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DEVELOPMENT OF AN AHP BASED SUPPLIER EVALUATION SYSTEM: A CASE STUDY IN A TURKISH DEFENSE FIRM

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DEVELOPMENT OF AN AHP BASED SUPPLIER EVALUATION SYSTEM: A CASE STUDY IN A TURKISH DEFENSE FIRM

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ABSTRACT

DEVELOPMENT OF AN AHP BASED
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A CASE STUDY IN A TURKISH DEFENSE FIRM

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Supply chain process is one of the key processes in manufacturing firms which consists of various business entities such as suppliers, manufacturers, distributors, retailers and consumers. In order to establish a sustainable supply chain system, suppliers should be monitored and controlled on a regular basis. Supplier evaluation plays a crucial role to sustain a well-performing supplier pool for large manufacturing firms. To build an effective supplier evaluation system, the set of criteria covering the whole supplier evaluation process should be considered. This study focuses on establishment of an effective supplier evaluation system for a Turkish defense firm. Analytic Hierarchy Process (AHP) is applied to structure the problem through six main criteria which are ramified in 19 sub-criteria. This study provides a numerical case which focuses on suppliers in the machining field of the chosen Turkish defense firm to evaluate their performances. In criteria weight determination, the decision maker and different experts based on their expertise are selected and their opinions are used. Suppliers are classified into three tiers regarding their performance and recommendations are provided to the firm in order to improve supplier evaluation process. Sensitivity analysis is conducted and it is observed that results of proposed AHP method is not

prone to changes. The benefits of the proposed method for supplier evaluation problem are presented.

Keywords: Supplier Evaluation, Supplier Selection, Analytic Hierarchy Process (AHP), Case Study

ÖZ

AHP TEMELLİ TEDARİKÇİ DEĞERLENDİRME SİSTEMİ GELİŞTİRİLMESİ: BİR TÜRK SAVUNMA SANAYİ FİRMASINDA VAKA ANALİZİ

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Tedarik zinciri yönetim süreci üretici firmalar bünyesindeki hayati süreçlerden biridir. Bir işletmede tedarik zinciri, tedarikçi, üretici, distribütör, toptancı, perakendeci ve müşteri bileşenlerinden meydana gelmektedir. Sürdürülebilir ve etkili bir tedarik zinciri sistemi kurabilmek için tedarikçiler düzenli olarak incelenmeli ve kontrol edilmelidir. Bu doğrultuda, tedarikçi değerlendirme süreci, üretici firmalar bünyesindeki tedarikçi havuzunun etkin bir şekilde sürdürülmesi açısından büyük rol oynamaktadır. Bundan dolayı, sağlam ve verimli bir tedarikçi değerlendirme sisteminin kurulması için tedarikçi değerlendirme sürecinin tüm aşamalarını içeren kriterler belirlenmelidir. Bu çalışma, seçilen savunma sanayi firmasında etkin bir tedarikçi değerlendirme sisteminin kurulmasını amaçlamaktadır. Çalışma boyunca Analitik Hiyerarşi Süreci'ne (AHS) başvurularak 6 ana kriter ve bu ana kriterleri takip eden 19 alt kriter belirlenmiştir. Çalışma, talaşlı imalat alanında faaliyet gösteren tedarikçilerin performanslarını sayısal verilerle desteklemektedir. Kriterlerin ağırlıkları farklı karar verici ve uzmanlar tarafından uzmanlık alanlarına göre belirlenmiştir. Tedarikçiler performanslarına göre 3 farklı kategoride sınıflandırılmış ve bu sınıflar göz önünde bulundurularak tedarikçi değerlendirme sürecinin geliştirilmesi adına seçilmiş Türk savunma sanayi firmasına önerilerde bulunulmuştur.

Çalışma sırasında duyarlılık analizi gerçekleştirilmiş ve önerilen AHS metodunun sonuçlarının değişikliğe yatkın olmadığı gözlenmiştir. Önerilen modelin tedarikçi değerlendirme süreci üzerindeki faydaları çalışmada sunulacaktır.

Anahtar Kelimeler: Tedarikçi Değerlendirme, Tedarikçi Seçimi, Analitik Hiyerarşi Süreci (AHS), Vaka Analizi

This thesis is dedicated to my family and my love

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
CBR	Case Based Reasoning
CI	Consistency Index
CNC	Computer Numerical Control
CR	Consistency Ratio
DEA	Data Envelopment Analysis
DM	Decision Maker
ERP	Enterprise Resource Planning
GSS	Green Supplier Selection
MCDM	Multi-Criteria Decision Making
MNV	Mean of Normalized Values
PCM	Pairwise Comparison Matrix
RI	Random Inconsistency Index

CHAPTER 1

INTRODUCTION

All manufacturing companies need strong supply chain processes which start from purchasing of raw materials and end at producing finished goods and transporting them to retailers or directly to consumers. Besides materials, accurate and timely flow of information, capital, manpower and equipment requires inevitable interaction of business entities involved in related supply chain process (Forrester, 1958). Hence, the whole supply chain process should be established on the basis of integration of different business entities such as suppliers, manufacturers, distributors, retailers and finally consumers (Beamon, 1998). The supply chain is initiated from upstream referring to suppliers which supply required raw materials to manufacturer firms. The increase in demand may cause firms to find new suppliers and encourage existing suppliers to improve their performances. Moreover, the uncertainty in consumer demand resulting in complexity in supply chain has led manufacturer firms to manage their suppliers in a more effective way (Gunasekaran et al., 2015). There are several practices related to supplier management such as supplier selection, supplier evaluation, supplier integration, supplier improvement, etc. (Chan, 2003).

The very first action of constituting an effective supply chain is selecting the right supplier which can supply raw materials in the right quality, right quantity and at the right time. In order to prevent supply risk, which is being unable to supply required raw materials, manufacturer firms should establish long-lasting relationships with suppliers (Hong et al., 2005; Zsidisin et al., 2004). This may provide comparative advantages to manufacturers in terms of negotiating with suppliers and providing suppliers to reserve their production lines to produce materials ordered by these manufacturers. Building a sustainable and powerful supplier pool will provide advantage to manufacturer firm compared to its rivals and may create entry barrier for

competitors (Jap, 2001). The main objective of supplier selection process is to reduce supply risk, boosting value to both supplier and manufacturer firm and increasing collaboration between supplier and manufacturer (Monczka et al., 1998).

Supplier selection process is the beginning of supply chain process. However, only choosing suppliers and giving orders to them are not sufficient to have a powerful supplier pool. Hence, a well-established supplier selection process should be supported with a well-organized supplier evaluation process. The difference between supplier selection and evaluation is that supplier selection is the process of adding new suppliers to supplier pool and giving order to them whereas supplier evaluation is the process of monitoring activities of suppliers and attaining scores regarding their performances and providing data for purchase order process. In order to sustain a powerful supplier pool, firms should monitor performance of each supplier separately and regularly. The main reason for monitoring is that the long-lasting business relationships are prone to being abused by suppliers in the lack of control mechanism of manufacturer firm (Kim, 2002). This monitoring activity will enable manufacturing firm to keep suppliers under control and warn them in case of low performance (Prahinski and Benton, 2004). Moreover, it may result in ending business relationship with some suppliers to purchase materials proper to documents prepared by manufacturer. Monitoring suppliers should be based on a systematic scheme which will ease the whole process and comparison of different suppliers supplying the same raw materials (Purdy and Safayeni, 2000). The systematic scheme should involve many different criteria appropriate to needs of manufacturer firm. Performance levels of suppliers may be reported to suppliers as feedback in order to enable them to improve their processes and prevent possible mistakes in future regarding raw material supply (Prahinski and Benton, 2004). While performance level is being measured, criteria regarding evaluation of suppliers providing raw materials have to be determined beforehand.

1.1. Research Aim

The problem of development of an effective supplier evaluation system for manufacturers by determining criteria for supplier evaluation of manufacturer has attracted many researchers as well as professionals employed by manufacturers. In order to provide a sustainable supply chain process and decrease supply risk, evaluating suppliers regarding criteria which are determined appropriately to supply environment of buyer firm play critical role for manufacturers.

The problem is that a chosen defense firm has a well-defined and documented supplier selection process, whereas it has a supplier evaluation process which only takes quality and delivery performances of suppliers into consideration to support purchasing order decisions. Moreover, current supplier evaluation system does not distinguish suppliers regarding their performances. It only separates suppliers into two groups which are successful or not. Additionally, evaluation scores are not recorded in anywhere, therefore recently hired domestic purchasing specialists do not have enough data to learn about suppliers beforehand and their learning processes take longer. Although price is the most important criterion in purchase order giving process, domestic purchasing specialists sometimes has to give orders to suppliers which did not offer the lowest price. If such a case occurs, the project leader has to prepare a signed document involving the reason of such decision and this process takes long time. These problems cause case company to have ineffective supplier evaluation system.

In this context, the aim of this study is to establish a well-defined and more effective supplier evaluation system for the chosen defense firm which will be called case company in following chapters due to confidentiality issues.

1.2. Research Method

The proposed multi-criteria decision-making method will focus on suppliers which are currently operating in machining field of case company. The reason behind choosing these suppliers performing in machining field is that although machining field is the

most vital part of domestic supply chain process, it is observed that it is also the most problematic segment of this process in terms of performance.

By applying Analytic Hierarchy Process (AHP) which is used in many studies related supplier evaluation process in literature (Akarte et al., 2001; Chan and Chan, 2004; Tahriri et al., 2008), overall goal is divided into main and sub-criteria which are determined regarding supply environment of manufacturer. Then, alternative suppliers which are chosen regarding their delivery revenue are added under each sub-criterion at bottom level. Data belonging sub-criteria are gathered and weights of main criteria and sub-criteria are determined by converting verbal expressions of the decision maker (DM) and experts. Results demonstrating ranking of suppliers' overall performances are presented. Lastly, sensitivity analysis is conducted to see whether results are prone to be affected by the change in weights.

1.3. Managerial Relevance

Case company is only taking quality and delivery into account in current supplier evaluation system. This study presents an examination on extensive set of supplier evaluation criteria which also includes case specific ones such as ERP program usage and having traceability programs. In this context, main criteria which are quality, delivery, flexibility, manufacturing capability, technology and firm characteristics are examined in detail and ramified to 19 sub-criteria covering whole supplier evaluation process in this study.

Through this analysis, necessary data which are required to calculate weights of main and sub-criteria and scores of alternatives was collected through different sources. Quantitative data are taken from Enterprise Resource Planning (ERP) program established in case company and are gathered by consulting the suppliers. Weights of main and sub-criteria are determined by verbal expressions of the DM and experts regarding to their expertise and experiences by conducting several interviews. One DM and four different experts in quality, production planning, domestic purchasing and supply chain fields contributed to PCM creation step of AHP in order to calculate scores of sub-criteria involving qualitative data.

In order to guarantee accountability in results, robustness of results calculated by proposed AHP method is checked by conducting an extensive sensitivity analysis which is realized by creating random numbers between ±5, ±10 and ±20 of global weight of each sub-criterion.

By adapting proposed supplier evaluation system, case company will be able to make this process transparent, since case company will be able to view current performance of suppliers and declare their performance status to suppliers. This feedback system will enable suppliers to view their weaknesses and encourage them to improve their processes. Moreover, supplier evaluation system which is developed for suppliers in machining field can be applied to suppliers in different production fields by adopting case specific criteria, if needed.

The rest of this study is organized as follows: Chapter 2 discusses the previous studies about supplier evaluation process and methods applied. In Chapter 3, how research method is realized is clarified. In this chapter, steps of AHP method will be stated first. Secondly, relation and differences of supplier selection, evaluation and purchase order giving process and current supplier evaluation process in case company will be stated. Later, how main criteria and sub-criteria are determined will be clarified. Moreover, data collection process is explained in detail. In Chapter 4, results of proposed method are demonstrated and sensitivity analysis is conducted. In the last chapter, the benefits of the proposed method for case company are stated. Later, theoretical and managerial contribution of this study will be stated. Finally, future study issues and conclusive remarks are presented.

CHAPTER 2

LITERATURE REVIEW

Supplier selection and supplier evaluation processes are used interchangeably in literature. The nature of both processes is complex and requires many different criteria to be taken into consideration; this makes these subjects to be researched in literature. Improvement in these processes may decrease cost, reduce supply risk and enhance suppliers' performances while supplying raw materials. If these processes can be applied for each purchased or outsourced material, manufacturer firm can reach excellence level in the beginning step of supply chain process. The main focus of this study is supplier evaluation, however supplier selection and evaluation are used interchangeably in literature, so not only the methods and criteria used in articles examining supplier evaluation, but also the methods and criteria used in articles examining supplier selection are taken into consideration. As it is stated before, both in selecting suppliers and giving orders and evaluating or monitoring supplier performance, many different criteria which are evaluated to be affecting supplier performance are determined by manufacturer firm. Hence both supplier selection and evaluation problems are multi-criteria decision-making problems and examined in literature widely. However, suppliers can only be evaluated by some criteria which are flexibility, past delivery performance, ERP program usage, relationship in the context of supplier evaluation process. Since, performance level of suppliers in terms of these criteria can only be observed by the realization of deliveries of several purchase orders suppliers cannot be evaluated by these criteria in the context of supplier selection process. Therefore, supplier evaluation criteria and methods will be examined more in detail comparing to supplier selection criteria and methods.

In this section, most examined supplier evaluation criteria will be clarified first. Later, most examined supplier evaluation methods which are multi-criteria decision-making methods will be explained.

2.1. Supplier Evaluation Criteria

The supplier evaluation process begins with determination of criteria which are specified according to needs of buyer and material to be purchased. The scientists and purchasing professionals have started to focus on analysis and determination of criteria which are used to select suppliers or evaluating their performances in 1960s.

The first study to determine different criteria belonged to Dickson (1966). He stated that the prior studies on vendor selection can be gathered from purchasing literature and at least 50 different criteria used to evaluate supplier performance may be found in the articles of various authors. 170 purchasing agents who are enrolled to National Association of Purchasing Agents in Canada and USA were sent a questionnaire and asked if companies they work for have a formal vendor performance evaluation system and which supplier selection criteria are important to them. 44% of respondents answered that their companies do not have a formal method to analyze vendors. It is also seen that many purchasing agents override lowest bid and check for other factors like quality, delivery, etc. Respondents who are applying a formal method to analyze vendors have declared the critical factors affecting their purchasing decisions. Quality is evaluated to have extreme importance in 23 criteria chosen by purchasing professionals. Additionally, criteria with considerable importance within 23 criteria are listed as delivery, performance history, warranties & claim policies, production capacity, price, technical capability and financial position according to responses from purchasing professionals. Dickson (1966) noticed that determined criteria for different purchasing situation vary, so four different purchasing cases has been offered to respondents and asked to determine critical criteria for four different cases. 23 different criteria predetermined by the author were ranked according to scores given by purchasing agents. Complex purchasing situation like purchasing computer for a satellite which will be placed in orbit was evaluated by criteria with higher mean

ratings. Overall, the most important criteria for these four different purchasing situations were determined to be meeting quality standards of buyer, delivering on time and past performance of vendor. Moreover, it was seen that price was less important in the case of purchasing high technology materials.

Weber et al. (1991) reviewed 74 articles which are published in well-known journals in between 1966 and 1991. Their aim was to detect whether 23 criteria which were determined in study of Dickson (1966) had been used by various authors in this time frame. Authors also tried to see usage frequency and importance of each criterion. Weber et al. (1991) found out that net price, delivery and quality were used in 80, 59 and 54 percent of articles respectively and were the most popular criteria. These criteria were evaluated to have extreme or considerable importance according to Dickson's study. Production capacity and facilities was discussed in 30% of articles and still had considerable importance as in Dickson's study. The biggest difference between two studies was the evaluation of geographic location, since geographical location was discussed in 21 percent of articles and ranked 5^{th} whereas it only had average importance and was ranked 20^{th} in Dickson's study. This showed that importance of geographical location increased in supplier selection. Another significant difference between two studies was warranties and claims policies. These 74 articles have never discussed warranties and claim policies whereas it was ranked 4^{th} in Dickson's study with considerable importance. These differences demonstrated that needs of firms are able to change by time and authors have adapted their studies accordingly.

Ho et al. (2010) reviewed 78 articles which were published in between 2000 and 2008 in the field of supplier evaluation. The most mentioned criterion has become quality which was used in 68 articles (87.2%). Delivery was the second by being mentioned in 64 papers (82.1%). Third one was price/cost which was preferred in 63 papers (80.8%). Price was referred as cost in some articles, since price of each purchased material is reflected as cost for the buyer firm. It can be referred that the importance of price/cost has decreased, since it was the most mentioned criteria in study of Weber

et al. (1991). These criteria are followed by manufacturing capability, service, management, technology and so on.

Besides criteria mentioned above, supplier evaluation criteria which were discussed in literature are presented in Table 1. These criteria are sorted according to usage frequency in literature.

Table 1 Supplier evaluation criteria discussed in literature

Criteria	**Authors**
Quality	Aghai et al., 2014; Arıkan, 2013; Chan and Kumar, 2007; Chen et al., 2010; Dweiri et al., 2016; Florez-Lopez, 2007; Garfamy, 2006; Ghodsypour and O'Brien, 2001; Govindan et al., 2017; Jain et al., 2004; Hong-jun and Bin, 2010; Liu and Hai, 2005; Muralidharan et al., 2002; Perçin, 2006; Ross et al., 2006; Thongchattu and Sripokapirom; 2010; Wang et al., 2017
Delivery	Arıkan, 2013; Bayazit, 2006; Braglia and Petroni, 2000; Cebi and Bayraktar, 2003; Chen et al., 2010; Florez-Lopez, 2007; Hong et al., 2005; Narasimhan et al., 2001; Sarkar and Mohapatra, 2006; Talluri and Narasimhan, 2005; Talluri and Sarkis, 2002; Wang et al., 2017
Price/Cost	Aghai et al., 2014; Akarte et al., 2001; Arıkan, 2013; Chen and Huang, 2007; Dweiri et al., 2016; Garfamy, 2006; Govindan et al., 2017; Liu et al., 2000; Mendoza and Ventura, 2008; Talluri and Baker, 2002; Talluri and Narasimhan, 2004; Thongchattu and Sripokapirom; 2010; Wang et al., 2004; Wang et al., 2017; Weber et al., 2000
Manufacturing Capability	Akarte et al., 2001; Barla, 2003; Bottani and Rizzi, 2008; Braglia and Petroni, 2000; Demirtas and Üstün, 2008; Ha and Krishnan, 2008; Liu et al., 2000; Perçin, 2006; Seydel, 2005; Talluri and Narasimhan, 2004; Xia and Wu, 2007
Service	Barla, 2003; Chan and Chan, 2004; Choy and Lee, 2003; Demirtas and Üstün, 2009; Gencer and Gürpinar, 2007; Ha and Krishnan, 2008; Liu and Hai, 2005; Mendoza and Ventura, 2008; Seydel, 2005; Wang et al., 2005

Table 1 (continued)

Management	Aghai et al., 2014; Bayazit, 2006; Braglia and Petroni, 2000; Büyüközkan and Çifçi, 2011; Chan et al., 2007; Florez-Lopez, 2007; Forker and Mendez, 2001; Gencer and Gürpinar, 2007; Liu and Hai, 2005; Narasimhan et al., 2001; Sarkar and Mohapatra, 2006; Talluri and Narasimhan, 2005
Technology	Aghai et al., 2014; Akarte et al., 2001; Braglia and Petroni, 2000; Büyüközkan and Çifçi, 2011; Florez-Lopez, 2007; Muralidharan et al., 2002; Ramanathan, 2007; Sarkar and Mohapatra, 2006; Sevkli et al., 2007; Seydel, 2005; Yang and Chen, 2006; Xia and Wu, 2007
Research and Development	Bevilacqua et al., 2006; Chan and Chan, 2004; Chen et al., 2010; Choy and Lee, 2002; Choy et al., 2005; Demirtas and Üstün, 2009; Forker and Mendez, 2001; Hou and Su, 2007; Kwong et al., 2002; Narasimhan et al., 2001; Talluri and Narasimhan, 2005; Wang et al., 2017
Environmental Management System	Amindoust et al., 2012; Chen et al., 2010; Grisi et al., 2009; Hong-jun and Bin, 2010; Kannan et al., 2013; Kuo et al., 2010; Li and Zhao, 2009; Shen et al., 2013; Torng and Tseng, 2013; Yan, 2009
Finance	Aghai et al., 2014; Büyüközkan and Çifçi, 2011; Chan, 2003; Choy and Lee, 2003; Çebi and Bayraktar, 2003; Gencer and Gürpinar, 2007; Govindan et al., 2017; Hong-jun and Bin, 2010; Huang and Keskar, 2007; Kahraman et al., 2003; Muralidharan et al., 2002; Wang et al., 2017
Flexibility	Bevilacqua et al., 2006; Büyüközkan and Çifçi, 2011; Chen et al., 2010; Çebi and Bayraktar, 2003; Demirtas and Üstün, 2008; Govindan et al., 2017; Huang and Keskar, 2007; Liao and Rittscher, 2007; Narasimhan et al., 2006
Reputation	Bevilacqua et al., 2006; Braglia and Petroni, 2000; Chan, 2003; Chan et al., 2007; Choy et al., 2005; Çebi and Bayraktar, 2003; Muralidharan et al., 2002
Green Image	Chen et al., 2010; Cheraghi et al., 2004; Grisi et al., 2009; Humphreys et al., 2006; Kannan et al., 2013; Shen et al., 2013; Wang et al., 2017
Design for Environment	Awasthi et al, 2010; Humphreys et al., 2006; Torng and Tseng, 2013
Environmental Competences	Amindoust et al., 2012; Büyüközkan and Çifçi, 2011; Grisi et al., 2009; Kannan et al., 2015

Table 1 continued

Risk	Chan and Kumar, 2007; Chan et al., 2007; Kull and Talluri, 2008
Safety and Environment	Chan et al., 2007; Huang and Keskar, 2007; Kwong et al., 2002
Carbon Accounting and Inventory	Hashemi et al., 2013; Hsu and Hu, 2009; Hsu et al., 2011
Firm	Chan et al., 2007; Hou and Chang, 2008; Sarkar and Mohapatra, 2006
Production Capacity	Arıkan, 2013; Govindan et al., 2017; Hou and Su, 2007; Sarkar and Mohapatra, 2006; Thongchattu and Sripokapirom; 2010
Number of Technical Staff	Sevkli et al., 2007
Volume Flexibility	Sarkis and Talluri, 2002; Wang et al., 2017
Productivity	Chen and Huang, 2007; Hong-jun and Bin, 2010
Relationship	Chen et al., 2006; Chen et al., 2010; Hong-jun and Bin, 2010
Conformance Rate at First Audit	Choy et al., 2002
Conformance Rate at Production Site	Choy et al., 2002
Number of Quality Personnel	Choy and Lee, 2003

Adapted from Govindan et al. (2015); Ho et al. (2010); Nielsen et al. (2014) and extended

Supplier evaluation problem has focused on monetary issues since it had been examined by authors and purchasing professionals from early 1960s. However, the context of criteria has changed since early 2000s; the reason can be stated that authors have begun to research the impact of this system to environment. Thus, supplier evaluation criteria which are about environmental effects have been started to be reviewed by authors more frequently in recent years. Moreover, the researches on criteria such as quality, delivery, price has decreased. Govindan et al. (2015) reviewed 33 papers which were published in between 1996 and 2011 in terms of environmental criteria usage frequency. The most mentioned criterion was environmental

management system which was mentioned in 11 of 33 papers. It was followed by green image, environmental competences, environmental performance and design for environment and so on. Increase in usage frequency of green supplier selection (GSS) criteria can be observed by examining Table 1, since articles mentioning GSS criteria are published in recent years. Moreover, it can be seen that 37 papers (64.9%) were published in 2010 and so on in the study of Nielsen et al. (2014) which reviewed 57 articles published in between 1996 and 2013.

It can be seen from Table 1 that the more comprehensive criteria such as quality, delivery, price/cost, manufacturing capability, service which can be further divided into more specific criteria like conformance rate at first audit and production, number of quality personnel which means number of employees working at quality department, volume flexibility, production capacity, productivity, number of technical staffs are discussed in literature more frequently. The importance and usage frequency of comprehensive criteria have not decreased and continued to be discussed. Specific criteria such as conformance rate at first audit and production site, number of quality personnel are used as case specific, so that usage frequency of these criteria is quite low. Although GSS criteria have been discussed more frequently in recent years, the usage frequency of quality, delivery, price/cost, manufacturing capability, service has not decreased, since these are core criteria to evaluate suppliers in many cases.

2.2. Supplier Evaluation Methods

Besides choosing related supplier selection and evaluation criteria, an appropriate method should be chosen to determine best supplier. Since supplier selection and evaluation problems involve many criteria to be considered, multi-criteria decision making (MCDM) methods are adopted to these studies mostly (Ho et al., 2010). Different methods and their usage frequency in supplier selection and evaluation literature will be mentioned.

Weber (1991) reviewed 74 different articles between 1966 and 1990 and it is seen that in early stages of supplier selection and evaluation studies, linear weighting models are preferred over other methods. In linear weighting models, weight for each criterion

is multiplied with the performance score of the supplier on the corresponding criterion and these terms are summed up to achieve a final score for the supplier. The second and the third methods preferred by the authors are mathematical programming models which are linear programming models and mixed integer optimization and statistical approaches, respectively. Wind et al. (1968) determined 10 different criteria and proposed a linear regression model. 20 purchasing agents of a company are requested to attain scores for both single criterion and multiplication of criteria to understand whether multiplicative effects are significant in the regression model. 10 criteria are ranked according to the scores given by purchasing agents and it is seen that multiplicative effects are insignificant and total effect of single criterion is sufficient to approximate total scores of suppliers. Lamberson (1976) and Mazurak (1985) were other authors who proposed linear weighting models in early years.

In order to solve supplier selection and evaluation problem, different methods like data envelopment analysis (DEA), analytical hierarchy process (AHP), case-based reasoning (CBR), analytic network process (ANP) and fuzzy set theories are preferred besides mathematical programming models like linear programming, integer linear programming, integer non-linear programming, goal programming and multi-objective programming (Ho et al., 2010).

DEA which was developed to evaluate more than one outcome by inserting many different inputs to model is used to solve MCDM problems. Rather than choosing among alternatives and attaining score by different methods like pairwise comparison or gathering scores for each criterion by surveys, DEA proposes weights for inputs which will make model to reach efficient score which means that weighted outputs are equal to weighted inputs.

Liu et al. (2000) introduced a simplified DEA model to calculate performance levels of different suppliers in each commodity group purchased by an agricultural and construction equipment manufacturer. Supply variety and quality are determined to be output factors whereas price index, delivery performance and distance factor are determined to be input factors and factors used in model are chosen as quantitative.

Besides evaluating overall performance of each supplier, model is constructed to determine low performance suppliers and decrease total number of suppliers by discarding them from supplier pool in order to increase relationship with smaller number of suppliers. It is proposed that inefficient suppliers which fail at price and delivery performance criteria out of 18 suppliers should be discarded, since they became last two performing suppliers out of 18. The orders given to these inefficient suppliers should be placed to their suppliers with efficient performance scores. Other than these two suppliers, there were 11 different suppliers with performance level less than one which shows efficiency. The model proposed required level for price and delivery which are inputs by keeping other inputs and outputs constant to match performance level of inefficient suppliers to efficient level.

Saen (2006) proposed DEA model in which cost of constructing a power plant is input whereas electricity capacity and amount of know-how transfer of supplier are outputs. The main difference of this study is considering a qualitative criterion like amount of know-how transfer in DEA. This criterion is evaluated by attaining scores which are decided by experts in company to each supplier on 1-5 scale. The model represented the results demonstrating which level of cost should be achieved by supplier to become efficient.

Kolodner (1993) asserts that CBR is a method which provides experts to solve a problem by searching comparable cases which occurred in past and getting knowledge out of them. This method is based on preventing human intervention in order not to take different decisions on similar cases, since there might be bias in evaluating similar cases. The main requirement of this method is to have a well-established database involving the cases company encountered before. However, this method may be inapplicable when similar cases are lacking or these cases are not recorded in a systematic way.

Choy and Lee (2003) established an intelligent generic supplier management tool using CBR method to automate purchase order system and to ease giving order to suppliers. The criteria determined by authors for this case are technical capability

including delivery, price, manufacturing capability, quality assessment including all steps starting from product development ending at inspection at buyer's side and organization profile including financial status, achievement towards sales and marketing. Some of these criteria are determined as sub-criteria under three main criteria which are technical capability, quality assessment and organization profile which are mentioned above. The developed tool chooses the supplier that meets the manufacturer firm's requirements mostly by attaining scores to each supplier based on their past performances with respect to the selected criteria.

AHP (Saaty, 1980) calculates scores of each alternative for overall goal. AHP as its name states involves hierarchy which overall goal includes some main criteria and main criteria may include several sub-criteria. The context of problem determines the number of hierarchy levels. When the hierarchy of the criteria is constructed properly for the corresponding problem context, alternatives are added to each criterion at the lowest level. The hierarchy structure helps to divide a complex problem into smaller parts and make it easy for people to understand problem. Moreover, AHP deals with both quantitative and qualitative data in the phase of calculating scores of alternatives. Quantitative data are inserted to method directly as scores of alternatives, whereas qualitative data is obtained by pairwise comparison matrix created by comparing pair of alternatives for a criterion in order to calculate scores of alternatives. The evaluation of pairwise comparison is realized by converting verbal expressions of DM into numbers defined in Fundamental Scale proposed by Saaty (1980).

Chan and Chan (2004) applied AHP to a case where a well-known semiconductor assembly equipment manufacturer needed to select suppliers which satisfy the requirement of manufacturer firm. The selection of AHP is due to the complexity of problem and hardness of structuring, existence of subjective criteria requiring expert opinion, requirement of large number of decision makers and the interdependencies between criteria which can be solved by setting a hierarchical method. In order to define criteria, they applied a questionnaire to related experts of manufacturer firm, supplier pool is controlled to choose related supplier which supplies the critical parts. In order to evaluate subjective criteria 1-5 Likert scale is used. Since group decision

making involving 26 experts were handled in this case, the geometric mean approach was adopted at each hierarchy level. Six main criteria which are cost, delivery, flexibility, innovation, quality and service were chosen and 19 sub-criteria were considered under related main criteria. There were only three alternative suppliers thus the number of required pairwise comparisons is less compared to higher number alternatives. The global weight of each sub-criterion which shows effect of each sub-criterion to overall goal was calculated to recognize effects separately. The weight of each main criterion is ranked to direct suppliers to improve themselves in related fields.

Akarte et al. (2001) applied AHP to select and evaluate casting supplier for an automobile company. The reason for using AHP is stated as ability to structure complex problems where many quantitative and qualitative criteria exist and to detect inconsistency of DMs. Authors also aimed to constitute a database where the activities of suppliers recorded with the information of delivery time, quality level, purchasing price, etc. Constituting a database will help firm to screen performance level of suppliers automatically and will automate order system and decrease labor hour spent by purchasing agents for each purchasing order. In order to evaluate and rank suppliers, four main criteria which are product development capability, manufacturing capability, quality capability, cost and time are used. 18 sub-criteria were chosen to support related main criteria. Two sub-criteria have two sub-sub-criteria each to cover all aspects related to sub-criteria. Some criteria are scored based on criterion value determined by experts in automobile company. The method is incorporated in a web-based platform developed to calculate, monitor and screen current performances of suppliers.

Tahriri et al. (2008) chose AHP to select suppliers for a steel manufacturing company in Malaysia. In order to construct AHP method, authors determined 13 criteria to begin with. These 13 criteria are evaluated by purchasing manager and two different project managers on basis of 0-9 points scale in the first interview. Six criteria which are trust, quality, cost, delivery, management and organization, and financial had more than seven points on average and are attained to be main criteria. Nine sub-criteria and 30 sub-sub-criteria are also determined by the same experts through interviews arranged

by authors. The third interview is arranged in order to determine the weights of main criteria, sub-criteria and sub-sub-criteria. The global weights of each sub-sub-criterion are calculated and trust between key men is selected as most important supplier selection criteria for this company. Net price, re-win percentage, percentage late delivery criteria followed trust between key men criterion. Suppliers are evaluated in terms of each sub-sub-criterion by the same experts at fourth and last interview. In order to ease calculation and attaining priority weights to all criteria, a software programming is established by using Microsoft Visual Studio. Authors have applied sensitivity analysis to the results of AHP in order to see the changes in ranking of four suppliers in the case of attaining different weights to main criteria. When the weight of delivery criteria is set to be larger than 23.9%, the third and fourth ranked suppliers are replaced in ranking.

Analytic network process (ANP) can be stated as higher level of AHP. The main difference of ANP and AHP is that ANP deals with the interdependencies of different criteria and clusters (Saaty, 2001a). Clusters in ANP can be defined as alternative set and main criteria which can include sub-criteria.

Bayazit (2006) proposed ANP to solve a case involving three suppliers and supplier's performance and supplier's capability are main criteria which include different sub-criteria. Firstly, pairwise comparison of sub-criteria under same main criteria and different alternatives is handled. The pairwise comparison of main criteria and alternatives and sub-criteria under different main-criteria are handled. The rest is calculation of weights and determining the best supplier among alternatives.

The methods mentioned above, their core features and studies they are used are presented in Table 2.

Table 2 Methods used to handle supplier evaluation problem in literature

Method	Core Feature	Author
AHP	Hierarchy structure can easily adjust to fit many complex problems Easy to apply	Akarte et al., 2001; Chan, 2003; Chan and Chan, 2004; Dweiri et al., 2016; Hong-jun and Bin, 2010; Hosseini and Khaled, 2019; Hou and Su, 2007; Liu and Hai, 2005; Saaty, 1980; Tahriri et al., 2008; Tongchattu and Siripokapirom, 2010; Wang et al., 2017
ANP	Dealing with the interdependencies of different criteria and clusters	Bayazit, 2006; Gencer and Gürpinar, 2007; Saaty, 2001a
DEA	Capable of handling multiple outputs Rating the efficiencies of alternatives against each other	Braglia and Petroni, 2000; Forker and Mendez, 2001; Liu et al., 2000; Narasimhan et al., 2001, Saen, 2006; Talluri and Baker, 2002
CBR	Retrieving cases similar to a problem from an existing database of cases	Choy and Lee, 2003; Hou and Su, 2007; Kolodner, 1993; Liu and Hai, 2005
Fuzzy-AHP	Deals with imprecise and uncertain data	Arıkan, 2013; Aghai et al., 2014; Büyüközkan and Çifçi, 2011; Govindan et al., 2017; Grisi et al., 2010; Shen et al. 2013;

Adapted from Ho et al. (2010); Velasquez and Hester (2013) and extended

The reason to choose AHP as a problem-solving method to this study is that problem is divided into smaller parts as main and sub-criteria which facilitates understanding of the process by the DM and experts. Case company does not apply an efficient method to evaluate suppliers in supplier pool and hence did not store necessary data to gather scores of alternatives for each sub-criterion. Therefore, qualitative data must be

involved in method. AHP can handle both qualitative and quantitative data in the same method. Opinions of DM and experts which leads the current process are taken into consideration while handling qualitative data via pairwise comparisons. Experts in this firm are familiar to AHP method since different projects are executed by using AHP method in chosen firm.

The reasons why ANP is not chosen as method to solve supplier evaluation problem in this study are that ANP is too sophisticated for an implementation as standard tool for practical decisions. DEA is best to use in case of multiple outputs, however only performance level of each alternative supplier is the output, therefore there occurs only one output. In order to use CBR, case company has to have a well-established case database involving different purchase orders; however, case company does not have such a database. The reason why fuzzy-AHP is not adapted to this study is that it is much harder to leading decision makers and experts to make their decisions. Additionally, fuzzy-AHP requires many simulations before use and this prevents its applicability for numerous updates in future.

CHAPTER 3

RESEARCH METHOD

In this chapter of the study, AHP methodology will be explained in detail first. Then, the flow and differences of supplier selection, evaluation and purchase order giving processes and current supplier evaluation process in case company will be clarified. Afterwards, how supplier evaluation main and sub-criteria are determined will be explained. Lastly, data collection process for main and sub-criteria weights and alternatives' scores will be clarified.

3.1. Analytic Hierarchy Process (AHP)

AHP is developed by T.L. Saaty to compare alternatives which cannot be compared easily at once, since many criteria should be taken into consideration while evaluating alternatives (Saaty, 1980). In order to ease the comprehension process, problem should be divided into smaller parts systematically to ease human brain fully understand problem. This dividing process results in a hierarchical structure for the problem. Therefore, definition of problem and construction of hierarchical representation of problem is the first step of AHP. There are five steps of AHP which will be explained in the following sections.

3.1.1. Definition and Hierarchical Representation of Problem

Saaty (1994) proposes a detailed design to structure hierarchy for a problem. The first step is identifying the overall goal. This step aims to define what is desired to be achieved by solving this problem. Second step is identifying main criteria that have to be satisfied fully to accomplish overall goal. Third step is to identify sub-criteria under each main criterion. The last step of the AHP methodology is to place alternatives under each lowest level sub-criterion in order to compare alternatives to each other in

terms of this sub-criterion. By placing alternatives to the bottom end of hierarchical structure, problem will be fully defined in a way which helps the DM to capture details and will ease decision making and comparison. Sample hierarchical representation of AHP method can be seen in Figure 1.

Sub-criteria should be defined in a way that they should not be irrelevant in order to be compared in pairs. If main criteria are divided too much and too many sub-criteria are determined, it could be tough for the DM to compare sub-criteria which are placed under the same main criterion, since sub-criteria does not have any common attribute anymore.

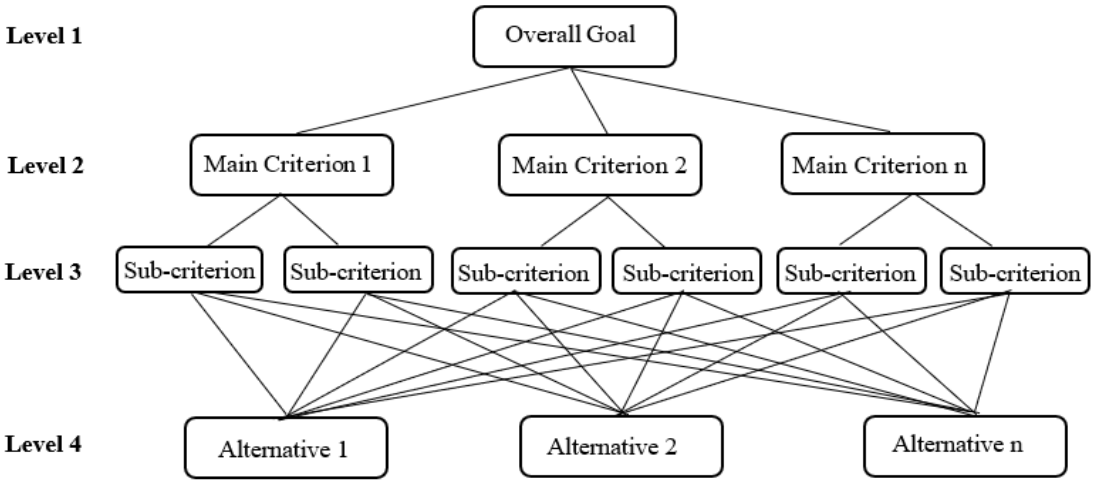

Figure 1 Sample hierarchical representation

3.1.2. Pairwise Comparison of Criteria

After completing the first step of AHP which is establishing hierarchical structure of method, the second step is to compare sub-criteria under same main criterion and main criteria under the overall goal. Fashoto et al. (2016) state that in order to deal with objective and subjective decisions effectively, pairwise comparison should be adapted.

There are different pairwise comparison scales offered by different authors. The first one is offered by Saaty (1980) when he established the AHP method. The verbal expressions of DMs are adapted to numerical values which are defined in pairwise

*comparison scale. The most commonly used pairwise comparison scale is Fundamental Scale which a linear scale between 1 and 9 founded by Saaty (1980), which is illustrated in Table 3.

Table 3 Saaty's Fundamental Scale

Degree of Importance	**Scale**	**Definition**
1	Equal importance	The two activities contribute equally to the goal
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	One activity is strongly favored over another; element is very dominant as shown in practice
9	Extremely important	The evidence is in favor of one activity over another, to the greatest extent possible
2,4,6,8	Intermediate values between two judgments	They are used to express preferences that are between the values of the above scale
Reciprocal Values	If activity i has one of the above numbers, by comparing i to j, the inverse of i with respect to j is obtained.	

Source: Saaty (1980)

The logic behind Fundamental Scale is that verbal judgment given by the DM while comparing two criteria which are tied to same higher-level criterion are converted to numbers given in Fundamental Scale in Table 3.

Pairwise comparison matrix (PCM) is filled with numbers according to verbal expressions of the DM. While converting these verbal expressions to numerical values, Fundamental Scale is used in this example.

DM compares criterion i in leftmost vertical column to criterion j in upmost horizontal column, and converted numerical value is defined as a_{ij}. Since comparing a criterion to itself is equal to one, all $a_{ij} = 1$ for all i=j at the diagonal of PCM.

For all $i \neq j$, $a_{ij} = 1/a_{ji}$ according to reciprocity axiom of AHP. Therefore, only comparisons which are in upper triangle of PCM should be decided by DM, the rest is calculated directly by reciprocity axiom. How reciprocity axiom of AHP is applied is shown in Table 4.

Table 4 Reciprocity axiom illustration of AHP method

	Main Criterion 1	**Main Criterion 2**	**Main Criterion 3**	**Main Criterion 4**
Main Criterion 1	1	x		
Main Criterion 2	$\frac{1}{x}$	1		
Main Criterion 3			1	
Main Criterion 4				1

3.1.3. Local Weight Derivation

The third step of AHP is to calculate local weights of criteria and accordingly the scores of alternatives. Since all PCMs at main criteria and sub-criteria level are filled with numerical values which are converted from verbal expressions of the DM, the weight (importance) of each main and sub-criterion should be calculated first. Not only the weights of main criteria and sub-criteria, but also score of each alternative under each sub-criterion are also calculated in this step.

The most frequently used local weight derivation method is eigenvalue method which is proposed by Saaty (Hefnawy and Mohammed, 2014). However, another method

which is mean of normalized values (MNV) is used to estimate values that can be determined by eigenvalue method without much deviation, due to its practicability (Mu and Pereyra-Rojas, 2017).

In AHP method, first local weights of sub-criteria in the same hierarchy level (level three) will be calculated separately, since they are tied to different main criterion. Later, weights of main criterion will be calculated. The calculation of weights will be executed from bottom to top. However, it can be reversed, since all weights are calculated by their own PCM created beforehand.

The first step of MNV method is to normalize values in every column. In order to normalize values, all the values in the same column are summed first. Each value (a_{ij}) will be divided by its own column sum. At the end of this step, values in every column will sum up to one which means that all values are normalized to one. In order to find local weights of each sub-criterion, average of each row is calculated and result in each row is equal to local weight of respective sub-criteria.

This process is applied to each PCM at main criteria, sub-criteria and alternatives level. Weights of main criteria, local weights of sub-criteria and scores of alternatives for each sub-criterion is calculated in the same manner.

3.1.4. Consistency Measurement and Control

AHP is a decision-making tool where humans give information which determines the numerical values of PCM. However, human brain is not sensitive enough to be fully consistent, since each DM may have different preferences, experience and expertise. All of these factors even the DM's mood can cause change in the information input of PCM. These reasons can affect the consistency of information given by DM, and consistency of information converted to numbers should be checked. Consistency measurement and control constitutes the fourth step of AHP.

In order to measure consistency, the definition of consistent matrix should be given first. Consistent matrix is that numerical pairwise comparison of two different criteria

i and j (a_{ij}) should be equal to the rate of local weights of these criteria (w_i/w_j). In the case of equality of all numerical pairwise comparisons are equal to the rates of local weights of related criteria pair, perfectly consistent PCM is achieved.

In order to achieve consistency in PCM, Saaty and Hu (1998) propose two different transitivity. The first one is ordinal transitivity which can be explained in a way that if criterion X is preferred to criterion Y and criterion Y to criterion Z, then criterion X has to be preferred to criterion Z. The second one is cardinal transitivity which is defined as if criterion X is preferred to criterion Y three times and criterion Y to criterion Z four times, then criterion X has to be preferred to criterion Z twelve times. Therefore, for a PCM to be consistent, this PCM has to be both ordinally and cardinally transitive.

As explained before, it is not completely possible for all PCMs with large size to be consistent since numerical values are decided by humans; Saaty (1980) proposed the term consistency index (CI) in order to measure consistency levels of PCMs. Definition of CI according to Saaty (1980) is as follows:

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

where n is the dimension of PCM which is a square matrix with dimension n x n and λ_{max} is the maximum eigenvalue of PCM. In the case of equality of λ_{max} and n, perfectly consistent PCM is achieved since denominator of consistency index formula becomes equal to zero.

In MNV method, rather than calculating λ_{max}, it is approximated. For an n x n matrix, n different λ estimations which are numerators of formula below are calculated. Later, average of these approximated values is computed. This approximate value is accepted to replace λ_{max} for the sake of calculation simplicity. The formula of approximate λ_{max} calculation is the following:

$$\frac{\sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} * w_i}{w_i}}{n} \; for \; i = 1, \dots, n.$$

Additionally, consistency ratio (CR) is also defined by Saaty (1980). In order to normalize CI value, where difference of λ_{max} and n gets larger when n increases, CI is divided to "Random Inconsistency Index" (RI). RI is average inconsistency calculated by randomly generated matrices for same dimension. The CR formula is the following:

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

There are lots of different RI values offered by different authors. However, when number of randomly generated matrices increases, RI values are observed to converge to some values. The most commonly used RI values are proposed by Saaty (1980) and shown in Table 5.

Table 5 RI values proposed by Saaty (1980)

	Matrix Dimension (n)								
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Source: Saaty (1980)

The corresponding CR value for a PCM should be less than 0.1 for PCM to be consistent. If CR is closer to zero, DM is considered as consistent. People are not always fully consistent, therefore Saaty (1980) proposed a cut-off point to separate consistent and inconsistent matrix. If CR is less than 0.1, then DM is accepted as consistent. If it is larger than 0.1, then in order to ensure PCM to be valid, DM revises its decisions until CR value for this matrix is less than 0.1.

3.1.5. Global Weight Derivation

The fifth and last step of AHP is to calculate global weights of each sub-criterion. Global weight can be explained as the contribution of each sub-criterion to the overall goal of AHP method. In order to calculate global weight of each sub-criterion, additive aggregation method will be used.

Additive aggregation proposed by Saaty (1980) is a method to calculate global weights of sub-criteria. Global weight of each sub-criterion is calculated by the product of weight of parent main criteria and local weight of related sub-criterion. After calculating global weights of all sub-criteria, sub-criteria could be ranked regarding magnitudes of their effects (global weights) to overall goal.

In order to find the best alternative among all alternatives, the total scores of alternatives have to be calculated based on additive aggregation method. Total score of an alternative is calculated by summing the product of global weight of each sub-criterion and score of this alternative in respective sub-criterion. When total scores of alternatives are compared, alternative with the highest total score becomes best alternative.

3.2. Case Company

In this part of the study, relation and differences of supplier selection, evaluation and purchase order giving processes related to machined materials of case company will be explained first. The reason to specifically choosing machined material suppliers is that machined material supply process is problematic as purchasing and production planning specialists stated. Then, it is followed by current supplier evaluation process adapted in case company.

3.2.1. Supplier Selection, Evaluation and Order Giving Processes

In this section, how supplier selection, evaluation and order giving processes in case company is realized and their interactions will be explained. The flow diagram including these processes is shown in Figure 2 below.

Figure 2 Chart of supplier selection, evaluation and order giving process in case company

First of all, candidate suppliers apply to Central Procurement Directorate of case company. These candidate suppliers are evaluated regarding three main criteria which are firm related issues, quality system and related production field like machining, sheet metal cutting, cable and coil production. Committee formed by case company makes a field visit to audit supplier. If candidate supplier is considered successful, it becomes an approved supplier of case company and hence is added to supplier pool of related production field. Process starting from candidates' application to Central Procurement Directorate of case company to add suppliers which meet the requirements to approved supplier pool forms the supplier selection process of case company.

Later, performances of suppliers are monitored regarding their actions during and after purchase orders realized. This performance monitoring process is called as supplier evaluation process of case company and will be clarified in detail in next section.

Performances of approved suppliers regarding price, quality and delivery are recorded in ERP program established in case company and used in next purchase orders while choosing which supplier to give purchase order. Domestic purchase order giving process is realized by domestic purchasing specialist. Bidding system is operated in

this process. Suppliers which are invited by domestic purchasing specialists have right to bid for related purchase order. Criterion which is given most importance is price in purchasing order giving process.

3.2.2. Current Supplier Evaluation Process

Suppliers which are approved by case company are monitored regularly. In the current system, quality department takes delivery and quality related data for each six months period from ERP system.

Data related to quality involve nonconformance notifications created on ERP program about materials which are found not convenient to its production documents in first audit or production site. If a portion of incoming material is rejected in terms of quality, then quality success of supplier for this material is the ratio of material which is convenient to its production documents divided by total number of materials. While accumulating success ratio of different orders, quantity of orders is ignored meaning that success ratio is equal to total of single order's success ratio. In other words, total success ratio is not calculated by total accepted material divided by number of whole incoming material, and hence it is not weighted average of quantity ordered. This affects the final success rates of suppliers. While calculating quality success ratio, delivery on time is disregarded. Conformance of incoming material is still controlled, although it is delivered later than required date.

Delivery data is measured whether supplier delivered the right material proper to quality standards at defined date in ERP system. Delivery success ratio is calculated in the same manner as quality success ratio. Success ratio of single material is percentage of material delivered on time divided by total number of each single order. Total delivery success ratio is not weighted average of total number of incoming materials.

The total score is calculated according to weights of main criteria which are 65% of quality and 35% of delivery. It is seen that quality scores are satisfying for 95% of whole suppliers, whereas average on time delivery is calculated to be 40%. Later,

responsible quality engineer forms a notification, if total score of a supplier is less than 60 points. If supplier fails again in next report which is six months later, the investigation committee visits the supplier in four months. However, this investigation is again based on document which is used supplier selection process. Since the supplier has already passed the supplier selection process, this will not be an eliminating factor and hence the process is not effective. The reason behind this inadequacy is that supplier selection documents do not involve any criterion about delivery. The current supplier performance measurement is summarized in Figure 3 below.

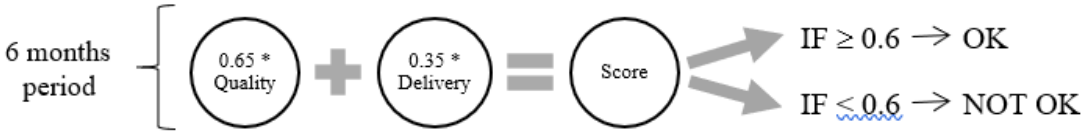

Figure 3 Current supplier performance measurement

There is a different committee which is formed of production and quality department engineers. Even though the supplier passed evaluation process applied by quality department, this committee can still warn the supplier by checking recent orders. If some serious problems occur on quality and delivery, the supplier might be subject to investigation which will be applied according to supplier selection document. If the committee considers that production capacity of approved suppliers is not enough to cover the purchase order, it applies to Central Purchasing Directorate to research new suppliers in related fields. The actions of this committee on suppliers are summarized in Figure 4.

Figure 4 Supplier performance evaluation by committee

The case company is working on a new supplier management system where suppliers can connect instantly and declare when they cannot deliver materials on time. Supplier evaluation criteria is redefined as quality, delivery, last committee examination at

supplier field, purchasing specialists' evaluation about supplier and lastly, views of purchasing specialists if any material supplied by long-term contracts covering with weights of 25%, 25%, 15%, 25% and 10%. If no material is supplied by contracts from a supplier, then 10% will be shared to other four factors and this new supplier evaluation system will be available in 2020.

There is no penalty applied to supplier firms in case of not delivering on time. Lack of penalty and proper supplier evaluation system causes suppliers not to deliver materials on time. There is no firm excluded from approved supplier pool ever because of late delivery. However, late delivery costs firm dramatically, since technicians have to work overtime for delivering finished goods to end customer on time.

If current supplier evaluation system applied in case company is examined, it can be seen that performance levels of suppliers regarding quality and delivery does not distinguish suppliers and does not affect purchase order giving process. If performance level of a supplier is larger than 60%, it is convenient to give a purchase order to this supplier. Moreover, only evaluating suppliers regarding quality and delivery is not sufficient, since there are many different criteria such as manufacturing capability, technology should be taken into consideration. Moreover, recently hired domestic purchasing specialists have no information recorded anywhere about suppliers, because of lack of information and experience. They can only get information from their more experienced chiefs and adaptation duration takes longer for them.

Domestic purchasing personnel cannot support their decisions when they have to give a purchase order to supplier with higher bids because of early due. The approval process sometimes takes one week, since it requires the project leaders to prepare signed documents. However, if the domestic purchasing specialist can view suppliers' performance levels regarding flexibility, it could be much easier to give purchase order in such a case. Therefore, more elaborate study should be made on supplier evaluation system adapted in case company.

3.3. Supplier Evaluation Criteria Selection

In order to evaluate suppliers in machining field of case company, six main criteria which are quality, delivery, flexibility, manufacturing capability, technology and firm are determined. Moreover, there are also sub-criteria under each main criterion which will be explained later. In order to ease understanding process, hierarchical representation of proposed AHP method will be illustrated before defining main and sub-criteria. Later, the main criteria will be explained and then sub-criteria under each main criterion will be clarified in detail.

Although price or cost is one of the most preferred supplier evaluation criteria in literature as it is stated in literature review section, the confidentiality issues do not allow reaching actual price offers of each supplier in bids realized by purchasing specialists. Only final purchasing order price which is not sufficient to examine this criterion in detail can be viewed. Therefore, price is excluded from main criteria list.

While determining main and sub-criteria, several interviews were conducted with the DM and experts. During these interviews, the determined main criteria met the expectations of the DM, therefore no update was needed at this process. However, while determining sub-criteria, some sub-criteria which are quality assurance certification, whole year availability, management structure and IT infrastructure were excluded, since they are not accepted as distinguishing factor for suppliers according to experts. Additionally, number of employees was changed to number of mechanical engineers and foremen, since domestic purchasing specialist (expert) stated that only authorized personnel in production affect the manufacturing capability of the supplier.

3.3.1. Hierarchical Representation of AHP Method

The first step of AHP which is definition and hierarchical representation of problem will be explained in parts below by defining problem, main criteria, and sub-criteria. The hierarchical representation of supplier evaluation problem in case company is illustrated in Figure 5. For the sake of simplicity, alternative suppliers are only connected to sub-criterion “Number of Quality Personnel”.

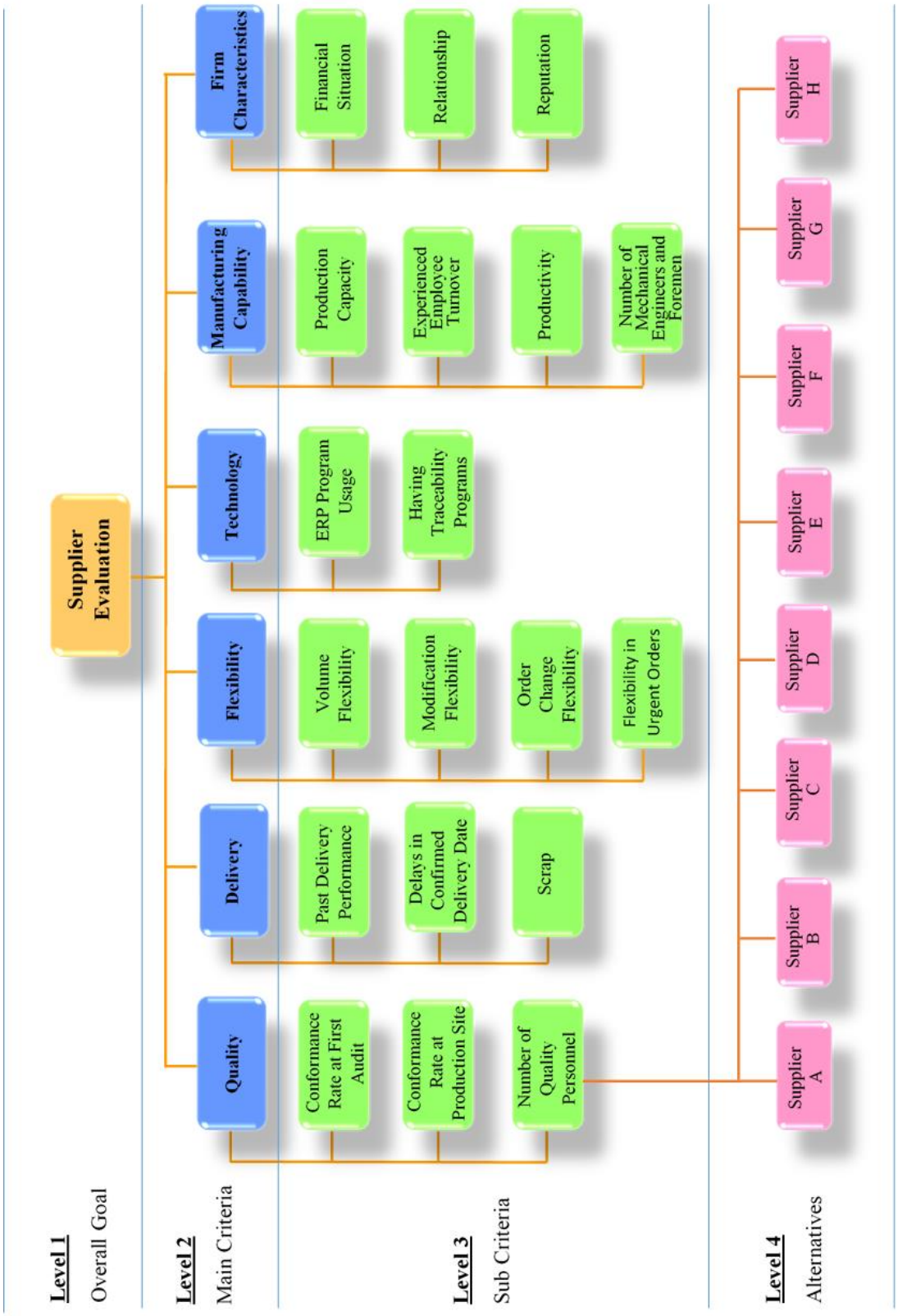

Figure 5 Hierarchical representation of supplier evaluation problem in case company

3.3.2. Quality

The first determined main criterion is *quality* which can be stated as conformity to production or technical drawing documents of incoming material in terms of functionality, visuality and measurement. Quality is chosen as main criterion as the reliability of raw material or semi-finished machined materials are important, since they might be used in extreme conditions such as wars and they must operate in any time and condition like extreme climate and environmental conditions which require water-proof and vibration resistance qualification.

Several studies highlight that quality is a core supplier selection/evaluation criterion (Liu and Hai, 2005; Muralidharan et al., 2002). While constructing hierarchical structure of supplier evaluation problem for case company, quality is a very general term to analyze, thus quality is further divided into sub-criteria which are i) *conformance rate at first audit, ii) conformance rate at production site* and iii) *number of quality personnel of supplier firm*.

Conformance rate at first audit determines whether incoming machined material is appropriate which is called non-defective regarding to its own production documents checked by quality personnel of case company at first audit. Choy et al. (2002) preferred rejection in incoming quality criterion which corresponds to reverse of conformance rate at first audit.

The second sub-criterion of quality is *conformance rate at production site*. Since military quality standards require 5% sampling for first audit and controlling each incoming material is quite time demanding, each incoming material are not controlled completely through quality personnel at first audit. Choy et al. (2002) proposed rejection in production line which refers to nonconformance rate at production site.

The last sub-criterion of quality is *number of quality personnel of supplier firm*. Quality personnel of some supplier firms are trained by case company according to expectations of itself. Choy and Lee (2003) asserted that the number of quality staff is also crucial while determining quality so preferred to be a sub-criterion of quality.

3.3.3. Delivery

The second main criterion is *delivery* which is widely discussed in the literature (Bayazit, 2006; Florez-Lopez, 2007; Sarkar and Mohapatra, 2006). Delivery should be realized in a way that suppliers should transport ordered material at the right quantity and at the right time to buyer firm. Since case company signs contract with strict contract delivery date and take penalty and lose reputation when finished goods cannot be delivered at the right quantity and at the contract delivery time to the end customer, suppliers should also deliver required material on time with appropriate quantity. Case company offers wide range of products and system solutions to its customers; therefore, the number of different machined material is quite high comparing to many mass production firms. Moreover, material variety is high and order quantities are low, supplier firms needs to change production setups for each material and the process takes too much time. This leads case company to widen its machined material supplier pool and monitor its suppliers strictly and regularly.

The most strictly monitored qualification of supplier firms by case company is delivery performance. This leads *past delivery performance* of supplier to be a critical sub-criterion of main criterion delivery. The delivery date of each material is kept by ERP program established in case company.

When there is one month left to the delivery date of material determined in ERP program, planning engineers start to inform supplier firm. This alert is applied through e-mails, phone calls and field visits by purchasing specialist. Firm declares delivery date for specific material again and might update the delivery date observed in ERP program. However, in most cases the delays in delivery of material take place, although supplier firm confirms and then delays delivery date many times. Since overtime might be declared before material delivery during day, this leads production plan changes and causes technicians both in production and quality departments to make overtime without required material delivery. Due to the fact that overtime is about twice daily wages of technicians, this extra and unnecessary overtime costs case

company. Therefore, *delays in confirmed delivery date* affects case company seriously and is determined as a sub-criterion of delivery.

Machined materials are not directly ordered to machining suppliers, firstly, casted materials are ordered to casting suppliers for many cases. Then, incoming casted materials are sent to machining supplier firms by case company. The determined scrap rate for machined materials requiring casted forms is about 2%. However, when there is excessive scrap realized by machining supplier, the required quantity cannot be provided on time, if case company does not hold extra related casted material. The variations in percent scrap of machining supplier might cause two different situations. The first one is holding excessive inventory for casted materials which causes extra cost to buyer firm and occupation of extra place in warehouse. The second situation might result in deficiency in quantity of required material which will result in delivering less finished goods to the end customer. Moreover, materials can be scrapped by supplier during packaging or transportation which will cause deficiency in quantity supplied. There *scrap* is determined as a sub-criterion of delivery.

3.3.4. Flexibility

Flexibility plays a crucial role in case of wide range of material order. Besides, flexibility in quantity and date are much more important for manufacturing firms, since production is a long process for high tech manufacturing firms. Moreover, case company cannot reject the contracts with short lead time, since the biggest end customers of case company are Turkish Army and Turkish National Security Forces. *Flexibility* is another main criterion highly cited in the literature (Demirtas and Üstün, 2008; Huang and Keskar, 2007; Liao and Rittscher, 2007).

Volume flexibility is a crucial aspect of flexibility and determined to be a sub-criterion. Since case company is operating in a very complicated sector, volumes (quantity) are changing often. Each change in system configuration which occurs too often can result in increase or decrease of required material. Therefore, being flexible in changing quantity is a vital factor while selecting appropriate suppliers. Volume flexibility can be defined as making change in ordered quantity in terms of both increase and

decrease. It is a well-known fact that when there is an increase in quantity request and the supplier firm is not ready for this request, case company may not deliver finished goods at the right quantity. On the other hand, if supplier firm rejects decrease request in quantity, case company must hold extra inventory which will create extra cost and slot in warehouse. Sarkis and Talluri (2002) proposed product volume changes as a sub-criterion under flexibility main criterion.

Since, case company produces customized finished goods proper to customer's needs, and frequent changes in electronic design resulting in changes in mechanical materials up until mass production of requested product, the production documents of machined materials are subject to change. Therefore, supplier firm should be flexible in terms of modifications and be able to keep up case company's needs. However, it may not be possible for supplier firm to apply modifications in production document, since they already completed the step requiring modification. The situations where supplier is not capable of dealing with modifications are excluded from evaluation. Therefore, *modification flexibility* plays a huge role while evaluating supplier firms' overall flexibility.

The changes in delivery dates of contracts demanded by end customer will require adjustment in delivery dates of raw material and semi-finished goods. The delivery date of material can be suspended or prioritized depending on the situation. In these situations, purchasing specialist may demand change in supplier's production schedule so it may even result in stopping the current process and replace it with another material. Hence, supplier firms need to meet certain changes without any objection. As a result, *order change flexibility* can be assumed very important dimension while determining flexibility and included as sub-criterion.

The last sub-criterion of flexibility is *flexibility in urgent orders*. Sometimes, orders can be demanded before predetermined lead time of material. Also, this adjustment should not suspend other scheduled materials' delivery dates. This may cause suppliers to make overtime even without demanding higher price for recently ordered material.

Since price of material cannot be increased in every order according to regulations of case company.

3.3.5. Technology

The fourth main criterion is determined to be *technology* which should be adapted to today's competition in any sector. Not only having technological infrastructure but also using updated and improved software on production machines creates competitive advantage over rivals. Proper to requirements of today's production and service sector, the importance of technology has increased and become subject of many articles (Braglia and Petroni, 2000; Sevkli et al., 2007; Xia and Wu, 2007).

In order to keep track of open orders and production, suppliers should utilize ERP programs or spreadsheets. However, many machining suppliers are not able to create spreadsheets in-house and do not prefer purchasing spreadsheets, they purchase several ERP programs. Having ERP program shortens response time of supplier to the buyer firm and improves coordination between supplier and buyer. Also, thanks to ERP program, supplier may have a chance to monitor production instantly and when problems occur in production. Thus, *ERP program usage* is crucial for both supplier and buyer and decided to be a sub-criterion of technology.

Increasing production capacity with less capital is vital for suppliers. Advancement provided by software (traceability program) which can monitor and control computer numerical control machines (CNC), suppliers do not have to employ extra worker to control CNC machine. This software enables this machine to operate on its own without requiring human support and let machine work all the time. Software stops machine in case of malfunctions and prevent extra cost that might be caused by continuing excessive production. Therefore, *having traceability program* for CNC machines create competitive advantage and affects buyer firm positively. Having traceability program is decided to become a sub-criterion of technology main criterion.

3.3.6. Manufacturing Capability

Since the subject of this thesis is to evaluate machining suppliers, *manufacturing capability* of suppliers plays a great role in their performances. Producing material which is proper to production documents of material can only be achieved by competent suppliers. At this stage, having high tech machinery and experienced employees might be advantageous for supplier. Having high tech and variety of machinery enables supplier to decrease process time, reduce scrap during manufacturing, and save cost during production. However, the capital required to purchase high tech machinery can cost higher comparing to purchase old fashioned machinery. In order to gain competitive advantage, supplier should trade off cost and excess revenue by having high tech equipment. As a result, features increase both production capacity and productivity. Perçin (2006) also selected manufacturing capability under decision criteria.

Having higher *production capacity* allows supplier to meet demands of buyer effectively and become more flexible. Also, supplier has a chance to join more bids although production capacity of its rivals is full. Establishing a variety of machinery slot with excessive production capacity can cause supplier extra cost, since supplier cannot fill its production capacity completely. Therefore, supplier should be careful while determining production capacity. Having a higher production capacity prevents supplier to change machinery setup less for high variety of materials being ordered and is time saving. Hence, production capacity can create a great competitive advantage and determined to be a sub-criterion of manufacturing capability main criterion. Production capacity is chosen as criterion in many articles (Hou and Su, 2007; Sarkar and Mohapatra, 2006).

Not only having high tech machinery with high variety, but also having experienced machinery engineers and foremen are vital for suppliers' manufacturing capability. Experienced employees are responsible for leading workers and training them regarding their work fields, planning operations and adjusting new machinery for production. To sustain competitive advantage, supplier needs to invest in human

resources and prevent its experienced employees to switch to rivals. If experienced employee turnover is high, supplier will suffer from managerial issues. Moreover, hiring a new experienced staff will be both costly and time demanding. Also, it is not easy to find available experienced staff to employ. Sustaining low level of *experienced employee turnover* is crucial and determined to be a sub-criterion of manufacturing capability dimension.

The following sub-criterion is defined as having higher *number of mechanical engineers and foremen*. There is a positive relationship between the number of staff and manufacturing capability. Hence, the number of mechanical engineers and foremen should be perfectly defined considering the needs, capacity and operational aspects. When there are insufficient number of skilled employees, productivity will decrease which also affect manufacturing capacity dramatically. With the previous sub-criterion, the qualification and number of experienced employees are both vital in the manufacturing capability criterion. Sevkli et al. (2007) preferred number of employees as sub-criterion in their study.

Productivity is crucial, since creating higher value with lower cost is tried to be achieved by all firms. Productivity can be defined as the rate of output divided by input in terms of cost. Suppliers with higher productivity boost their competitive advantage against their competitors. Productivity is also advantageous in terms of profitability since supplier can offer lower prices and increase revenue while not decreasing its profit. It is expected that firms with higher productivity can deliver material with appropriate quality at the right time at the right quantity. Therefore, the benefits provided by productivity helped to be accepted as sub-criterion of manufacturing capability. Chen and Huang (2007) determined that value-added productivity as sub-criterion.

3.3.7. Firm Characteristics

Lastly, the final main criterion which plays a huge role while selecting suppliers is *firm characteristics*. Organizational structure and culture have an impact on suppliers' management style, decision-making system, functionality, communication ways and.

However, it is observed that most of suppliers are family businesses which differentiate suppliers in terms of managerial process. Since these suppliers are not large entities; bureaucracy is low, so decision-making process takes shorter time. Firm characteristics are preferred as criterion in different articles in literature (Chan et al., 2007; Hou and Chang, 2008; Sarkar and Mohapatra, 2006). Additionally, firms are evaluated through their financial situation, relationships and their reputation. After analyzing each sub-criterion in detail, firms' overall situation is determined and it influences supplier evaluation process.

First of all, *financial situation* is one of the most important sub-criteria while defining firm's situation. There are many ways to measure financial performance. However, in order to attain accurate indicator, only current ratio taken into consideration while determining supplier's financial performance. Braglia and Petroni (2000) asserted that financial stability can be measured by debt ratio and current ratio. Muralidharan et al. (2002) stated that liquidity is crucial while defining financial situation of firms. Current ratio which is one of the indicators of liquidity is ability to convert firms' assets into cash quickly and cover short-term debt. Since case company do not prefer ordering longer than 10 months period, long term liabilities cannot be covered with balance orders. Therefore, debt ratio cannot be adapted to measure financial performances of suppliers. Liquidity is crucial for the case company as an indicator of bankruptcy risk of supplier in short term. If supplier firm's liquidity is high, it shows that supplier can meet their obligations properly and it reduces firms' bankruptcy risk in one-year period. Therefore, liquidity specific financial performance analysis is selected as sub-criterion under firm main criterion.

On the other hand, *relationship with the supplier* affects supplier evaluation process significantly. In spite of case company in dominant position comparing to its suppliers, having long-term relationship is preferable. Hence, building an effective relationship with supplier is important and it brings positive results such as conformance to lead times, providing transparency, effective communication, adaptation to changes, decrease in damaged goods, etc. Moreover, Chen et al. (2006) asserted that relationship closeness is an important factor and determined as criterion. As a result, having good

relationship bilaterally crucial for both buyer and supplier firms and it affects firm's overall situation.

The third sub-criterion can be defined as *firm's reputation* which is the overall assessment of firm's attractiveness in the industry. Especially, reputation and evaluation between other defense industry firms and well-known leading firms in different sectors are very important indicator while selecting suppliers. Past actions of firms demonstrate supplier's overall reputation. Reputation can be built considering financial stability, quality of management, product and service quality, delivery rates, relationships with buyers, etc. If supplier firm has good reputation in the sector, it will be prioritized by the case company. Reputation as a criterion is given importance in literature and preferred by various authors (Bevilacqua et al., 2006; Chan et al., 2007; Choy et al., 2005). In conclusion, firm related issues are the final main criterion which is the overall evaluation of financial situation, relationship and reputation and it affects notably supplier selection process.

Green supplier selection and evaluation criteria are thought to be added as criteria to this study. Case company requires suppliers in machining field to deliver all solid wastes to certificated solid waste collecting firms and battery wastes to licensed institutions. Additionally, suppliers must have environment license given by Ministry of Environment and Urbanization. Suppliers must document possible threats to environment due to wastes of supplier and must state the solution to prevent environmental pollution in the content of Environmental Dimensions and Effects Evaluation Form. Suppliers also must have ISO 14001 Environmental Management System Certificate to become an approved supplier. These certificates and documents are all checked at supplier selection process. Since, all documents defining environmental effects are obligatory to have for suppliers, no distinguishing criteria for supplier can be found and added as criteria to this study.

3.4. Data Collection

In order to operate AHP method which is constructed in previous parts, alternative suppliers should be determined first. Later, necessary data to create PCMs in main

criteria and sub-criteria level and determine scores of alternative suppliers' scores should be gathered. In first part of this section, how alternative suppliers are chosen will be explained. In second part, how PCM in main criteria level is created will be explained. Then, creation of PCMs in sub-criteria level will be clarified. In last part of this section, how data used for calculating alternative suppliers' score is collected will be defined.

3.4.1. Identifying Alternative Suppliers

The data belong to current supplier evaluation system could not be found. Therefore, suppliers are compared regarding their delivery revenues to case company. Moreover, the frequency and size of purchase orders given to suppliers are similar.

There are 72 suppliers in machining field in supplier pool of case company. However, buyer firm do not actively work with all of suppliers when it is checked by ERP program. Since ERP program is established in buyer firm in 2005, only data which belongs to this time interval could be extracted. Revenue data is collected between years 2007 and 2017. The reason behind choosing 2007 as starting point is that two firms with higher revenue comparing to other substitutes has joined to supplier pool in 2007. While determining alternative suppliers, the ones which joined to supplier pool later are discarded, because not enough revenue and hence delivery data can be found. Besides, one of the firms with higher revenue is also discarded, since it gave up working with buyer firm in 2015. The firms which are chosen are suppliers which case company currently working with.

Suppliers in machining field also operate in different areas like casting and sheet metal cutting fields. Since some materials are placed in wrong material group in ERP program, materials which are ordered before are controlled by purchasing specialists in detail and the ones which are irrelevant are discarded. It was seen that only 34 of suppliers are preferred to work with between the years of 2007 and 2017. Also, last 10 firms are only preferred when the capacity of suppliers with higher revenues are full, since last 10 firms offer higher prices to materials in bids stated by purchasing specialist.

In order to cover suppliers which constitute most of the total revenue between years of 2007 and 2017, firms are ranked according to their revenues and it is seen that 8 of these 34 firms which are actively preferred constitute the 81.64% of total revenue and are accepted as subject of this case study, is shown in Figure 6.

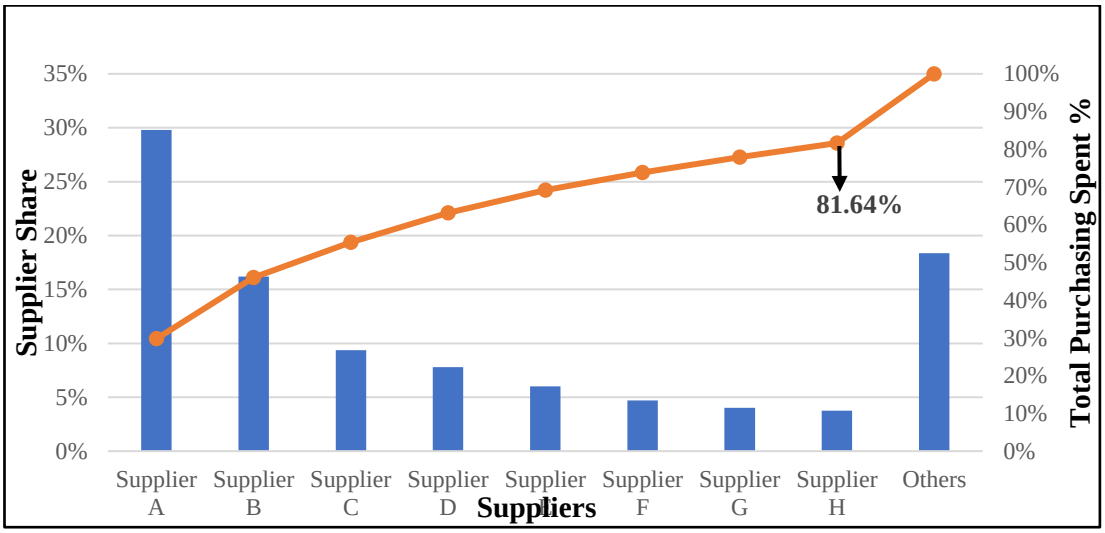

Figure 6 Pareto chart of supplier share in total purchasing spent

The ninth firm has 2.1% of total revenue. After this supplier, rest of the suppliers have revenue share less than 2.1%. There are two reasons of excluding ninth and following suppliers. First one is to keep number of alternative suppliers' minimum in order to decrease DM's bias while comparing suppliers in terms of evaluating qualitative criterion. Since qualitative criterion is managed by forming PCMs, increasing number of suppliers will increase dimension of PCM, and is inclined to increase bias. Second reason is that covering more than 80% of total revenue is sufficient according to Pareto principle.

The reason why left axis of Pareto chart is formed with percentages rather than real revenue figures is based on confidentiality of case company. Moreover, the suppliers cannot be demonstrated with their real names because of confidential issues as well. They were defined as Supplier A, B,…, H and ranked biggest to smallest based on their revenue sizes and will be used same in following sections. Firm A represents the firm with the highest revenue and alphabetic order is maintained proper to ranking.

3.4.2. Creating PCM in Main Criteria Level

During interviews conducted with the DM and experts, the methodology of AHP has been explained. Later, hierarchical structure of proposed AHP method was shown to ease understanding process. The logic behind Fundamental Scale of Saaty (1980) is explained and how pairwise comparisons should be expressed verbally and conversion of these verbal expressions to numerical values defined in Fundamental Scale of Saaty (1980) was clarified. After the DM and experts stated their decisions on pairwise comparisons, CR of each PCM is calculated and no revision is needed, since all PCM was consistent at first study.

Stating problem definition and hierarchical representation of supplier evaluation problem in section 3.3 is followed by creating PCM in main criteria level. In order to determine weights, pairwise comparison matrix of main criteria should be filled according to verbal expressions of the DM which is chosen as domestic purchasing chief of case company who has 10 years of experience in this field.

These expressions are converted into numerical values and PCM in level main criteria level is formed is given in Table 6.

Table 6 Pairwise comparison matrix of main criteria in main criteria level

	Quality	**Delivery**	**Flexibility**	**Technology**	**Manufacturing Capability**	**Firm Characteristics**
Quality	1	1/4	1/3	5	1/6	1/6
Delivery	4	1	1	7	1/3	1
Flexibility	3	1	1	5	1/5	1/2
Technology	1/5	1/7	1/5	1	1/8	1/7
Manufacturing Capability	6	3	5	8	1	1
Firm Characteristics	6	1	2	7	1	1

3.4.3. Creating PCMs in Sub-criteria Level

Rather than choosing one specific DM to help creating all PCMs in all hierarchy levels, experts who are experienced in related main criterion are chosen to create PCMs in sub-criteria level of AHP method adapted in this study.

Quality control engineer who is responsible for incoming domestic mechanical parts is chosen as expert to create PCM for sub-criteria under main criterion "Quality", related PCM is given in Table 7.

Table 7 PCM for sub-criteria under main criterion quality

	Conformance Rate at First Audit	**Conformance Rate at Production Site**	**Number of Quality Personnel**
Conformance Rate at First Audit	1	6	7
Conformance Rate at Production Site	1/6	1	3
Number of Quality Personnel	1/7	1/3	1

For main criterion "Delivery", 10-year experienced production planning engineer is assigned as expert to fill related PCM, which is provided in Appendix A.

For main criteria "Flexibility", "Technology" and "Manufacturing Capability", purchasing specialist who has three years of experience in machined material supply, is assigned as expert. The related PCMs for main criteria "Flexibility", "Technology" and "Manufacturing Capability" are given in Appendix A.

For the last main criterion "Firm Characteristics", one white collar from Central Purchase Directorate who is responsible for choosing domestic suppliers and monitoring their performances and expert chosen for abovementioned three criteria declared their preferences by coming to consensus. The PCM for main criterion "Firm Characteristics" is provided in Appendix A.

PCM at main criteria and sub-criteria level creation process and which personnel contributed to this process are summarized in Table 8.

Table 8 Contributions to PCM creation process

Hierarchy Level	**Dimension to be Weighted**	**The DM and Experts**
Main Criteria Level	Main Criteria	Domestic Purchasing Chief (the DM)
Sub-criteria Level	Quality	Quality Engineer (Expert)
	Delivery	Planning Engineer (Expert)
	Flexibility	Domestic Purchasing Specialist (Expert)
	Technology	Domestic Purchasing Specialist (Expert)
	Manufacturing Capability	Domestic Purchasing Specialist (Expert)
	Firm Characteristics	Supply Chain Specialist (Expert) and Domestic Purchasing Specialist (Expert)

3.4.4. Determination of Alternative Suppliers' Scores

In this section, how necessary data belonging to each sub-criterion is gathered will be explained. There are two different data types which can be defined quantitative and qualitative data. In terms of quantitative data, data is collected by ERP program or by asking alternative suppliers. However, qualitative data cannot be gathered by same ways as quantitative data, so related experts have stated their preferences depending on criteria and alternatives. Firstly, how quantitative data belonging to some sub-criterion will be explained. Later, how qualitative data belonging to rest of sub-criterion will be clarified.

3.4.4.1. Determination of Quantitative Data

Data belonging to sub-criteria "Conformance Rate at First Audit", "Conformance Rate at Production Site" and "Past Delivery Performance" were taken from ERP system of case company. Since revenue data of suppliers are taken between years of 2007 and 2017, data belonging to these sub-criteria are also acquired for the same 11 years period.

Conformance rate is defined as percentage of incoming material quantity accepted by quality personnel.

I = set of purchase orders (1, 2, … , n)

J = set of suppliers (1, 2, … , 8)

q_{ij} = Conformance rate of order i sent by supplier j at first audit i ∈ I, j ∈ J

Conformance score of supplier j at first audit = $\frac{\sum_{i=1}^{n} q_{ij}}{n}$ ∀ j ∈ J

Conformance rate at production site of suppliers can be calculated by replacing q_{ij} by p_{ij} in the formula above which can be defined as following:

p_{ij} = Conformance rate of order i sent by supplier j at production site i ∈ I, j ∈ J

Data of sub-criterion "Number of Quality Personnel" is gathered by simply asking alternative suppliers.

Past delivery performance for single order i sent by supplier j is denoted by d_{ij} and past delivery performance of supplier j is calculated by formula below.

$$d_{ij} = \begin{cases} 1, & \text{if order i sent by supplier j is delivered on time } i \in I, j \in J \\ 0, & \text{otherwise} \end{cases}$$

Past delivery score of supplier j = $\frac{\sum_{i=1}^{n} d_{ij}}{n}$ ∀ j ∈ J

Whether traceability programs are installed on CNC machines and how often these programs are used are asked to suppliers.

Since, variety of materials ordered by case company is too high and process time of different materials vary greatly, it is not easy to measure production capacity for alternative suppliers. When production capacity is asked to alternative suppliers, they could not easily answer. Therefore, purchasing specialist chose a material which can be produced by all alternative suppliers. The process of chosen material involves machining process and coating, but does not involve dyeing process, since only approximately 30% of all materials ordered by case company require dyeing process. Production capacity of each subject supplier is determined as maximum quantity of chosen material which can be produced by suppliers.

Experienced Employee Turnover of alternative suppliers is calculated by total number of separations of experienced personnel which takes engineers with more than three years of experience and foremen with more than five years of experience divided by average number of experienced engineers and foremen for one year. This data is gathered by asking alternative suppliers.

Productivity is defined as total output over total input used to produce total output. The product variety of machining suppliers are too high and labor, energy and capital separated to each product cannot be calculated by supplier, therefore productivity of each supplier is computed by total productivity formula stated by Hannula (2000) which is given below:

$$P_T = \frac{O}{I_L + I_C + I_M + I_E + I_Q}$$

where P_T is total productivity, O is total output, I_L is labor input, I_C is capital input, I_M is material input, I_E is energy input and I_Q is miscellaneous input. All input values and also total output is taken as monetary values declared by eight alternative suppliers. Since the biggest customer of these eight suppliers are case company and

they all join in same bids and compete with each other, net sales is assumed as total output.

Number of mechanical engineers and foremen is total number of engineers and foremen who are working in production. The reason to state engineers as mechanical engineers is that all alternative suppliers employ only mechanical engineers in production. Data belonging to this sub-criterion is acquired by inquiring alternative suppliers.

How financial situations of alternative suppliers can be derived and why debt ratio cannot be used is explained in section 3.3.7. Therefore, only current ratio formula is adapted to measure financial performance of suppliers. Current ratio formula can be seen below and this information is acquired by asking alternative suppliers.

$$\text{Current Ratio} = \frac{\text{Current Assets}}{\text{Current Liabilities}}$$

Whole data belonging to sub-criteria mentioned above is given in Appendix B.

3.4.4.2. Filling PCMs in Alternative Suppliers Level for Qualitative Data

Not all sub-criteria is based on quantitative data like in section 3.4.4.1, data belonging to sub-criteria "Delays in Confirmed Delivery Date", "Scrap", "Volume Flexibility", "Modification Flexibility", "Order Change Flexibility", Flexibility in Urgent Orders", "ERP Program Usage", "Relationship" and "Reputation" cannot be gathered by asking suppliers, taken from ERP program, or any other ways.

Data belonging to scrap seem quantitative and can be derived from ERP program at first glance, however, demands of suppliers for extra material for scrap is managed by a "Material Request Form" by case company's personnel and this application is independent from ERP program. When material movements (in and out) are checked by ERP program, there is scrap code defined for these demands and also quantity can be acquired. However, in order to learn which supplier requested material to replace

scrap can only be viewed in the explanation part of form identified by abovementioned application. Since number of forms created for these demands are quite high and controlling forms are also time consuming, it is not possible to derive data for this sub-criterion. Rather than obtaining data from these forms, a production planning engineer is assigned as expert to create PCM for this sub-criterion.

While evaluating these qualitative sub-criteria, DM took some dimensions which are given below into account.

Relationship

- Accessibility of supplier via phone/mail
- Response time
- Reliability of confirmations

Reputation

- References from leaders of other sectors and from defense firms
- Duration of working for references
- Background

For volume flexibility, modification flexibility, order change flexibility and flexibility urgent orders

- Attitude in past cases via phone/mail

ERP program usage

- Accuracy of order information in dispatch list and receipts
- Response time for questions about delivery

Scrap

- Percentage of extra casted material demanded to complete order
- Number of occurrences

Delays in confirmed delivery date

- Number of occurrences
- Repeated number of delays for single order

Experts who are assigned to main criteria are the same for sub-criterion under related main criteria. PCM created for obtaining scores of alternative suppliers under sub-criterion “Delays in Confirmed Delivery Date” is given in Table 9.

Table 9 PCM for suppliers under sub-criterion delays in confirmed delivery date

	Supplier A	**Supplier B**	**Supplier C**	**Supplier D**	**Supplier E**	**Supplier F**	**Supplier G**	**Supplier H**
Supplier A	1	1/5	1	1/9	1/7	1/3	1/3	1/3
Supplier B	5	1	3	1/3	1	3	3	1
Supplier C	1	1/3	1	1/7	1/5	1/3	1/3	1/5
Supplier D	9	3	7	1	3	5	7	3
Supplier E	7	1	5	1/3	1	3	5	3
Supplier F	3	1/3	3	1/5	1/3	1	3	3
Supplier G	3	1/3	3	1/7	1/5	1/3	1	1/3
Supplier H	3	1	5	1/3	1/3	1/3	3	1

The rest of PCMs which are created for determining scores of alternative suppliers in hierarchy alternative supplier level are provided in Appendix C.

Data belonging to sub-criteria

How data belonging to each sub-criterion are gathered and data type of each sub-criteria are summarized in Table 10.

Table 10 Data type and sources of sub-criteria

Sub-criteria	**Data Type**	**Data Source**
Conformance Rate at First Audit	Quantitative	ERP
Conformance Rate at Production Site	Quantitative	ERP
Past Delivery Performance	Quantitative	ERP

Table 10 (continued)

Number of Quality Personnel	Quantitative	Alternative Suppliers
Having Traceability Programs	Quantitative	Alternative Suppliers
Production Capacity	Quantitative	Alternative Suppliers
Experienced Employee Turnover	Quantitative	Alternative Suppliers
Productivity	Quantitative	Alternative Suppliers
Number of Mechanical Engineers and Foremen	Quantitative	Alternative Suppliers
Financial Situation	Quantitative	Alternative Suppliers
Delays in Confirmed Delivery Date	Qualitative	Planning Engineer (Expert)
Scrap	Qualitative	Planning Engineer (Expert)
Volume Flexibility	Qualitative	Domestic Purchasing Specialist (Expert)
Modification Flexibility	Qualitative	Domestic Purchasing Specialist (Expert)
Order Change Flexibility	Qualitative	Domestic Purchasing Specialist (Expert)
Flexibility in Urgent Orders	Qualitative	Domestic Purchasing Specialist (Expert)
ERP Program Usage	Qualitative	Domestic Purchasing Specialist (Expert)
Relationship	Qualitative	Domestic Purchasing Specialist (Expert)
Reputation	Qualitative	Domestic Purchasing Specialist (Expert)

CHAPTER 4

RESULTS

In this chapter, results of proposed AHP method will be stated and evaluated first. Then, robustness of sub-criteria's global weights will be examined. Finally, benefits of proposed AHP method over current situation will be elaborated.

4.1. Results of Proposed AHP Method

Before demonstrating results, how data belonging to sub-criteria adapted before using will be clarified. Scores of alternatives under sub-criteria which are determined by PCMs are already normalized to one and are provided in Appendix D. The consistency ratio of each PCM in alternative supplier level is calculated as less than 0.1 which is the acceptable level (please see Appendix E for details).

Quantitative data of sub-criteria "Conformance Rate at First Audit", "Conformance Rate at Production Site" and "Past Delivery Performance", "Having Traceability Programs", "Production Capacity", "Financial Situation" are directly normalized to 1. Since high level of experienced employee turnover is not preferred, data of sub-criterion "Experienced Employee Turnover" is changed to percentage of experienced employees who stay in supplier and then normalized to one.

When sub-criteria "Number of Quality Personnel" and "Number of Mechanical Engineers and Foremen" are examined, it is seen that these sub-criteria are positively correlated with the supplier size, and hence with the production capacity of supplier as it can be seen in Figures 7 and 8. The correlation coefficient of sub-criteria "Number of Quality Personnel" and "Production Capacity" is calculated as 0.9141 which means that there is high level of positive correlation. Additionally, the correlation coefficient of sub-criteria "Number of Mechanical Engineer and Foremen" and "Production

Capacity" is computed 0.8567 which is again stated as high positive correlation. Therefore, before normalization data of these two sub-criteria are divided by production capacity first and then normalized to one. Normalized forms of quantitative data are given in Appendix F.

The reason behind normalizing all quantitative data to one is to equalize effects of quantitative data with scores determined by PCMs and evaluate all data in the same scale. Moreover, quantitative data is normalized to emphasize global weights of sub-criteria instead of emphasizing itself.

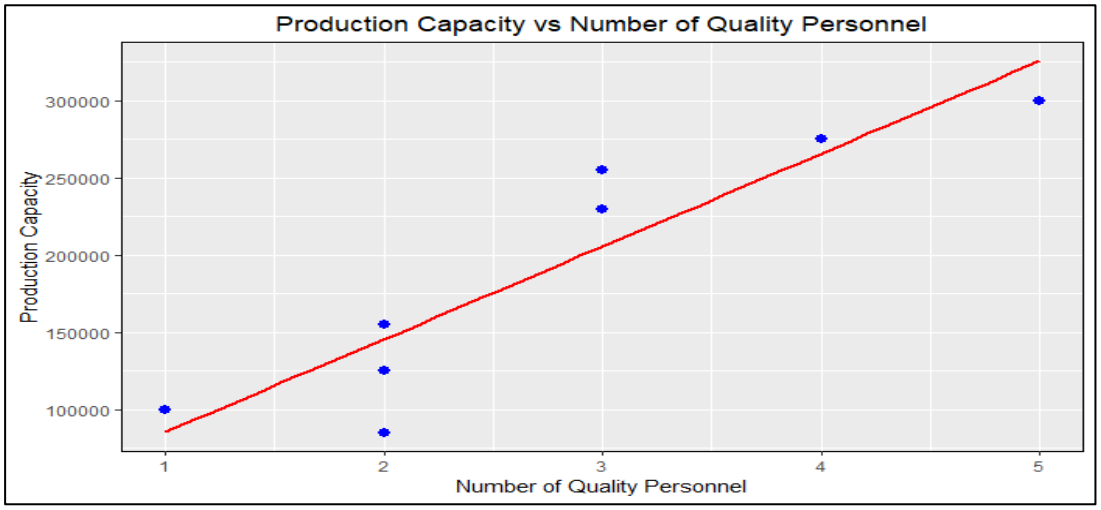

Figure 7 Scatter plot of production capacity vs number of quality personnel

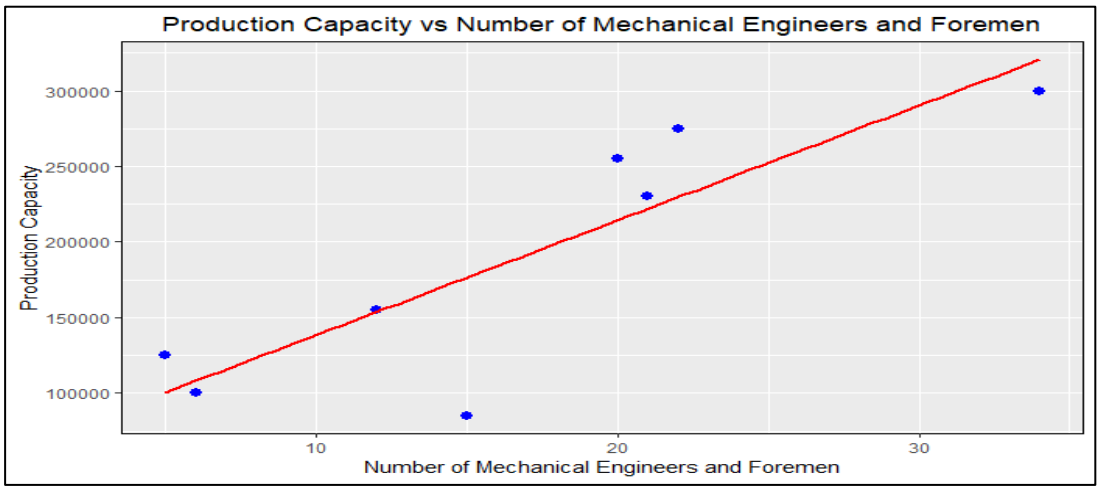

Figure 8 Scatter plot of production capacity vs number of mechanical engineers and foremen

As mentioned in case study section, PCM in main criteria level which is given in Table 6 is determined by the domestic purchasing chief. The weights of main criteria which are “Quality”, “Delivery”, “Flexibility”, “Technology”, “Manufacturing Capability” and “Firm Characteristics” are calculated as 0.0664, 0.1743, 0.1227, 0.0271, 0.3600 and 0.2495, respectively. The corresponding consistency ratio is 0.0615 and less than 0.1; therefore, judgments of DM is accepted as consistent. It can be seen that “Manufacturing Capability” is evaluated as the most important main criteria with weight of 0.3600. Since manufacturing capability of suppliers affects other criteria significantly, the result is expected. If manufacturing capability of a supplier is not sufficient, it also affects other main criteria dramatically and supplier cannot survive in such a competitive environment. “Technology” is determined as the least important criteria with weight of 0.0271. Although “Quality” expected to have higher weight rather than current evaluation, since finished goods might be used in extreme environmental conditions. Also, reliability which can be ensured by using high quality materials is important for both case company and its customers. However, quality was measured as second last criteria with weight of 0.0664. The reason behind this can be explained as since all suppliers have more than 90% success in terms of conformance rate at first audit and production site, they already supply high quality products with non-distinctive rates. It is seen that alternative supplier has leaded its suppliers to improve their quality performances in the past; hence “Quality” is not evaluated as one of the most important criteria.

Depending on six PCMs in sub-criteria level created in section 3.4.3, local weights of all sub-criteria are computed and given in Table 11. Consistency ratios for five PCMs which are created to determine local weights of sub-criteria under “Quality”, “Delivery”, “Flexibility”, “Manufacturing Capability” and “Firm Characteristics” are 0.0882, 0.0567, 0.0624, 0.0163 and 0.031, respectively. Since each consistency ratio is less than 0.1, there is no inconsistency issue. Consistency ratio of fourth PCM under main criteria “Technology” is not calculated; since there are only two sub-criteria under it.

Table 11 Local weights of sub-criteria

Main Criteria	Sub-Criteria	Local Weights
Quality	Conformance Rate at First Audit	0.7394
	Conformance Rate at Production Site	0.1788
	Number of Quality Personnel	0.0818
Delivery	Past Delivery Performance	0.0833
	Delays in Confirmed Delivery Date	0.7235
	Scrap	0.1932
Flexibility	Volume Flexibility	0.0903
	Modification Flexibility	0.0445
	Order Change Flexibility	0.2913
	Flexibility in Urgent Orders	0.5739
Technology	ERP Program Usage	0.1250
	Having Traceability Programs	0.8750
Manufacturing Capability	Production Capacity	0.3889
	Experienced Employee Turnover	0.3889
	Productivity	0.1535
	Number of Mechanical Engineers and Foremen	0.0687
Firm Characteristics	Financial Situation	0.3092
	Relationship	0.5813
	Reputation	0.1096

Local weights of sub-criteria given in Table 11 only demonstrate effect of sub-criteria to the main criterion it is tied to. Hence sub-criterion can only be compared to other sub-criteria which are tied to same main criterion. In order to see effect of each sub-criterion to overall aim, global weights of each sub-criterion should be computed and ranked for comparison. We provide these global weights in Table 12.

Table 12 Global weights of sub-criteria in ranked order

Sub-Criteria	Global Weights
Relationship	0.1450
Production Capacity	0.1400
Experienced Employee Turnover	0.1400
Delays in Confirmed Delivery Date	0.1261
Financial Situation	0.0771
Flexibility in Urgent Orders	0.0704
Productivity	0.0552
Conformance Rate at First Audit	0.0491
Order Change Flexibility	0.0357
Scrap	0.0337
Reputation	0.0273
Number of Mechanical Engineers and Foremen	0.0247
Having Traceability Programs	0.0237
Past Delivery Performance	0.0145
Conformance Rate at Production Site	0.0119
Volume Flexibility	0.0111
Modification Flexibility	0.0055
Number of Quality Personnel	0.0054
ERP Program Usage	0.0034

When global weights of sub-criteria are examined, the most important sub-criterion for the case company is observed as relationship with suppliers and this indicates that building long term relationship with its suppliers is seen more important than having variety of suppliers. Thus, only 34 out of 72 suppliers in supplier pool in machining field are given purchase orders and only eight of these suppliers constitute 81.6% of total revenue. Case company's aim to build long term relationship with its suppliers supports the fact that case company gives importance to financial situation of its

suppliers and supports them. In this context, case company pays bills in 30 days to its suppliers, whereas many leading companies pays bills in 60 days.

On the other hand, delays in confirmed delivery date by mail, phone call or field visit plays important role while evaluating suppliers. Average past delivery performances of suppliers show that only 66% of materials are provided on time. This low level of past delivery performance might have increased the number of delays in confirmed delivery date. Therefore, suppliers are prone to abusing this long-term relationship supported by subject supplier mostly. Since case company is the main customer of these eight alternative suppliers and their resources are mostly used in delivery of case company's orders, it can be deduced that total production capacity of alternative suppliers is not enough to meet demands of case company on time. Hence, production capacity of a supplier is evaluated as the second most important sub-criterion. Moreover, it can be inferred that repetitive delays in confirmed delivery date are much more important than delays in delivery times shown in ERP program for DM and experts.

Purchasing specialists meet or talk to not only purchasing specialists of alternative suppliers but also production and quality personnel of alternative suppliers and know how production and quality processes of suppliers proceed. It can be inferred that domestic purchasing specialist (expert) recognized that change in experienced employees who manage production, and quality plays an important role in performances of suppliers. Thus, experienced employee turnover is evaluated as third most important criterion.

When selecting suppliers and adding them to supplier pool, it is observed that reputation plays important role; when supplier selection documents of case company are examined, however, its importance gets weaker after it is added to pool as expected. The reason why importance of reputation decreases is that case company does not take other customers of alternative suppliers into consideration, if they are not capable of filling high portion of production capacity of supplier and prevent case company to lead supplier as being biggest customer. Since demands of end customers are subject

to change and mostly accepted by case company, flexibility in urgent orders are evaluated as the seventh most important criteria.

ERP program usage is the least important criterion with a global weight of 0.0034. That shows us that purchasing specialists are not affected by effective ERP program usage of suppliers and suppliers inform them without delays and wrong information although confirmations are subject to change in many cases.

After computing global weights of sub-criteria and scores of alternatives for each sub-criterion, overall scores of suppliers in terms of supplier evaluation problem should be determined. Total scores of alternative suppliers are provided in Table 13.

Table 13 Overall scores of alternative suppliers

Suppliers	**Revenue Rank**	**Overall Scores**
Supplier D	4	0.1765
Supplier A	1	0.1527
Supplier E	5	0.1301
Supplier G	7	0.1189
Supplier B	2	0.1187
Supplier F	6	0.1144
Supplier H	8	0.1004
Supplier C	3	0.0883

When overall scores of alternative suppliers are evaluated, Supplier D which is ranked 4th in delivery revenue is the best supplier in machining field and keen on working with case company. Supplier D outperforms its rivals in main criteria “Quality”, “Delivery”, “Technology” and “Firm Characteristics”, and became 2nd in “Manufacturing Capability”, whereas it is the 3rd least flexible supplier.

Supplier with highest revenue is evaluated as 2nd in overall score as being most flexible supplier. Although its delivery performance is not satisfying, since it is placed as 3rd least performer in main criteria “Delivery”, when case company faced configuration

or delivery changes by its end customers, Supplier A meets subject supplier's demands most of the time, since it is the most flexible supplier.

Supplier C which is 3rd in delivery revenue is evaluated as the worst supplier with being worst performer in main criteria "Delivery", "Technology", "Manufacturing Capability" and "Firm Characteristics". This low level of performance caused Supplier C's delivery revenue to decrease in 2017 comparing to 2016, while revenues of the rest are increasing.

If suppliers are grouped according to their overall scores, Suppliers D and A can be determined as top tier suppliers with highest performances and supply 37.58% of total revenue. Suppliers E, G, B and F whose overall performances are close to each other are involved in mid-tier and have share of 30.95 % of total revenue. Lastly, Suppliers H and C who provide 13.11% of total revenue are the worst performers and are involved in bottom tier. It is seen that performance of suppliers are directly proportional to delivery revenue realized, since top tier suppliers delivers more comparing to bottom tier suppliers in terms of revenue.

4.2. Sensitivity Analysis

Results of proposed AHP method are presented in Section 4.1. However, in order to check robustness of results, values of global weights of sub-criteria are randomly generated for 100 different scenarios between -5% and +5% of final values by using Microsoft Excel's random number generation function. By doing so, we aimed to see whether ranking of suppliers will change. Later, randomly generated global weights are normalized to 1, since sum of all global weights was 1 at the beginning. Normalized forms of randomly generated global weights of 100 different scenarios are given in Appendix G. How final scores of alternative suppliers have changed can be seen in Figure 9. The reason to use boxplot is to see outliers and how overall score data of each suppliers is dispersed among quartiles and minimum and maximum values.

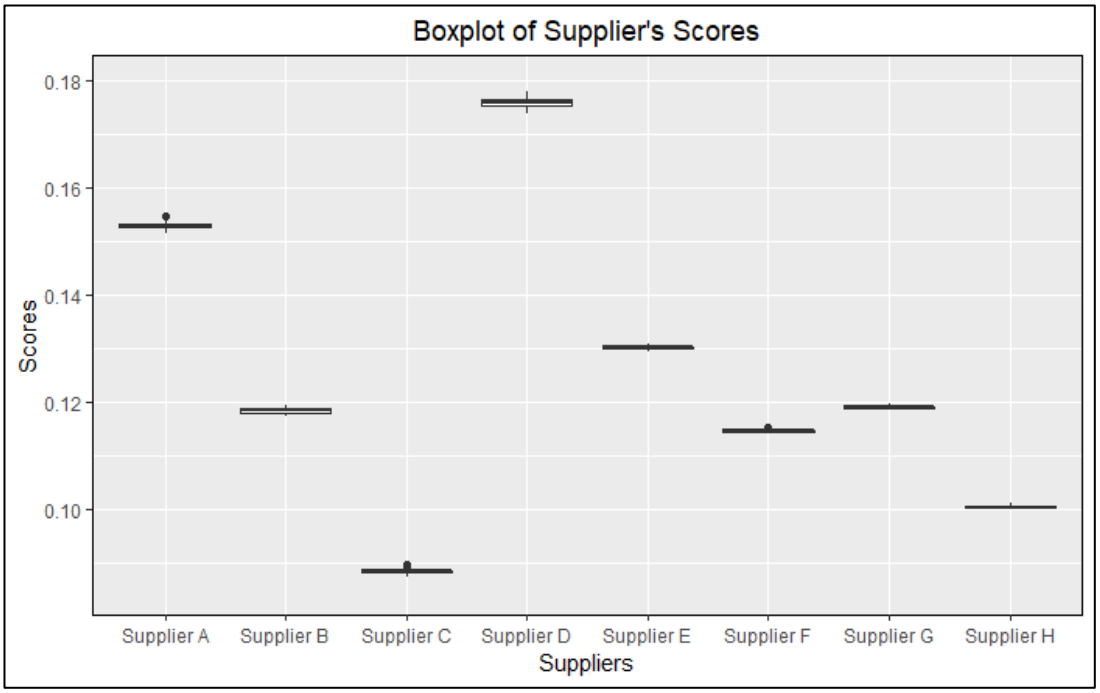

Figure 9 Boxplot of suppliers' scores for 100 scenarios in ±5% interval

It is obvious that no suppliers in different tiers are able to pass to a higher or lower tier. Ranks of suppliers in top and bottom tiers do not change; however, ranks of suppliers in mid-tier change in some scenarios. Supplier G which was 4th according to overall scores became 4th in 78 scenarios, 5th in 22 scenarios. In overall, Supplier G is placed to 4th rank in most cases in accordance to final result. Only ranks of Supplier G and Supplier B have changed according to randomly generated global weights in ±5% interval.

While comparing Supplier B and G, it is seen that minimum and maximum values of Supplier G (0.1184, 0.1197) are larger than those of Supplier B (0.1172, 0.1195). Moreover, median of Supplier B (0.1184) is less than median of Supplier G (0.1190). In parallel with this, mean of Supplier B (0.1184) is less than mean of Supplier G (0.1191). Therefore, Supplier G stayed at its rank at most of the scenarios.

While comparing Supplier B and G, although Supplier G has larger total score, Supplier B is best in terms of manufacturing capability. Supplier B offers larger production capacity to case company with its more experienced employees and

delivers higher quality materials comparing to Supplier G. Also, it is best to choose when there is a probability that documents of a material might change after purchase order is given. However, Supplier B is more flexible in terms of production order change, volume change and urgent orders.

When Figure 9 is examined, it is seen that there are three different outliers shown with thick points which are maximum values of Suppliers A, C, F. The first outlier which belongs to Supplier A occurred in the 49th scenario. It is seen that increase in flexibility in which Supplier A had the best score favors Supplier A. This proves that Supplier A should be preferred even more, since the overall score of Supplier A increased most (0.1546 - 0.1527 = 0.0019) compared to the final results in case of order change in production and occurrence of urgent needs.

The second outlier which appears in boxplot of Supplier C occurred in the 29th scenario. It is again observed in a case where flexibility is given more importance. In this scenario, the most increase happened in overall score of Supplier A like first outlier but is not enough to be an outlier at maximum for Supplier A (0.1544 < 0.1546). Supplier C is the second-best supplier in terms of flexibility, purchase order might be given to it in case of a capacity constraint for Supplier A, since Supplier C is the worst performing supplier in overall.

The last outlier appearing on boxplot of Supplier F occurred in the 30th scenario where experienced employee turnover was given more importance. Some production processes are not easy to apply to materials, although materials' production documents are detailed enough. Some materials are harder to produce and require deeper knowledge about production processes and applying these by machinery. When such a case occurs, Supplier F with its experienced employees which are working in firm for a longer time will be able to produce material appropriately.

Since change in the final results could be more than the first experiment, same process is applied in ±10% interval. Randomly generated global weights of sub-criteria are given in Appendix H. To illustrate how final scores of alternatives are affected, Figure 10 is given below.

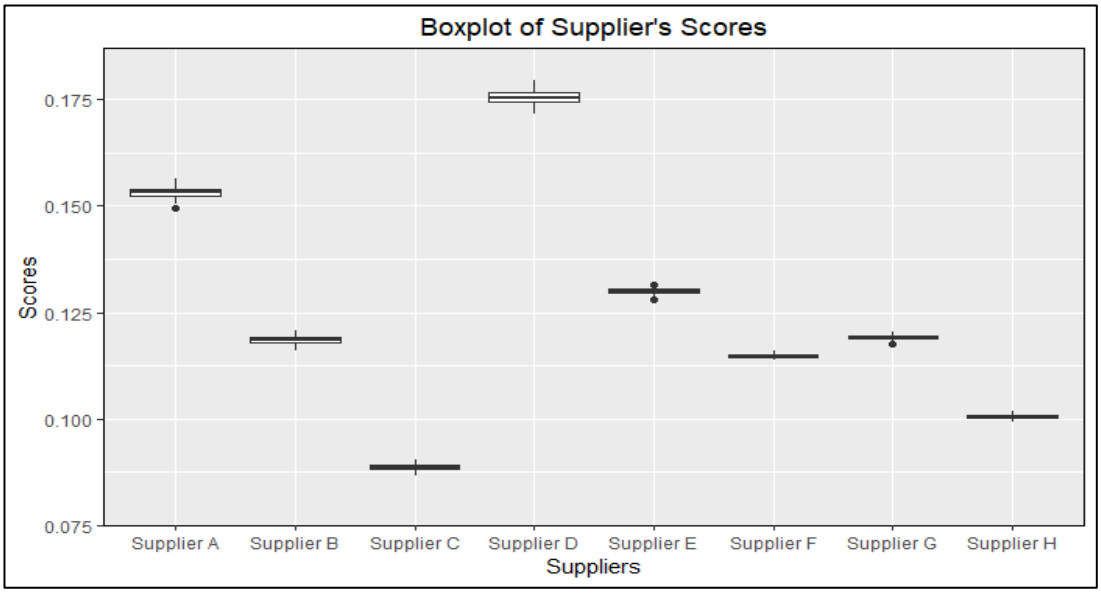

Figure 10 Boxplot of suppliers' scores for 100 scenarios in ±10% interval

It is again observed that suppliers in top and bottom tiers positioned separate than suppliers in mid-tier. Not being different from the first experiment, only intervals of Supplier G and Supplier B's overall scores intersected. Supplier G has scores between 0.1176 and 0.1205, while Supplier B has scores between 0.1161 and 0.1206. Supplier B's maximum score is higher than that of Supplier G and it has a wider range for the scores than that of Supplier G. According to 100 different scenarios, Supplier G stays at its rank for 66 scenarios and is passed by Supplier B and became 5^{th} in 34 scenarios. Supplier F which was 6^{th} in final results is still positioned at the 6^{th} rank, while differences in its scores and Supplier B's are getting smaller.

While comparing Supplier B and G, it is seen that minimum value of Supplier G (0.1176) is larger than Supplier B's (0.1161), whereas maximum values of Supplier G (0.1205) is less than Supplier B's (0.1206). Moreover, median of Supplier B (0.1186) is less than median of Supplier G (0.1191). In parallel with this, mean of Supplier B (0.1186) is less than mean of Supplier G (0.1191). Therefore, Supplier G stayed at its rank at most of the scenarios.

Outliers which appeared as the minimum values of Suppliers A and G and the maximum value of Supplier E occurred in a case where flexibility is less important

and production capacity is more important. Some materials are ordered in higher quantities and with a delivery schedule proper to predetermined lead time of material. In these cases, suppliers should have free production capacity to reserve for case company. Production capacity of Supplier A which had the highest delivery revenue is nearly full all the time. Purchase orders given to Supplier G have exceeded its production capacity, so that its delivery performance is quite low. However, Supplier E which has purchased new machinery and increased its production capacity by 30%, can meet requirements of case company in this case.

The last outlier which is the minimum value of Supplier E occurs in a case where production capacity and delays in confirmed delivery date are given less importance. Case company can order materials which are less in quantity and not depended to a strict contract which delays can occur. In these cases, extra delays might not cause case company to lose reputation against customers.

In order to see whether suppliers in different tiers will pass to higher or lower tiers, same process is operated in ±20% interval for the last experiment. Randomly generated global weights of sub-criteria are provided in Appendix I. In order to see where suppliers' scores lie comparing to each other, boxplots can be seen in Figure 11.

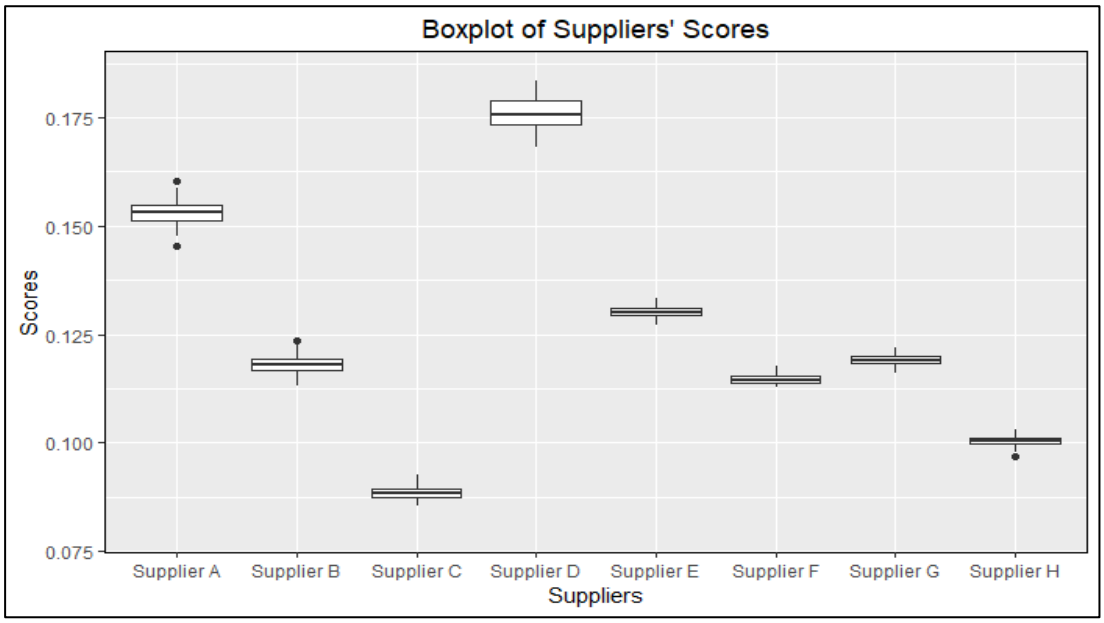

Figure 11 Boxplot of suppliers' scores for 100 scenarios in ±20% interval

Since interval where random numbers are generated got larger, the distance between the 1st and 3rd quartiles have increased for each supplier. Therefore, the width of boxplots has increased. Although difference between maximum and minimum values of sub-criteria's global weights got larger, suppliers are positioned at same tiers. However, as interval width is increasing suppliers in mid-tier which are Suppliers B, E, F and G are getting closer. The minimum and maximum scores for these suppliers are [0.1131, 0.1236], [0.1273, 0.1332], [0.1128, 0.1176] and [0.1161, 0.1220], respectively. Supplier E stayed at its rank for all scenarios conducted in this experiment. Supplier G stays at the 4th rank at 65 scenarios, whereas it is passed by Supplier B by 35 scenarios. Supplier B is positioned in 5th rank at 58 scenarios; however, Supplier F takes its place at 7 scenarios. As interval width has increased, ranks of suppliers have changed more. However, each supplier stays at its original position most of the time.

While comparing Supplier B and G, it is seen that minimum value of Supplier G (0.1161) is larger than Supplier B's (0.1131), whereas maximum values of Supplier G (0.1220) is less than Supplier B's (0.1236). Median of Supplier B (0.1181) is less than median of Supplier G (0.1190). In addition to that mean of Supplier B (0.1182) is less than mean of Supplier G (0.1191). Hence, Supplier G stayed at its rank at most of the scenarios.

Minimum and maximum values of Supplier F (0.1128, 0.1177) are less than Supplier B's (0.1131, 0.1236) and Supplier G's (0.1161, 0.1220). Also, Supplier F has a right skewed distribution, since the distance between minimum value and median of Supplier F (0.0018) is less than the distance between median and maximum value of Supplier G (0.0031). Hence, its mean (0.1147) is larger than its median (0.1146) and both are less than Supplier B and G's. Supplier F was unable to pass Supplier G, however the interval data of Supplier F dispersed overlaps with Supplier B's more comparing to Supplier G's. Therefore, Supplier F is able to pass Supplier B at seven scenarios.

When Supplier B and Supplier F is compared, it is seen that Supplier F had better scores in sub-criteria which are volume flexibility, order change flexibility and flexibility in urgent orders. Although Supplier B had higher total score, Supplier F can present better performance in abovementioned criteria and should be chosen when quantity or time material required is subject to change.

Supplier A which is the last member of top tier has scores between 0.1454 and 0.1604 and is positioned above Suppliers B, E, F and G which are members of mid-tier. Additionally, Supplier H which is 7^{th} in final results, has scores between 0.0970 and 0.1031 and quite far from Supplier F. Therefore, it can be deduced that suppliers at different tiers are positioned far from each other.

Outlier which appears as the maximum value of Supplier A occurred in a case where relationship between supplier and buyer is important due to necessity of flexible production. In line with the occurrence in the first experiment, Supplier A is the best to handle cases which production order should be changed or an urgent order arrives.

Outlier which is the minimum value of Supplier A is caused by production capacity inadequacy of Supplier A. Supplier A has difficulty to deliver materials on time since its capacity is exceeded.

The third outlier which is the maximum value of Supplier B occurs in extreme cases where supplier has to purchase high valued raw materials or invest in machinery to start production. Since Supplier B is best in financial situation, it will be preferred in such a case.

The last outlier is the minimum value of Supplier H which is the second least performing supplier. When a material requiring deeper knowledge in production is ordered, Supplier H is the worst performer, since it cannot keep its experienced employees at firm for long time, hence should not be preferred.

Suppliers in different tiers might also present better performances from each other in some cases. When the last member of top tier which is Supplier A and the first member

of mid-tier which is Supplier E is compared, it is observed that Supplier E is performing better in terms of quality. Therefore, Supplier E should be preferred over Supplier A when quality is the most important criterion of order. Moreover, it has a more stable financial situation. Purchase orders with longer lead times should be given to Supplier E rather than Supplier A. Supplier A should be preferred in any other cases not involving these conditions.

When the last member of mid-tier which is Supplier F is compared to first member of bottom tier which is Supplier H, it is observed that Supplier H delivers material with less defects and should be preferred when quality is the most important criterion. Moreover, past delivery performance of Supplier H is better comparing to Supplier F and therefore, Supplier H should be preferred when getting materials on time is the most important criterion for case company. However, Supplier H is more flexible and should be preferred in case of urgent orders which causes change in production order of supplier.

It can be stated that proposed AHP method is robust, since suppliers did not change their tiers in any scenario in three different experiments. Additionally, suppliers in mid-tier which take each others' positions in different scenarios stay at their original positions at most of the scenarios.

Although distance between possible minimum and maximum values that sub-criteria's global weights can get is enlarged by increasing interval that random numbers are generated from ±5% to ±10% and to ±20% at last, suppliers are positioned at tiers where they were positioned at final results most of the scenarios. It can be inferred that although ranks of some suppliers changed in some cases, it does not affect the results radically and results of proposed AHP method is stated as robust.

According to results which are also checked by sensitivity analysis, case company should give much more importance to suppliers in top tier and improve relationships with them, since these suppliers add most value to supply chain process of machined materials. Suppliers at mid-tier which are positioned closer to each other should be supported by case company to increase their performances, since they provide 30.95%

of total revenue. Replacing them with new suppliers is not achievable in short or midterm. Mid-tier suppliers should be monitored closely and warned if their performances drop and get closer to those of bottom tier suppliers. Bottom tier suppliers cannot perform as well as suppliers in top and mid-tier, however, case company still continues to work with them. These suppliers should be changed in mid-term by adding new suppliers to supplier pool or working with other suppliers which are already in supplier pool more.

CHAPTER 5

DISCUSSIONS AND CONCLUSIONS

All organization whether working in service or production area needs suppliers to provide raw materials or semi-finished goods. Selecting suppliers at first step and giving them purchase orders are not sufficient to build an effective supply chain, although suppliers are selected through criteria which are well-defined and applied by buyer firms. Monitoring suppliers which purchase orders are given to is an important aspect to sustain effective supply chain, since long term relationships are prone to be abused even by high performing suppliers. Therefore, beside a well-organized supplier selection system, buyer firms should design a well-defined and properly working supplier evaluation system. Our study focuses on building an effective and comprehensive supplier evaluation system to monitor suppliers in machining field for a case company.

In our study, we determine main criteria to fully cover the problem and ramify these main criteria to sub-criteria until all aspects of main criteria are taken into consideration. While determining criteria, articles involving case studies realized on both service and manufacturing organizations are examined to define both main criteria and sub-criteria. Additionally, some case specific sub-criteria are incorporated to involve different aspects of chosen work environment. Since quantifiable and non-quantifiable criteria should be dealt with at the same time and evaluation process mostly depend on purchasing specialists' experience and skills, AHP is preferred to construct a supplier evaluation system for case company. Moreover, AHP helps to construct a hierarchical model of supplier evaluation problem and eases the process of comparing and dealing with many criteria at the same time.

In the Case Study section, why main criteria which are quality, delivery, flexibility, technology, manufacturing capability and firm characteristics and their sub-criteria are

chosen in order to evaluate suppliers in machining field of case company is clarified first. Second, rather than evaluating all suppliers which may cause bias due to increasing size of PCM, eight suppliers which delivers the 81.6% of total revenue in machining field are chosen as alternative suppliers. Last, the DM and experts are attained to fill PCMs in main criteria and sub-criteria level based on their expertise. In addition to that, quantitative and qualitative data which are scores of alternative suppliers are gathered by two different methods. Quantitative data belongs to three sub-criteria are collected by taking data out of ERP program established in case company. Quantitative data of seven different sub-criteria are gathered by asking alternative suppliers. In order to deal with qualitative data, PCM which are filled by attained experts.

In the Result section, scores of alternative suppliers for each sub-criterion are computed. Scores based on quantitative data are normalized in order to emphasize weights of main and sub-criteria which are determined by experts. Later, weights are main criteria, local weights of sub-criteria and global weights of sub-criteria are calculated according to PCMs created in Case Study section. Lastly, overall scores of alternative suppliers are calculated and it turns out to that Firm D which is 4^{th} in delivery revenue is best supplier in machining field. Suppliers are grouped in top, mid and bottom tier according to their overall scores. Best three performing suppliers are attained to top tier, second three become members of mid-tier, and worst two performing suppliers joined to bottom tier.

In order to see whether the results of proposed AHP method is robust, sensitivity analysis is applied. Values which are between ±5%, ±10% and ±20% of final values of sub-criteria's global weights are created randomly for three different experiments involving 100 scenarios for each and normalized to one before calculating overall scores of alternative suppliers for 100 different scenarios. It turns out that suppliers are different tiers did not change ranks in any experiments. However, suppliers in mid-tier take positions of each others in different scenarios in each experiment. Suppliers in mid-tier stayed at their positions in most of the scenarios. Therefore, it can be stated that results of proposed AHP method is robust.

In this part of the study, benefits of proposed AHP method over current situation will be stated first. Secondly, theoretical contributions of this study will be stated. Thirdly, Managerial contributions of this study will be explained. Lastly, limitations of this study and future research directions will be explained.

5.1. Benefits of Proposed AHP Method over Current Situation

In current situation, performances of suppliers are not recorded and monitored for most of the criteria determined in this study. Quality and delivery performances of suppliers are checked in every six months; however, trend in performances are not monitored. Therefore, even purchasing specialists cannot know whether suppliers are improving their performances or not. The lack of a system which keeps suppliers' current performances might cause purchasing specialist to give an order to a supplier whose production capacity is already full.

The current system does not enable purchasing specialist to monitor production capacity of suppliers and it is not taken into consideration most of the time. However, in the proposed AHP method, sub-criterion "Production Capacity" is determined as the second most important sub-criterion. This result shows that production capacity of suppliers should be monitored and should be eliminating criteria while inviting suppliers to bids of materials' purchase order. The reason why delivery performances of suppliers are quite low is deduced as lack of supplier production capacity monitoring system. In this case, there are two options to increase total production capacity of suppliers. First is to encourage suppliers to increase their production capacity. Second one is to search for new suppliers which are eligible to work with case company.

Moreover, experienced employee turnover is also crucial and purchasing specialists might inform suppliers about performances of their employees. By doing so, suppliers will have more information about their employees and might be keen on working with good performing ones and might give them incentives. The ones who cannot perform well might be warned or laid off.

When the most important sub-criterion “Relationship” is examined, domestic purchasing chief (DM) stated that building strong relationship with suppliers will increase case company’s flexibility and earnings. By building strong relationships with suppliers, case company is able to convince suppliers to decrease their prices or change their production schedule in short time.

The proposed AHP method which will be used by case company will help new purchasing specialists most. Since recently hired purchasing specialists do not know much about suppliers, performance records of suppliers and short notes attached to them will shorten learning processes of recently hired purchasing specialists. Moreover, they can negotiate with suppliers according to their performances. For example, if a material is needed urgently, then purchasing specialist can give order to supplier with high flexibility and price also should be checked.

Case company organizes events in order to improve relationship with suppliers by inviting suppliers and letting them socialize with its personnel. In these events, good performing suppliers are rewarded with plaques. While deciding good performing suppliers, there is not enough data to support these decisions. By the help of this study and its application, case company will have information of suppliers’ performances and rewarding system will operate fairly. Moreover, some high performing suppliers are chosen as strategic partners of case company. The ranking system will enable case company to evaluate suppliers in a chosen period regularly and will be able to track their performances. Suppliers which are performing well in different fields will be candidate to be chosen as strategic partner of case company.

When final version of this study is shown to the DM and personnel who is responsible from choosing new suppliers from Central Purchasing Directorate, they requested a more comprehensive study including price as main criteria whose whole data will be provided by case company. The proposed AHP method will be used as a tool to evaluate suppliers and considered to be updated every 6 months.

The supplier relationship management system which connects suppliers to case company will involve current performances of suppliers. By doing so, suppliers will

be able to see their current performances and will know which attributes they should improve in order to be evaluated better by case company and hence they might take more purchase orders. It is expected that suppliers which are evaluated well will gain motivation. These suppliers might be keen on increasing their performances and increase their production capacity by more capital investment, since they will consider that case company will give more purchase orders to them according to results of supplier evaluation.

Case company applies internal auditing all around the company. Since purchasing departments are dealing with capital, purchasing activities are more intensely checked. In case of internal auditing, purchasing specialists will have proof about why they gave a purchase order to a supplier, since performances of suppliers would be viewed at the purchase order giving time.

The proposed AHP method will improve purchasing processes of case company and it could be applied to other production fields like sheet metal forming, cable production, bobbin winding or even purchase process of electronic parts which are supplied from abroad. Since this study will exist in case company's institutional memory, it will lead studies in different production fields and be realized in-house.

When proposed supplier evaluation system will be involved automatic web-based platform which will be developed later, updating data required in method periodically will enable purchasing specialists to have information about whether new suppliers are improving themselves or not. For example, new suppliers might not take high points in terms of sub-criterion "Relationship", since they are not used to work with case company. As they take more purchase orders in trial period, they will learn how they should react to case company's requests and will be evaluated better in next evaluation term.

Moreover, purchasing specialists will be able to make risk analysis before giving purchase orders to suppliers by looking at their total evaluation scores or score for a specific criterion which may change according to purchase order condition. By the help of evaluation records, risk of delays will be minimized.

5.2. Updates to Proposed Supplier Evaluation System

By the help of this study, we proposed a well-established and more comprehensive supplier evaluation system. This system will be adopted by case company via developing an automatic web-based platform. However, the decision maker or experts might demand some changes in main criteria, sub-criteria or even alternatives. Moreover, data gathered should also be changed in order to keep system updated. We presented how each of these changes will affect the system and should be adapted to system. For the sake of simplicity, adaptation of changes in main criteria, sub-criteria and alternatives are shown separately. Firstly, the decision maker and experts might demand changes in main criteria. How changes in main criteria will be managed is shown in Figure 12 below.

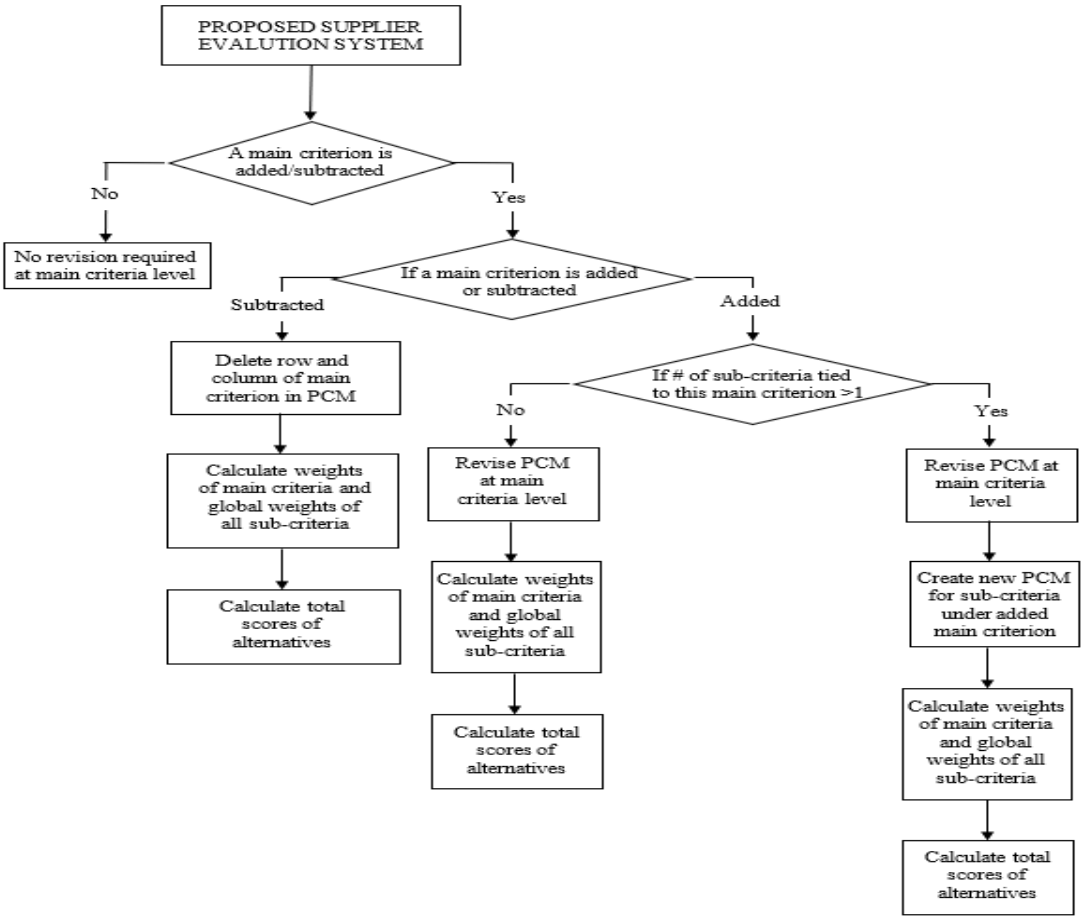

Figure 12 Flowchart of adaptation of changes in main criteria to proposed supplier evaluation system

Additionally, the decision maker and experts might request changes in sub-criteria. How changes in main criteria will be adapted to proposed supplier evaluation system is shown in Figure 13 below.

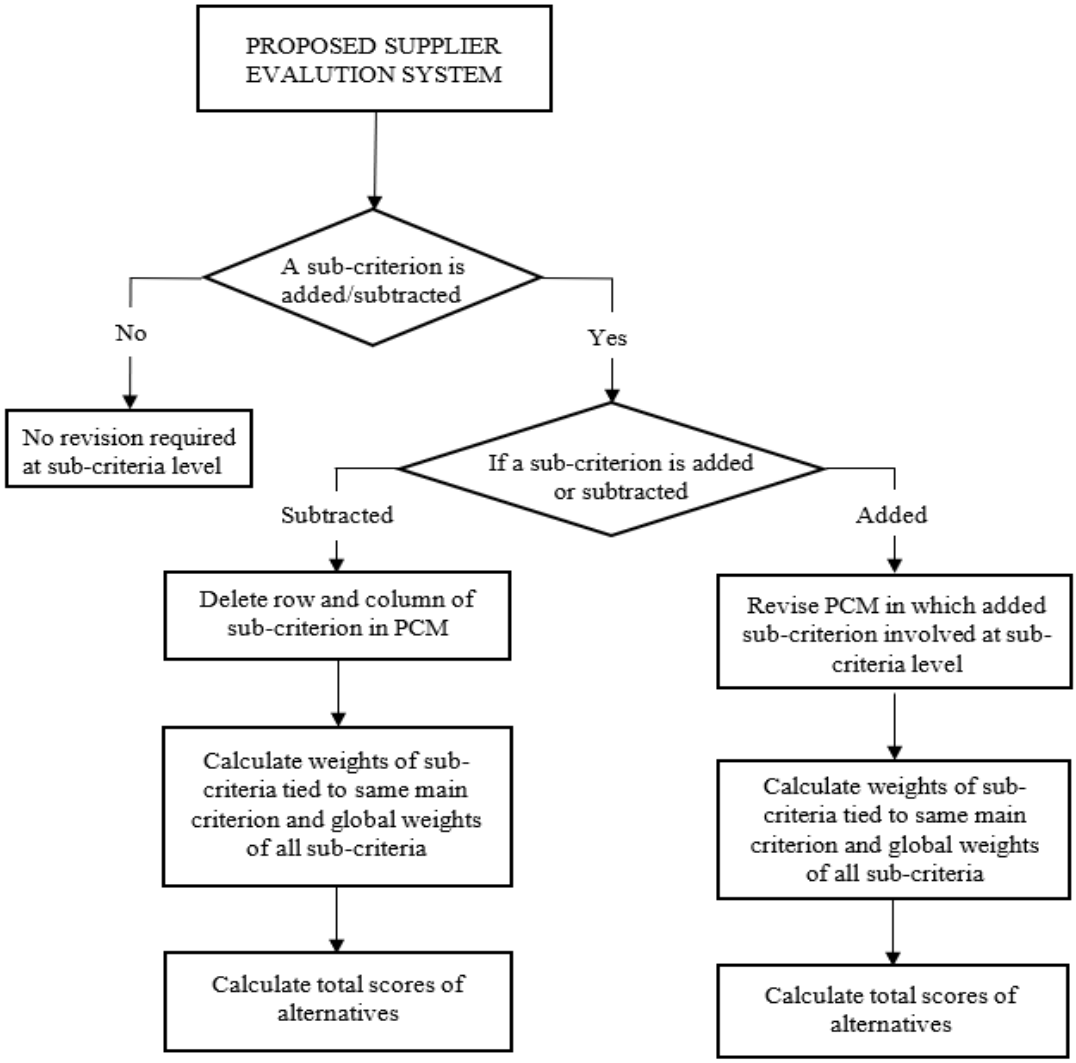

Figure 13 Flowchart of adaptation of changes in sub-criteria to proposed supplier evaluation system

Lastly, alternatives might be requested to be added or subtracted by personnel of case company. In this situation, requested changes will be adapted to proposed supplier evaluation system as shown in Figure 14.

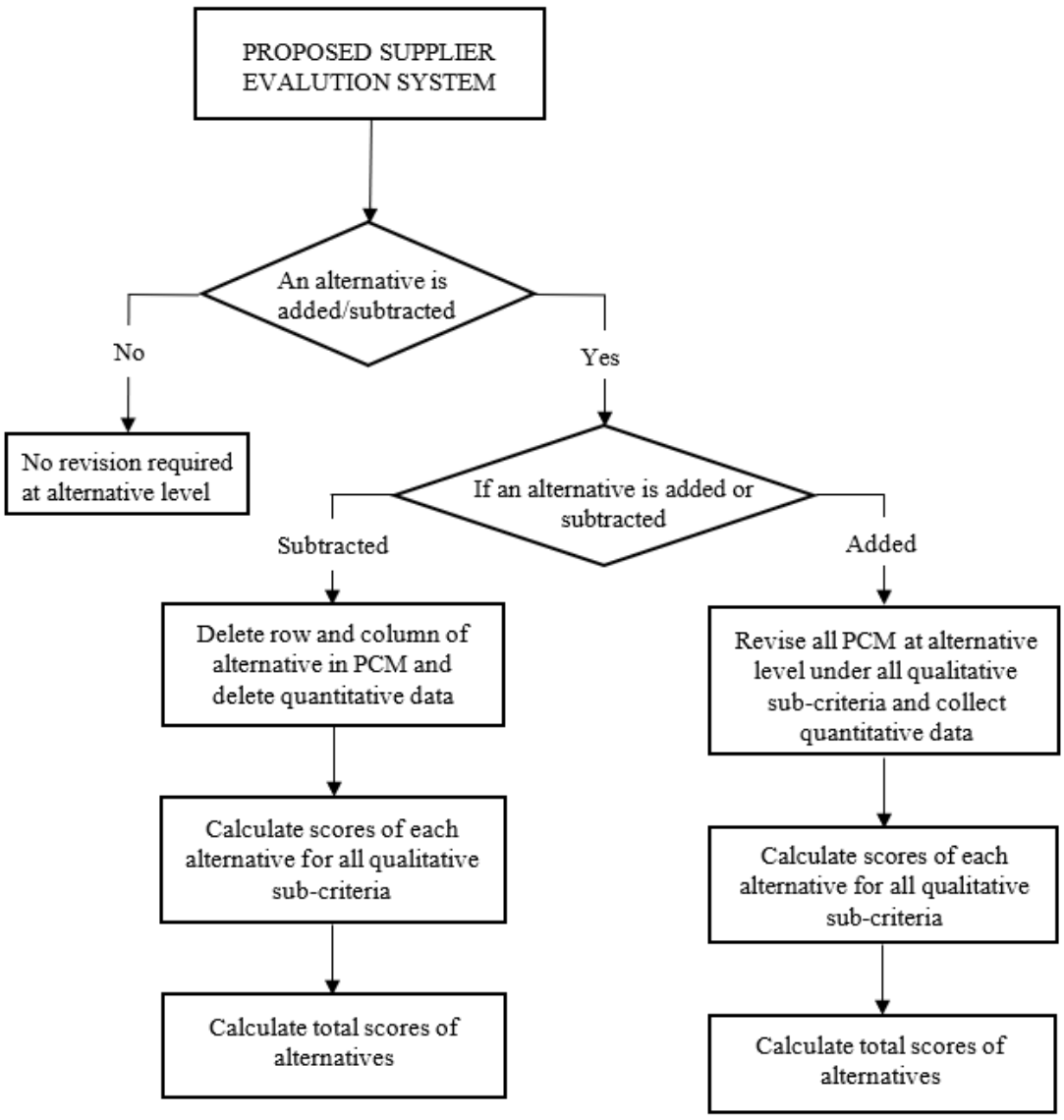

Figure 14 Flowchart of adaptation of changes in alternatives to proposed supplier evaluation system

Besides requesting changes in main criteria, sub-criteria and alternatives, the weights of main criteria, sub-criteria and scores of alternatives might be changed by the decision maker or experts. Moreover, the DM stated that data used to calculate weights of main criteria and sub-criteria in proposed AHP method should be updated every 6 months, if required. Moreover, data used to calculate for scores of alternatives should be changed with recent data to evaluate suppliers better every 6 months. How updating data will affect proposed supplier evaluation system is shown in Figure 15.

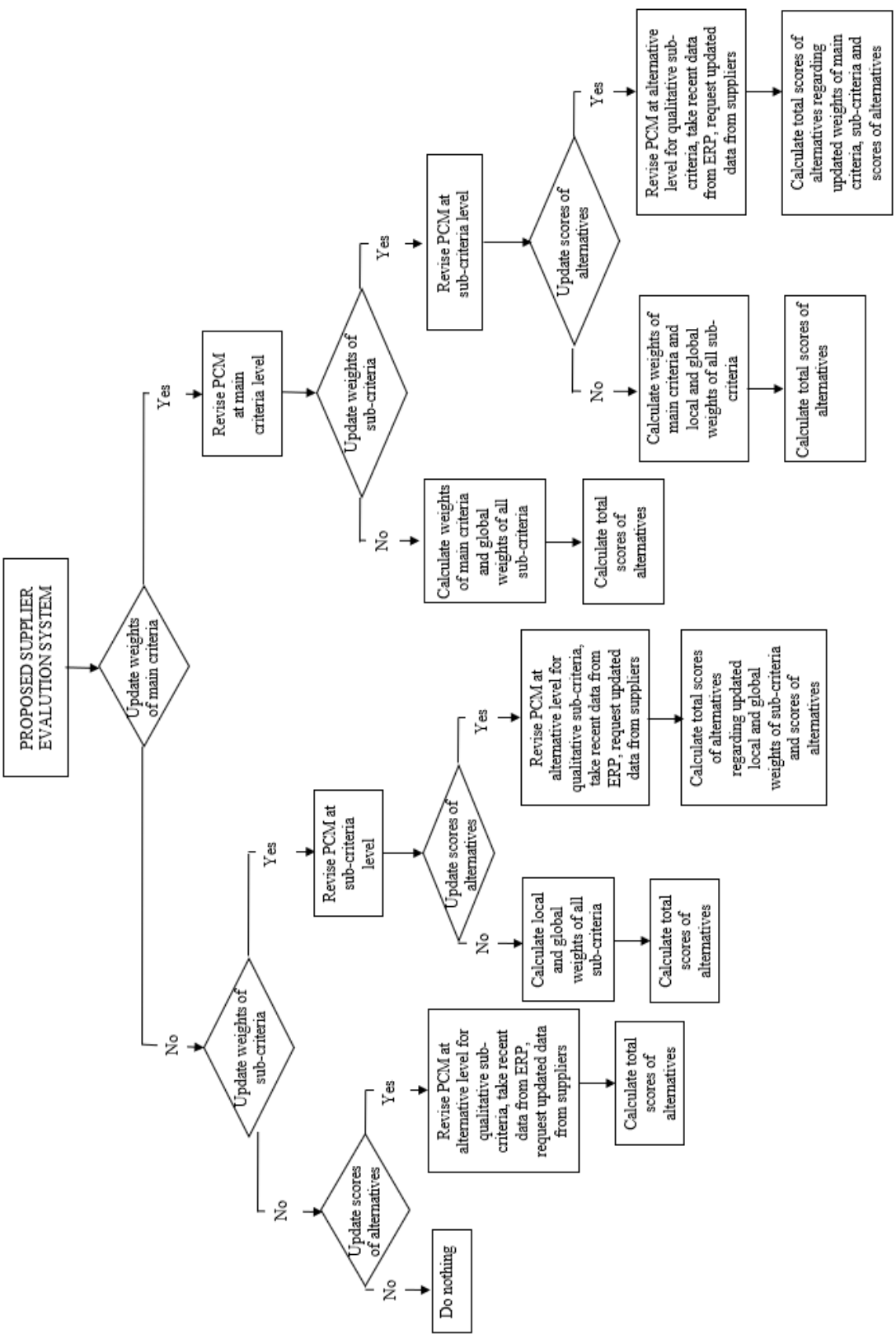

Figure 15 Flowchart of updating data in proposed supplier evaluation system

In order to keep proposed supplier evaluation system updated, data used to calculate scores of alternatives has to be updated in defined intervals. Data involving financial instruments like financial situation and productivity will be updated yearly, since suppliers are preparing their financial statements yearly. Data involving personnel information will be requested yearly from suppliers, since the DM considers that data will be more accurate this way. Because of easiness of taking data out of ERP, data which will be taken out of ERP will be extracted monthly. The summary for data update interval is given in Table 14 below.

Table 14 Update interval of data used to calculate scores of alternatives

Sub-criteria	**Update Interval**	**Data Source**
Conformance Rate at First Audit	Monthly	ERP
Conformance Rate at Production Site	Monthly	ERP
Past Delivery Performance	Monthly	ERP
Number of Quality Personnel	Yearly	Alternative Suppliers
Having Traceability Programs	Semi-annually	Alternative Suppliers
Production Capacity	Semi-annually	Alternative Suppliers
Experienced Employee Turnover	Yearly	Alternative Suppliers
Productivity	Yearly	Alternative Suppliers
Number of Mechanical Engineers and Foremen	Yearly	Alternative Suppliers
Financial Situation	Yearly	Alternative Suppliers
Delays in Confirmed Delivery Date	Semi-annually	Planning Engineer (Expert)
Scrap	Semi-annually	Planning Engineer (Expert)
Volume Flexibility	Semi-annually	Domestic Purchasing Specialist (Expert)

Table 14 (continued)

Modification Flexibility	Semi-annually	Domestic Purchasing Specialist (Expert)
Order Change Flexibility	Semi-annually	Domestic Purchasing Specialist (Expert)
Flexibility in Urgent Orders	Semi-annually	Domestic Purchasing Specialist (Expert)
ERP Program Usage	Semi-annually	Domestic Purchasing Specialist (Expert)
Relationship	Semi-annually	Domestic Purchasing Specialist (Expert)
Reputation	Semi-annually	Domestic Purchasing Specialist (Expert)

For each data update of proposed supplier evaluation system, the DM and experts have to contribute, if they request changes in weights of main criteria, sub-criteria and alternatives. It is measured that creating PCM at main criteria level took 15 minutes approximately. Creating PCMs which varies in size at sub-criteria level took five to ten minutes. PCMs in alternative level are the biggest in size and creating them took 25 minutes. For quantitative data, taking data out of ERP is negligible, since personnel can deal with other works while ERP is operating. Lastly, suppliers send requested data in the same day.

Adding new main criterion or sub-criterion might prolong these durations. A regular data update which will be realized every 6 months will take one man/day approximately.

Adding new main criterion or sub-criterion might increase the accuracy of results, but time required to update data will take longer. However, increase in number of main criteria, sub-criteria and alternatives increases DM and experts' cognitive work and might result decrease in accuracy. DM stated that this extra time required for update is negligible comparing to total purchasing spent in this production field. Therefore, increasing the accuracy of results will be first priority, if possible.

Domestic purchasing chief (the DM) and experts who contributes to proposed supplier evaluation system might change due to rotation in case company or resign from case company. In these conditions, other experienced employees take their places and they

will also be working with these alternatives for many years as a representative of case company. Moreover, these recently assigned employees will have enough knowledge to contribute this system. However, change in decision maker and experts might affect the results of proposed AHP method. In order to see whether results are prone to change, sensitivity analysis is conducted for 40% (±20%) interval. Although ranks of three suppliers changed in some scenarios, no supplier has changed its tier. It is thought that 40% change in global weights of sub-criteria is sufficient to cover possible diversity of decision among different DMs and experts. Additionally, although some criteria are qualitative and based on views of experts, pairwise comparisons for these sub-criteria are realized based on experiences which occurred via phone or mail. Therefore, there is actually evidence to support decisions of experts.

The number of experts might seem limited, however all employees dealing with these processes in quality, purchasing and supplier management departments contributed to this study. Therefore, we used all possible resources to create PCMs and hence evaluate suppliers.

Another threat to validity of this study is suppliers' attitudes while sharing data. However, case company is working with these suppliers more than 10 years and visits them regularly, therefore bias in data sent by suppliers will be recognized by employees of case company easily. Moreover, they will be able to see their scores in all sub-criteria by the help of the feedback system. It is expected that they will give importance to criteria which they are evaluated worse to take more purchase orders from case company. This will lead improvement in suppliers' performances and case company will benefit from this possible situation.

5.3. Managerial Contribution

Our study contributes to case company in different aspects. First is to presenting and detailed examination of supplier evaluation criteria which also includes case specific ones such as ERP program usage and having traceability programs. Current supplier system was only taking quality and delivery into account as evaluation criteria and hence it was limited. Main criteria which are quality, delivery, flexibility,

manufacturing capability, technology and firm specific issues are examined in detail and ramified to 19 sub-criteria and covered all aspects of supplier evaluation process.

Second contribution is that necessary data adopted to calculate alternative suppliers' scores are collected in a rigorous way by gathering information from different sources. Quantitative data is gathered by both the ERP system of the case company and by consulting to alternative suppliers. Scores of alternatives under sub-criteria involving qualitative data is calculated by PCMs which are created by the contributions of experts in case company. In addition to that, weights of main and sub-criteria are determined by verbal expressions of the DM and experts regarding to their expertise and experiences by conducting several interviews. One DM and four different experts in quality, production planning, domestic purchasing and supply chain fields contributed to PCM creation step of AHP in order to calculate scores of sub-criteria involving qualitative data.

Whether the results of proposed AHP method are prone to change is controlled by applying sensitivity analysis. Values which are between ±5%, ±10% and ±20% of final values of sub-criteria's global weights are created by Microsoft Excel's random number generation function for three different experiments involving 100 scenarios for each. These experiments demonstrate that results of proposed AHP method is robust.

Moreover, supplier evaluation system which is developed for suppliers in machining field can be applied to suppliers in different production fields by adopting case specific criteria, if needed.

By adapting proposed supplier evaluation system, case company will be able to make this process transparent, since case company will be able to view current performances of suppliers and declare their performance status to suppliers. This feedback system will enable suppliers to view their weaknesses and encourage them to improve their processes.

An automatic web-based platform involving proposed supplier evaluation process is being developed in-house by case company. This system will automate data handling process and show current performance status of suppliers instantly. Moreover, this automatic web-based platform will work as a decision support system and help purchasing specialists during purchase order giving process and be able to show risk of giving a purchase to a supplier.

5.4. Limitations and Future Research Directions

The comparison of current and proposed supplier evaluation system is realized based on delivery revenues of suppliers comparing to the results of proposed AHP method rather than performance scores of suppliers in current system. The reason behind this is that past data of performance scores are not recorded and hence cannot be found for comparison.

In the current purchase order giving process of case company, price is the most important criteria. However, bids given by each supplier cannot be viewed due to confidentiality issues. If price would be added as a main criterion to proposed AHP method, the results might be affected. Firms with higher revenues might take higher scores, since they must bid the lowest for many purchase orders regarding rules set up by case company.

Another important aspect is that case company cannot view capacity fill rate of suppliers. If current capacity of suppliers should be viewed instantly, it would a sub-criterion to manufacturing capability and affects purchase order giving decision in case of urgency specially.

Some sub-criteria like production capacity and scrap cannot be measured by alternative suppliers since variety and quantity of materials are too high. However, these sub-criteria can be measured in different production fields and adapted to AHP method. By doing so, assumption of producing a specific material to measure production capacity can be eliminated. Limitation to measure scrap can be eliminated by taking data out of ERP program. Moreover, limitation to calculating solidity ratio

which shows long-term stability of firm to measure financial situation can be removed in case of giving long-term purchase orders or declaring long-term forecasts to suppliers.

Another limitation of this study is that formal scales are not developed for qualitative criteria. These criteria are evaluated based on experiences via phone or mail of experts.

In our study, only suppliers in machining field are taken into consideration, since delays in delivery in machining field occurs more than other production or direct purchasing fields. This study can be applied to different production fields which case company purchases material from by adding case specific criteria, if needed. Rather than focusing on specific suppliers, all suppliers can be evaluated in any fields. Not only case company or firms in defense industry, but also firms in different sectors can also adapt this proposed AHP method to their supplier evaluation processes.

In line with suggestions above, we aim to build an effective supplier evaluation system covering all suppliers in supplier pool in all production fields of case company and maximize overall performances of all suppliers. Meetings on integrating proposed supplier evaluation system to supplier relation management module of case company is being discussed and would be realized with the addition of price as main criteria.

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APPENDICES

A. PCMs CREATED IN MAIN CRITERIA LEVEL

Main Criterion: Delivery	Past Delivery Performance	Delays in Confirmed Delivery Date	Scrap
Past Delivery Performance	1	1/7	1/3
Delays in Confirmed Delivery Date	7	1	5
Scrap	3	1/5	1

Main Criterion: Flexibility	Volume Flexibility	Modification Flexibility	Order Change Flexibility	Flexibility in Urgent Orders
Volume Flexibility	1	3	1/5	1/7
Modification Flexibility	1/3	1	1/7	1/9
Order Change Flexibility	5	7	1	1/3
Flexibility in Urgent Orders	7	9	3	1

Main Criterion: Technology	ERP Program Usage	Having Traceability Programs
ERP Program Usage	1	1/7
Having Traceability Programs	7	1

Main Criterion: Manufacturing Capability	Production Capacity	Experienced Employee Turnover	Productivity	Number of Mechanical Engineers and Foremen
Production Capacity	1	1	3	5
Experienced Employee Turnover	1	1	3	5
Productivity	1/3	1/3	1	3
Number of Mechanical Engineers and Foremen	1/5	1/5	1/3	1

Main Criterion: Firm Characteristics	Financial Situation	Relationship	Reputation
Financial Situation	1	1/2	3
Relationship	2	1	5
Reputation	1/3	1/5	1

B. SUPPLIERS' SCORES FOR QUANTITATIVE SUB-CRITERIA

Suppliers/ Sub-Criteria	Conformance Rate at First Audit	Conformance Rate at Production Site	Number of Quality Personnel	Past Delivery Performance	Having Traceability Programs	Production Capacity	Productivity	Experienced Employee Turnover	Number of Mechanical Engineers and Foremen	Financial Position
Supplier A	0.9773	0.9636	3	0.6189	0.5	255000	1.3564	0.4	20	1.8906
Supplier B	0.9709	0.9834	5	0.6755	0.8	300000	1.3727	0.25	34	2.1245
Supplier C	0.9913	0.9709	1	0.5925	0	100000	1.2653	0.5	6	1.5672
Supplier D	0.9829	0.9094	4	0.67	0.9	275000	1.4006	0.2	22	2.0684
Supplier E	0.9938	0.9876	3	0.4607	0.9	230000	1.2503	0.35	21	2.0161
Supplier F	0.9622	0.9162	2	0.7158	0.7	125000	1.2817	0.2	5	1.8481
Supplier G	0.9292	0.9496	2	0.685	0.7	155000	1.3025	0.35	12	1.7305
Supplier H	0.9645	0.9866	2	0.897	1	85000	1.2354	0.3	15	1.6252

C. PCMs CREATED IN SUB-CRITERIA LEVEL

Sub-criterion: Scrap	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Supplier A	1	5	3	7	7	3	3	5
Supplier B	1/5	1	1/3	3	1	1/3	1/3	1
Supplier C	1/3	3	1	5	5	1	1	3
Supplier D	1/7	1/3	1/5	1	1/3	1/5	1/5	1/3
Supplier E	1/7	1	1/5	3	1	1/3	1/5	1
Supplier F	1/3	3	1	5	3	1	1	3
Supplier G	1/3	3	1	5	5	1	1	3
Supplier H	1/5	1	1/3	3	1	1/3	1/3	1

Sub-criterion: Volume Flexibility	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Supplier A	1	5	3	3	5	3	3	9
Supplier B	1/5	1	1/5	1/3	1	1/5	1/5	1
Supplier C	1/3	5	1	3	5	1	1	5
Supplier D	1/3	3	1/3	1	3	1/3	1/5	3
Supplier E	1/5	1	1/5	1/3	1	1/5	1/5	1/3
Supplier F	1/3	5	1	3	5	1	1	5
Supplier G	1/3	5	1	5	5	1	1	5
Supplier H	1/9	1	1/5	1/3	3	1/5	1/5	1

Sub-Criterion: Modification Flexibility	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Supplier A	1	1/5	1/5	1/9	1/5	1/3	1/3	1/5
Supplier B	5	1	3	1/5	1	3	3	1
Supplier C	5	1/3	1	1/7	1/3	1	1	1/3
Supplier D	9	5	7	1	5	7	7	5
Supplier E	5	1	3	1/5	1	3	3	1
Supplier F	3	1/3	1	1/7	1/3	1	1	1/3
Supplier G	3	1/3	1	1/7	1/3	1	1	1/3
Supplier H	5	1	3	1/5	1	3	3	1

Sub-criterion: Order Change Flexibility	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Supplier A	1	9	5	9	7	5	5	7
Supplier B	1/9	1	1/5	3	1/3	1/5	1/5	1
Supplier C	1/5	5	1	7	5	1	1	5
Supplier D	1/9	1/3	1/7	1	1/5	1/7	1/7	1/5
Supplier E	1/7	3	1/5	5	1	1/3	1/3	1
Supplier F	1/5	5	1	7	3	1	1	5
Supplier G	1/5	5	1	7	3	1	1	5
Supplier H	1/7	1	1/5	5	1	1/5	1/5	1

Sub-criterion: Flexibility in Urgent Orders	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Supplier A	1	7	1	5	3	3	3	5
Supplier B	1/7	1	1/5	1	1	1/3	1/3	1
Supplier C	1	5	1	5	3	1	1	3
Supplier D	1/5	1	1/5	1	1/3	1/3	1/3	3
Supplier E	1/3	1	1/3	3	1	1/3	1/3	1
Supplier F	1/3	3	1	3	3	1	1	3
Supplier G	1/3	3	1	3	3	1	1	3
Supplier H	1/5	1	1/3	1/3	1	1/3	1/3	1

Sub-criterion: ERP Program Usage	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Supplier A	1	1/7	1/3	1/9	1/5	1/3	1/3	1/7
Supplier B	7	1	5	1/3	3	5	3	1
Supplier C	3	1/5	1	1/5	1	1	1	1/3
Supplier D	9	3	5	1	5	5	5	3
Supplier E	5	1/3	1	1/5	1	1	3	1
Supplier F	3	1/5	1	1/5	1	1	1	1/5
Supplier G	3	1/3	1	1/5	1/3	1	1	1/5
Supplier H	7	1	3	1/3	1	5	5	1

Sub-criterion: Relationship	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Supplier A	1	1/7	1/3	1/9	1/5	1/3	1/3	1/7
Supplier B	7	1	5	1/3	3	5	3	1
Supplier C	3	1/5	1	1/5	1	1	1	1/3
Supplier D	9	3	5	1	5	5	5	3
Supplier E	5	1/3	1	1/5	1	1	3	1
Supplier F	3	1/5	1	1/5	1	1	1	1/5
Supplier G	3	1/3	1	1/5	1/3	1	1	1/5
Supplier H	7	1	3	1/3	1	5	5	1

Sub-criterion: Reputation	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Supplier A	1	1/5	1/3	1/7	1/5	1/3	1/3	1/3
Supplier B	5	1	3	1/3	1	3	3	5
Supplier C	3	1/3	1	1/5	1/5	1/3	1/3	1
Supplier D	7	3	5	1	3	3	3	5
Supplier E	5	1	5	1/3	1	5	5	6
Supplier F	3	1/3	3	1/3	1/5	1	1	3
Supplier G	3	1/3	3	1/3	1/5	1	1	3
Supplier H	3	1/5	1	1/5	1/6	1/3	1/3	1

D. SCORES OF ALTERNATIVES IN QUALITATIVE SUB-CRITERIA

Sub-Criterion/ Supplier	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Delays in Confirmed Delivery Date	0.0285	0.1417	0.0321	0.3441	0.1905	0.1048	0.054	0.1044
Scrap	0.3417	0.0584	0.1578	0.0277	0.051	0.1471	0.1578	0.0584
Volume Flexibility	0.3154	0.0358	0.1602	0.0788	0.033	0.1602	0.1758	0.0408
Modification Flexibility	0.0237	0.1281	0.0587	0.4296	0.1281	0.0518	0.0518	0.1281
Order Change Flexibility	0.4129	0.0349	0.1508	0.0191	0.0588	0.1386	0.1386	0.0465
Flexibility in Urgent Orders	0.287	0.0473	0.195	0.0564	0.069	0.1484	0.1484	0.0487
ERP Program Usage	0.0993	0.1407	0.0844	0.1228	0.1101	0.1351	0.1089	0.1986
Relationship	0.1903	0.0349	0.0517	0.2361	0.1261	0.0912	0.1671	0.1025
Reputation	0.0281	0.1726	0.0488	0.3026	0.2252	0.0885	0.0885	0.0455

E. CONSISTENCY RATIOS FOR PCM IN ALTERNATIVE SUPPLIER LEVEL

Sub-Criterion/Supplier	Consistency Ratio
Scrap	0.023
Volume Flexibility	0.0493
Modification Flexibility	0.0298
Order Change Flexibility	0.0616
Flexibility in Urgent Orders	0.0444
ERP Program Usage	0.0415
Relationship	0.0571
Reputation	0.0601

F. NORMALIZED FORM OF ALTERNATIVES' SCORES UNDER QUANTITATIVE SUB-CRITERIA

Sub-Criterion/ Supplier	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G	Supplier H
Conformance Rate at First Audit	0.1257	0.1249	0.1276	0.1265	0.1279	0.1238	0.1196	0.1241
Conformance Rate at Production Site	0.1257	0.1283	0.1266	0.1186	0.1288	0.1195	0.1239	0.1287
Number of Quality Personnel	0.0993	0.1407	0.0844	0.1228	0.1101	0.1351	0.1089	0.1986
Past Delivery Performance	0.1164	0.1271	0.1115	0.126	0.0867	0.1347	0.1289	0.1688
Having Traceability Programs	0.0909	0.1455	0	0.1636	0.1636	0.1273	0.1273	0.1818
Production Capacity	0.1672	0.1967	0.0656	0.1803	0.1508	0.082	0.1016	0.0557
Experienced Employee Turnover	0.1101	0.1376	0.0917	0.1468	0.1193	0.1468	0.1193	0.1284
Productivity	0.1296	0.1312	0.1209	0.1338	0.1195	0.1225	0.1245	0.1181
Number of Mechanical Engineers and Foremen	0.1094	0.1581	0.0837	0.1116	0.1273	0.0558	0.108	0.2461
Financial Situation	0.1271	0.1429	0.1054	0.1391	0.1356	0.1243	0.1164	0.1093

G. RANDOMLY GENERATED GLOBAL WEIGHTS OF SUB-CRITERIA IN ±5% INTERVAL

Sub-criteria/Scenarios	Final Results	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Relationship	0.145	0.147	0.139	0.142	0.152	0.14	0.141	0.14	0.147	0.14	0.144	0.144	0.151	0.149	0.141	0.146	0.143	0.139	0.147	0.139	0.14
Production Capacity	0.14	0.138	0.14	0.144	0.134	0.144	0.14	0.144	0.135	0.146	0.142	0.142	0.139	0.141	0.145	0.141	0.136	0.146	0.139	0.146	0.143
Experienced Employee Turnover	0.14	0.137	0.142	0.138	0.136	0.141	0.148	0.146	0.14	0.14	0.145	0.142	0.135	0.136	0.145	0.138	0.137	0.136	0.144	0.134	0.134
Delays in Confirmed Delivery Date	0.126	0.129	0.128	0.122	0.129	0.126	0.129	0.122	0.128	0.122	0.122	0.126	0.131	0.126	0.127	0.131	0.123	0.123	0.127	0.13	0.129
Financial Situation	0.077	0.073	0.075	0.077	0.078	0.076	0.076	0.075	0.074	0.079	0.079	0.077	0.078	0.075	0.075	0.08	0.082	0.076	0.079	0.079	0.081
Flexibility in Urgent Orders	0.07	0.071	0.07	0.069	0.069	0.07	0.07	0.071	0.07	0.071	0.07	0.069	0.067	0.071	0.069	0.068	0.075	0.073	0.071	0.073	0.069
Productivity	0.055	0.057	0.058	0.056	0.054	0.053	0.053	0.054	0.057	0.055	0.056	0.056	0.053	0.056	0.055	0.052	0.057	0.058	0.054	0.053	0.056
Conformance Rate at First Audit	0.049	0.05	0.05	0.051	0.048	0.051	0.048	0.051	0.049	0.05	0.047	0.048	0.05	0.047	0.047	0.048	0.048	0.048	0.049	0.05	0.052
Order Change Flexibility	0.036	0.037	0.035	0.036	0.037	0.037	0.036	0.035	0.037	0.036	0.036	0.034	0.038	0.037	0.036	0.036	0.035	0.035	0.034	0.035	0.037
Scrap	0.034	0.032	0.035	0.035	0.033	0.034	0.033	0.033	0.034	0.034	0.033	0.034	0.032	0.034	0.035	0.034	0.035	0.035	0.031	0.034	0.033
Reputation	0.027	0.028	0.026	0.029	0.028	0.029	0.028	0.027	0.029	0.027	0.027	0.026	0.027	0.028	0.028	0.027	0.029	0.029	0.027	0.028	0.026
Number of Mechanical Engineers and Foremen	0.025	0.024	0.026	0.025	0.026	0.024	0.024	0.025	0.025	0.026	0.024	0.025	0.026	0.024	0.024	0.024	0.026	0.026	0.024	0.026	0.025
Having Traceability Programs	0.024	0.024	0.023	0.025	0.024	0.023	0.023	0.024	0.024	0.023	0.024	0.024	0.023	0.025	0.024	0.022	0.023	0.023	0.023	0.024	0.024
Past Delivery Performance	0.015	0.015	0.015	0.014	0.014	0.015	0.014	0.015	0.015	0.015	0.014	0.015	0.014	0.015	0.014	0.014	0.014	0.015	0.015	0.015	0.015
Conformance Rate at Production Site	0.012	0.012	0.012	0.012	0.012	0.012	0.011	0.012	0.012	0.011	0.012	0.012	0.012	0.011	0.011	0.012	0.012	0.012	0.011	0.011	0.012
Volume Flexibility	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.011	0.011	0.01	0.011	0.012	0.011	0.011	0.011	0.011
Modification Flexibility	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.006	0.005	0.005	0.006	0.006	0.005	0.006	0.005
Number of Quality Personnel	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.005	0.006	0.005	0.006	0.006	0.005	0.005	0.005	0.006
ERP Program Usage	0.003	0.003	0.003	0.004	0.003	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004

Table G (continued)

Sub-criteria/Scenarios	Final Results	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Relationship	0.145	0.148	0.148	0.15	0.148	0.146	0.15	0.146	0.147	0.14	0.139	0.151	0.14	0.148	0.149	0.142	0.147	0.147	0.143	0.15	0.149
Production Capacity	0.14	0.144	0.139	0.141	0.142	0.139	0.136	0.136	0.141	0.139	0.134	0.133	0.136	0.142	0.139	0.141	0.141	0.139	0.138	0.137	0.145
Experienced Employee Turnover	0.14	0.134	0.135	0.133	0.137	0.141	0.138	0.136	0.146	0.138	0.144	0.135	0.146	0.145	0.139	0.145	0.133	0.143	0.141	0.135	0.138
Delays in Confirmed Delivery Date	0.126	0.127	0.125	0.131	0.129	0.13	0.13	0.13	0.122	0.123	0.125	0.128	0.131	0.121	0.13	0.126	0.128	0.122	0.127	0.13	0.126
Financial Situation	0.077	0.079	0.078	0.079	0.077	0.077	0.078	0.077	0.08	0.078	0.077	0.079	0.077	0.08	0.078	0.078	0.074	0.078	0.077	0.08	0.077
Flexibility in Urgent Orders	0.07	0.07	0.071	0.07	0.071	0.073	0.07	0.07	0.067	0.074	0.073	0.074	0.07	0.069	0.067	0.069	0.072	0.071	0.07	0.072	0.068
Productivity	0.055	0.054	0.057	0.054	0.054	0.055	0.056	0.057	0.053	0.055	0.057	0.055	0.053	0.052	0.055	0.053	0.057	0.056	0.057	0.055	0.053
Conformance Rate at First Audit	0.049	0.05	0.05	0.049	0.049	0.047	0.049	0.048	0.049	0.052	0.05	0.049	0.05	0.048	0.048	0.05	0.05	0.047	0.049	0.047	0.049
Order Change Flexibility	0.036	0.034	0.035	0.034	0.035	0.037	0.034	0.035	0.036	0.038	0.037	0.036	0.036	0.034	0.034	0.035	0.037	0.035	0.036	0.036	0.035
Scrap	0.034	0.033	0.034	0.035	0.033	0.032	0.034	0.033	0.032	0.035	0.034	0.032	0.034	0.034	0.034	0.035	0.034	0.035	0.035	0.033	0.035
Reputation	0.027	0.027	0.028	0.027	0.026	0.028	0.026	0.028	0.027	0.028	0.029	0.028	0.027	0.026	0.028	0.027	0.026	0.026	0.028	0.028	0.027
Number of Mechanical Engineers and Foremen	0.025	0.023	0.026	0.026	0.025	0.024	0.025	0.026	0.025	0.024	0.024	0.025	0.024	0.026	0.024	0.025	0.025	0.025	0.025	0.024	0.025
Having Traceability Programs	0.024	0.024	0.023	0.023	0.023	0.022	0.024	0.025	0.023	0.023	0.024	0.023	0.024	0.024	0.023	0.024	0.024	0.024	0.024	0.023	0.022
Past Delivery Performance	0.015	0.015	0.015	0.014	0.014	0.014	0.015	0.015	0.014	0.015	0.014	0.015	0.015	0.015	0.015	0.014	0.015	0.015	0.014	0.014	0.015
Conformance Rate at Production Site	0.012	0.012	0.012	0.012	0.011	0.011	0.011	0.012	0.011	0.012	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Volume Flexibility	0.011	0.011	0.011	0.011	0.012	0.01	0.011	0.011	0.011	0.012	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.011	0.011	0.011	0.01
Modification Flexibility	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.006	0.006	0.006	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005
Number of Quality Personnel	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005
ERP Program Usage	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.004	0.003	0.003

Table G (continued)

Sub-criteria/Scenarios	Final Results	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Relationship	0.145	0.147	0.15	0.149	0.148	0.148	0.15	0.151	0.149	0.146	0.141	0.149	0.149	0.147	0.142	0.148	0.139	0.152	0.14	0.151	0.145
Production Capacity	0.14	0.141	0.137	0.144	0.144	0.143	0.144	0.134	0.144	0.143	0.139	0.137	0.139	0.142	0.142	0.138	0.147	0.144	0.141	0.136	0.14
Experienced Employee Turnover	0.14	0.135	0.141	0.14	0.134	0.141	0.133	0.142	0.137	0.143	0.136	0.135	0.14	0.144	0.139	0.136	0.145	0.138	0.144	0.136	0.14
Delays in Confirmed Delivery Date	0.126	0.13	0.125	0.126	0.126	0.123	0.13	0.12	0.125	0.121	0.133	0.129	0.132	0.127	0.125	0.125	0.125	0.121	0.123	0.131	0.13
Financial Situation	0.077	0.074	0.076	0.073	0.078	0.078	0.078	0.079	0.076	0.075	0.077	0.078	0.077	0.078	0.079	0.081	0.074	0.079	0.075	0.077	0.079
Flexibility in Urgent Orders	0.07	0.074	0.073	0.069	0.072	0.069	0.071	0.069	0.069	0.073	0.071	0.073	0.068	0.066	0.07	0.073	0.07	0.067	0.072	0.068	0.072
Productivity	0.055	0.054	0.057	0.055	0.056	0.055	0.054	0.057	0.055	0.056	0.056	0.054	0.054	0.052	0.056	0.055	0.055	0.055	0.055	0.056	0.055
Conformance Rate at First Audit	0.049	0.048	0.048	0.047	0.047	0.048	0.048	0.05	0.05	0.047	0.05	0.047	0.047	0.047	0.048	0.047	0.049	0.047	0.05	0.048	0.049
Order Change Flexibility	0.036	0.036	0.035	0.036	0.034	0.036	0.034	0.036	0.035	0.037	0.035	0.036	0.034	0.035	0.037	0.036	0.036	0.036	0.036	0.035	0.034
Scrap	0.034	0.033	0.032	0.033	0.032	0.034	0.032	0.032	0.034	0.034	0.033	0.033	0.032	0.033	0.033	0.034	0.034	0.033	0.034	0.035	0.033
Reputation	0.027	0.028	0.028	0.028	0.028	0.026	0.027	0.028	0.028	0.026	0.027	0.028	0.028	0.028	0.028	0.028	0.026	0.027	0.027	0.026	0.026
Number of Mechanical Engineers and Foremen	0.025	0.024	0.024	0.024	0.025	0.025	0.024	0.026	0.025	0.025	0.026	0.025	0.025	0.025	0.024	0.024	0.024	0.024	0.026	0.024	0.023
Having Traceability Programs	0.024	0.025	0.022	0.025	0.024	0.022	0.023	0.023	0.023	0.023	0.024	0.024	0.023	0.024	0.023	0.023	0.023	0.024	0.023	0.024	0.023
Past Delivery Performance	0.015	0.014	0.015	0.014	0.014	0.015	0.014	0.014	0.015	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.015	0.015	0.015	0.014	0.014
Conformance Rate at Production Site	0.012	0.012	0.012	0.012	0.012	0.012	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.013	0.012	0.012	0.012	0.011
Volume Flexibility	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.011	0.011	0.01
Modification Flexibility	0.005	0.006	0.006	0.006	0.005	0.005	0.006	0.006	0.006	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.005
Number of Quality Personnel	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.006
ERP Program Usage	0.003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,004	0,003	0,003	0,004	0,004	0,003	0,003

Table G (continued)

Sub-criteria/Scenarios	Final Results	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Relationship	0.145	0.144	0.144	0.141	0.148	0.148	0.146	0.147	0.142	0.136	0.144	0.146	0.151	0.143	0.149	0.15	0.146	0.141	0.151	0.15	0.145
Production Capacity	0.14	0.138	0.145	0.146	0.136	0.135	0.143	0.134	0.138	0.144	0.134	0.138	0.133	0.144	0.138	0.146	0.141	0.143	0.136	0.14	0.142
Experienced Employee Turnover	0.14	0.138	0.141	0.142	0.136	0.139	0.134	0.14	0.137	0.141	0.14	0.137	0.133	0.142	0.136	0.139	0.137	0.144	0.137	0.135	0.139
Delays in Confirmed Delivery Date	0.126	0.128	0.127	0.123	0.129	0.128	0.129	0.127	0.128	0.125	0.129	0.124	0.131	0.125	0.131	0.121	0.128	0.12	0.122	0.131	0.126
Financial Situation	0.077	0.08	0.076	0.074	0.077	0.075	0.078	0.077	0.079	0.077	0.079	0.078	0.078	0.074	0.076	0.081	0.074	0.073	0.081	0.076	0.078
Flexibility in Urgent Orders	0.07	0.069	0.069	0.071	0.074	0.07	0.07	0.07	0.074	0.073	0.07	0.071	0.07	0.068	0.069	0.067	0.07	0.073	0.068	0.069	0.072
Productivity	0.055	0.054	0.054	0.057	0.055	0.057	0.054	0.055	0.053	0.056	0.054	0.055	0.057	0.054	0.055	0.056	0.057	0.057	0.056	0.058	0.054
Conformance Rate at First Audit	0.049	0.051	0.048	0.05	0.048	0.05	0.05	0.048	0.051	0.051	0.05	0.049	0.049	0.048	0.051	0.047	0.051	0.049	0.052	0.047	0.051
Order Change Flexibility	0.036	0.036	0.036	0.035	0.035	0.035	0.035	0.035	0.035	0.036	0.037	0.036	0.037	0.038	0.034	0.034	0.035	0.037	0.034	0.035	0.035
Scrap	0.034	0.033	0.035	0.035	0.033	0.033	0.033	0.034	0.034	0.034	0.035	0.035	0.033	0.035	0.033	0.032	0.034	0.033	0.034	0.032	0.033
Reputation	0.027	0.027	0.027	0.027	0.027	0.028	0.028	0.028	0.028	0.027	0.027	0.029	0.027	0.028	0.026	0.027	0.026	0.028	0.026	0.026	0.028
Number of Mechanical Engineers and Foremen	0.025	0.025	0.024	0.024	0.024	0.025	0.025	0.026	0.025	0.024	0.024	0.025	0.026	0.024	0.025	0.024	0.024	0.026	0.026	0.025	0.023
Having Traceability Programs	0.024	0.024	0.023	0.024	0.024	0.025	0.023	0.025	0.024	0.024	0.024	0.024	0.023	0.023	0.023	0.025	0.024	0.023	0.025	0.024	0.024
Past Delivery Performance	0.015	0.014	0.015	0.014	0.014	0.015	0.014	0.015	0.014	0.015	0.014	0.015	0.014	0.015	0.015	0.014	0.014	0.014	0.014	0.015	0.014
Conformance Rate at Production Site	0.012	0.012	0.012	0.012	0.013	0.012	0.011	0.012	0.012	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.011
Volume Flexibility	0.011	0.012	0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.012	0.011	0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.011
Modification Flexibility	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.005	0.006	0.005	0.006
Number of Quality Personnel	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.005	0.005
ERP Program Usage	0.003	0,003	0,003	0,004	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,004	0,003	0,004

Table G (continued)

Sub-criteria/Scenarios	Final Results	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Relationship	0.145	0.14	0.14	0.143	0.14	0.151	0.147	0.147	0.148	0.138	0.148	0.148	0.147	0.151	0.141	0.145	0.149	0.141	0.151	0.14	0.145
Production Capacity	0.14	0.141	0.144	0.145	0.14	0.142	0.141	0.141	0.136	0.145	0.138	0.145	0.143	0.136	0.138	0.146	0.134	0.137	0.138	0.14	0.136
Experienced Employee Turnover	0.14	0.145	0.136	0.141	0.14	0.139	0.141	0.141	0.145	0.14	0.135	0.136	0.136	0.142	0.138	0.134	0.135	0.139	0.137	0.145	0.141
Delays in Confirmed Delivery Date	0.126	0.122	0.129	0.131	0.13	0.121	0.127	0.123	0.123	0.128	0.126	0.122	0.125	0.124	0.13	0.125	0.129	0.125	0.125	0.129	0.123
Financial Situation	0.077	0.079	0.076	0.076	0.08	0.08	0.076	0.078	0.073	0.078	0.079	0.077	0.078	0.077	0.08	0.08	0.08	0.08	0.078	0.077	0.079
Flexibility in Urgent Orders	0.07	0.069	0.068	0.069	0.07	0.068	0.07	0.073	0.073	0.072	0.07	0.072	0.068	0.071	0.071	0.07	0.07	0.073	0.068	0.073	0.074
Productivity	0.055	0.057	0.055	0.052	0.057	0.058	0.054	0.052	0.057	0.053	0.057	0.054	0.056	0.057	0.056	0.055	0.055	0.056	0.056	0.053	0.057
Conformance Rate at First Audit	0.049	0.048	0.052	0.047	0.047	0.047	0.048	0.048	0.049	0.051	0.051	0.048	0.051	0.049	0.049	0.048	0.049	0.048	0.048	0.048	0.047
Order Change Flexibility	0.036	0.036	0.038	0.037	0.037	0.037	0.035	0.037	0.035	0.037	0.036	0.036	0.035	0.035	0.036	0.037	0.037	0.037	0.037	0.035	0.036
Scrap	0.034	0.034	0.035	0.033	0.033	0.034	0.033	0.033	0.035	0.033	0.033	0.035	0.034	0.032	0.033	0.032	0.033	0.033	0.033	0.033	0.033
Reputation	0.027	0.027	0.027	0.027	0.026	0.026	0.027	0.027	0.026	0.026	0.027	0.028	0.028	0.028	0.027	0.027	0.027	0.028	0.028	0.028	0.026
Number of Mechanical Engineers and Foremen	0.025	0.025	0.025	0.023	0.024	0.025	0.026	0.024	0.024	0.024	0.026	0.025	0.025	0.025	0.026	0.025	0.025	0.024	0.024	0.024	0.026
Having Traceability Programs	0.024	0.025	0.024	0.024	0.024	0.023	0.023	0.023	0.024	0.024	0.023	0.024	0.023	0.024	0.024	0.023	0.024	0.025	0.024	0.023	0.024
Past Delivery Performance	0.015	0.014	0.014	0.014	0.015	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.014	0.014	0.014	0.015	0.015	0.015	0.015	0.014	0.014
Conformance Rate at Production Site	0.012	0.012	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.011	0.012	0.012	0.012	0.011	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Volume Flexibility	0.011	0.011	0.012	0.011	0.011	0.011	0.012	0.011	0.011	0.012	0.011	0.01	0.011	0.011	0.012	0.012	0.011	0.011	0.011	0.011	0.011
Modification Flexibility	0.005	0.005	0.006	0.006	0.005	0.006	0.006	0.006	0.005	0.005	0.006	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005
Number of Quality Personnel	0.005	0.006	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.005
ERP Program Usage	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003

H. RANDOMLY GENERATED GLOBAL WEIGHTS OF SUB-CRITERIA IN ±10% INTERVAL

Sub-criteria/Scenarios	Final Results	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Relationship	0.145	0.147	0.131	0.149	0.156	0.145	0.15	0.14	0.148	0.141	0.145	0.153	0.142	0.146	0.158	0.147	0.141	0.148	0.135	0.148	0.153
Production Capacity	0.14	0.144	0.149	0.147	0.148	0.13	0.139	0.133	0.138	0.138	0.138	0.134	0.146	0.149	0.145	0.137	0.138	0.129	0.132	0.145	0.138
Experienced Employee Turnover	0.14	0.143	0.148	0.147	0.144	0.149	0.143	0.14	0.149	0.135	0.135	0.133	0.149	0.134	0.14	0.131	0.15	0.148	0.142	0.133	0.125
Delays in Confirmed Delivery Date	0.126	0.129	0.122	0.127	0.114	0.114	0.119	0.127	0.117	0.135	0.134	0.138	0.121	0.127	0.113	0.116	0.128	0.129	0.129	0.118	0.133
Financial Situation	0.077	0.069	0.083	0.074	0.079	0.074	0.077	0.078	0.082	0.082	0.078	0.08	0.075	0.068	0.077	0.084	0.074	0.078	0.083	0.08	0.08
Flexibility in Urgent Orders	0.07	0.073	0.071	0.067	0.065	0.075	0.074	0.069	0.074	0.07	0.068	0.064	0.073	0.073	0.076	0.074	0.073	0.069	0.075	0.067	0.069
Productivity	0.055	0.059	0.052	0.056	0.051	0.055	0.055	0.061	0.056	0.055	0.053	0.056	0.051	0.056	0.054	0.056	0.051	0.055	0.056	0.06	0.058
Conformance Rate at First Audit	0.049	0.046	0.053	0.049	0.048	0.054	0.046	0.053	0.048	0.047	0.049	0.045	0.049	0.047	0.047	0.054	0.049	0.05	0.047	0.052	0.043
Order Change Flexibility	0.036	0.035	0.035	0.031	0.037	0.038	0.034	0.038	0.035	0.034	0.038	0.035	0.035	0.038	0.033	0.039	0.037	0.032	0.034	0.036	0.037
Scrap	0.034	0.032	0.032	0.031	0.032	0.037	0.033	0.033	0.034	0.035	0.036	0.036	0.035	0.034	0.03	0.035	0.031	0.034	0.035	0.032	0.034
Reputation	0.027	0.028	0.027	0.028	0.027	0.025	0.028	0.025	0.025	0.028	0.025	0.027	0.028	0.029	0.026	0.026	0.027	0.027	0.029	0.028	0.028
Number of Mechanical Engineers and Foremen	0.025	0.023	0.023	0.023	0.025	0.024	0.024	0.027	0.022	0.025	0.025	0.025	0.026	0.024	0.024	0.026	0.024	0.026	0.027	0.024	0.025
Having Traceability Programs	0.024	0.023	0.023	0.021	0.023	0.026	0.025	0.023	0.025	0.025	0.024	0.025	0.021	0.024	0.025	0.022	0.025	0.023	0.023	0.024	0.024
Past Delivery Performance	0.015	0.014	0.015	0.014	0.014	0.016	0.013	0.015	0.013	0.014	0.015	0.013	0.013	0.014	0.014	0.015	0.015	0.014	0.016	0.014	0.015
Conformance Rate at Production Site	0.012	0.011	0.011	0.011	0.011	0.012	0.013	0.012	0.013	0.011	0.011	0.011	0.011	0.012	0.012	0.013	0.012	0.012	0.012	0.012	0.012
Volume Flexibility	0.011	0.011	0.011	0.011	0.012	0.012	0.011	0.012	0.01	0.011	0.012	0.01	0.011	0.01	0.012	0.012	0.012	0.011	0.012	0.011	0.012
Modification Flexibility	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.006	0.006	0.005	0.005	0.005	0.006	0.005	0.006
Number of Quality Personnel	0.005	0.006	0.005	0.005	0.006	0.005	0.006	0.006	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.005
ERP Program Usage	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003

Table H (continued)

Sub-criteria/Scenarios	Final Results	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Relationship	0.145	0.136	0.148	0.137	0.151	0.148	0.151	0.142	0.147	0.15	0.152	0.147	0.139	0.15	0.143	0.149	0.149	0.138	0.146	0.14	0.143
Production Capacity	0.14	0.139	0.131	0.147	0.129	0.145	0.145	0.127	0.137	0.136	0.131	0.135	0.142	0.142	0.149	0.135	0.143	0.15	0.139	0.154	0.154
Experienced Employee Turnover	0.14	0.153	0.151	0.131	0.147	0.14	0.14	0.151	0.13	0.133	0.128	0.147	0.15	0.127	0.128	0.149	0.138	0.136	0.145	0.134	0.134
Delays in Confirmed Delivery Date	0.126	0.129	0.125	0.123	0.131	0.124	0.129	0.129	0.135	0.122	0.139	0.12	0.13	0.123	0.123	0.123	0.125	0.134	0.127	0.117	0.117
Financial Situation	0.077	0.073	0.083	0.076	0.075	0.071	0.072	0.082	0.078	0.081	0.082	0.084	0.071	0.081	0.073	0.078	0.078	0.071	0.077	0.083	0.084
Flexibility in Urgent Orders	0.07	0.071	0.068	0.074	0.076	0.074	0.064	0.069	0.072	0.073	0.064	0.068	0.064	0.074	0.077	0.066	0.065	0.072	0.073	0.064	0.068
Productivity	0.055	0.054	0.053	0.054	0.054	0.059	0.054	0.052	0.057	0.061	0.052	0.054	0.058	0.055	0.052	0.059	0.053	0.058	0.054	0.057	0.051
Conformance Rate at First Audit	0.049	0.053	0.048	0.049	0.05	0.044	0.046	0.047	0.05	0.048	0.047	0.048	0.049	0.05	0.052	0.044	0.052	0.053	0.044	0.055	0.05
Order Change Flexibility	0.036	0.034	0.037	0.038	0.036	0.035	0.035	0.036	0.036	0.034	0.039	0.036	0.037	0.036	0.035	0.037	0.033	0.033	0.037	0.036	0.034
Scrap	0.034	0.034	0.032	0.035	0.031	0.033	0.036	0.034	0.036	0.035	0.032	0.035	0.035	0.036	0.034	0.034	0.032	0.032	0.034	0.031	0.034
Reputation	0.027	0.026	0.027	0.029	0.025	0.025	0.027	0.029	0.026	0.029	0.03	0.029	0.028	0.027	0.027	0.027	0.029	0.028	0.026	0.027	0.028
Number of Mechanical Engineers and Foremen	0.025	0.024	0.023	0.026	0.023	0.026	0.027	0.027	0.025	0.023	0.025	0.024	0.024	0.026	0.027	0.024	0.025	0.027	0.025	0.027	0.026
Having Traceability Programs	0.024	0.022	0.024	0.025	0.023	0.022	0.024	0.025	0.023	0.025	0.025	0.023	0.021	0.024	0.026	0.024	0.025	0.021	0.023	0.022	0.022
Past Delivery Performance	0.015	0.014	0.015	0.016	0.015	0.016	0.014	0.013	0.015	0.014	0.015	0.013	0.015	0.015	0.014	0.015	0.013	0.013	0.014	0.015	0.016
Conformance Rate at Production Site	0.012	0.011	0.011	0.012	0.011	0.012	0.013	0.012	0.011	0.012	0.013	0.012	0.011	0.012	0.012	0.013	0.013	0.011	0.011	0.012	0.013
Volume Flexibility	0.011	0.012	0.011	0.012	0.01	0.012	0.011	0.011	0.01	0.011	0.011	0.011	0.011	0.01	0.012	0.01	0.012	0.011	0.011	0.011	0.011
Modification Flexibility	0.005	0.006	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006
Number of Quality Personnel	0.005	0.006	0.005	0.006	0.005	0.005	0.006	0.006	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.006	0.006	0.005	0.006	0.005
ERP Program Usage	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.004	0.003

Table H (continued)

Sub-criteria/Scenarios	Final Results	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Relationship	0.145	0.14	0.135	0.15	0.148	0.136	0.156	0.137	0.149	0.139	0.135	0.148	0.143	0.141	0.138	0.132	0.144	0.14	0.137	0.138	0.139
Production Capacity	0.14	0.148	0.137	0.143	0.142	0.146	0.147	0.13	0.144	0.151	0.149	0.131	0.142	0.137	0.142	0.148	0.144	0.129	0.136	0.148	0.149
Experienced Employee Turnover	0.14	0.134	0.142	0.139	0.141	0.144	0.131	0.151	0.132	0.132	0.152	0.151	0.136	0.146	0.133	0.149	0.14	0.148	0.151	0.128	0.141
Delays in Confirmed Delivery Date	0.126	0.127	0.119	0.131	0.125	0.135	0.118	0.121	0.129	0.121	0.117	0.135	0.124	0.131	0.125	0.124	0.122	0.136	0.134	0.13	0.117
Financial Situation	0.077	0.076	0.085	0.075	0.083	0.07	0.075	0.081	0.072	0.073	0.074	0.073	0.084	0.076	0.082	0.073	0.078	0.07	0.07	0.071	0.077
Flexibility in Urgent Orders	0.07	0.065	0.078	0.071	0.067	0.066	0.076	0.071	0.073	0.077	0.075	0.07	0.069	0.065	0.074	0.074	0.066	0.075	0.067	0.07	0.066
Productivity	0.055	0.057	0.057	0.051	0.058	0.054	0.053	0.055	0.057	0.05	0.057	0.051	0.053	0.059	0.058	0.059	0.06	0.055	0.056	0.057	0.062
Conformance Rate at First Audit	0.049	0.05	0.046	0.05	0.047	0.053	0.049	0.051	0.05	0.05	0.049	0.045	0.054	0.049	0.046	0.048	0.049	0.05	0.047	0.053	0.051
Order Change Flexibility	0.036	0.039	0.038	0.036	0.033	0.033	0.039	0.039	0.036	0.039	0.036	0.037	0.034	0.033	0.04	0.038	0.039	0.034	0.036	0.04	0.037
Scrap	0.034	0.035	0.032	0.031	0.031	0.031	0.031	0.031	0.033	0.036	0.03	0.035	0.034	0.035	0.034	0.033	0.032	0.031	0.034	0.037	0.033
Reputation	0.027	0.025	0.028	0.027	0.025	0.03	0.026	0.029	0.027	0.029	0.028	0.029	0.027	0.025	0.026	0.026	0.027	0.029	0.029	0.029	0.027
Number of Mechanical Engineers and Foremen	0.025	0.027	0.028	0.022	0.024	0.025	0.022	0.026	0.023	0.026	0.024	0.024	0.023	0.027	0.027	0.024	0.026	0.024	0.024	0.026	0.026
Having Traceability Programs	0.024	0.025	0.023	0.023	0.023	0.024	0.024	0.025	0.026	0.026	0.022	0.021	0.025	0.023	0.022	0.021	0.023	0.024	0.026	0.023	0.023
Past Delivery Performance	0.015	0.014	0.014	0.014	0.014	0.015	0.016	0.013	0.014	0.014	0.013	0.013	0.014	0.016	0.014	0.013	0.013	0.015	0.016	0.015	0.016
Conformance Rate at Production Site	0.012	0.012	0.012	0.011	0.012	0.012	0.011	0.013	0.011	0.012	0.011	0.013	0.012	0.012	0.012	0.013	0.012	0.012	0.011	0.012	0.012
Volume Flexibility	0.011	0.012	0.011	0.01	0.01	0.012	0.012	0.011	0.011	0.011	0.01	0.011	0.012	0.011	0.012	0.011	0.011	0.011	0.011	0.01	0.012
Modification Flexibility	0.005	0.006	0.006	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.006	0.006	0.006	0.005	0.006
Number of Quality Personnel	0.005	0.005	0.006	0.005	0.006	0.006	0.005	0.006	0.006	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.005	0.006	0.005	0.005	0.005
ERP Program Usage	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.004	0.004	0.003	0.004	0.004	0.004	0.003	0.004	0.003	0.003

Table H (continued)

Sub-criteria/Scenarios	Final Results	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Relationship	0.145	0.153	0.149	0.134	0.152	0.152	0.139	0.142	0.136	0.138	0.134	0.144	0.136	0.139	0.145	0.156	0.139	0.151	0.146	0.147	0.136
Production Capacity	0.14	0.139	0.151	0.129	0.127	0.144	0.151	0.139	0.133	0.142	0.15	0.137	0.142	0.142	0.143	0.129	0.145	0.151	0.137	0.136	0.152
Experienced Employee Turnover	0.14	0.135	0.136	0.15	0.131	0.134	0.147	0.141	0.15	0.146	0.133	0.133	0.141	0.145	0.136	0.145	0.135	0.128	0.138	0.145	0.149
Delays in Confirmed Delivery Date	0.126	0.13	0.126	0.125	0.127	0.126	0.123	0.114	0.132	0.133	0.126	0.127	0.13	0.134	0.118	0.128	0.133	0.115	0.118	0.125	0.119
Financial Situation	0.077	0.081	0.069	0.081	0.075	0.08	0.072	0.084	0.083	0.074	0.076	0.074	0.073	0.069	0.078	0.072	0.079	0.081	0.084	0.076	0.069
Flexibility in Urgent Orders	0.07	0.066	0.071	0.076	0.072	0.071	0.073	0.071	0.073	0.065	0.077	0.078	0.069	0.074	0.07	0.072	0.072	0.068	0.068	0.067	0.071
Productivity	0.055	0.053	0.056	0.06	0.055	0.056	0.051	0.058	0.05	0.053	0.059	0.059	0.057	0.058	0.058	0.052	0.054	0.061	0.056	0.051	0.059
Conformance Rate at First Audit	0.049	0.045	0.05	0.049	0.054	0.047	0.044	0.052	0.05	0.047	0.052	0.052	0.053	0.045	0.052	0.05	0.045	0.049	0.049	0.051	0.049
Order Change Flexibility	0.036	0.035	0.033	0.037	0.038	0.037	0.037	0.036	0.034	0.035	0.034	0.035	0.037	0.035	0.039	0.036	0.035	0.034	0.038	0.036	0.034
Scrap	0.034	0.031	0.031	0.035	0.036	0.032	0.034	0.03	0.033	0.037	0.035	0.032	0.036	0.033	0.031	0.036	0.034	0.031	0.037	0.035	0.034
Reputation	0.027	0.029	0.027	0.025	0.03	0.024	0.028	0.03	0.025	0.027	0.026	0.029	0.027	0.028	0.026	0.026	0.027	0.027	0.026	0.029	0.03
Number of Mechanical Engineers and Foremen	0.025	0.027	0.027	0.026	0.025	0.022	0.026	0.027	0.025	0.027	0.024	0.024	0.024	0.023	0.026	0.025	0.026	0.025	0.025	0.023	0.026
Having Traceability Programs	0.024	0.025	0.021	0.022	0.025	0.024	0.022	0.024	0.025	0.024	0.024	0.024	0.024	0.021	0.026	0.022	0.024	0.026	0.025	0.025	0.024
Past Delivery Performance	0.015	0.014	0.015	0.016	0.015	0.015	0.016	0.015	0.015	0.015	0.015	0.015	0.014	0.015	0.016	0.015	0.014	0.014	0.015	0.016	0.015
Conformance Rate at Production Site	0.012	0.013	0.011	0.011	0.012	0.011	0.012	0.011	0.011	0.011	0.011	0.012	0.012	0.012	0.011	0.011	0.012	0.011	0.013	0.013	0.011
Volume Flexibility	0.011	0.011	0.01	0.011	0.011	0.01	0.01	0.011	0.01	0.012	0.01	0.011	0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.012	0.01
Modification Flexibility	0.005	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.006	0.005	0.006	0.006	0.005
Number of Quality Personnel	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005
ERP Program Usage	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.004	0.003	0.003	0.003

Table H (continued)

Sub-criteria/Scenarios	Final Results	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Relationship	0.145	0.145	0.15	0.166	0.151	0.139	0.131	0.157	0.135	0.143	0.131	0.159	0.137	0.156	0.14	0.148	0.146	0.14	0.137	0.145	0.134
Production Capacity	0.14	0.15	0.138	0.132	0.143	0.14	0.15	0.13	0.141	0.14	0.135	0.136	0.148	0.148	0.139	0.146	0.151	0.13	0.134	0.133	0.148
Experienced Employee Turnover	0.14	0.14	0.134	0.132	0.13	0.148	0.136	0.126	0.136	0.146	0.15	0.139	0.136	0.139	0.139	0.134	0.134	0.152	0.142	0.131	0.149
Delays in Confirmed Delivery Date	0.126	0.115	0.131	0.125	0.122	0.116	0.119	0.136	0.12	0.117	0.13	0.123	0.135	0.116	0.123	0.12	0.117	0.123	0.12	0.131	0.121
Financial Situation	0.077	0.082	0.076	0.075	0.078	0.082	0.081	0.081	0.084	0.082	0.078	0.076	0.079	0.072	0.078	0.084	0.081	0.077	0.077	0.081	0.081
Flexibility in Urgent Orders	0.07	0.072	0.075	0.07	0.068	0.069	0.075	0.074	0.075	0.074	0.072	0.071	0.07	0.072	0.077	0.064	0.065	0.075	0.071	0.074	0.065
Productivity	0.055	0.053	0.056	0.055	0.052	0.056	0.055	0.055	0.061	0.054	0.059	0.054	0.054	0.052	0.059	0.059	0.057	0.054	0.061	0.055	0.059
Conformance Rate at First Audit	0.049	0.047	0.046	0.048	0.051	0.05	0.049	0.049	0.047	0.044	0.049	0.047	0.05	0.044	0.047	0.046	0.052	0.046	0.049	0.052	0.048
Order Change Flexibility	0.036	0.034	0.034	0.035	0.038	0.037	0.036	0.034	0.037	0.039	0.039	0.036	0.035	0.035	0.034	0.036	0.038	0.036	0.041	0.037	0.033
Scrap	0.034	0.033	0.032	0.032	0.034	0.032	0.036	0.032	0.036	0.034	0.033	0.032	0.031	0.036	0.036	0.035	0.032	0.033	0.034	0.036	0.036
Reputation	0.027	0.027	0.025	0.027	0.029	0.026	0.029	0.027	0.028	0.025	0.025	0.029	0.026	0.026	0.026	0.029	0.029	0.029	0.026	0.027	0.028
Number of Mechanical Engineers and Foremen	0.025	0.025	0.026	0.026	0.026	0.024	0.025	0.024	0.027	0.025	0.027	0.024	0.025	0.027	0.027	0.026	0.023	0.025	0.027	0.026	0.024
Having Traceability Programs	0.024	0.022	0.021	0.026	0.026	0.026	0.026	0.025	0.023	0.023	0.022	0.022	0.023	0.025	0.023	0.025	0.025	0.026	0.025	0.022	0.025
Past Delivery Performance	0.015	0.015	0.016	0.014	0.016	0.016	0.014	0.015	0.015	0.015	0.013	0.013	0.014	0.013	0.014	0.013	0.013	0.016	0.016	0.015	0.014
Conformance Rate at Production Site	0.012	0.013	0.011	0.011	0.011	0.013	0.013	0.011	0.012	0.012	0.013	0.011	0.012	0.013	0.012	0.011	0.011	0.013	0.012	0.012	0.011
Volume Flexibility	0.011	0.012	0.012	0.011	0.012	0.012	0.011	0.01	0.011	0.012	0.011	0.012	0.011	0.012	0.012	0.011	0.011	0.011	0.012	0.01	0.011
Modification Flexibility	0.005	0.005	0.006	0.005	0.005	0.006	0.006	0.005	0.006	0.006	0.005	0.006	0.006	0.006	0.006	0.005	0.006	0.005	0.006	0.005	0.005
Number of Quality Personnel	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.006	0.006	0.005	0.005	0.006	0.006	0.006	0.006	0.005	0.005
ERP Program Usage	0.003	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003

I. RANDOMLY GENERATED GLOBAL WEIGHTS OF SUB-CRITERIA IN ±20% INTERVAL

Sub-criteria/Scenarios	Final Results	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Relationship	0.145	0.141	0.139	0.136	0.125	0.14	0.159	0.138	0.141	0.152	0.125	0.16	0.148	0.162	0.123	0.13	0.138	0.128	0.15	0.167	0.144
Production Capacity	0.14	0.139	0.144	0.123	0.139	0.126	0.152	0.131	0.163	0.112	0.155	0.147	0.151	0.156	0.138	0.129	0.155	0.156	0.156	0.151	0.12
Experienced Employee Turnover	0.14	0.117	0.118	0.158	0.14	0.145	0.141	0.13	0.116	0.15	0.176	0.131	0.122	0.124	0.151	0.151	0.114	0.159	0.124	0.129	0.15
Delays in Confirmed Delivery Date	0.126	0.15	0.137	0.128	0.131	0.112	0.138	0.146	0.131	0.117	0.106	0.14	0.116	0.125	0.124	0.132	0.127	0.111	0.129	0.134	0.149
Financial Situation	0.077	0.064	0.091	0.072	0.084	0.089	0.073	0.08	0.068	0.086	0.074	0.077	0.09	0.065	0.088	0.084	0.081	0.071	0.079	0.068	0.066
Flexibility in Urgent Orders	0.07	0.083	0.059	0.057	0.078	0.067	0.065	0.077	0.082	0.074	0.062	0.07	0.061	0.072	0.078	0.08	0.078	0.073	0.077	0.066	0.075
Productivity	0.055	0.048	0.06	0.063	0.051	0.058	0.051	0.054	0.049	0.06	0.047	0.054	0.057	0.059	0.056	0.048	0.059	0.051	0.059	0.046	0.059
Conformance Rate at First Audit	0.049	0.053	0.048	0.055	0.053	0.055	0.04	0.049	0.041	0.055	0.046	0.041	0.045	0.049	0.044	0.052	0.057	0.045	0.041	0.042	0.044
Order Change Flexibility	0.036	0.037	0.034	0.038	0.029	0.035	0.031	0.037	0.041	0.038	0.044	0.028	0.042	0.031	0.041	0.032	0.041	0.04	0.031	0.038	0.03
Scrap	0.034	0.034	0.04	0.034	0.037	0.041	0.034	0.028	0.04	0.036	0.03	0.03	0.038	0.037	0.033	0.034	0.028	0.029	0.037	0.031	0.042
Reputation	0.027	0.033	0.031	0.03	0.029	0.026	0.023	0.03	0.028	0.025	0.033	0.029	0.03	0.022	0.026	0.027	0.03	0.034	0.023	0.029	0.023
Number of Mechanical Engineers and Foremen	0.025	0.023	0.029	0.025	0.023	0.027	0.024	0.028	0.025	0.025	0.021	0.025	0.023	0.021	0.023	0.03	0.022	0.022	0.021	0.027	0.022
Having Traceability Programs	0.024	0.026	0.019	0.025	0.025	0.026	0.019	0.024	0.024	0.018	0.024	0.02	0.024	0.026	0.023	0.02	0.023	0.027	0.021	0.023	0.023
Past Delivery Performance	0.015	0.015	0.014	0.016	0.013	0.015	0.015	0.012	0.012	0.012	0.016	0.011	0.016	0.015	0.017	0.013	0.012	0.015	0.016	0.012	0.014
Conformance Rate at Production Site	0.012	0.01	0.01	0.012	0.013	0.011	0.011	0.012	0.012	0.013	0.012	0.011	0.013	0.011	0.011	0.012	0.012	0.014	0.01	0.013	0.013
Volume Flexibility	0.011	0.011	0.011	0.012	0.012	0.011	0.012	0.012	0.013	0.012	0.013	0.009	0.01	0.01	0.012	0.012	0.009	0.011	0.012	0.011	0.011
Modification Flexibility	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.006	0.006	0.007	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.006	0.005	0.006
Number of Quality Personnel	0.005	0.006	0.005	0.006	0.006	0.007	0.005	0.004	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.004	0.006	0.005
ERP Program Usage	0.003	0.004	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.003	0.004	0.004	0.003	0.003	0.004	0.004	0.003	0.003	0.003

Table I (continued)

Sub-criteria/Scenarios	Final Results	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Relationship	0.145	0.12	0.143	0.126	0.157	0.159	0.166	0.135	0.155	0.17	0.147	0.124	0.17	0.149	0.144	0.133	0.158	0.159	0.133	0.134	0.147
Production Capacity	0.14	0.126	0.126	0.135	0.149	0.136	0.161	0.122	0.146	0.13	0.119	0.129	0.138	0.111	0.133	0.153	0.141	0.123	0.152	0.126	0.155
Experienced Employee Turnover	0.14	0.127	0.132	0.132	0.142	0.124	0.14	0.129	0.128	0.141	0.148	0.159	0.138	0.152	0.136	0.115	0.12	0.121	0.123	0.142	0.13
Delays in Confirmed Delivery Date	0.126	0.154	0.127	0.148	0.137	0.149	0.107	0.15	0.125	0.124	0.105	0.118	0.107	0.125	0.136	0.15	0.144	0.135	0.139	0.123	0.139
Financial Situation	0.077	0.086	0.095	0.089	0.074	0.073	0.071	0.094	0.062	0.074	0.09	0.09	0.087	0.088	0.066	0.074	0.074	0.066	0.065	0.086	0.065
Flexibility in Urgent Orders	0.07	0.083	0.061	0.078	0.061	0.082	0.073	0.071	0.073	0.068	0.077	0.063	0.077	0.07	0.063	0.064	0.073	0.076	0.081	0.072	0.067
Productivity	0.055	0.054	0.068	0.059	0.049	0.045	0.048	0.057	0.061	0.051	0.062	0.062	0.051	0.053	0.066	0.062	0.051	0.061	0.058	0.05	0.05
Conformance Rate at First Audit	0.049	0.052	0.049	0.051	0.05	0.042	0.049	0.051	0.054	0.05	0.057	0.048	0.048	0.049	0.056	0.043	0.048	0.043	0.056	0.054	0.053
Order Change Flexibility	0.036	0.036	0.033	0.037	0.037	0.035	0.03	0.034	0.031	0.032	0.033	0.035	0.028	0.037	0.033	0.041	0.036	0.044	0.034	0.039	0.028
Scrap	0.034	0.033	0.038	0.027	0.036	0.03	0.031	0.029	0.032	0.031	0.031	0.035	0.028	0.039	0.034	0.029	0.035	0.029	0.035	0.036	0.037
Reputation	0.027	0.032	0.025	0.023	0.022	0.024	0.023	0.027	0.032	0.031	0.024	0.028	0.029	0.027	0.032	0.027	0.022	0.03	0.029	0.027	0.03
Number of Mechanical Engineers and Foremen	0.025	0.026	0.024	0.021	0.023	0.027	0.027	0.025	0.026	0.024	0.027	0.029	0.028	0.027	0.021	0.029	0.024	0.028	0.026	0.03	0.022
Having Traceability Programs	0.024	0.021	0.027	0.021	0.02	0.022	0.024	0.022	0.021	0.023	0.029	0.026	0.026	0.024	0.028	0.029	0.024	0.028	0.019	0.028	0.025
Past Delivery Performance	0.015	0.016	0.012	0.017	0.013	0.015	0.012	0.015	0.015	0.014	0.013	0.014	0.012	0.013	0.013	0.015	0.015	0.014	0.013	0.015	0.014
Conformance Rate at Production Site	0.012	0.01	0.014	0.011	0.012	0.012	0.012	0.014	0.012	0.009	0.014	0.013	0.01	0.011	0.012	0.011	0.013	0.012	0.011	0.011	0.012
Volume Flexibility	0.011	0.012	0.011	0.009	0.009	0.011	0.012	0.01	0.011	0.013	0.012	0.014	0.01	0.009	0.012	0.011	0.01	0.014	0.012	0.012	0.01
Modification Flexibility	0.005	0.005	0.005	0.006	0.004	0.005	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.006	0.006	0.005	0.006	0.006	0.007	0.006
Number of Quality Personnel	0.005	0.005	0.005	0.005	0.004	0.006	0.006	0.007	0.006	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.007	0.006	0.005	0.005
ERP Program Usage	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.004	0.004	0.003	0.003	0.004	0.004	0.003	0.003	0.004	0.004	0.003	0.004	0.004

Table I (continued)

Sub-criteria/Scenarios	Final Results	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Relationship	0.145	0.155	0.171	0.169	0.161	0.163	0.159	0.148	0.122	0.153	0.148	0.119	0.157	0.165	0.122	0.154	0.167	0.152	0.166	0.127	0.139
Production Capacity	0.14	0.11	0.125	0.163	0.13	0.119	0.15	0.117	0.115	0.126	0.131	0.155	0.132	0.143	0.124	0.132	0.148	0.122	0.15	0.157	0.12
Experienced Employee Turnover	0.14	0.137	0.117	0.12	0.159	0.145	0.122	0.138	0.168	0.148	0.126	0.133	0.125	0.111	0.153	0.128	0.124	0.13	0.164	0.159	0.15
Delays in Confirmed Delivery Date	0.126	0.149	0.142	0.099	0.12	0.15	0.125	0.149	0.118	0.124	0.127	0.135	0.11	0.133	0.119	0.122	0.112	0.15	0.111	0.132	0.138
Financial Situation	0.077	0.066	0.064	0.084	0.07	0.075	0.08	0.091	0.075	0.08	0.089	0.065	0.07	0.089	0.092	0.091	0.077	0.064	0.074	0.068	0.073
Flexibility in Urgent Orders	0.07	0.061	0.064	0.073	0.072	0.071	0.058	0.065	0.082	0.065	0.074	0.082	0.077	0.074	0.08	0.062	0.074	0.08	0.058	0.077	0.082
Productivity	0.055	0.063	0.065	0.058	0.06	0.045	0.052	0.06	0.056	0.051	0.056	0.061	0.054	0.045	0.064	0.05	0.064	0.057	0.053	0.048	0.049
Conformance Rate at First Audit	0.049	0.047	0.043	0.056	0.046	0.041	0.049	0.04	0.053	0.053	0.043	0.048	0.053	0.042	0.055	0.061	0.043	0.044	0.044	0.045	0.054
Order Change Flexibility	0.036	0.042	0.038	0.028	0.033	0.03	0.041	0.033	0.042	0.041	0.041	0.038	0.04	0.03	0.043	0.033	0.03	0.037	0.037	0.033	0.038
Scrap	0.034	0.037	0.036	0.028	0.032	0.029	0.03	0.037	0.031	0.036	0.035	0.037	0.03	0.034	0.03	0.034	0.032	0.033	0.029	0.034	0.04
Reputation	0.027	0.022	0.033	0.025	0.027	0.031	0.025	0.025	0.034	0.022	0.026	0.03	0.033	0.029	0.029	0.028	0.03	0.023	0.023	0.023	0.023
Number of Mechanical Engineers and Foremen	0.025	0.028	0.025	0.027	0.021	0.021	0.03	0.021	0.02	0.025	0.029	0.021	0.028	0.021	0.02	0.03	0.026	0.028	0.021	0.024	0.02
Having Traceability Programs	0.024	0.026	0.022	0.02	0.02	0.025	0.025	0.028	0.028	0.021	0.022	0.026	0.03	0.028	0.02	0.023	0.022	0.025	0.02	0.023	0.021
Past Delivery Performance	0.015	0.017	0.016	0.016	0.015	0.016	0.014	0.013	0.015	0.017	0.013	0.014	0.018	0.016	0.015	0.016	0.016	0.014	0.012	0.014	0.015
Conformance Rate at Production Site	0.012	0.013	0.013	0.012	0.01	0.014	0.013	0.011	0.015	0.011	0.012	0.014	0.014	0.012	0.011	0.01	0.011	0.014	0.011	0.012	0.012
Volume Flexibility	0.011	0.013	0.011	0.011	0.012	0.013	0.013	0.012	0.013	0.013	0.011	0.011	0.014	0.01	0.012	0.012	0.011	0.012	0.012	0.009	0.01
Modification Flexibility	0.005	0.006	0.006	0.004	0.004	0.005	0.005	0.004	0.006	0.005	0.007	0.004	0.006	0.006	0.005	0.006	0.006	0.006	0.006	0.006	0.006
Number of Quality Personnel	0.005	0.005	0.006	0.004	0.006	0.005	0.006	0.004	0.005	0.005	0.006	0.005	0.007	0.006	0.005	0.005	0.005	0.005	0.004	0.006	0.006
ERP Program Usage	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004

Table I (continued)

Sub-criteria/Scenarios	Final Results	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Relationship	0.145	0.142	0.171	0.145	0.149	0.171	0.159	0.138	0.144	0.158	0.135	0.116	0.154	0.16	0.146	0.128	0.119	0.138	0.132	0.167	0.157
Production Capacity	0.14	0.12	0.126	0.156	0.136	0.125	0.136	0.141	0.129	0.119	0.129	0.118	0.126	0.144	0.14	0.174	0.122	0.132	0.127	0.112	0.122
Experienced Employee Turnover	0.14	0.165	0.131	0.135	0.144	0.126	0.141	0.12	0.167	0.137	0.132	0.165	0.138	0.108	0.125	0.126	0.148	0.158	0.138	0.152	0.161
Delays in Confirmed Delivery Date	0.126	0.127	0.126	0.115	0.131	0.124	0.134	0.134	0.107	0.155	0.126	0.126	0.126	0.141	0.138	0.107	0.131	0.104	0.157	0.135	0.114
Financial Situation	0.077	0.067	0.069	0.069	0.063	0.069	0.067	0.069	0.085	0.064	0.079	0.091	0.066	0.085	0.065	0.094	0.091	0.064	0.073	0.069	0.083
Flexibility in Urgent Orders	0.07	0.084	0.07	0.068	0.065	0.082	0.061	0.08	0.058	0.063	0.083	0.076	0.076	0.074	0.065	0.06	0.071	0.082	0.069	0.072	0.067
Productivity	0.055	0.046	0.061	0.065	0.064	0.045	0.056	0.048	0.06	0.053	0.066	0.054	0.064	0.045	0.063	0.059	0.065	0.063	0.057	0.045	0.048
Conformance Rate at First Audit	0.049	0.041	0.043	0.048	0.05	0.052	0.048	0.061	0.055	0.051	0.048	0.052	0.057	0.055	0.057	0.053	0.053	0.056	0.048	0.054	0.045
Order Change Flexibility	0.036	0.041	0.035	0.043	0.037	0.041	0.035	0.039	0.03	0.037	0.042	0.042	0.031	0.039	0.03	0.036	0.039	0.037	0.031	0.038	0.036
Scrap	0.034	0.04	0.029	0.034	0.028	0.039	0.029	0.04	0.035	0.041	0.031	0.033	0.036	0.035	0.032	0.031	0.04	0.041	0.029	0.035	0.035
Reputation	0.027	0.026	0.033	0.029	0.032	0.025	0.031	0.024	0.026	0.023	0.029	0.028	0.028	0.025	0.033	0.026	0.022	0.027	0.031	0.026	0.032
Number of Mechanical Engineers and Foremen	0.025	0.021	0.024	0.021	0.023	0.028	0.027	0.03	0.025	0.022	0.025	0.021	0.024	0.021	0.026	0.026	0.024	0.028	0.025	0.02	0.024
Having Traceability Programs	0.024	0.026	0.025	0.02	0.027	0.022	0.022	0.022	0.023	0.024	0.024	0.027	0.021	0.023	0.028	0.029	0.025	0.024	0.03	0.023	0.021
Past Delivery Performance	0.015	0.017	0.015	0.013	0.016	0.017	0.013	0.014	0.014	0.014	0.013	0.013	0.015	0.013	0.014	0.015	0.013	0.012	0.015	0.014	0.013
Conformance Rate at Production Site	0.012	0.014	0.012	0.013	0.01	0.012	0.012	0.014	0.014	0.014	0.011	0.011	0.012	0.009	0.012	0.013	0.014	0.011	0.011	0.011	0.014
Volume Flexibility	0.011	0.011	0.013	0.011	0.009	0.01	0.014	0.012	0.012	0.011	0.012	0.013	0.013	0.009	0.012	0.009	0.01	0.009	0.011	0.012	0.013
Modification Flexibility	0.005	0.004	0.006	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.007	0.006	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.006
Number of Quality Personnel	0.005	0.006	0.006	0.005	0.006	0.005	0.005	0.006	0.006	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.006	0.005	0.006	0.006	0.005
ERP Program Usage	0.003	0.003	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.004

Table I (continued)

Sub-criteria/Scenarios	Final Results	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Relationship	0.145	0.155	0.144	0.144	0.133	0.158	0.169	0.117	0.152	0.125	0.13	0.12	0.153	0.148	0.164	0.171	0.126	0.152	0.12	0.153	0.122
Production Capacity	0.14	0.159	0.118	0.156	0.137	0.161	0.109	0.157	0.15	0.163	0.157	0.135	0.121	0.155	0.127	0.158	0.167	0.129	0.161	0.158	0.144
Experienced Employee Turnover	0.14	0.135	0.162	0.121	0.153	0.126	0.15	0.142	0.135	0.13	0.163	0.153	0.152	0.118	0.154	0.114	0.121	0.125	0.144	0.126	0.145
Delays in Confirmed Delivery Date	0.126	0.104	0.141	0.126	0.112	0.113	0.121	0.113	0.111	0.153	0.107	0.142	0.129	0.11	0.102	0.103	0.113	0.133	0.112	0.13	0.141
Financial Situation	0.077	0.069	0.077	0.072	0.071	0.073	0.076	0.085	0.072	0.064	0.088	0.083	0.064	0.093	0.077	0.07	0.074	0.067	0.087	0.062	0.068
Flexibility in Urgent Orders	0.07	0.078	0.069	0.077	0.073	0.068	0.055	0.062	0.062	0.064	0.061	0.062	0.06	0.063	0.07	0.08	0.072	0.069	0.058	0.066	0.076
Productivity	0.055	0.061	0.049	0.047	0.063	0.047	0.064	0.065	0.058	0.045	0.052	0.052	0.06	0.055	0.047	0.051	0.058	0.054	0.061	0.053	0.064
Conformance Rate at First Audit	0.049	0.058	0.046	0.043	0.051	0.052	0.057	0.049	0.051	0.057	0.051	0.05	0.054	0.043	0.055	0.055	0.056	0.054	0.057	0.052	0.056
Order Change Flexibility	0.036	0.032	0.041	0.043	0.031	0.038	0.042	0.032	0.044	0.038	0.04	0.039	0.041	0.043	0.037	0.042	0.041	0.04	0.038	0.035	0.037
Scrap	0.034	0.03	0.029	0.039	0.041	0.034	0.039	0.039	0.039	0.036	0.031	0.032	0.036	0.032	0.038	0.029	0.037	0.037	0.031	0.037	0.028
Reputation	0.027	0.027	0.029	0.027	0.03	0.025	0.022	0.026	0.027	0.023	0.024	0.028	0.028	0.033	0.03	0.029	0.031	0.029	0.032	0.03	0.024
Number of Mechanical Engineers and Foremen	0.025	0.023	0.022	0.027	0.025	0.026	0.023	0.025	0.021	0.025	0.026	0.025	0.027	0.029	0.02	0.022	0.025	0.025	0.026	0.028	0.026
Having Traceability Programs	0.024	0.023	0.023	0.024	0.026	0.029	0.019	0.028	0.023	0.022	0.022	0.026	0.027	0.02	0.025	0.023	0.022	0.028	0.024	0.021	0.023
Past Delivery Performance	0.015	0.014	0.015	0.015	0.012	0.014	0.015	0.017	0.016	0.017	0.013	0.016	0.012	0.017	0.016	0.015	0.018	0.018	0.014	0.012	0.012
Conformance Rate at Production Site	0.012	0.011	0.011	0.012	0.015	0.011	0.012	0.014	0.011	0.014	0.009	0.011	0.013	0.01	0.013	0.014	0.013	0.011	0.01	0.013	0.011
Volume Flexibility	0.011	0.009	0.009	0.013	0.01	0.012	0.012	0.012	0.012	0.01	0.012	0.012	0.009	0.012	0.012	0.011	0.01	0.012	0.009	0.01	0.01
Modification Flexibility	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.005	0.005	0.006	0.006	0.006	0.005	0.006
Number of Quality Personnel	0.005	0.005	0.006	0.005	0.007	0.005	0.006	0.006	0.007	0.006	0.004	0.006	0.005	0.007	0.005	0.005	0.006	0.007	0.005	0.006	0.005
ERP Program Usage	0.003	0.004	0.003	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.003

J. TURKISH SUMMARY / TÜRKÇE ÖZET

GİRİŞ

Tüm üretim şirketleri, ham maddenin satın alımından başlayıp nihai ürünü üretip perakendeciye veya direkt olarak müşteriye nakletmeyle son bulan güçlü bir tedarik zinciri sürecine ihtiyaç duyarlar. Malzeme dışında, doğru ve zamanında bilgi akışı, sermaye, iş gücü ve ekipman farklı ticari işletmelerin ilgili tedarik zinciri sürecinde etkileşim içinde bulunmalarını kaçınılmaz hale getirir (Forrester, 1958). Bu sebeple, tüm tedarik zinciri süreci tedarikçiler, üreticiler, distribütörler, perakendeciler ve müşterilerin entegrasyonu temeli üzerine kurulmalıdır (Beamon, 1998). Etkili bir tedarik zinciri kurmanın ilk eylemi, ham maddeleri doğru kalitede, miktarda ve zamanda tedarik edebilecek tedarikçileri seçmektir. Artan rekabet sebebiyle, tedarik riskini en aza indirgemek için üreticiler, tedarikçileriyle uzun süreçli ilişkiler kurmalı ve bu sayede onların üretim kapasitelerini kendilerine kaydırmalarını sağlamalıdırlar (Gunasekaran et al., 2015).

Tedarikçi seçimi, tedarik zincirinin ilk adımı olmakla beraber sadece tedarikçileri seçmek yeterli değildir. Güçlü bir tedarik zinciri kurmak ve devamlılığını sağlamak için üretici tedarikçilerin performanslarını düzenli olarak izlemelidir. Bu kapsamda, tedarikçi değerlendirmesi tedarikçilerin performanslarının düzenli olarak izlenmesi ve belirlenen kriterlere göre puan verilmesi sürecini içerir. Tedarikçilerin izlenmesi ve düşük performans sebebiyle uyarılması, tedarikçilerin süreçlerini düzeltmeleri için onlara fırsat sunar ve bu sayede üretici tedarik sorunuyla karşılaşmamış olur.

Üretici için uygun kriterleri belirleyerek tedarikçi değerlendirme sisteminin geliştirilmesi, araştırmacıların ve hatta birçok profesyonel çalışanın ilgisini çekmiştir. Bu kapsamda, bu çalışmanın amacı mevcut durumda sadece kalite ve teslimat kriterlerini göz önünde bulunduran bir tedarikçi değerlendirme sistemine sahip olan seçilmiş Türk Savunma Sanayi firmasına iyi tanımlanmış ve dokümante edilmiş kapsamlı bir tedarikçi değerlendirme sistemi geliştirilmesidir.

Önerilen çok kriterli karar verme modeli, firmanın talaşlı imalat alanında faaliyet gösteren tedarikçilerinin değerlendirilmesi üzerine olacaktır. Talaşlı imalat alanındaki tedarikçilerin seçilmesinin sebebi, bu firmaların performanslarının karar vericiler tarafından yeterli görülmemesi ve teslimat zamanlarında yaşanılan ciddi aksaklıklardır. Problemin çözümü için Analitik Hiyerarşi Süreci (AHS) kullanılacak olup bundaki amaç çok kriterli bu problemi ana ve alt kriterlere hiyerarşik bir düzende ayırarak problemin çözümünü kolaylaştırmaktır.

Bu çalışma geniş bir tedarikçi değerlendirme kriter setini incelemiş olup Kurumsal Kaynak Planlaması (KKP) programı kullanımı ve firmaların üretim tezgahlarında takip programları kullanması gibi vakaya özgü kriterler içermektedir.

Problem için gerekli olan veriler, birçok farklı kaynaktan çekilmiş olup nicel veriler tedarikçilerden ve firmanın KKP programından çekilmiştir. Nitel veriler ise "karar verici ve çeşitli uzmanlardan alınan görüşler doğrultusunda oluşturulan İkili Karşılaştırma Matrisleri (İKM)" yardımıyla hesaplanmıştır. Ana ve alt kriterlerin ağırlıkları da yine karar vericinin ve çeşitli uzmanların uzmanlık alanları dahilindeki ana kriter ve alt kriter için verdikleri görüşler doğrultusunda oluşturulmuştur. Ayrıca, bu çalışma kapsamında önerilen AHS metodunun sonuçlarının herhangi bir değişikliğe açık olup olmadığı duyarlılık analizi yapılarak kontrol edilmiştir.

Bu çalışma sonucunda, seçilmiş firma tedarikçilerinin performanslarına yönelik geri dönüşler yapabilecek ve tedarikçiler güçlü ve zayıf yönlerini öğrenebileceklerdir. Bu da firma ve tedarikçileri arasında şeffaflık sağlayacaktır. Ayrıca mevcut durumda kısıtlı bir kriter seti ile yapılan değerlendirmenin kapsamı genişletilecek ve firmanın daha kapsamlı bir tedarikçi değerlendirme sistemine kavuşması sağlanacaktır.

LİTERATÜR TARAMASI

Literatürde tedarikçi seçimi ve değerlendirmesi üzerine birçok çalışma bulunmaktadır. Bu iki konu birbirlerinin yerine sıkça kullanılmış ve ikisi ile de ilgili benzer kriterler ve metotlar tercih edilmiştir. Hem tedarikçi seçimi hem de tedarikçi değerlendirme süreci, tedarikçi firmaların değerlendirileceği kriterlerin belirlenmesi ile başlar.

Bu iki konu üzerine çalışmalar 1960'lı yıllarda başlamış olup kriterlerin belirlenmesi üzerine ilk çalışma Dickson (1966) tarafından yapılmıştır. Yazar bu çalışmasında Amerika ve Kanada'da Ulusal Satın Alma Çalışanları Birliği'ne kayıtlı 170 satın alma uzmanına anket yollamış ve onlara firmalarında tedarikçi performanslarının ölçülüp ölçülmediğini sormuştur. Çalışmaya katılanlardan %44' ü firmalarında tedarikçi performans değerlendirme sistemi olmadığını belirtmiş ve en düşük teklifi verene siparişi bağladıklarını belirtmişlerdir. Çalıştıkları firmalarda tedarikçi performans sistemi kullanılan satın alma uzmanları kendilerine göre önemli olan kriterleri belirtmiş ve bunun sonucunda 23 kriter tedarikçi seçim ve değerlendirme kriteri olarak belirlenmiştir. Bunların içinden en önemlileri kalite, teslimat, tedarikçinin performans geçmişi, garanti politikası, üretim kapasitesi, fiyat, teknik kabiliyet ve finansal durum satın alma uzmanları tarafından en önemli kriterler olarak belirlenmiştir.

Ho ve diğerleri (2008), yaptıkları literatür çalışmasında 2000 ile 2008 yılları arasında tedarikçi seçimi ve tedarikçi değerlendirmesi konuları üzerine yazılmış 78 makaleyi incelemiştir. Çalışmada en çok bahsedilen kriter olan kalitenin 68 makalede, ardından teslimatın 64 makalede ve fiyat/maliyetin 63 makalede incelendiğini ortaya çıkarmışlardır.

Tedarikçilerin değerlendirileceği kriterlerin belirlenmesinden sonra, problemin çözümünün yapılacağı metodun belirlenmesi gerekmektedir. Literatürde bu konular üzerinde yapılan çalışmalarda çoğunlukla çok kriterli karar verme metotlarının kullanıldığı görülmüştür.

Weber (1991), yaptığı çalışmada 1966 ile 1990 yılları arasında bu konular üzerine yazılmış 74 makaleyi incelemiştir. Çalışmaya göre en çok tercih edilen metot doğrusal ağırlıklandırma metodu olmuştur. Devamında en çok tercih edilen metotlar matematiksel programlama metotları ve istatistiksel yaklaşımlar olmuştur.

Sonraki yıllarda yayınlanan çalışmalar incelendiğinde çok kriterli karar verme metotlarının kullanımının arttığı gözlemlenmiştir. Veri zarflama analizi, analitik hiyerarşi süreci, vaka tabanlı muhakeme, analitik ağ süreci ve bulanık küme teorisi, matematiksel programlama modelleri olan doğrusal programlama, doğrusal tam sayı

programlama, doğrusal olmayan tam sayı programlama, amaç programlaması ve çok amaçlı programlama ile birlikte kullanılmıştır.

Saaty (1980), bir çok kriterli karar verme metodu olan AHS'i geliştirmiştir. AHS isminden de anlaşılacağı üzere ana, alt ve altta sıralanan diğer kriterlerin hiyerarşik olarak aşağı doğru birbirlerine bağlanmasını amaçlar. Bu sayede karar verici birçok kriteri aynı anda karşılaştırmak yerine sadece aynı üst kritere bağlı kriterleri birbiriyle karşılaştırır. AHS hem nicel hem de nitel kriterlerin modele adapte edilmelerini sağlar. Nicel kriterler direkt olarak alternatiflerin skorları olarak modele eklenirken, nitel kriterlerin skorları alternatiflerin ikili karşılaştırmalarıyla hesaplanır.

Chan ve Chan (2004), çalışmalarında yarı iletken montaj ekipmanı üreten bir firmanın tedarikçi seçimini incelemiştir. Bu çalışmada AHS kullanılmasının sebebi problemin karmaşıklığı, karar vericinin görüşlerine ihtiyaç duyulan nitel kriterlerin bulunması, çok sayıda karar vericinin problemin çözümüne katkı vermesinin gerekmesi ve kriterler arasındaki bağlılıktır. Kriterleri belirlemek amacıyla firmada çalışan ilgili uzmanlara bir anket sunulmuş ve kendileri için önemli olan kriterleri belirtmeleri istenmiştir. Nitel kriterler, alternatif tedarikçilere 1-5 arası puanlar verilerek modele adapte edilmiştir. Bu çalışmada maliyet, teslimat, esneklik, yenilik, kalite, servis olmak üzere 6 ana kriter ve bunlara bağlı 19 alt kriter belirlenmiştir. Problem kapsamında değerlendirilen tedarikçi sayısı 3 olarak belirlenmiş ve sayının küçük olması ikili karşılaştırma sayısını ve olası sapmaları önlemiştir.

Akarte ve diğerleri (2001) yaptıkları çalışmada bir otomobil firması için döküm üreten firmaları incelemişler. Çalışmada AHS'nin tercih edilme sebebi problemin birçok nitel ve nicel kriteri içeriyor olması ve karar vericilerin tutarsızlıklarının da ölçülebilmesidir. Ayrıca, yazarlar tedarikçilerin teslimat süresi, kalite seviyesi, satın alma fiyatı vb. aktivitelerinin de kayıt altına alınabilmesi için bir veri tabanı oluşturulması gerektiğini belirtmişlerdir. Bu sayede tedarikçilerin performanslarına kolayca ulaşılabilecek ve sipariş bağlama operasyonu otomatikleştirilecektir. Firmaların değerlendirilmesi kapsamında ürün geliştirme kabiliyeti, üretim kabiliyeti, kalite kabiliyeti ve maliyet olmak üzere 4 ana kriter ve bunlara bağlı 19 alt kriter

belirlenmiştir. Ayrıca, 2 alt kriter ikişer adet daha 4. seviyede alt kriter içermektedir. Çalışma tedarikçilerin performanslarını hesaplamayı, izlemeyi ve görüntülemeyi sağlayan bir web tabanlı uygulamanın kurulmasıyla tamamlanmıştır.

Bu çalışmamızda, AHS kullanılmasının sebepleri tedarikçi değerlendirme sisteminin birçok karar vericinin fikrine başvurabiliyor olması, nitel kriterlerin var olması, sürecin hiyerarşik bir düzen içerisinde kurulup anlamayı kolaylaştırıyor olması, nitel ve nicel kriterlerin birlikte ele alınabiliyor olması, yalnızca aynı üst kritere bağlı kriterlerin karşılaştırılıyor olması ve firmadaki uzmanların AHS ile daha önce yapılan çalışmalarla ilgili bilgilerinin olmasıdır.

ANALİTİK HİYERARŞİ SÜRECİ

AHS metodu beş ana basamaktan oluşmaktadır. Bunlar, problemin tanımlanması ve hiyerarşik yapının oluşturulması, kriterler ve alternatiflerin ikili karşılaştırılması, yerel ağırlıkların belirlenmesi, tutarlılık ölçümü ve kontrolü ve son olarak ağırlıkların bütünleştirilmesidir. İlk aşamada, problemin ne olduğuna karar vererek ana amaç belirlenir. Ardından onu destekleyen ana kriterler belirlenerek hiyerarşik düzenin ikinci seviyesi oluşturulur. Ana kriterleri destekleyen alt kriterler belirlenir ve 4. seviye oluşturulur. Varsa eğer daha alt seviyedeki kriterler de belirlenerek, tüm kriterler yeterince detaylandırılana kadar devam edilir. Son olarak her en alttaki kriterin altına alternatifler bağlanarak son seviye oluşturulur ve böylece hiyerarşik gösterim tamamlanmış olur.

İkili karşılaştırmalar Saaty'nin (1980) geliştirdiği doğrusal "Ana Ölçek" üzerinden yapılacaktır. Karar vericinin sözel olarak ifade ettiği karşılaştırmalar, 1-9 arası sayılara dönüştürülür ve İKM'e işlenir. AHS'nin karşılık aksiyomuna göre, $i \neq j$, $a_{ij} = 1/a_{ji}$dir. İKM köşegeni üzerindeki tüm ikili karşılaştırmalar bir kriter veya alternatif kendisi ile karşılaştırıldığı için bire eşittir. İKM'nin doldurulmasının ardından "Standartlaştırılmış Değerlerin Ortalaması" yöntemi uygulanarak kriterlerin ağırlıkları veya alternatiflerin puanları hesaplanır. Bu yöntemde, önce her sütundaki sayı toplanır, ardından her sayı kendi sütun toplamına bölünür ve böylece standartlaştırılmış olur.

Ardından her satırdaki sayıların ortalaması alınarak ağırlık hesaplanır. Bu hesaplama yöntemi ile ana ve alt kriterlerin ağırlıkları ile alternatiflerin skorları hesaplanmış olur.

Ardından karar vericilerin tutarlılıkları hesaplanır. Bir matrisin tutarlı olması için Saaty ve Hu (1998) tarafından geliştirilen geçicilik kurallarına uygun olması gerekir. Nitel ve nicel olarak iki tür geçicilik belirtilmiştir. Bunlardan nitel olanda eğer X, Y'ye tercih ediliyorsa ve Y de Z'ye tercih ediliyorsa X de Z'ye tercih edilmelidir. Nicel olanda ise eğer X, Y'ye 3 kere, Y de Z'ye 4 kere tercih ediliyorsa X de Z'ye 12 kere tercih edilmelidir.

Standartlaştırılmış Değerlerin Ortalaması yönteminde, λ_{max}'ı tam hesaplamak yerine daha kısa yoldan yaklaşık bir değer hesaplanır. Çıkan bu değer matrisin boyutundan çıkarılır ardından da matrisin boyutunun bir eksiğine bölünür ve bu sayede tutarlılık endeksi hesaplanmış olur. Saaty (1980) çalışmalarında matris boyutu büyüdükçe, bir sapma oluştuğunu belirlemiş ve bu sapmayı da standartlaştırmak için matris boyutuna göre kullanılacak Rastlantısal Kararsızlık Endeksi'ni oluşturmuştur. Tutarlılık endeksinin matris boyutuna göre belirlenmiş rastlantısal kararsızlık endeksine bölünmesi ile tutarlılık endeksi hesaplanır. Eğer ortaya çıkan değer 0,1'den küçükse karar verici tutarlı olarak değerlendirilir.

AHS yönteminin son adımı ağırlıkların bütünleştirilmesidir. Bu aşamada alt seviyelerdeki kriterlerin ana amaca etkilerini görebilmek ve birbirleriyle karşılaştırabilmek için alt kriterin ağırlığı sırasıyla bağlı olduğu üst kriterlerin ağırlıkları ile çarpılır. Ortaya çıkan sonuçta alt kriterin ana amaca etkisi göstermekte ve bu sayede aynı seviyedeki alt kriterler birbirleri ile karşılaştırılabilmektedir.

SEÇİLMİŞ FİRMADAKİ MEVCUT DURUM

Sürecin ilk adımı tedarikçi seçimi olup bu aşamada tedarikçiler seçilen firmanın belirlemiş olduğu firmaya ait bilgileri, üretim süreçleri ve kalite sisteminden oluşan 3 kriterli bir denetimden geçmektedirler. Bu denetimden yeterli puanı alan tedarikçiler onaylı tedarikçi havuzuna alınmaktadır. Onaylı tedarikçi havuzundaki firmalar satın alma siparişi ihalelerine katılabilir ve kendilerine satın alma siparişi verilebilir.

Tedarikçilerin satın alma siparişlerindeki performansları incelenir ve sonraki satın alma siparişleri için veri oluşturarak satın alma siparişlerinin verilmesi sürecine etki eder.

Satın alma siparişi verme süreci ihale sistemi ile çalışır. Her bir satın alma siparişi için ihaleye davet edilen tedarikçiler teklif verirler ve içlerinden en düşük fiyatlı teklif sunan sipariş seçilir.

Mevcut tedarikçi değerlendirme sistemi kapsamında izlenen kriterlerin birisi kalite uygunsuzluklarıdır. Tedarikçilerin sevk ettiği malzemeler kontrol edilir ve malzeme dokümanlarına uygun gelmemişse kalite tarafından KKP programında uygunsuzluk bildirimi başlatılır. Tedarikçiler bu kriterden sevk ettikleri malzemelerden uygun bulunan malzemeler oranından puan alır. Ayrıca tedarikçilerin KKP programında görünen teslimat tarihlerine uyup uymadıkları kontrol edilir. Bu iki kriter kapsamında hesaplanan sonuçlar sırasıyla %65 ve %35 ağırlıkla çarpılarak firmanın nihai skoruna ulaşılır. Eğer bu skor 60'dan fazla ise firma ile çalışmaya devam edilir. Eğer 60'dan düşükse firma uyarılır ve 3 ay boyunca sürekli takip edilerek performansını düzeltmesi beklenir. Eğer firma performansını düzeltmezse, kendisi ile iş ilişkisi kesilir ve en az bir yıl tekrar onaylı tedarikçi havuzuna alınmaz.

Mevcut tedarikçi değerlendirme sistemi, sadece iki kriteri göz önünde bulundurmakta ve bu kriterlerden yeterli skoru almış olmaları gereklidir. Aldıkları skorlar firmaları ayırt etmez ve sonraki satın alma siparişlerinin verilmesi sürecine de etki etmez. Ayrıca, işe yeni başlayan satın alma sorumluları, sistemde firmalarla ilgili ayrıntılı bilgi bulunmadığı için firmaları tanımak için ciddi bir süre harcarlar ve uzun bir süre sadece şeflerinin kendilerine öğrettikleri kadarına bilirler. Ayrıca, mevcut sistem sipariş geçilme sürecine etki etmediği için satın alma sorumluları fiyat dışında verdikleri kararı destekleyecek bilgiyi iç denetim sorumlularına sunamazlar. Düşük teklifi veren firma dışındaki bir firmaya çeşitli sebeplerle sipariş verebilmek için ayrıntılı dokümanların hazırlanması gerekmekte ve birçok yöneticinin onayına sunulmaktadır. Bu sebeple de süreç çok uzamakta ve zaman kaybedilmektedir.

TEDARİKÇİ DEĞERLENDİRME KRİTERİ SEÇİMİ

Seçilen firmayı değerlendirmek üzere altı ana kriter belirlenmiştir. Bunlar, kalite, teslimat, esneklik, üretim kabiliyeti, teknoloji ve firma niteliğidir. Bunun yanı sıra, bu 6 ana kritere bağlı 19 alt kriter de belirlenmiştir. Fiyat en önemli kriterlerden biri olmasına rağmen gizlilik sebebiyle tedarikçilerin ihalelere verdiği fiyat teklifleri görüntülenememektedir.

Ana ve alt kriterleri belirlerken karar verici (yurtiçi satın alma şefi), ve uzmanlar (planlama uzmanı, tedarik kalite uzmanı, yurtiçi satın alma uzmanı ve tedarik zinciri uzmanı) ile mülakatlar yapılmış olup kriterlerle ilgili görüşleri sorulmuştur. Bu kapsamda tüm ana kriterlerde değişiklik yapılmadan hem fikir olunmuş ancak bazı alt kriterler ayrıştırıcı faktör olmadıklarından listeden çıkarılmıştır. Kalite güvence sertifikasyonu, tedarikçinin yönetim yapısı bunlardan bazılarıdır.

İlk ana kriter *kalite* olarak belirlenmiştir. Kalite, malzemelerin üretim veya teknik çizim dokümanlarına göre görsel, işlevsel ve ölçüsel açıdan uygun olması durumudur. Seçilen firma ürünleri silahlı kuvvetler ve emniyet güçlerine sattığı ve bu ürünlerin savaş gibi uç durumlarda kullanılabilecek olmasından dolayı malzemelerin dayanıklılığı ve güvenilirliğinin yüksek olması oldukça önemlidir. Kalite, *ilk denetimde uygunluk oranı*, *üretim sahasında uygunluk oranı* ve *tedarikçi firmanın kalite personeli sayısı* olarak üç alt kritere bölünmüştür.

İlk denetimde uygunluk oranı, gelen malzemelerin firmaya ilk geldiğinde tedarik kalite birimi tarafından denetlenip teknik dokümanlarına uygun olması durumudur. Gelen malzemeler askeri standartlara göre %5 oranında rastgele seçilip denetlenmektedir. İlk denetim tamamlandıktan sonra malzemeler üretime aktarılır ve kullanım esnasında üretim personeli tarafından kontrol edilir. Üretim sahasında *uygunluk oranı*, üretim sahasına ulaşmış malzemelerin teknik dokümanlarına uygunluk oranıdır. Kalitenin son alt kriteri *tedarikçi firmanın kalite personeli sayısı* olup tedarikçilerin kalite personeli seçilen firma tarafından sırasıyla eğitilmektedir.

İkinci ana kriter *teslimattır*. Bu ana kriter sipariş edilen malzemelerin seçilen firmaya doğru miktarda, doğru zamanında ve dokümanlarına uygun şekilde teslim edilmesini içerir. Bu bağlamda, teslimat *tedarikçinin geçmiş teslimat performansı*, *onaylanan tarihten sapma* ve *fire* olmak üzere üç alt kritere ayrılmıştır. Seçilen firma müşterileri ile belli ve kısıtlı zamanlı sözleşmeler imzalamakta ve bu terminlere sadık kalmak durumundadır. Aksi durumda hakkında cezai işlem uygulanmakta ve saygınlığı sarsılmaktadır. *Geçmiş teslimat performansı*, tedarikçinin geçtiğimiz senelerde yaptığı teslimatların KKP programında belirtilen tarihe uygun olup olmadığını denetler. Malzemenin gelmesi gereken tarihe kısa süre kala planlama sorumlusu malzemenin durumunu tedarikçiye sorar. Tedarikçi de malzemeyi teslim edeceği tarihi mail veya telefon yolu ile belirtir. Sonrasında firmanın onayladığı bu tarihten sapması üretim programının sapmasına ve seçilen firmanın personelinin gereksiz mesai yapmasına sebep olmaktadır. *Fire* de tedarikçinin gönderilen alt malzemeyi kullanarak doğru miktarda nihai ürünü göndermesinin kontrol edilmesini hedeflemektedir.

Üçüncü ana kriter *esneklik* olup tedarikçinin, seçilen firmanın talepleri doğrultusunda gerekli değişiklikleri yaparak talebi karşılaması durumudur. Bu kapsamda sipariş miktarı esnekliği, *modifikasyon esnekliği*, *üretim sırası esnekliği* ve *acil taleplere karşı esneklik* olarak belirlenmiştir. *Sipariş miktarı esnekliği*, seçilen firmanın müşterilerinin konfigürasyonlarda sık sık değişiklik talep etmesinden kaynaklı alt malzeme ihtiyaç miktarlarının değişmesi sebebi ile önemlidir. Seçilen firma müşterilerinin talepleri doğrultusunda yeni ürün tasarlamakta, yeni teknolojilerin ve isterlerin gerçekleşmesi için malzemelerin dokümanlarında değişiklik yapabilmektedir ve tedarikçinin de değişikliğe maruz kalan malzemelere değişikliği uygulamaya gönüllü olması seçilen firma açısından önemlidir.

Üretim sırası esnekliği ise değişen ihtiyaç tarihleri sebebi ile tedarikçinin üretim alanında yaptığı üretim programının değişmesine karşı olan tavrıdır. Son alt kriter olan *acil taleplere karşı esneklik* ise seçilen firmanın çok kısa sürede istediği malzeme taleplerine karşı firmanın tavrıdır.

Tedarikçilerin değerlendirileceği dördüncü ana kriter *teknolojidir*. *KKP programının kullanılması* ve *üretim tezgâhlarında takip programlarının var olması* da bu ana kriterin alt kriterleridir. Firmanın *KKP programına sahip olması* ve etkin bir şekilde kullanması kendi üretim programını kolaylıkla takip etmesi ve seçilen firmanın çalışanlarına da güncel bilgileri hızlı bir şekilde iletmesi için önemlidir. *Üretim tezgahlarında takip programı olması* ise malzemenin insan faktörü olmadan doğru şekilde üretilmesine, üretim kapasitesinin artırılmasına yardımcı olur.

Üretim kabiliyeti, tedarikçilerin değerlendirileceği beşinci ana kriter olarak belirlenmiştir. *Üretim kapasitesi*, *tecrübeli personelin firmada kalma süresi*, *verimlilik, makine mühendisi ve ustabaşı sayısı* üretim kabiliyetinin alt kriterleridir. *Üretim kapasitesi* firmanın büyüklüğünü belirler. *Tecrübeli çalışanların firmada kalma süresi* firmanın yetkinliği açısından önemlidir. *Verimlilik* firma karlılığında önemli rol oynar ve firmanın verdiği fiyat tekliflerine doğrudan etki eder. Son olarak *makine mühendisi ve ustabaşı sayısı* firmanın üretim yeteneği ve üretim kapasitesi hakkında bilgi verip esnekliği artırabilir.

Son ana kriter *firma niteliği* olarak belirlenmiş olup bu kriter tedarikçinin *finansal durumu, tedarikçi ile ilişki* ve *tedarikçinin saygınlığı* olmak üzere üç alt kritere bölünmüştür. Tedarikçinin faaliyetlerini sürdürebilmesi için finansal olarak güçlü olması ve varlığını sürdürebilmesi seçilmiş firma için önemlidir. *Firma ile ilişkiler,* firmanın genel tutumunu yansıtmakta olup işbirliğine yatkın olup olmadığını göstermektedir. *Tedarikçinin saygınlığı* ise çalıştığı diğer firmaların sektörlerinde bulundukları konum ve büyüklükleri ile ilgili olup tedarikçi hakkında bilgi vermektedir.

VERİ TOPLANMASI

Bu bölümde tedarikçilerin nasıl seçildiği, ana ve alt kriterlerin ağırlıklarının hesaplanması ve alternatif tedarikçilerin skorlarının hesaplanmasını sağlayan verilerin nasıl toplandığı anlatılacaktır.

Seçilen firmanın talaşlı imalat onaylı tedarikçi havuzunda 72 tedarikçi bulunmakta ve 2007-2017 yılları arasında bunlardan yalnızca 34'ü ile çalışılmıştır. Tedarikçiler son 11 yılda yaptıkları teslimat cirolarına göre sıralanmış olup toplam cironun %81.64'ünü tedarik etmiş olan sekiz tedarikçi bu çalışmada değerlendirilecek alternatif tedarikçiler olarak seçilmiştir. Gizlilik sebebiyle, alternatif tedarikçiler ciro büyüklüklerine göre A,B, … , H olarak adlandırılmıştır.

Ana ve alt kriterlerin ağırlıklarının belirlenmesi ve alternatif tedarikçilerin alt kriterler kapsamında aldıkları skorların belirlenmesi gerekmektedir. Ana ve alt kriterlerinin belirlenmesi için İKM'ler oluşturulmuştur. Bunların oluşturulması sürecinde karar verici ve uzmanların görüşlerine başvurulmuş olup onlardan ana kriter, alt kriter ve alternatif tedarikçileri ikili olarak birbirleri ile karşılaştırmaları istenmiştir.

Karar verici olan yurtiçi satın alma şefinin görüşleri doğrultusunda oluşturulan İKM, ana kriterlerin ağırlıklarının hesaplanmasına yardımcı olmuştur. Alt kriterlerin ağırlıklarının hesaplanması için çeşitli uzmanlar uzmanlık alanlarına göre görüş vermişlerdir. Kalite için tedarik kalite uzmanı, teslimat için üretim planlama uzmanı, esneklik, teknoloji ve üretim kabiliyeti için yurtiçi satın alma uzmanı ve son olarak firma niteliği için yurt içi satın alma uzmanı ve tedarik zinciri uzmanı birlikte görüş vermişlerdir.

Alternatiflerin skorlarının belirlenmesi için veriler çeşitli kaynaklardan toplanmıştır. Alt kriterlerden ilk denetimde uygunluk oranı, üretim sahasında uygunluk oranı ve geçmiş teslimat performansına ait veriler KKP programından elde edilmiştir. Bu üç kriterin ölçülmesi için her bir siparişin başarı oranı hesaplanmakta ve bir tedarikçiye bu alanda verilmiş tüm siparişlerin başarı ortalaması alınmaktadır. Üretim kapasitesinin belirlenebilmesi için firmalara bir parça gönderilmiş ve bundan kaçar adet üretilebilecekleri sorulmuştur. Yine aynı şekilde tecrübeli çalışanların firmada kalma süresi, verimlilik, makine mühendisi ve ustabaşı sayısı, kalite personeli sayısı ve finansal durumu ölçen cari oran tedarikçilerden alınan bilgiler ışığında hesaplanmıştır.

Bu alt kriterler dışında kalan dokuz adet alt kriter açısından alternatif tedarikçilerin aldıkları skorların hesaplanması için İKM'ler oluşturulmuştur. Bu İKM'lerin oluşturulması için görüşleri, alt kriterlerin ağırlıklarının belirlenmesi için görüş veren uzmanlar vermiştir. Bu sayede alternatif tedarikçiler tüm alt kriterlere göre skorlarını almış olup ayrıca ana ve alt kriterlerin de ağırlıkları belirlenmiştir.

SONUÇLAR

Alt kriterlerden kalite personeli sayısı, makine mühendisi ve ustabaşı sayısının tedarikçinin üretim kapasitesi ile pozitif orantılı oldukları görüldüğünden bu kriterler için alternatiflerin skorları hesaplanmadan önce bildirilen sayılar üretim kapasitesine bölünüp sonra skorlar bire normalleştirilmiştir. Nicel verilerle skorları hesaplanan alt kriterler toplamları bir olacak şekilde normalleştirilmiştir.

Oluşturulan İKM'ye göre kalite, teslimat, esneklik, teknoloji, üretim kabiliyeti ve firma niteliği ana kriterlerinin ağırlıkları sırası ile 0,0664, 0,1743, 0,1227, 0,0271, 0,3600 ve 0,2495 olarak hesaplanmıştır. İlgili İKM'nin tutarlılık oranı 0,0615 olarak hesaplanmış ve 0,1'den küçük olduğu için karar verici tutarlı bulunmuştur.

Ardından alt kriter seviyesinde oluşturulan İKM'ler yardımı ile alt kriterlerin yerel ağırlıkları hesaplanmıştır. Yerel ağırlıklar bir alt kriterin sadece bağlı olduğu ana kritere etkisini göstermektedir. Bu sebeple alt kriterlerin ana kritere etkisi de hesaplanmıştır. Bu hesaplamalara göre tedarikçi ile ilişki 0,145 ağırlık ile en etkili alt kriter olmuştur. Üretim kapasitesi, tecrübeli çalışanların firmada kalma süresi, onaylanan tarihten sapma ve finansal durum, 0,14, 0,14, 0,1261 ve 0,0771 ağırlıkları ile en etkili alt kriterler olmuştur. Modifikasyon esnekliği, tedarikçinin kalite personeli sayısı ve KKP programı kullanımı da 0,0055, 0,0054 ve 0,0034 ağırlıkları ile en önemsiz alt kriterler olarak belirlenmiştir.

Bu sonuçlara göre tedarikçi ile ilişkilerin iyi olması diğer alt kriterleri de doğrudan veya dolaylı olarak etkilediği ve tedarikçi ile anlaşabilme konusunda önemli olduğu için en önemli kriter olarak seçilmiş olması normaldir. Tedarikçinin üretim kapasitesi de aynı şekilde sipariş almasını doğrudan etkilediği için en önemli kriterlerdendir.

Onaylanan tarihten sapma da malzemelerin sadece %66'sı zamanında teslim edilebildiğinden ve bu aksamaların seçilmiş firmaya ekstra maliyet oluşturmasından dolayı önemlidir. Seçilmiş firmanın satın alma sorumluları sadece firmanın planlama ve satış sorumluları ile değil aynı zamanda üretim personeli ile de görüşmektedir. Bu sebeple üretim çalışanlarının firmada kalması işlerin işlerliğine etki etmektedir. Bu sebeple tecrübeli çalışanların firmada kalma süresi en önemli alt kriterlerden biri olarak belirlenmiştir.

Alt kriterlerin ana amaca etkileri ve her bir alt kriter için alternatif tedarikçilerin skorlarının hesaplanmasıyla tedarikçilerin toplam skorları bulunmuştur. Buna göre teslimat cirosundan dördüncü olan D tedarikçisi 0,1765 ağırlık ile birinci firma olmuş olup en çok teslimat cirosuna sahip olan A tedarikçisi 0,1527 ağırlık ile ikinci firma olmuştur. Teslimat cirosuna göre üçüncü olan C tedarikçisi ise 0,0883 ağırlık ile sonuncu firma olmuştur. C firmasının performansında düşüş olduğu seçilen firmanın satın alma sorumluları tarafından fark edilmiş olup C tedarikçisinin 2016 ve 2017 yıllarında teslimat cirosu düşüş göstermiştir.

Bu sonuçlara göre tedarikçiler performanslarına göre üç gruba ayrılmıştır. Birinci ve ikinci olan tedarikçiler üst gruba, üçüncü, dördüncü, beşinci ve altıncı olan tedarikçiler orta gruba, son olarak yedinci ve sekizinci olan tedarikçiler son gruba dahil edilmiştir.

Önerilen AHS metodunun sonuçlarının değişime açık olup olmadığını anlamak amacı ile duyarlılık analizi uygulanmıştır. Bu analizi uygulamak için alt kriterlerin ana amaca etkilerinin öncelikle ±%5'i aralığından Microsoft Excel'in rastgele sayı yaratma işlevi ile 100'er farklı senaryo oluşturulmuştur. Ardından alt kriterlerin ana amaca etkileri bire normalleştirilmiş ve tedarikçilerin toplam skorları her bir senaryo için ayrı ayrı hesaplanmıştır. Buna göre dördüncü olan G tedarikçisi 22 senaryoda yerini beşinci olan B tedarikçisine kaptırmış, kalan 78 senaryoda kendi sırasında kalmıştır. Bu çalışmanın sonucuna göre başka değişiklik ve gruplar arasında geçiş olmamıştır.

Aynı çalışma ±10% aralığında tekrar edilmiş olup dördüncü olan G tedarikçisi 34 senaryoda yerini beşinci olan B tedarikçisine kaptırmış, kalan 66 senaryoda kendi

sırasında kalmıştır. Bu çalışmanın sonucuna göre başka değişiklik ve gruplar arasında geçiş olmamıştır.

Son olarak çalışma ±20% aralığında gerçekleştirilmiş olup dördüncü olan G tedarikçisi 65 senaryoda yerine kalmış, 35 senaryoda beşinci olan B tedarikçisine geçilmiştir. Diğer iki deneyden farklı olarak beşinci olan B tedarikçisi 7 senaryoda altıncı olan F tedarikçisine geçilmiştir ve toplamda 58 senaryoda kendi yerinde kalmıştır. Bunlar dışında diğer tedarikçilerinin sıralamalarında değişiklik meydana gelmemiş olup gruplar arası geçiş de olmamıştır.

Duyarlılık analizinin sonuçlarına göre önerilen AHS metodunun sonuçlarının değişime açık olmadığı görülmüştür.

TARTIŞMA ve KAPANIŞ

Çalışmamızda, seçilen firmanın talaşlı imalat malzemelerini içeren tedarik ortamı için detaylı bir kriter araştırması yapılmış ve AHS kapsamında hiyerarşik gösterimi yapılmıştır. Bu kapsamda altı ana kriter ve 19 alt kriter belirlenmiş olup teslimat cirolarına göre sekiz alternatif tedarikçi belirlenmiştir. Problemin çözümü için gerekli olan veriler seçilen firmanın KKP programından, tedarikçilerden, karar verici ve uzmanların görüşlerine başvurularak toplanmıştır. Toplanan veriler ışığında alt kriterlerin ana amaca etkileri ve sekiz alternatif tedarikçinin toplam skorları hesaplanmıştır. Ardından sonuçların değişime açık olup olmadığını görmek için duyarlılık analizi yapılmış ve sonuçların güvenilir olduğu ispatlanmıştır.

Bu çalışma, seçilen firmaya tedarikçilerin performanslarını anlık olarak takip etme fırsatı sunmaktadır. Seçilen firmanın satın alma sorumluları tedarikçilerin üretim personelini de tecrübeli çalışanların firmada kalma süresi kriteri üzerinden değerlendirmiş olacak ve tedarikçiye bununla ilgili bilgi verecektir. Tedarikçi ile ilişkileri iyi tutmanın önemi ortaya çıkmış olup bunun esneklik kriteri ve fiyat üzerinde etkisinin olduğu da karar verici tarafından belirtilmiştir. Bu çalışma sayesinde işe yeni başlayan satın alma sorumluları tedarikçilerle ilgili güncel bilgileri görüntüleyebilecek ve alışma süreçleri kısalmış olacaktır. Seçilen firma tedarikçi zirveleri düzenlemekte

ve bu zirvelerde başarılı tedarikçilere ödül vermektedir. Bu çalışmanın sonuçları, ödül sisteminin adil olmasına da katkıda bulunacaktır. Ayrıca, tedarikçilere güçlü ve zayıf yönleri bildirilebilecek ve kendilerini geliştirmeleri gereken alanları öğrenmiş olacaklardır. Sistemde görüntülenebilecek performans durumlarına göre satın alma sorumluları sipariş bazında risk analizi yapabilecektir. Ayrıca iç denetçilere siparişlerin geçilme sebebini göstermek için de ellerinde veri olacaktır. Çalışmamız, literatüre geniş bir kriter setinin ayrıntılı olarak incelenmesi ve ERP kullanımı ve üretim tezgahlarında takip sistemi bulundurulması gibi vakaya özgü kriterler sunarak katkıda bulunmuştur. Ayrıca veriler çeşitli kaynaklardan toplanmıştır. Bu çalışma sonucunda kurulacak web ara yüzü karar destek sistemi olarak çalışacak ve satın alma sorumlularına geçecekleri sipariş için bilgi verebilecek ve riski gösterecektir.

Fiyat mevcut sistemde en önemli kriter olmasına rağmen gizlilik sebebiyle çalışmaya dahil edilememiştir. Eğer çalışmaya ana kriter olarak dahil edilebilseydi, yüksek cirolu firmaların daha düşük fiyat vererek siparişleri alması sebebi ile daha iyi değerlendirmelerine sebep olabilecekti. Ayrıca, firmaların kapasite dolulukları görüntülenemediği için çalışmaya eklenememiştir. Bu kriter, firmaların geçmiş teslimat performansları ile ilgili de bilgi verebilecek olup satın alma sorumlularına sipariş aşamasında bilgi verecekti.

Bu çalışma kapsamında sadece talaşlı imalat üreticileri değerlendirilmiş olup çalışma seçilen firmanın çalıştığı diğer üretim alanları için de yapılabilir. Bu durumda vakaya özgü kriterlerin eklenmesi gerekebilir. Bu çalışma sadece seçilen firma ve diğer savunma sanayi firmaları tarafından değil, talaşlı imalat malzemeleri tedarik eden diğer firmalar tarafından kendi tedarik ortamlarına uygun olarak kullanılabilir.

Bu öneriler ışığında, seçilen firmaya tüm imalat alanlarında tedarikçilerin performanslarını görüntüleyebileceği etkin ve kapsamlı bir tedarikçi değerlendirme sistemi kurmayı hedefledik. Önerilen tedarikçi değerlendirme sisteminin tedarikçi ilişkileri yönetimi modülüne aktarılması ile ilgili çalışmalar yapılmakta ve fiyatın ana kriter olarak eklenmesi ile hayata geçirilebilmesi konuşulmaktadır.

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