage of refused products	20	
	High quality employee	15	
	Product performance	25	
Cost	Discount dependent on purchasing quantity	40	80
	Lateness cost	20	
	Holding cost	20	
Delivery Time & Transportation	Delivery speed	25	80
	Just in time delivery	25	
	Transportation costs	10	
	Flexibility on delivery time	20	
Minimum Order Quantity	Holding stock on desired quantity	20	70
	Supplier's adaptation to requested quantity	50	
Production Capacity, Technology & Flexibility	Utilization of the capacity	15	70
	Product variety that can be produced by the supplier	20	
	Operation amendment tendency	20	
	Able to respond to changes of quantity	15	
Holding Stock	Special stock holding for the firm, separately	80	80
Payment Term	On time payment	35	70
	Abide by payment conditions	25	
	Type of payment	10	

Table III-4 Points of Supplier C

Criteria (According to their importance)	Sub Criteria	Sub Criteria Points	Total Points
Quality	Quality inspection methods	30	90
	Percentage of refused products	20	
	High quality employee	15	
	Product performance	25	
Cost	Discount dependent on purchasing quantity	35	70
	Lateness cost	25	
	Holding cost	10	
Delivery Time & Transportation	Delivery speed	20	80
	Just in time delivery	15	
	Transportation costs	20	
	Flexibility on delivery time	25	
Minimum Order Quantity	Holding stock on desired quantity	25	60
	Supplier's adaptation to requested quantity	35	
Production Capacity, Technology & Flexibility	Utilization of the capacity	25	70
	Product variety that can be produced by the supplier	0	
	Operation amendment tendency	20	
	Able to respond to changes of quantity	25	
Holding Stock	Special stock holding for the firm, separately	60	60
Payment Term	On time payment	25	70
	Abide by payment conditions	30	
	Type of payment	15	

Table III-5 Points of Supplier D

Criteria (According to their importance)	Sub Criteria	Sub Criteria Points	Total Points
Quality	Quality inspection methods	15	50
	Percentage of refused products	10	
	High quality employee	10	
	Product performance	15	
Cost	Discount dependent on purchasing quantity	25	70
	Lateness cost	35	
	Holding cost	10	
Delivery Time & Transportation	Delivery speed	10	70
	Just in time delivery	15	
	Transportation costs	30	
	Flexibility on delivery time	15	
Minimum Order Quantity	Holding stock on desired quantity	15	60
	Supplier's adaptation to requested quantity	45	
Production Capacity, Technology & Flexibility	Utilization of the capacity	15	60
	Product variety that can be produced by the supplier	10	
	Operation amendment tendency	15	
	Able to respond to changes of quantity	20	
Holding Stock	Special stock holding for the firm, separately	60	60
Payment Term	On time payment	20	70
	Abide by payment conditions	35	
	Type of payment	15	

In the light of these data, some linear weighting methods will be implemented for the evaluation and selection of these 4 suppliers in terms of the manufacturer firm's benefits.

III.2.3 Implementation of the Selected Methods

Three linear weighting methods were selected to implement which are AHP, TOPSIS, and ELECTRE.

III.2.3.1 Implementation of Analytic Hierarchy Process

The analytic hierarchy process (AHP) is one of the most used methods in the supplier selection processes. Because of AHP is a powerful and understandable methodology that allows groups or individuals to combine qualitative and quantitative factors in decision making process; it is a multi criteria decision making method for complicated and unstructured problems and also it is an approach that uses a hierarchical model having levels of goal, criteria, possible sub-criteria, and alternatives.

In this study, there are 7 criteria, 21 sub criteria of these criteria, 4 alternatives (suppliers) and 1 goal (to select the best supplier) defined. If it is needed to explain the case clearly, the following figure can be helpful.

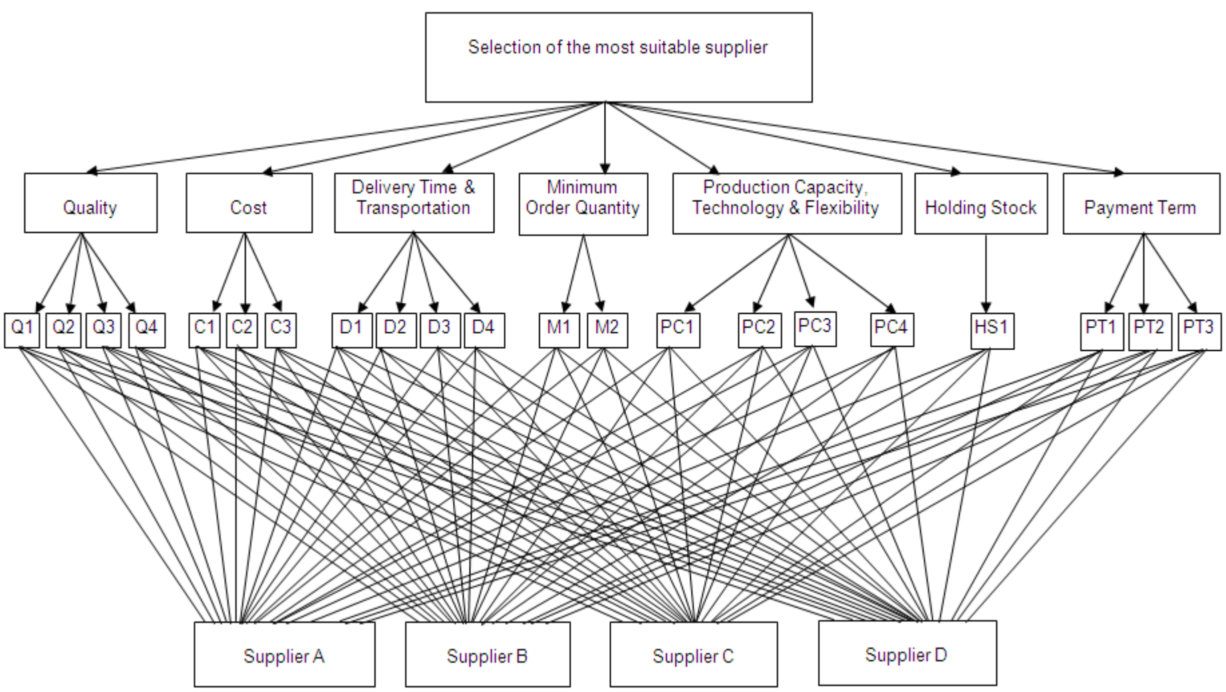

Figure III-1 Hierarchical Structure of the Supplier Selection Process according to AHP Method

In the light of suppliers' points, comparison matrix between the criteria is formed by using the values from Table II-5 importance scale. Then, the weights of these criteria in total, in other words the percentage importance distribution, column vectors, which constitute the comparison matrix, are used and the column vector which has n units with n components is constituted. Using the constituted matrix; percentage importance distributions, which show the criteria importance value according to each other, can be gotten. Therefore, arithmetic average of row components, which is comprised constituted matrix, is taken and then a column vector which is called priority vector is attained as the weights of the criteria. Afterwards, to check the consistency in criteria comparisons a couple of operations are done and then λ_{max} (principal value), consistency index (CI), random consistency index (RI) and consistency ratio (CR) are calculated, respectively. Eventually, if the CR value is less than or equal to 0.10, comparisons that made by decision maker are consistent. Otherwise, there could be a calculation error or there is an inconsistency in the comparisons of decision maker. In this case, to provide the consistency in the criteria comparisons; the values which are used in comparison matrix are revised.

In the real case, comparison matrix was formed, the percentages of importance distributions were attained, the priority vector was constituted and according to these calculations; λ_{max}, CI, RI and CR are computed. But the CR value was more than 0.10. So the values which were used in comparison matrix were revised and the changed values of the comparison matrix are seen with dark colored cells in the following table. Then, all these steps were repeated to have a consistent value and they are all seen in the table which is called supplier selection criteria comparisons and the solution stages.

In addition, these implemented steps are all similar for each of the evaluation criteria such as quality, cost, delivery time, and etc. So, they will all shown in the following tables after Table III-6, consecutively, as Table III-7, Table III-8, Table III-9, Table III-10, Table III-11, Table III-12, and Table III-13. Calculations of AHP implementation for Table III-7 are given below.

Table III-6 Supplier Selection Criteria Comparisons and the Solution Stages

1.

		1	2	3	4	5	6	7
		Quality	Cost	Delivery Time & Transportation	Minimum Order Quantity	Production Capacity, Technology & Flexibility	Holding Stock	Payment Term
1	Quality	1	4	5	6	9	8	7
2	Cost	1/4	1	2	4	8	6	7
3	Delivery Time & Transportation	1/5	1/2	1	3	6	7	8
4	Minimum Order Quantity	1/6	1/4	1/3	1	3	4	5
5	Production Capacity,	1/9	1/8	1/6	1/3	1	1/3	1/2
6	Holding Stock	1/8	1/6	1/7	1/4	3	1	1/3
7	Payment Term	1/7	1/7	1/8	1/5	2	3	1
+		1,996	6,185	8,768	14,783	32,000	29,333	28,833

2. 3. 4.

		1	2	3	4	5	6	7		Row Total			Weights of Criteria	
		Quality	Cost	Delivery Time & Transportation	Minimum Order Quantity	Production Capacity, Technology & Flexibility	Holding Stock	Payment Term						
1	Quality	0,501	0,647	0,570	0,406	0,281	0,273	0,243	=	2,921	/	7	0,417	W_1
2	Cost	0,125	0,162	0,228	0,271	0,250	0,205	0,243	=	1,483	/	7	0,212	W_2
3	Delivery Time & Transportation	0,100	0,081	0,114	0,203	0,188	0,239	0,277	=	1,202	/	7	0,172	W_3
4	Minimum Order Quantity	0,084	0,040	0,038	0,068	0,094	0,136	0,173	=	0,633	/	7	0,090	W_4
5	Capacity, Technology &	0,056	0,020	0,019	0,023	0,031	0,011	0,017	=	0,177	/	7	0,025	W_5
6	Holding Stock	0,063	0,027	0,016	0,017	0,094	0,034	0,012	=	0,262	/	7	0,037	W_6
7	Payment Term	0,072	0,023	0,014	0,014	0,063	0,102	0,035	=	0,322	/	7	0,046	W_7
													1,000	

Table III-6 Supplier Selection Criteria Comparisons and the Solution Stages (continued)

5.

$$\begin{vmatrix} 1 & 4 & 5 & 6 & 9 & 8 & 7 \\ 1/4 & 1 & 2 & 4 & 8 & 6 & 7 \\ 1/5 & 1/2 & 1 & 3 & 6 & 7 & 8 \\ 1/6 & 1/4 & 1/3 & 1 & 3 & 4 & 5 \\ 1/9 & 1/8 & 1/6 & 1/3 & 1 & 1/3 & 1/2 \\ 1/8 & 1/6 & 1/7 & 1/4 & 3 & 1 & 1/3 \\ 1/7 & 1/7 & 1/8 & 1/5 & 2 & 3 & 1 \end{vmatrix} * \begin{vmatrix} 0{,}417 \\ 0{,}212 \\ 0{,}172 \\ 0{,}090 \\ 0{,}025 \\ 0{,}037 \\ 0{,}046 \end{vmatrix} = \begin{vmatrix} 3{,}515 \\ 1{,}771 \\ 1{,}415 \\ 0{,}726 \\ 0{,}192 \\ 0{,}263 \\ 0{,}338 \end{vmatrix}$$

6.

$$\begin{vmatrix} 3{,}515 \\ 1{,}771 \\ 1{,}415 \\ 0{,}726 \\ 0{,}192 \\ 0{,}263 \\ 0{,}338 \end{vmatrix} / \begin{vmatrix} 0{,}417 \\ 0{,}212 \\ 0{,}172 \\ 0{,}090 \\ 0{,}025 \\ 0{,}037 \\ 0{,}046 \end{vmatrix} = \begin{vmatrix} 8{,}425 \\ 8{,}358 \\ 8{,}240 \\ 8{,}027 \\ 7{,}593 \\ 7{,}033 \\ 7{,}360 \end{vmatrix}$$

$+$

$\sum =$ 55,035 $\Rightarrow$

7. λmax (55,035 / 7)	8. Consistency Index (CI)	9. Random Cons. Index (RI)
	$\lambda \max - n / n-1$	$1{,}98 * (n-2) / n$
7,862	0,144	1,41

10. **Consistency Ratio (CR)**

CI / RI **0,10** $\leq 0{,}10$ $\Rightarrow$ √

According to the agreed points by staff, comparison matrices are constituted in the light of values from importance scale in Table II-5.

$$1+\tfrac{1}{5}+\tfrac{1}{3}+\tfrac{1}{9}=1{,}644 \qquad 5+1+3+\tfrac{1}{5}=9{,}20$$

$$3+\tfrac{1}{3}+1+\tfrac{1}{7}=4{,}476 \qquad 9+5+7+1=22{,}000$$

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	1	5	3	9
Supplier_B	1/5	1	1/3	5
Supplier_C	1/3	3	1	7
Supplier_D	1/9	1/5	1/7	1
+	1,644	9,200	4,476	22,000

After that; percentage importance distribution of the criteria are determined by this formula and its vector is pointed as:

$$b_{ij}=\frac{a_{ij}}{\sum_{i=1}^{n}a_{ij}} \qquad B_i=\begin{bmatrix} b_{11} \\ b_{21} \\ . \\ . \\ . \\ b_{n1} \end{bmatrix}$$

$$b_{11}=\frac{a_{11}}{\sum_{1}^{4}a_{11}}=\frac{1}{1{,}644}=0{,}608 \qquad b_{12}=\frac{5}{9{,}200}=0{,}543 \qquad b_{13}=\frac{3}{4{,}476}=0{,}670$$

$$b_{14}=\frac{9}{22{,}000}=0{,}409 \qquad b_{21}=\frac{1/5}{1{,}644}=0{,}122 \qquad b_{22}=\frac{1}{9{,}200}=0{,}109$$

$$b_{23}=\frac{1/3}{4{,}476}=0{,}074 \qquad b_{24}=\frac{5}{22{,}000}=0{,}227 \qquad b_{31}=\frac{1/3}{1{,}644}=0{,}203$$

$$b_{32}=\frac{3}{9{,}200}=0{,}326 \qquad b_{33}=\frac{1}{4{,}476}=0{,}223 \qquad b_{34}=\frac{7}{22{,}000}=0{,}318$$

$$b_{41} = \frac{1/9}{1,644} = 0,068 \qquad b_{42} = \frac{1/5}{9,200} = 0,022 \qquad b_{43} = \frac{1/7}{4,476} = 0,032$$

$$b_{44} = \frac{1}{22,000} = 0,045$$

When 4 units of column vector *B* are gathered in a matrix format, matrix *C* that is shown below will be created.

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix}$$

C=

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	0,608	0,543	0,670	0,409
Supplier_B	0,122	0,109	0,074	0,227
Supplier_C	0,203	0,326	0,223	0,318
Supplier_D	0,068	0,022	0,032	0,045

Row totals of matrix *C* is calculated as:

$$0,608 + 0,543 + 0,670 + 0,409 = 2,231$$

$$0,122 + 0,109 + 0,074 + 0,227 = 0,532$$

$$0,203 + 0,326 + 0,223 + 0,318 = 1,070$$

$$0,068 + 0,022 + 0,032 + 0,045 = 0,167$$

Row Total
2,231
0,532
1,070
0,167

Using matrix *C*; percentage importance distributions, which show the criteria importance value according to each other, can be gotten. Therefore, arithmetic average of row components, which is comprised matrix *C*, is taken and then column vector *W* which is called priority vector is attained.

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \qquad W = \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix}$$

$$w_1 = \frac{\sum_{j=1}^{4} c_{11}}{4} = \frac{2,231}{4} = 0,558 \qquad w_2 = \frac{0,532}{4} = 0,133$$

$$w_3 = \frac{1,070}{4} = 0,268 \qquad w_4 = \frac{0,167}{4} = 0,042$$

	Row Total				**Weights of Quality Criteria**
***W*=**	2,231	/	4	=	0,558
	0,532		4		0,133
	1,070		4		0,268
	0,167		4		0,042
					1,000

Then, consistency in factor comparisons is calculated

$$D = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix}$$

$$D = \begin{vmatrix} 1 & 5 & 3 & 9 \\ 1/5 & 1 & 1/3 & 5 \\ 1/3 & 3 & 1 & 7 \\ 1/9 & 1/5 & 1/7 & 1 \end{vmatrix} * \begin{vmatrix} 0{,}558 \\ 0{,}133 \\ 0{,}268 \\ 0{,}042 \end{vmatrix} = \begin{vmatrix} 2{,}401 \\ 0{,}542 \\ 1{,}144 \\ 0{,}168 \end{vmatrix}$$

Division of the corresponding elements of column vector *D*, which is found above, with column vector *W* constitutes the Principal Value (*E*) for every evaluation criteria.

$$E_i = \frac{d_i}{w_i} \qquad (i = 1,2,...,n) \qquad E_1 = \frac{d_1}{w_1} = \frac{2{,}401}{0{,}558} = 4{,}304$$

$$E_2 = \frac{0{,}542}{0{,}133} = 4{,}076 \qquad E_3 = \frac{1{,}144}{0{,}268} = 4{,}276 \qquad E_4 = \frac{0{,}168}{0{,}042} = 4{,}043$$

$$\sum E_i = 4{,}304 + 4{,}076 + 4{,}276 + 4{,}043 = 16{,}699$$

$$E = \begin{vmatrix} 2{,}401 \\ 0{,}542 \\ 1{,}144 \\ 0{,}168 \end{vmatrix} / \begin{vmatrix} 0{,}558 \\ 0{,}133 \\ 0{,}268 \\ 0{,}042 \end{vmatrix} = \begin{vmatrix} 4{,}304 \\ 4{,}076 \\ 4{,}276 \\ 4{,}043 \end{vmatrix}$$

$$\sum = 16{,}699$$

The arithmetic average of these values gives the principal value (λ) according to comparison. In the light of $\sum_{i=1}^{4} E_i$, principal value (λ) can be calculated as:

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \qquad \lambda = \frac{\sum_{i=1}^{4} E_i}{4} = \frac{16{,}699}{4} = 4{,}175$$

After λ is calculated, Consistency Index (CI) can be computed as:

$$CI = \frac{\lambda - n}{n - 1} \qquad CI = \frac{4,175 - 4}{4 - 1} = 0,058$$

At the last stage, CI divided by Random Index (RI) which is shown as standard correction value in Table II-6 and then Consistency Ratio (CR) is obtained. Also, Random Index (RI) can be calculated with the following formula:

$$RI = 1,98 \times \frac{(n-2)}{n} \qquad RI = 1,98 \times \frac{(4-2)}{4} = 0,99$$

When the calculated CR value is less than 0.10, comparisons that made by decision maker are consistent. If the CR value is more than 0.10, either there could be a calculation error or there is an inconsistency in the comparisons of decision maker.

$$CR = \frac{CI}{RI} \qquad CR = \frac{0,058}{0,99} = 0,06$$

As it seen above, CR value is less than 0.10, so the comparison is consistent. If it had been more than 0.10, AHP implementation steps would be replicated. Following tables are calculated in a similar way. Furthermore; in TOPSIS implementation, AHP part for TOPSIS is also done by this way.

Table III-7 Suppliers' Comparison According to Quality Criterion

1.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	1	5	3	9
Supplier_B	1/5	1	1/3	5
Supplier_C	1/3	3	1	7
Supplier_D	1/9	1/5	1/7	1
+	1,644	9,200	4,476	22,000

2. 3. 4.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D		Row Total			Weights of Quality Criteria	
Supplier_A	0,608	0,543	0,670	0,409	=	2,231	/	4	0,558	W_1A
Supplier_B	0,122	0,109	0,074	0,227	=	0,532	/	4	0,133	W_1B
Supplier_C	0,203	0,326	0,223	0,318	=	1,070	/	4	0,268	W_1C
Supplier_D	0,068	0,022	0,032	0,045	=	0,167	/	4	0,042	W_1D
									1,000	

5.

$$\begin{vmatrix} 1 & 5 & 3 & 9 \\ 1/5 & 1 & 1/3 & 5 \\ 1/3 & 3 & 1 & 7 \\ 1/9 & 1/5 & 1/7 & 1 \end{vmatrix} * \begin{vmatrix} 0,558 \\ 0,133 \\ 0,268 \\ 0,042 \end{vmatrix} = \begin{vmatrix} 2,401 \\ 0,542 \\ 1,144 \\ 0,168 \end{vmatrix}$$

6.

$$\begin{vmatrix} 2,401 \\ 0,542 \\ 1,144 \\ 0,168 \end{vmatrix} / \begin{vmatrix} 0,558 \\ 0,133 \\ 0,268 \\ 0,042 \end{vmatrix} = \begin{vmatrix} 4,304 \\ 4,076 \\ 4,276 \\ 4,043 \end{vmatrix}$$

+

$\sum$ = 16,699 $\Longrightarrow$

7. **λmax (16,699 / 4)**

4,175

8. **Consistency Index (CI)**

$\lambda \max - n / n-1$

0,058

9. **Random Cons. Index (RI)**

$1,98 * (n-2) / n$

0,99

10. **Consistency Ratio (CR)**

CI / RI **0,06** $\leq 0,10$ $\Longrightarrow$ $\surd$

Table III-8 Suppliers' Comparison According to Cost Criterion

1.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	1	5	3	1
Supplier_B	1/5	1	2	1
Supplier_C	1/3	1/2	1	1/2
Supplier_D	1	1	2	1
+	2,533	7,500	8,000	3,500

2., 3., 4.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D		Row Total			Weights of Cost Criteria	
Supplier_A	0,395	0,667	0,375	0,286	=	1,722	/	4	0,431	W_2A
Supplier_B	0,079	0,133	0,250	0,286	=	0,748	/	4	0,187	W_2B
Supplier_C	0,132	0,067	0,125	0,143	=	0,466	/	4	0,117	W_2C
Supplier_D	0,395	0,133	0,250	0,286	=	1,064	/	4	0,266	W_2D
									1,000	

5.

$$\begin{vmatrix} 1 & 5 & 3 & 1 \\ 1/5 & 1 & 2 & 1 \\ 1/3 & 1/2 & 1 & 0,5 \\ 1 & 1 & 2 & 1 \end{vmatrix} * \begin{vmatrix} 0,431 \\ 0,187 \\ 0,117 \\ 0,266 \end{vmatrix} = \begin{vmatrix} 1,981 \\ 0,772 \\ 0,487 \\ 1,117 \end{vmatrix}$$

6.

$$\begin{vmatrix} 1,981 \\ 0,772 \\ 0,487 \\ 1,117 \end{vmatrix} / \begin{vmatrix} 0,431 \\ 0,187 \\ 0,117 \\ 0,266 \end{vmatrix} = \begin{vmatrix} 4,601 \\ 4,129 \\ 4,175 \\ 4,198 \end{vmatrix}$$

$+$

Σ = 17,104 $\Rightarrow$

7. **λmax (17,261 / 4)**

4,276

8. **Consistency Index (CI)**

$\lambda \max - n / n-1$

0,092

9. **Random Cons. Index (RI)**

$1,98 * (n-2) / n$

0,99

10. **Consistency Ratio (CR)**

CI / RI **0,09** $\leq 0,10$ $\Rightarrow$ √

Table III-9 Suppliers' Comparison According to Delivery Time Criterion

1.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	1	1/3	3	1
Supplier_B	3	1	3	5
Supplier_C	1/3	1/3	1	2
Supplier_D	1	1/5	1/2	1
+	5,333	1,867	7,500	9,000

2., 3., 4.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D		3. Row Total			4. Weights of Delivery Criteria	
Supplier_A	0,188	0,179	0,400	0,111	=	0,877	/	4	0,219	W_3A
Supplier_B	0,563	0,536	0,400	0,556	=	2,054	/	4	0,513	W_3B
Supplier_C	0,063	0,179	0,133	0,222	=	0,597	/	4	0,149	W_3C
Supplier_D	0,188	0,107	0,067	0,111	=	0,472	/	4	0,118	W_3D
									1,000	

5.

$$\begin{vmatrix} 1 & 1/3 & 3 & 1 \\ 3 & 1 & 3 & 5 \\ 1/3 & 1/3 & 1 & 2 \\ 1 & 1/5 & 1/2 & 1 \end{vmatrix} * \begin{vmatrix} 0{,}219 \\ 0{,}513 \\ 0{,}149 \\ 0{,}118 \end{vmatrix} = \begin{vmatrix} 0{,}956 \\ 2{,}209 \\ 0{,}630 \\ 0{,}515 \end{vmatrix}$$

6.

$$\begin{vmatrix} 0{,}956 \\ 2{,}209 \\ 0{,}630 \\ 0{,}515 \end{vmatrix} / \begin{vmatrix} 0{,}219 \\ 0{,}513 \\ 0{,}149 \\ 0{,}118 \end{vmatrix} = \begin{vmatrix} 4{,}359 \\ 4{,}303 \\ 4{,}221 \\ 4{,}358 \end{vmatrix}$$

+

$\sum =$ 17,241 $\Longrightarrow$

7. **λmax (18,389/ 4)**

4,310

8. **Consistency Index (CI)**

$\lambda \max - n / n - 1$

0,103

9. **Random Cons. Index (RI)**

$1{,}98 * (n-2) / n$

0,99

10. **Consistency Ratio (CR)**

CI / RI **0,10** $\leq 0{,}10$ $\Longrightarrow$ √

Table III-10 Suppliers' Comparison According to Minimum Order Quantity Criterion

1.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	1	1/3	2	1/2
Supplier_B	3	1	3	3
Supplier_C	1/2	1/3	1	1/2
Supplier_D	2	1/3	2	1
+	6,500	2,000	8,000	5,000

2., 3., 4.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D		Row Total			Weights of Min. Order Q. Criteria	
Supplier_A	0,154	0,167	0,250	0,100	=	0,671	/	4	0,168	W_4A
Supplier_B	0,462	0,500	0,375	0,600	=	1,937	/	4	0,484	W_4B
Supplier_C	0,077	0,167	0,125	0,100	=	0,469	/	4	0,117	W_4C
Supplier_D	0,308	0,167	0,250	0,200	=	0,924	/	4	0,231	W_4D
									1,000	

5.

$$\begin{vmatrix} 1 & 1/3 & 2 & 1/2 \\ 3 & 1 & 3 & 3 \\ 1/2 & 1/3 & 1 & 1/2 \\ 2 & 1/3 & 2 & 1 \end{vmatrix} * \begin{vmatrix} 0,168 \\ 0,484 \\ 0,117 \\ 0,231 \end{vmatrix} = \begin{vmatrix} 0,679 \\ 2,032 \\ 0,478 \\ 0,962 \end{vmatrix}$$

6.

$$\begin{vmatrix} 0,679 \\ 2,032 \\ 0,478 \\ 0,962 \end{vmatrix} / \begin{vmatrix} 0,168 \\ 0,484 \\ 0,117 \\ 0,231 \end{vmatrix} = \begin{vmatrix} 4,050 \\ 4,197 \\ 4,079 \\ 4,163 \end{vmatrix}$$

$+$

$\sum =$ 16,489 $\Rightarrow$

7. **λmax (16,489/ 4)**

4,122

8. **Consistency Index (CI)**

$\lambda \max - n / n-1$

0,041

9. **Random Cons. Index (RI)**

$1,98 * (n-2) / n$

0,99

10. **Consistency Ratio (CR)**

CI / RI **0,04** $\leq 0,10$ $\Rightarrow$ √

Table III-11 Suppliers' Comparison According to Production Capacity, Technology & Flexibility Criterion

1.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	1	5	3	7
Supplier_B	1/5	1	1/3	2
Supplier_C	1/3	3	1	5
Supplier_D	1/7	1/2	1/5	1
+	1,676	9,500	4,533	15,000

2., 3., 4.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D		Row Total			Weights of Production Criteria	
Supplier_A	0,597	0,526	0,662	0,467	=	2,251	/	4	0,563	W_5A
Supplier_B	0,119	0,105	0,074	0,133	=	0,431	/	4	0,108	W_5B
Supplier_C	0,199	0,316	0,221	0,333	=	1,069	/	4	0,267	W_5C
Supplier_D	0,085	0,053	0,044	0,067	=	0,249	/	4	0,062	W_5D
									1,000	

5.

$$\begin{vmatrix} 1 & 5 & 3 & 7 \\ 1/5 & 1 & 1/3 & 2 \\ 1/3 & 3 & 1 & 5 \\ 1/7 & 1/2 & 1/5 & 1 \end{vmatrix} * \begin{vmatrix} 0,563 \\ 0,108 \\ 0,267 \\ 0,062 \end{vmatrix} = \begin{vmatrix} 2,339 \\ 0,434 \\ 1,089 \\ 0,250 \end{vmatrix}$$

6.

$$\begin{vmatrix} 2,339 \\ 0,434 \\ 1,089 \\ 0,250 \end{vmatrix} / \begin{vmatrix} 0,563 \\ 0,108 \\ 0,267 \\ 0,062 \end{vmatrix} = \begin{vmatrix} 4,155 \\ 4,022 \\ 4,077 \\ 4,021 \end{vmatrix}$$

$+$

$\Sigma =$ 16,275 $\Rightarrow$

7. λmax (16,275/ 4)	8. Consistency Index (CI)	9. Random Cons. Index (RI)
	$\lambda \max - n / n-1$	$1,98 * (n-2) / n$
4,069	0,023	0,99

10. **Consistency Ratio (CR)**

CI / RI **0,02** $\leq 0,10$ $\Rightarrow$ $\surd$

Table III-12 Suppliers' Comparison According to Holding Stock Criterion

1.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	1	1/5	3	2
Supplier_B	5	1	5	6
Supplier_C	1/3	1/5	1	3
Supplier_D	1/2	1/6	1/3	1
+	6,833	1,567	9,333	12,000

2. 3. 4.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D		Row Total			Weights of Hold. Stock Criteria	
Supplier_A	0,146	0,128	0,321	0,167	=	0,762	/	4	0,191	W_6A
Supplier_B	0,732	0,638	0,536	0,500	=	2,406	/	4	0,601	W_6B
Supplier_C	0,049	0,128	0,107	0,250	=	0,534	/	4	0,133	W_6C
Supplier_D	0,073	0,106	0,036	0,083	=	0,299	/	4	0,075	W_6D
									1,000	

5.

$$\begin{vmatrix} 1 & 1/5 & 3 & 2 \\ 5 & 1 & 5 & 6 \\ 1/3 & 1/5 & 1 & 3 \\ 1/2 & 1/6 & 1/3 & 1 \end{vmatrix} * \begin{vmatrix} 0,191 \\ 0,601 \\ 0,133 \\ 0,075 \end{vmatrix} = \begin{vmatrix} 0,860 \\ 2,669 \\ 0,541 \\ 0,315 \end{vmatrix}$$

6.

$$\begin{vmatrix} 0,860 \\ 2,669 \\ 0,541 \\ 0,315 \end{vmatrix} / \begin{vmatrix} 0,191 \\ 0,601 \\ 0,133 \\ 0,075 \end{vmatrix} = \begin{vmatrix} 4,515 \\ 4,438 \\ 4,057 \\ 4,215 \end{vmatrix}$$

$+$

$\sum =$ 17,224 $\Longrightarrow$

7.

λmax (17,224/ 4)

4,306

8.

Consistency Index (CI)

$\lambda \max - n \big/ n-1$

0,102

9.

Random Cons. Index (RI)

$1{,}98 * (n-2) \big/ n$

0,99

10.

Consistency Ratio (CR)

$CI \big/ RI$ **0,10** $\leq 0{,}10$ $\Rightarrow$ √

Table III-13 Suppliers' Comparison According to Payment Term Criterion

1.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D
Supplier_A	1	1	2	3
Supplier_B	1	1	2	3
Supplier_C	1/2	1/2	1	3
Supplier_D	1/3	1/3	1/3	1
+	2,833	2,833	5,333	10,000

2., 3., 4.

	Supplier_A	Supplier_B	Supplier_C	Supplier_D		Row Total			Weights of Payment Term Criteria	
Supplier_A	0,353	0,353	0,375	0,300	=	1,381	/	4	0,345	W_7A
Supplier_B	0,353	0,353	0,375	0,300	=	1,381	/	4	0,345	W_7B
Supplier_C	0,176	0,176	0,188	0,300	=	0,840	/	4	0,210	W_7C
Supplier_D	0,118	0,118	0,063	0,100	=	0,398	/	4	0,099	W_7D
									1,000	

5.

$$\begin{vmatrix} 1 & 1 & 2 & 3 \\ 1 & 1 & 2 & 3 \\ 1/2 & 1/2 & 1 & 3 \\ 1/3 & 1/3 & 1/3 & 1 \end{vmatrix} * \begin{vmatrix} 0,345 \\ 0,345 \\ 0,210 \\ 0,099 \end{vmatrix} = \begin{vmatrix} 1,409 \\ 1,409 \\ 0,854 \\ 0,400 \end{vmatrix}$$

6.

$$\begin{vmatrix} 1,409 \\ 1,409 \\ 0,854 \\ 0,400 \end{vmatrix} / \begin{vmatrix} 0,345 \\ 0,345 \\ 0,210 \\ 0,099 \end{vmatrix} = \begin{vmatrix} 4,081 \\ 4,081 \\ 4,063 \\ 4,018 \end{vmatrix}$$

+

$\sum$ = 16,244 $\Longrightarrow$

7. **λmax (16,244/ 4)**: 4,061

8. **Consistency Index (CI)**: $\dfrac{\lambda\max - n}{n-1}$ = 0,020

9. **Random Cons. Index (RI)**: $1{,}98 * (n-2)/n$ = 0,99

10. **Consistency Ratio (CR)**: CI/RI = **0,02** $\leq 0{,}10$ $\Longrightarrow$ √

If it is needed to state a result according to entire calculations, the sum of all the weights are checked to provide “1,000” value. Then the related weights are sum up for each of the suppliers. According to the results of these computations, Supplier A has the highest composite weights. Hence, Supplier A is the best choice. The computations are shown more detailed in the following table.

Table III-14 Computations of Composite Weights for the Best Alternative

Weights of Criteria								
W_1	W_2	W_3	W_4	W_5	W_6	W_7		
0,417	0,212	0,172	0,090	0,025	0,037	0,046	=	1,000

Weights of Quality Criteria					
W_1A	W_1B	W_1C	W_1D		
0,558	0,133	0,268	0,042	=	1,000

Weights of Cost Criteria					
W_2A	W_2B	W_2C	W_2D		
0,431	0,187	0,117	0,266	=	1,000

Weights of Delivery Criteria					
W_3A	W_3B	W_3C	W_3D		
0,219	0,513	0,149	0,118	=	1,000

Weights of Min. Order Quantity Criteria					
W_4A	W_4B	W_4C	W_4D		
0,168	0,484	0,117	0,231	=	1,000

Weights of Production Criteria					
W_5A	W_5B	W_5C	W_5D		
0,563	0,108	0,267	0,062	=	1,000

Weights of Holding Stock Criteria					
W_6A	W_6B	W_6C	W_6D		
0,191	0,601	0,133	0,075	=	1,000

Weights of Payment Term Criteria					
W_7A	W_7B	W_7C	W_7D		
0,345	0,345	0,210	0,099	=	1,000

For Supplier_A: W_1 * W_1A + W_2 *W_2A + W_3 * W_3A + W_4 * W_4A + W_5 * W_5A + W_6 * W_6A + W_7 * W_7A = **0,414**

Supplier_A has the highest composite weight. Hence, Supplier_A is the best choice.

For Supplier_B: W_1 * W_1B + W_2 *W_2B + W_3 * W_3B + W_4 * W_4B + W_5 * W_5B + W_6 * W_6B + W_7 * W_7B = **0,268**

For Supplier_C: W_1 * W_1C + W_2 *W_2C + W_3 * W_3C + W_4 * W_4C + W_5 * W_5C + W_6 * W_6C + W_7 * W_7C = **0,194**

For Supplier_D: W_1 * W_1D + W_2 *W_2D + W_3 * W_3D + W_4 * W_4D + W_5 * W_5D + W_6 * W_6D + W_7 * W_7D = **0,124**

III.2.3.2 Implementation of TOPSIS

TOPSIS is a multiple criteria decision making method to identify solutions from a finite set of alternatives. TOPSIS depends on decision points' nearness to ideal solution.

In this thesis, weights that will be used in TOPSIS implementation were acquired from an AHP implementation to sub criteria of the each supplier selection and evaluation criterion. For this reason, to pass to the TOPSIS analysis, weights should be calculated with AHP. As it is mentioned in the AHP implementation, same stages will be achieved to attain the weights which are needed by TOPSIS implementation. There is an exception for the holding stock criterion because it has only 1 sub criterion. So it is not needed a new weight calculation. For further information, following 6 tables can be investigated which are called Table III-15, Table III-16, Table III-17, Table III-18, Table III-19, and Table III-20. After these tables TOPSIS implementation will be started and told in Table III-21.

Table III-15 Weights' Computation According to Quality's Sub-Criteria

	Q1	Q2	Q3	Q4
Q1	1	1/7	1/5	1/6
Q2	7	1	5	2
Q3	5	1/5	1	1/5
Q4	6	1/2	5	1
+	19,000	1,843	11,200	3,367

	Q1	Q2	Q3	Q4		Row Total			Weights of Quality Criteria	
Q1	0,053	0,078	0,018	0,050	=	0,198	/	4	0,049	W_Q1
Q2	0,368	0,543	0,446	0,594	=	1,952	/	4	0,488	W_Q2
Q3	0,263	0,109	0,089	0,059	=	0,520	/	4	0,130	W_Q3
Q4	0,316	0,271	0,446	0,297	=	1,331	/	4	0,333	W_Q4
									1,000	

$$\begin{vmatrix} 1 & 1/7 & 1/5 & 1/6 \\ 7 & 1 & 5 & 2 \\ 5 & 1/5 & 1 & 1/5 \\ 6 & 1/2 & 5 & 1 \end{vmatrix} * \begin{vmatrix} 0,049 \\ 0,488 \\ 0,130 \\ 0,333 \end{vmatrix} = \begin{vmatrix} 0,201 \\ 2,149 \\ 0,541 \\ 1,523 \end{vmatrix}$$

$$\begin{vmatrix} 0,201 \\ 2,149 \\ 0,541 \\ 1,523 \end{vmatrix} / \begin{vmatrix} 0,049 \\ 0,488 \\ 0,130 \\ 0,333 \end{vmatrix} = \begin{vmatrix} 4,061 \\ 4,405 \\ 4,159 \\ 4,579 \end{vmatrix}$$

$\sum =$ 17,205

λmax (17,205 / 4)	Consistency Index (CI)	Random Cons. Index (RI)
	$\lambda \max - n / n-1$	$1{,}98 * (n-2) / n$
4,301	0,100	0,99

Consistency Ratio (CR)			
CI / RI	0,10	≤ 0,10	√

Table III-16 Weights' Computation According to Cost's Sub-Criteria

	C1	C2	C3
C1	1	5	8
C2	1/5	1	4
C3	1/8	1/4	1
+	1,325	6,250	13,000

	C1	C2	C3		Row Total			Weights of	
C1	0,755	0,800	0,615	=	2,170	/	3	0,723	W_C1
C2	0,151	0,160	0,308	=	0,619	/	3	0,206	W_C2
C3	0,094	0,040	0,077	=	0,211	/	3	0,070	W_C3
								1,000	

$$\begin{vmatrix} 1 & 5 & 8 \\ 1/5 & 1 & 4 \\ 1/8 & 1/4 & 1 \end{vmatrix} * \begin{vmatrix} 0{,}723 \\ 0{,}206 \\ 0{,}070 \end{vmatrix} = \begin{vmatrix} 2{,}318 \\ 0{,}633 \\ 0{,}212 \end{vmatrix}$$

$$\begin{vmatrix} 2{,}318 \\ 0{,}633 \\ 0{,}212 \end{vmatrix} / \begin{vmatrix} 0{,}723 \\ 0{,}206 \\ 0{,}070 \end{vmatrix} = \begin{vmatrix} 3{,}204 \\ 3{,}068 \\ 3{,}016 \end{vmatrix}$$

Σ = 9,288

λmax (9,288 / 3)	Consistency Index (CI)	Random
	$\lambda \max - n / n-1$	$1{,}98 * (n-2) / n$
3,096	0,048	0,66

Consistency Ratio (CR)			
CI / RI	0,07	$\leq$ 0,10	$\surd$

Table III-17 Weights' Computation According to Delivery Time's Sub-Criteria

	DT1	DT2	DT3	DT4
DT1	1	2	1/3	1/5
DT2	1/2	1	1/3	1/4
DT3	3	3	1	1/2
DT4	5	4	2	1
+	9,500	10,000	3,667	1,950

	DT1	DT2	DT3	DT4		Row Total			Weights of Delivery Time Criteria	
DT1	0,105	0,200	0,091	0,103	=	0,499	/	4	0,125	W_DT1
DT2	0,053	0,100	0,091	0,128	=	0,372	/	4	0,093	W_DT2
DT3	0,316	0,300	0,273	0,256	=	1,145	/	4	0,286	W_DT3
DT4	0,526	0,400	0,545	0,513	=	1,985	/	4	0,496	W_DT4
									1,000	

$$\begin{vmatrix} 1 & 2 & 1/3 & 1/5 \\ 1/2 & 1 & 1/3 & 1/4 \\ 3 & 3 & 1 & 1/2 \\ 5 & 4 & 2 & 1 \end{vmatrix} * \begin{vmatrix} 0{,}125 \\ 0{,}093 \\ 0{,}286 \\ 0{,}496 \end{vmatrix} = \begin{vmatrix} 0{,}505 \\ 0{,}375 \\ 1{,}187 \\ 2{,}064 \end{vmatrix}$$

$$\begin{vmatrix} 0{,}505 \\ 0{,}375 \\ 1{,}187 \\ 2{,}064 \end{vmatrix} / \begin{vmatrix} 0{,}125 \\ 0{,}093 \\ 0{,}286 \\ 0{,}496 \end{vmatrix} = \begin{vmatrix} 4{,}052 \\ 4{,}032 \\ 4{,}148 \\ 4{,}160 \end{vmatrix}$$

$$+$$

$$\sum = 16{,}391$$

λmax (16,391 / 4)	Consistency Index (CI)	Random Cons. Index (RI)
	$\lambda \max - n / n-1$	$1{,}98 * (n-2) / n$
4,098	0,033	0,99

Consistency Ratio (CR)			
CI / RI	0,03	$\leq 0{,}10$	√

Table III-18 Weights' Computation According Minimum Order Quantity's Sub-Criteria

	C1	C2
C1	1	1/5
C2	5	1
+	6,000	1,200

	C1	C2		Row Total			Weights of MOQ Criteria	
C1	0,167	0,167	=	0,333	/	2	0,167	W_MOQ1
C2	0,833	0,833	=	1,667	/	2	0,833	W_MOQ2
							1,000	

$$\begin{vmatrix} 1 & 1/5 \\ 5 & 1 \end{vmatrix} * \begin{vmatrix} 0,167 \\ 0,833 \end{vmatrix} = \begin{vmatrix} 0,333 \\ 1,667 \end{vmatrix}$$

$$\begin{vmatrix} 0,333 \\ 1,667 \end{vmatrix} / \begin{vmatrix} 0,167 \\ 0,833 \end{vmatrix} = \begin{vmatrix} 2,000 \\ 2,000 \end{vmatrix}$$

$$+ \qquad \sum = 4,000$$

λmax (4,000 / 2)	Consistency Index (CI)	Random Cons. Index (RI)
	$\lambda \max - n \big/ n-1$	$1,98 * (n-2) \big/ n$
2,000	0,000	0

Consistency Ratio (CR)			
$CI \big/ RI$	0,00	≤ 0,10	√

Table III-19 Weights' Computation According to Production Capacity, Technology & Flexibility's Sub-Criteria

	PC1	PC2	PC3	PC4
PC1	1	1/5	1/4	1/5
PC2	5	1	5	3
PC3	4	1/5	1	1/3
PC4	5	1/3	3	1
+	15,000	1,733	9,250	4,533

	PC1	PC2	PC3	PC4		Row Total			Weights of Production Cap. Criteria	
PC1	0,067	0,115	0,027	0,044	=	0,253	/	4	0,063	W_PC1
PC2	0,333	0,577	0,541	0,662	=	2,113	/	4	0,528	W_PC2
PC3	0,267	0,115	0,108	0,074	=	0,564	/	4	0,141	W_PC3
PC4	0,333	0,192	0,324	0,221	=	1,071	/	4	0,268	W_PC4
									1,000	

$$\begin{vmatrix} 1 & 1/5 & 1/4 & 1/5 \\ 5 & 1 & 5 & 3 \\ 4 & 1/5 & 1 & 1/3 \\ 5 & 1/3 & 3 & 1 \end{vmatrix} * \begin{vmatrix} 0,063 \\ 0,528 \\ 0,141 \\ 0,268 \end{vmatrix} = \begin{vmatrix} 0,258 \\ 2,352 \\ 0,589 \\ 1,183 \end{vmatrix}$$

$$\begin{vmatrix} 0,258 \\ 2,352 \\ 0,589 \\ 1,183 \end{vmatrix} / \begin{vmatrix} 0,063 \\ 0,528 \\ 0,141 \\ 0,268 \end{vmatrix} = \begin{vmatrix} 4,071 \\ 4,454 \\ 4,179 \\ 4,420 \end{vmatrix}$$

$$+ \qquad \sum = 17,124$$

λmax (17,124 / 4)	Consistency Index (CI)	Random Cons. Index (RI)
	$\lambda \max - n / n - 1$	$1,98 * (n-2)/n$
4,281	0,094	0,99

Consistency Ratio (CR)			
CI/RI	0,09	≤ 0,10	√

Table III-20 Weights' Computation According to Payment Term's Sub-Criteria

	PT1	PT2	PT3
PT1	1	5	7
PT2	1/5	1	3
PT3	1/7	1/3	1
+	1,343	6,333	11,000

	PT1	PT2	PT3		Row Total			Weights of Payment Term Criteria	
PT1	0,745	0,789	0,636	=	2,171	/	3	0,724	W_PT1
PT2	0,149	0,158	0,273	=	0,580	/	3	0,193	W_PT2
PT3	0,106	0,053	0,091	=	0,250	/	3	0,083	W_PT3
								1,000	

$$\begin{vmatrix} 1 & 5 & 7 \\ 1/5 & 1 & 3 \\ 1/7 & 1/3 & 1 \end{vmatrix} * \begin{vmatrix} 0,724 \\ 0,193 \\ 0,083 \end{vmatrix} = \begin{vmatrix} 2,273 \\ 0,588 \\ 0,251 \end{vmatrix}$$

$$\begin{vmatrix} 2,273 \\ 0,588 \\ 0,251 \end{vmatrix} / \begin{vmatrix} 0,724 \\ 0,193 \\ 0,083 \end{vmatrix} = \begin{vmatrix} 3,141 \\ 3,043 \\ 3,014 \end{vmatrix}$$

$$+$$

$$\sum = 9,197$$

λmax (9,197 / 3)	Consistency Index (CI)	Cons. Index
	$\lambda \max - n / n-1$	$1,98 * (n-2) / n$
3,066	0,033	0,66

Consistency Ratio (CR)			
CI / RI	0,05	≤ 0,10	√

After all the weights were calculated, TOPSIS steps are started to implement. First of all; normalized decision matrix r_{ij} is calculated from x_{ij} according to the suppliers' points which were given in Table III-2, Table III-3, Table III-4, and Table III-5. Normalization process is done for the convenience of comparison by converting different units of the supplier selection criteria to a unified unit. Second, in the light of the data from normalized decision matrix r_{ij}; the weighted normalized decision matrix v_{ij} is calculated by the multiplication of weights from Table III-15 to Table III-20 (w_{ij}) and r_{ij}. Third, the positive ideal solution A^{+} and the negative ideal solution A^{-} are determined. Fourth, the separation measures S_i^{+} and S_i^{-} are calculated by using the n-dimensional Euclidean distance. Fifth, the relative closeness C_i^{*} to the ideal solution is calculated. If C_i^{*} takes a value between $0 \le C_i^{*} \le 1$ intervals and $C_i^{*} = 1$ shows the absolute closeness of related decision point to the ideal solution, $C_i^{*} = 0$ shows the absolute closeness of related decision point to the negative ideal solution. Finally, the alternative suppliers with respect to C_i in the descending order are ranked. The preferred supplier should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution, where a higher C_i would mean higher preference. According to these explanations, the computation of the composite weights and ranking of suppliers can be seen in the following Table III-21.

In the light of weights, which are calculated by the AHP implementation for TOPSIS in Table-III-15, Table-III-16, Table-III-17, Table-III-18, Table-III-19, and Table-III-20; first column of Table III-21 is constituted.

Weight	0,049	0,488	0,130	0,333	0,723	0,206	0,070	0,125	0,093	0,286	0,496	0,167	0,833	0,063	0,528	0,141	0,268	1,000	0,724	0,193	0,083

Then, points of suppliers according to selection criteria and sub criteria come from Table III-2, Table III-3, Table III-4, and Table III-5 as values of decision matrix (x_{ij}).

	Alternatives	**Q1**	**Q2**	**Q3**	**Q4**	**C1**	**C2**	**C3**	**DT1**	**DT2**	**DT3**	**DT4**	**MOQ1**	**MOQ2**	**PC1**	**PC2**	**PC3**	**PC4**	**HS1**	**PT1**	**PT2**	**PT3**
x_{ij}	Supplier A	25	25	10	30	40	25	15	15	15	20	30	30	40	15	25	20	20	70	30	30	20
	Supplier B	20	20	15	25	40	20	20	25	25	10	20	20	50	15	20	20	15	80	35	25	10
	Supplier C	30	20	15	25	35	25	10	20	15	20	25	25	35	25	0	20	25	60	25	30	15
	Supplier D	15	10	10	15	25	35	10	10	15	30	15	15	45	15	10	15	20	60	20	35	15

Afterwards, normalized decision matrix r_{ij} is calculated from x_{ij} with this formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n$$

For instance; r_{ij} values are calculated for quality sub criterion *Q1* as it seen below:

$$r_{11} = \frac{x_{11}}{\sqrt{\sum_{i=1}^{4} x_{ij}^2}} = \frac{25}{\sqrt{25^2 + 20^2 + 30^2 + 15^2}} = 0{,}539 \qquad r_{21} = \frac{20}{\sqrt{25^2 + 20^2 + 30^2 + 15^2}} = 0{,}431$$

$$r_{31} = \frac{30}{\sqrt{25^2 + 20^2 + 30^2 + 15^2}} = 0{,}647 \qquad r_{41} = \frac{15}{\sqrt{25^2 + 20^2 + 30^2 + 15^2}} = 0{,}323$$

For delivery time sub criterion *DT2;*

$$r_{19} = \frac{x_{19}}{\sqrt{\sum_{i=1}^{4} x_{ij}^2}} = \frac{15}{\sqrt{15^2 + 25^2 + 15^2 + 15^2}} = 0{,}416 \qquad r_{29} = \frac{25}{\sqrt{15^2 + 25^2 + 15^2 + 15^2}} = 0{,}693$$

$$r_{39} = \frac{15}{\sqrt{15^2 + 25^2 + 15^2 + 15^2}} = 0{,}416 \qquad r_{49} = \frac{15}{\sqrt{15^2 + 25^2 + 15^2 + 15^2}} = 0{,}416$$

Subsequent r_{ij} values are calculated similarly.

	Alternatives	Q1	Q2	Q3	Q4	C1	C2	C3	DT1	DT2	DT3	DT4	MOQ1	MOQ2	PC1	PC2	PC3	PC4	HS1	PT1	PT2	PT3
r_{ij}	Supplier A	0,539	0,640	0,392	0,616	0,563	0,466	0,522	0,408	0,416	0,471	0,647	0,647	0,467	0,416	0,745	0,530	0,492	0,515	0,535	0,497	0,649
	Supplier B	0,431	0,512	0,588	0,513	0,563	0,373	0,696	0,680	0,693	0,236	0,431	0,431	0,583	0,416	0,596	0,530	0,369	0,588	0,624	0,414	0,324
	Supplier C	0,647	0,512	0,588	0,513	0,493	0,466	0,348	0,544	0,416	0,471	0,539	0,539	0,408	0,693	0,000	0,530	0,615	0,441	0,445	0,497	0,487
	Supplier D	0,323	0,256	0,392	0,308	0,352	0,653	0,348	0,272	0,416	0,707	0,323	0,323	0,525	0,416	0,298	0,397	0,492	0,441	0,356	0,579	0,487

After r_{ij} table is constituted, weighted normalized decision matrix v_{ij} is calculated by the multiplication of weights from Table III-15 to Table III-20 (w_{ij}) and r_{ij}. If it is needed to give example;

$$v_{ij} = (w_j)(r_{ij}) \qquad i = 1,2,\ldots,m;\ j = 1,2,\ldots,n$$

For quality sub criterion *Q1;*

$$v_{11} = w_1 \times r_{11} = 0{,}049 \times 0{,}539 = 0{,}027 \qquad v_{21} = w_1 \times r_{21} = 0{,}049 \times 0{,}431 = 0{,}021$$

$$v_{31} = w_1 \times r_{31} = 0{,}049 \times 0{,}647 = 0{,}032 \qquad v_{41} = w_1 \times r_{41} = 0{,}049 \times 0{,}323 = 0{,}016$$

For quality sub criterion *C1;*

$$v_{15} = w_5 \times r_{15} = 0{,}723 \times 0{,}563 = 0{,}407 \qquad v_{25} = w_5 \times r_{25} = 0{,}723 \times 0{,}563 = 0{,}407$$

$$v_{35} = w_5 \times r_{35} = 0{,}723 \times 0{,}493 = 0{,}356 \qquad v_{45} = w_5 \times r_{45} = 0{,}049 \times 0{,}352 = 0{,}254$$

Subsequent v_{ij} values are calculated similarly.

	Weight	0,049	0,488	0,130	0,333	0,723	0,206	0,070	0,125	0,093	0,286	0,496	0,167	0,833	0,063	0,528	0,141	0,268	1,000	0,724	0,193	0,083
	Alternatives	**Q1**	**Q2**	**Q3**	**Q4**	**C1**	**C2**	**C3**	**DT1**	**DT2**	**DT3**	**DT4**	**MOQ1**	**MOQ2**	**PC1**	**PC2**	**PC3**	**PC4**	**HS1**	**PT1**	**PT2**	**PT3**
v_{ij}	Supplier A	0,027	0,312	0,051	0,205	0,407	0,096	0,037	0,051	0,039	0,135	0,321	0,108	0,389	0,026	0,394	0,075	0,132	0,515	0,387	0,096	0,054
	Supplier B	0,021	0,250	0,077	0,171	0,407	0,077	0,049	0,085	0,064	0,067	0,214	0,072	0,486	0,026	0,315	0,075	0,099	0,588	0,451	0,080	0,027
	Supplier C	0,032	0,250	0,077	0,171	0,356	0,096	0,025	0,068	0,039	0,135	0,268	0,090	0,340	0,044	0,000	0,075	0,165	0,441	0,322	0,096	0,041
	Supplier D	0,016	0,125	0,051	0,102	0,254	0,135	0,025	0,034	0,039	0,202	0,161	0,054	0,437	0,026	0,157	0,056	0,132	0,441	0,258	0,112	0,041

After weighted normalized decision matrix is constituted, the positive ideal solution (A^{+}) and negative ideal solution (A^{-}) are determined according to the following formulas.

$$A^{+}=\left\{\left(\max_{i} v_{ij} \mid j\in J\right),\left(\min_{i} v_{ij} \mid j\in J'\right), i=1,2,\ldots,m\right\}=\left\{v_1^{+},v_2^{+},\ldots,v_n^{+}\right\}$$

$$A^{-}=\left\{\left(\min_{i} v_{ij} \mid j\in J\right),\left(\max_{i} v_{ij} \mid j\in J'\right), i=1,2,\ldots,m\right\}=\left\{v_1^{-},v_2^{-},\ldots,v_n^{-}\right\}$$

where J is a set of benefit attributes and J' is a set of cost attributes.

v_{ij}	Supplier A	0,027	**0,312**	**0,051**	**0,205**	**0,407**	0,096	0,037	0,051	**0,039**	0,135	**0,321**	**0,108**	0,389	**0,026**	**0,394**	**0,075**	0,132	0,515	0,387	0,096	**0,054**
	Supplier B	0,021	0,250	**0,077**	0,171	0,407	**0,077**	**0,049**	**0,085**	**0,064**	**0,067**	0,214	0,072	**0,486**	0,026	0,315	0,075	**0,099**	**0,588**	**0,451**	**0,080**	**0,027**
	Supplier C	**0,032**	0,250	0,077	0,171	0,356	0,096	**0,025**	0,068	0,039	0,135	0,268	0,090	**0,340**	**0,044**	**0,000**	0,075	**0,165**	**0,441**	0,322	0,096	0,041
	Supplier D	**0,016**	**0,125**	0,051	**0,102**	**0,254**	**0,135**	0,025	**0,034**	0,039	**0,202**	**0,161**	**0,054**	0,437	0,026	0,157	**0,056**	0,132	0,441	**0,258**	**0,112**	0,041
A^+		0,032	0,312	0,077	0,205	0,407	0,135	0,049	0,085	0,064	0,202	0,321	0,108	0,486	0,044	0,394	0,075	0,165	0,588	0,451	0,112	0,054
A^-		0,016	0,125	0,051	0,102	0,254	0,077	0,025	0,034	0,039	0,067	0,161	0,054	0,340	0,026	0,000	0,056	0,099	0,441	0,258	0,080	0,027

After ideal solution (A^+) and negative ideal solution (A^-) are determined, the separation measures (S_i^+ and S_i^-), which are using the *n*-dimensional Euclidean distance, are calculated.

The separation of each alternative from the positive ideal solution;

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \qquad i = 1, 2, ..., m$$

$$S_1^+ = \sqrt{(v_{11} - v_1^+)^2 + (v_{21} - v_2^+)^2 + ... + (v_{20,1} - v_{20}^+)^2 + (v_{21,1} - v_{21}^+)^2} = \sqrt{(0{,}027 - 0{,}032)^2 + (0{,}312 - 0{,}312)^2 + ... + (0{,}096 - 0{,}112)^2 + (0{,}054 - 0{,}054)^2} = 0{,}171$$

$$S_2^+ = \sqrt{(v_{12} - v_1^+)^2 + (v_{22} - v_2^+)^2 + ... + (v_{20,2} - v_{20}^+)^2 + (v_{21,2} - v_{21}^+)^2} = \sqrt{(0{,}021 - 0{,}032)^2 + (0{,}250 - 0{,}312)^2 + ... + (0{,}080 - 0{,}112)^2 + (0{,}027 - 0{,}054)^2} = 0{,}228$$

$$S_3^+ = \sqrt{(v_{13} - v_1^+)^2 + (v_{23} - v_2^+)^2 + ... + (v_{20,3} - v_{20}^+)^2 + (v_{21,3} - v_{21}^+)^2} = \sqrt{(0{,}032 - 0{,}032)^2 + (0{,}250 - 0{,}312)^2 + ... + (0{,}096 - 0{,}112)^2 + (0{,}041 - 0{,}054)^2} = 0{,}483$$

$$S_4^+ = \sqrt{(v_{14} - v_1^+)^2 + (v_{24} - v_2^+)^2 + ... + (v_{20,4} - v_{20}^+)^2 + (v_{21,4} - v_{21}^+)^2} = \sqrt{(0{,}016 - 0{,}032)^2 + (0{,}125 - 0{,}312)^2 + ... + (0{,}112 - 0{,}112)^2 + (0{,}041 - 0{,}054)^2} = 0{,}471$$

The separation of each alternative from the negative ideal solution;

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \qquad i = 1, 2, \ldots, m$$

$$S_1^- = \sqrt{(v_{11} - v_1^-)^2 + (v_{21} - v_2^-)^2 + \ldots + (v_{20,1} - v_{20}^-)^2 + (v_{21,1} - v_{21}^-)^2} = \sqrt{(0{,}027 - 0{,}016)^2 + (0{,}312 - 0{,}125)^2 + \ldots + (0{,}096 - 0{,}080)^2 + (0{,}054 - 0{,}027)^2} = 0{,}534$$

$$S_2^- = \sqrt{(v_{12} - v_1^-)^2 + (v_{22} - v_2^-)^2 + \ldots + (v_{20,2} - v_{20}^-)^2 + (v_{21,2} - v_{21}^-)^2} = \sqrt{(0{,}021 - 0{,}016)^2 + (0{,}250 - 0{,}125)^2 + \ldots + (0{,}080 - 0{,}080)^2 + (0{,}027 - 0{,}027)^2} = 0{,}481$$

$$S_3^- = \sqrt{(v_{13} - v_1^-)^2 + (v_{23} - v_2^-)^2 + \ldots + (v_{20,3} - v_{20}^-)^2 + (v_{21,3} - v_{21}^-)^2} = \sqrt{(0{,}032 - 0{,}016)^2 + (0{,}250 - 0{,}125)^2 + \ldots + (0{,}096 - 0{,}080)^2 + (0{,}041 - 0{,}027)^2} = 0{,}245$$

$$S_4^- = \sqrt{(v_{14} - v_1^-)^2 + (v_{24} - v_2^-)^2 + \ldots + (v_{20,4} - v_{20}^-)^2 + (v_{21,4} - v_{21}^-)^2} = \sqrt{(0{,}016 - 0{,}016)^2 + (0{,}125 - 0{,}125)^2 + \ldots + (0{,}112 - 0{,}080)^2 + (0{,}041 - 0{,}027)^2} = 0{,}241$$

By the calculation of separation measures (S_i^+ and S_i^-), the relative closeness to the ideal solution are calculated and the alternatives with respect to C_i in the descending order are ranked, and finally following table is acquired. In the light of these data, the result can be concluded as Supplier A is the best alternative among all the suppliers.

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \qquad i = 1, 2, \ldots, m; \;\; 0 \le C_i \le 1$$

$$C_1^* = \frac{S_1^-}{S_1^+ + S_1^-} = \frac{0{,}534}{0{,}171 + 0{,}534} = 0{,}757 \qquad C_2^* = \frac{S_2^-}{S_2^+ + S_2^-} = \frac{0{,}481}{0{,}228 + 0{,}481} = 0{,}678$$

$$C_3^* = \frac{S_3^-}{S_3^+ + S_3^-} = \frac{0{,}245}{0{,}483 + 0{,}245} = 0{,}336 \qquad C_4^* = \frac{S_4^-}{S_4^+ + S_4^-} = \frac{0{,}241}{0{,}471 + 0{,}241} = 0{,}339$$

	S_i^+	S_i^-	C_i	**Rank**
Supplier A	0,171	0,534	0,757	1
Supplier B	0,228	0,481	0,678	2
Supplier C	0,483	0,245	0,336	4
Supplier D	0,471	0,241	0,339	3

Table III-21 Computations of Composite Weights for the Selection of Best Alternative and Ranking of the Suppliers

	Attributes																					
	Weight	0,049	0,488	0,130	0,333	0,723	0,206	0,070	0,125	0,093	0,286	0,496	0,167	0,833	0,063	0,528	0,141	0,268	1,000	0,724	0,193	0,083
	Alternatives	**Q1**	**Q2**	**Q3**	**Q4**	**C1**	**C2**	**C3**	**DT1**	**DT2**	**DT3**	**DT4**	**MOQ1**	**MOQ2**	**PC1**	**PC2**	**PC3**	**PC4**	**HS1**	**PT1**	**PT2**	**PT3**
x_{ij}	Supplier A	25	25	10	30	40	25	15	15	15	20	30	30	40	15	25	20	20	70	30	30	20
	Supplier B	20	20	15	25	40	20	20	25	25	10	20	20	50	15	20	20	15	80	35	25	10
	Supplier C	30	20	15	25	35	25	10	20	15	20	25	25	35	25	0	20	25	60	25	30	15
	Supplier D	15	10	10	15	25	35	10	10	15	30	15	15	45	15	10	15	20	60	20	35	15
r_{ij}	Supplier A	0,539	0,640	0,392	0,616	0,563	0,466	0,522	0,408	0,416	0,471	0,647	0,647	0,467	0,416	0,745	0,530	0,492	0,515	0,535	0,497	0,649
	Supplier B	0,431	0,512	0,588	0,513	0,563	0,373	0,696	0,680	0,693	0,236	0,431	0,431	0,583	0,416	0,596	0,530	0,369	0,588	0,624	0,414	0,324
	Supplier C	0,647	0,512	0,588	0,513	0,493	0,466	0,348	0,544	0,416	0,471	0,539	0,539	0,408	0,693	0,000	0,530	0,615	0,441	0,445	0,497	0,487
	Supplier D	0,323	0,256	0,392	0,308	0,352	0,653	0,348	0,272	0,416	0,707	0,323	0,323	0,525	0,416	0,298	0,397	0,492	0,441	0,356	0,579	0,487
v_{ij}	Supplier A	0,027	0,312	0,051	0,205	0,407	0,096	0,037	0,051	0,039	0,135	0,321	0,108	0,389	0,026	0,394	0,075	0,132	0,515	0,387	0,096	0,054
	Supplier B	0,021	0,250	0,077	0,171	0,407	0,077	0,049	0,085	0,064	0,067	0,214	0,072	0,486	0,026	0,315	0,075	0,099	0,588	0,451	0,080	0,027
	Supplier C	0,032	0,250	0,077	0,171	0,356	0,096	0,025	0,068	0,039	0,135	0,268	0,090	0,340	0,044	0,000	0,075	0,165	0,441	0,322	0,096	0,041
	Supplier D	0,016	0,125	0,051	0,102	0,254	0,135	0,025	0,034	0,039	0,202	0,161	0,054	0,437	0,026	0,157	0,056	0,132	0,441	0,258	0,112	0,041
A^{+}		0,032	0,312	0,077	0,205	0,407	0,135	0,049	0,085	0,064	0,202	0,321	0,108	0,486	0,044	0,394	0,075	0,165	0,588	0,451	0,112	0,054
A^{-}		0,016	0,125	0,051	0,102	0,254	0,077	0,025	0,034	0,039	0,067	0,161	0,054	0,340	0,026	0,000	0,056	0,099	0,441	0,258	0,080	0,027

		S_i^{+}	S_i^{-}	C_i	**Rank**
	Supplier A	0,171	0,534	0,757	1
	Supplier B	0,228	0,481	0,678	2
	Supplier C	0,483	0,245	0,336	4
	Supplier D	0,471	0,241	0,339	3

III.2.3.3 Implementation of ELECTRE

ELECTRE is a multiple criteria decision making method which was in response to deficiencies of existing decision making solution methods and it is answered a real-world problem. ELECTRE method provides a different approach. This method concentrates the analysis on the dominance relations among the alternatives. That is why; this method is based on the study of outranking relations, exploiting notions of concordance. These outranking relations are built in such a way that it is possible to compare alternatives. The information required by ELECTRE consists of information among the criteria and information within each criterion. ELECTRE depends on dual priority comparisons for every evaluation criteria between alternative decision points. First of all, standard decision matrix is constituted, just like seen in the Table III-22.

Table III-22 Evaluation Table

		Suppliers					
	j \ i	1	2	3	4	Productivity Measurement (h_i)	Importance Measurement (a_i)
Criteria	1	90	80	90	50	0	1
	2	80	80	70	70	90	1
	3	80	80	80	70	80	2
	4	70	70	60	60	80	2
	5	80	70	70	60	70	4
	6	70	80	60	60	80	3
	7	80	70	70	70	80	3

While a decision point is connecting with a related evaluation criterion, in here the aim is weighting the related evaluation criterion according to other evaluation criteria. So, productivity and importance measurements are determined. Then, according to these measurement values, weighted standard decision matrix is formed. Later on, the concordance (C_{ij}) and discordance (D_{ij}) sets generated with the calculations of concordance and discordance values of every alternatives to each other and then with these sets, concordance (C) and discordance matrices (D) are constituted. Calculations of the concordance operations are seen below:

$$C(1,2) = \frac{a_2 + a_3 + a_6}{\sum_1^7 a} = \frac{8}{16} = 0,5 \qquad C(1,3) = \frac{a_1 + a_3}{\sum_1^7 a} = \frac{3}{16} = 0,1875$$

$$C(1,4) = \frac{0}{\sum_1^7 a} = \frac{0}{16} = 0$$

$$C(2,1) = \frac{a_1 + a_2 + a_3 + a_4 + a_5 + a_7}{\sum_1^7 a} = \frac{13}{16} = 0,8125$$

$$C(2,3) = \frac{a_1 + a_3 + a_5 + a_7}{\sum_1^7 a} = \frac{10}{16} = 0,625 \qquad C(2,4) = \frac{a_7}{\sum_1^7 a} = \frac{3}{16} = 0,1875$$

$$C(3,1) = \frac{a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7}{\sum_1^7 a} = \frac{16}{16} = 1$$

$$C(3,2) = \frac{a_2 + a_3 + a_4 + a_5 + a_6 + a_7}{\sum_1^7 a} = \frac{15}{16} = 0,9375$$

$$C(3,4) = \frac{a_2 + a_4 + a_6 + a_7}{\sum_1^7 a} = \frac{9}{16} = 0,5625$$

$$C(4,1) = \frac{a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7}{\sum_1^7 a} = \frac{16}{16} = 1$$

$$C(4,2) = \frac{a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7}{\sum_1^7 a} = \frac{16}{16} = 1$$

$$C(4,3) = \frac{a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7}{\sum_1^7 a} = \frac{16}{16} = 1$$

According to these operations concordance matrix is constituted as Table III-23.

Table III-23 Concordance Matrix

		Sup. A	Sup. B	Sup. C	Sup. D
	Sup. A	0	0,5	0,8175	0
C=	Sup. B	0,8125	0	0,625	0,8175
	Sup. C	1	0,9375	0	0,5625
	Sup. D	1	1	1	0

Calculations of the discordance operations are seen below:

$$d(S,S') = \begin{cases} 0 & , \text{ if } D(S,S') = \emptyset \\ \frac{1}{h}\max\left(\left|f_{i,s'} - f_{i,s}\right|\right) & , \text{ else } D(S,S') \neq 0 \qquad i \in D(S,S') \end{cases}$$

$D(1,2) = \frac{1}{90} \cdot 10 = 0{,}111$ $\qquad$ $D(1,3) = \frac{1}{80} \cdot 10 = 0{,}125$ $\qquad$ $D(1,4) = \frac{1}{90} \cdot 40 = 0{,}444$

$D(2,1) = \frac{1}{80} \cdot 10 = 0{,}125$ $\qquad$ $D(2,3) = \frac{1}{80} \cdot 20 = 0{,}25$ $\qquad$ $D(2,4) = \frac{1}{90} \cdot 30 = 0{,}333$

$D(3,1) = 0$ $\qquad$ $D(3,2) = 0$ $\qquad$ $D(3,4) = \frac{1}{90} \cdot 40 = 0{,}444$

$D(4,1) = 0$ $\qquad$ $D(4,2) = 0$ $\qquad$ $D(4,3) = 0$

According to these operations discordance matrix is constituted as Table III-24.

Table III-24 Discordance Matrix

		Sup. A	Sup. B	Sup. C	Sup. D
	Sup. A	0	0,111	0,125	0,444
D=	Sup. B	0,125	0	0,25	0,333
	Sup. C	0	0	0	0,444
	Sup. D	0	0	0	0

After all, a couple of threshold values are determined for the elements of concordance matrix and the elements of the discordance matrix. These threshold values are; p which is wanted to be more than or equal to 0,80 and q which is less than or equal to 0,20. According to these values, the common elements of concordance and discordance matrices are defined and selected.

Table III-25 Threshold Values of Concordance and Discordance Matrices

$p \geq 0{,}80$	$q \leq 0{,}20$
2,1*	1,2
3,1*	1,3
3,2*	2,1*
4,1*	3,1*
4,2*	3,2*
4,3*	4,1*
	4,2*
	4,3*

Starred cells are common for concordance and discordance matrices. According to data, the conclusion is defined just like in the Table III-25.

These starred cells show how to draw the arrows' directions. For example; $2{,}1^{*}$ cell states that to draw the related arrow from second supplier to the first supplier, and $3{,}1^{*}$ cell states to draw the related arrow from third supplier to first supplier, and this process goes so on. As it is known; A represents the first supplier, B represents the second supplier, C represents the third supplier and D represents the fourth supplier. In conclusion, the best supplier is which is shown by the most number of arrows. So, the Supplier A is the best one and it is seen in the conclusion figure.

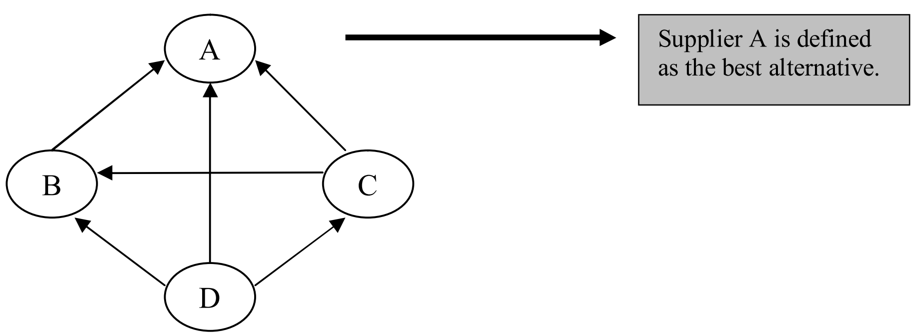

Figure III-2 Conclusion of ELECTRE

CHAPTER IV : CONCLUSIONS

The main aim of this study is to shed some light to the supplier evaluation and selection processes and to define the usage of various kinds of multiple criteria decision making methods in supplier selection. In the literature survey, every method can be used for different kinds of situations. For example; TOPSIS is used if there are too many criteria. AHP is used if there are subjective observations and opinions. But it is not suitable for the problems which have too many criteria, because it can take a long time to analyze it. ELECTRE is also useful in subjective observations and it depends on dual comparisons of the alternatives. Mathematical programming models are suitable when it is not necessary to decide the best alternative because of its multiple sourcing structures. These models are used for distributing orders to several suppliers under some restrictions. When the decision criteria are subjective, mathematical programming models are inconvenient. Cost based models need detailed cost data and because of the privacy policy of the firms, it is not suitable for this kind of implementations.

While coming into the end of the literature survey, it is easily realized that for this kind of studies and implementations; decision maker should analyze the case of his/her firm, investigate data well and decide to the most appropriate decision making method to make a healthy implementation.

In the implementation part of this study, it is understood that the data of the manufacturer firm can be analyzed by the single sourcing methodologies; because the manufacturer firm has been requesting to determine the ranking among the 4 suppliers of the cap screws and wants to decide the best supplier for making collaboration in the future to develop a good supply chain management system. But it does not mean that every single sourcing methodology is suitable for the firm's case. For example; artificial intelligence based methods were eliminated because they need either historical data or expert knowledge that were not available. Cost based methods are eliminated because of the privacy policy of the manufacturer firm; they did not share detailed cost data. Mathematical programming models aim to select more than one choice under some restrictions such as quality and require data.

But it is aimed to select the best supplier to work cooperative base as a supply chain and historical data were not available. So they are used for multiple sourcing strategies as it is told above. So they are eliminated. Remained methods are linear weighting methods and in this thesis, 3 of these methods (AHP, TOPSIS and ELECTRE) were implemented.

Reverse logistics can be considered as a systematic form of product returns and recovery and is defined as the process of managing all of the flow of returned products and information from the point of consumption to the origin. It can be regarded as one of the processes of supply chain. Product recovery becomes very important in terms of factors such as; economic factors, environmentally-conscious laws, to make green "image" as an important market tag, to provide customer satisfaction, environment – oriented programs by governments, social responsibilities, and products responsibilities until the end of products' life belong to manufacturers. It is not a new case collecting products and materials and reusing of them. However, the pressures on firm bring along some systematic ways in reverse logistics. So the firm should notice reverse logistics activities and should make the required arrangements to support this "reverse flow" in the processes. In the case of reverse logistics, the selection criteria would be revised and the problem would be analyzed again with the selected methods. Especially, environmental consciousness, firms' social responsibilities, sustainable development and minimization of materials and resources use would be deterministic to decide on the selection criteria.

In the light of the data and information which was taken from the related staff, supplier evaluation points are composed according to the criteria and their sub criteria. Afterwards; AHP, TOPSIS and ELECTRE implementations are executed. It can be seen from all of these methods' results Supplier A is the best alternative among all 4 suppliers. However, the ranking of the alternatives has been changing after the first one. According to AHP, the second alternative is set as Supplier B, third alternative is Supplier C and the fourth one is Supplier D. TOPSIS is differentiated by selecting Supplier B as second, Supplier D as third and Supplier C as fourth one. But results of ELECTRE are the same with AHP; just like the second alternative is Supplier B, third alternative is Supplier C and the fourth one is Supplier D.

As final comments; this thesis has been showing that the different kinds of supplier selection methodologies can be more efficient in various kinds of cases according to type of the problem and constraints of the situation. Therefore; it is recommended that the decision maker should take all the issues into account before selecting the method and model to be used on a given case.

Future research can be done by using fuzzy AHP, fuzzy TOPSIS, and fuzzy ELECTRE for the same case when the decision makers' evaluations are vague. Furthermore, agent based supplier selection can be considered as a further study.

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RESUME

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