AGILE SUPPLIER SELECTION EMPLOYING FUZZY MULTI CRITERIA DECISION MAKING APPROACHES

(BULANIK ÇOK KRİTERLİ KARAR VERME YAKLAŞIMLARI KULLANIMI İLE ÇEVİK TEDARİKÇİ SEÇİMİ)

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LIST OF SYMBOLS

SCM	:	Supply chain management
AHP	:	Analytic Hierarchy Process
ANP	:	Analytic Network Process
VPA	:	Vendor Profile Analysis
MOP	:	Multiple Objective Programming
FMLMCDM	:	Fuzzy Multi-Level Multi-Criteria Decision Making
TOPSIS	:	Techniques for Order Preference by Similarity to Ideal Solution
MOORA	:	Multi-Objective Optimization on the basis of Ratio Analysis
CI	:	Collective Index
MCDM	:	Multi-Criteria Decision Making
DEA	:	Data Envelopment Analysis
DEMATEL	:	Decision Making Trial and Evaluation Laboratory
MIMOP	:	Mixed Integer Multi-Objective Programming
RBF	:	Radial Basis Function
ANN	:	Artificial Neural Networks
MCDA	:	Multi-Criteria Decision Analysis
MADM	:	Multi-Attribute Decision Making
MODM	:	Multi-Objective Decision Making
PIS	:	Positive Ideal Solution
NIS	:	Negative Ideal Solution

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ABSTRACT

As a consequence of technological developments, pace of life have become faster than as it was previously. Instantaneous changes may occur in any time that should be responded appropriately. The corresponding changes fluctuates the stability of the business environment as well. Increased competitiveness of the market enforces companies to respond quickly and appropriately to sudden changes in the market in order to adapt to continuously updated conditions of business environment and keep their survivals. Agility concept rises at this level due to necessity of coping with unpredictable changes and uncertainty. Agility enables the firms responsiveness in a quick and an effective way to the set of interdependent changes required in design, production, marketing and organization of the companies. These fields are mainly belong to Manufacturing and Supply Chain approaches. Since the Supply Chain is a comprehensive concept which have direct or indirect effects on production and marketing aspects of the companies, it is crucial for the companies to implement agility concept through the supply chain. This procedure starts with selecting the appropriate supplier which provides the requirements for agile concept. These requirements belong to a variety of criteria contains of both quantitative and qualitative entities needed to be dealt with. In this regard; One of the most effective methodologies is implementing Fuzzy Multi Criteria Decision Making techniques in order to cope with the complexity of differentiated criteria in terms of units and entities. This study addresses agile supplier selection problem. It is presented two fuzzy multi criteria decision making approaches while examining the corresponding problem. First methodology is named as Hierarchical Fuzzy Multi Criteria Decision Making approach and the second one is Hierarchical Fuzzy Technique for Order Preference by Similarity to Ideal Solution approach. A case study for agile supplier selection problem is conducted in an airline company as well.

ÖZET

Teknolojik gelişmelerin sonucunda, yaşam temposu daha önce olduğundan hızlı bir hal almıştır. Değişimler her an gerçekleşebilir ve uygun bir biçimde tepki verilmesi gerekmektedir. Sözkonusu değişimler iş ortamınının durağanlığını da dalgalandırmaktadır. Piyasalarda yükselen rekabet, iş ortamının sürekli güncellenen koşullarına ayak uydurmak ve varlıklarını sürdürebilmek adına, şirketleri anlık değişimlere çabuk ve uygun bir biçimde tepki vermeye mecbur bırakmaktadır. Çeviklik kavramı da öngörülemeyen değişimlerin ve belirsizliğin üstesinden gelinmesi gerekliliğinden dolayı bu aşamada ortaya çıkmıştır. Çeviklik işletmelere tasarım, üretim, pazarlama ve organizasyon alanlarında gereken birbirine bağımlı değişimlere hızlı çözüm oluşturma yeteneği katmaktadır. Bu alanlar ağırlıklı olarak İmalat ve Tedarik zinciri yaklaşımları ile bağlantılıdır. Tedarik Zinciri, işletmelerin Üretim ve Pazarlama alanlarına doğrudan veya dolaylı etkilere sahip olduğundan dolayı, Çeviklik kavramının Tedarik Zinciri üzerinde uygulanması, şirketler için çok önemlidir. Bu süreç, Çeviklik kavramının gerekliliklerini temin eden tedarikçilerin seçimi ile başlamaktadır. Bu gereklilikler nitel ve nicel mevcudiyetler barındıran ve ele alınması gereken çeşitli kriterlere dayanır. Bu bağlamda en etkili yöntemlerden bir tanesi, birimler ve oluşumlar bakımından farklılaşan kriterlerin karmaşıklığını ele almak amacı ile Bulanık Çok Kriterli Karar Verme tekniklerinin uygulanmasıdır. Bu çalışma çevik tedarikçi seçimi problemi ele almaktadır. İlgili problem incelenirken iki adet Bulanık Çok Kriterli Karar Verme yaklaşımı anlatılmıştır. Birinci yöntem Bulanık Hiyerarşik Çok Kriterli Karar verme yaklaşımı olarak ismlendirilmiş olup, ikinci yöntem ise Hiyerarşik Bulanık TOPSIS yaklaşımıdır. Çevik tedarikçi seçimi problemi için bir havayolu firmasında vaka analizi de yürütülmüştür.

1.INTRODUCTION

In recent years, due to rise of competition in market, international cooperation with vertical disintegration have been rising. This makes competing as single autonomous entities impossible for individual businesses. It is essential to design and manage a network of interdependent relationships prospered and supported through strategic collaboration (Chen & Paulraj, 2004). Moreover; this novel perspective has created a challenge of focusing on core activities have led to the notion that firms are links in a networked supply chain. This leads to result that the eventual success of the single business will depend on management's capability for integration of the firm's intricate network of business relationships, which is enhanced by an effective supply chain. Furthermore; although success indicators for manufacturing firms are generally lower manufacturing costs, shorter cycle times, shorter lead times, as much as less inventory, high quality characteristics with better customer satisfaction, these are not adequate to convince that the firm is successful by itself. Additionally, the firm would need to balance the levels demand, supply and production to determine the success level. Therefore, concept of effective supply chain is an irreplaceable element for companies.

The basis of the supply chain conception has been reinforced by a variety of research areas including, the quality innovation, concepts of materials management and integrated logistics, an increased focus in industrial markets and networks, the notion of growing interest and effectual industry focused studies.

Supply chain is an integration of manufacturing process in which raw materials are converted into final goods. Afterwards; the goods are delivered to customer. In the most complex cases, a supply chain encompasses two stepped interdependent and integrated processes: former process is Production Planning and Inventory Control.

Process and the latter one is Distribution and Logistics Process. The processes mentioned are illustrated below in Figure 1.1, for providing the basic scheme for the movement and transformation of raw materials into final goods.

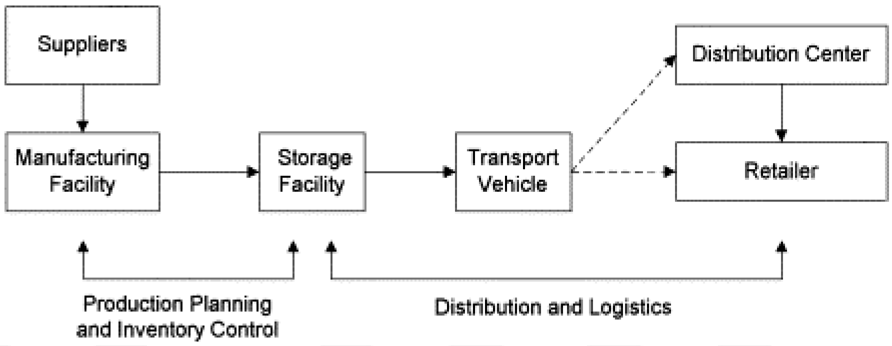

Figure 1.1: The Supply Chain Process

The Production Planning and Inventory Control Process comprises the manufacturing and storage activities, and their interactions. Particularly, the focus of production planning is based on the design, implementation and control of the entire manufacturing process from macro perspective of capacity planning to micro perspective of scheduling. The focus of inventory control is based on the organization of the inventory policies and procedures for raw materials, work-in-process inventories, and final products.

The Distribution and Logistics Process designs and manages retrieving and transportation processes of products from the storage facilities such as warehouses to retailers. The transportation may possibly be accomplished to retailers directly, or indirectly through the distribution centers. This process includes the management of inventory retrieval, transportation, and final product delivery.

The interaction and integration of these processes is considerably important since an effective design and implementation of these processes would result in such a supply chain operates as a whole unit to achieve organizational performance objectives (Beamon, 1998).

Supply chain incorporates multiple attributes such as supplier, manufacturer/servicer and customer. These attributes are involved in multiple relationships which is considerably challenging to manage with. progressively, management of identified relationships is being referred as supply chain management (SCM) which is the series of actions for designing, performing and controlling the procedures of the supply chain effectively. SCM comprehends every endeavor including all activities and storage of raw materials, work-in-process inventory, and finished goods from the point-of-provide to the point-of-demand. SCM Supply chain management focuses on improving performance through using internal and external resources effectively to design and create a perfectly coordinated supply chain, thus elevating inter-company competition to inter-supply chain competition (Chen & Paulraj, 2004).

Many firms aim to cooperate with the suppliers they work with to improve their management effectiveness and competitive power (Shin et al.,2000). The modernized supply management is to sustain long term alliance with suppliers, in limitation of using as much as fewer but reliable suppliers. In this case; purchasing activity is accepted as a critical element in institutions. Customer and supplier connections in companies deserves a considerable attention. Thus, choosing the right suppliers requires much more than cost comparison, and selections will be anticipated by a wide range of quantitative and qualitative factors. After a supplier is completely integrated into a sufficiently conducted and organized supply chain, the relationship at issue will possess a long termed impact on the competitive power of the whole supply chain. Thus, the supplier selection problem has a crucial role for organizing an effective system for supply chain. General aim of supplier selection problem is for reduction in risk of purchase, maximization in comprehensive value to the customer, and construct intimacy and long-term connections between consumer and suppliers (Chen et al.,2006).

A variety of methodologies have been suggested for the supplier selection problem. The orderly analysis for supplier selection incorporates, weighted point method, analytic hierarchy process (AHP) and analytic network process (ANP), matrix approach and vendor performance matrix approach, vendor profile analysis (VPA), categorical method, mathematical programming and multiple objective programming (MOP) (Boran et al., 2009).

Most of these methodologies do not appear to discuss the complicated and unstructured character and framework of contemporary purchasing decisions (de Boer et al., 1998). Only quantitative criteria have predominantly been focused on for supplier selection in existing decision models in the literature. Various influence elements are often not considered in the decision-making process, such as incomplete information, additional qualitative criteria and imprecision preferences (Boran et al., 2009). Moreover; these ignored influence elements generate the source of environmental uncertainty.

Uncertainty has been an important issue in a variety of fields, including organization theory, marketing, and strategic management. Supply chains are plagued by Uncertainty, emerges from three different sources. Firstly, supplier uncertainty is a consequence of on-time performance, average lateness, and degree of inconsistency etc. Secondly, manufacturing uncertainty is a result of process performance, machine breakdown, supply chain performance, etc. Thirdly, customer or demand uncertainty, is a drawback of forecasting errors, irregular orders and so on (Chen & Paulraj, 2004).

Agility for businesses, is emerged from the need of dealing with unpredictable changes and uncertainty. To comprehend the progression of the scope of the agility concept, sufficiently representative definitions of agility in the literature is stated as follows; The capability to advance the movements on a critical path that initiated with the recognition of a market requirement and completed with shipment of a customer designated product A comprehensive reaction to commercial difficulties of profiting from rapid change, continuously decomposition of global markets for highly competent and accomplished customized goods and services. Qualification for producing and marketing fairly a wide range of low cost, high quality customized products with short lead times in varying lot sizes, which afford embellished value to particular consumers. The capability of a company to give immediate response successfully to change. The ability of surviving by replying instantaneously and effectively to market changes compelled by customized products and services. The competence of an institution to grow in an unpredictable, continuously changing business environment. The capability of companies to deal with sudden changes, to survive exceptional threats from the global market, and seize benefit of changes as opportunities. The enterprise's ability to acquire competitive advantage by cleverly, very quickly and proactively taking opportunities and responding to threats. It is the competency to either create or react to change for profiting in a fluctuating business environment. A set of interdependent changes in design, production, marketing and organization. The capability for competently changing performing states to respond to demand uncertainty and changes. As it is possible to observe from the outstanding examples of the existing literature, agility concept is categorized through two different perspectives which are manufacturing and supply chain perspectives.

Over the manufacturing perspective, the idea of agility introduced in related area and became popular in 1991 by researchers at the Iaccoca Institute of Lehigh University. The idea emerged through the perception of industry authorities whose objective was to achieve a significant contribution in the manufacturing perspective to focus on revolutions in the global market which is hardly competitive. The term agility is defined as: An exceptionally capable manufacturing system within competence including technologies and human resources with trained management, information, in response to the quick change in needs such as flexibility and responsiveness of the market environment in a group of product lines or product models perfectly in real-time reaction to consumer need.

Agile manufacturing, continually aims to adapt new technologies and respond quickly to the customized expectations which requires high responsiveness at all fractions of the business, however, it is considerably challenging to implement on the production stage. One of the most critical needs for execution of an agile manufacturing system is to enhance its control system to give quick responses and to adapt rapid changes in production variables. Furthermore; flexibility, openness, scalability and being reconfigurable is essential for an agile manufacturing system to cope with more complex and uncertain information flows (Kootbally, 2016).

Through the supply chain perspective; objective of the agility concept is similar with one for the manufacturing perspective, which is adaptation for rapid changes in the global environment to keep competitive ability. In agile supply chain research area, the agile supply chain modeling is an important approach. Supply chain agility is defined and redefined many times in the literature; Sharp et al. (1999) formed a concept for supply chain agility as the capability for quickly reacting to changes, occurred in business environment and customer requirements, however; Ismail & Sharifi (2006) defined it as the ability of the supply chain and its elements acting as an entire entity for immediately cooperation of the network with the underlying activities in order to respond to fluctuating customer needs. One and the other of these descriptions are alike to ones for organizational and manufacturing agility, in which it was emphasized the capability to give immediate responses to varied customer requirements. Moreover; Li et al. (2008) described the agility as the consequence of combining readiness for changes which emerged from internal and external sources, which introduces both favorable and unfavorable circumstances, with a competency to utilize resources in order to give proactive or reactive response to corresponding changes, at the right time and in a flexible way.

An agile supply chain needs to carry characteristics, which are a high degree of synergetic relationships, customer/marketing sensitivity, process and information integration, will lead to discrimination of abilities: flexibility, quickness, responsiveness, and competency. Additionally, several other common elements, organizational structure, mobilization of core competencies, change as opportunity and customization are used to describe the concept of supply chain agility.

Since gaining competitive power is crucial for the firms and one of the most efficient concepts occurs a great fit to be utilized to achieve as mentioned power is agility, agile manufacturing catches great deal of attention. In this point achieving manufacturing agility is not adequate by itself, it is essential that manufacturing agility should be supported by supply chain agility as well. To achieve supply chain agility, agile supplier selection with relevant evaluation methodology and criteria becomes the considerably important problem to be questioned in this thesis. Rest of the thesis is organized as follows: In section 2, existing literature is reviewed. In section 3, Multi Criteria Decision Making problem and the corresponding methodologies are introduced. Fuzzy set is mentioned in section 4. In section 5, proposed methodology is clarified step by step. In section 6, application is clarified and in section 7 the conclusion is provided.

2. LITERATURE REVIEW

Although, literature on concepts, supply chain management, agility and agile manufacturing has started to accumulate earlier, agile supplier selection is a new paradigm, emerged in the last few years. Thus, the existing literature is not providing a wide range of agile supplier selection, however; criteria considered varies in a satisfactory level. The review is conducted through the Thomson Reuters Web of Science Tool and the quote “Agile Supplier Selection” is searched in topics between the years 1975-2016. Findings will be presented starting from the newest in chronological order.

Matawale et al. (2016) proposed a research with an application feasibility of fuzzy multi-level multi-criteria decision making (FMLMCDM) approach (Chu and Velásquez, 2009; Chu and Varma, 2012) examined with Fuzzy-techniques for order preference by similarity to ideal solution (TOPSIS) as well as Fuzzy-MOORA to assist the progress of suppliers’ selection and evaluation in an agile supply chain. Potential of the fuzzy multi-level multi-criteria decision making (FMLMCDM) approach proposed by Chu and Velásquez (2009) and Chu and Varma (2012) has been applied as methodology and compared to that of Fuzzy-techniques for order preference by similarity to ideal solution (TOPSIS) and Fuzzy-MOORA in the context of supplier selection in ASC. Five main criteria, flexibility, responsiveness, competency, balance and cost and sub-criteria also exist. The results provided, similar ranking order is reached in FMLMCDM as well as Fuzzy-TOPSIS. In Fuzzy-MOORA, the best alternative is kept same as in case of FMLMCDM as well as Fuzzy-TOPSIS; however; for other alternatives ranking order differentiated. A comprehensive comparison has also been made in perspective of working principles of FMLMCDM, Fuzzy-TOPSIS as well as Fuzzy-MOORA.

Matawale et al. (2016) conducted another study in which aims to focus on of a supplier selection procedure in the context of ASC. Linguistic attributes are considered to examine appropriateness rating additional to priority weights for individual criterions which are both quantitative and qualitative. Afterwards, the candidate supplier alternatives ordered by rank adequately and resolved by using vague set theory instead of fuzzy sets. Management and technological ability, financial quality, company resources and quality considered as criteria and sub-criteria exist. A case study has been conducted. It has been proved that the methodology would be effective in considering various evaluation criterion; may be contradicting within beneficial and cost criterions. The superiority of application of vague set theory has also been proved for studying under uncertain (fuzzy) decision-making environment in comparison to fuzzy set theory.

Sahu et al. (2016) provided a research to develop a multiple criterion evaluation model for supplier/partner alternative firm criterion perspective under similar agile supply chain structure. Subjective evaluation information indices have been transformed by fuzzy-based computation module. A new interval-valued fuzzy number set conjunction with altered "technique for order preference by similarity to ideal solution" method was conducted by ranking order of firm under similar criterion point of view of supplier firms. The seven main criteria are stated as follows; Production and logistics management, Technology and knowledge management, Partnership management, Marketing Capability, Financial capability, Organizational and Industrial competitiveness and Human resource management. In the related study, "fuzzy mathematical equation" has been developed in sensitive for figure out the priority weights and appropriateness ratings of first-level measures which reduced the acquisition of supplementary priority weights and appropriateness ratings assessment in linguistic terms from group decision makers (DMs) for first-level indices. A case study has been conducted ranking order the candidate partner/supplier alternative through collective index (CI) value. The higher degree of performance extent is reflected by Lower value of "CI". The authors found out that the proposed methodology works effectively and validly for constructed evaluation module.
Felice et al.(2015) demonstrated an effective application of MCDM concept for the supplier selection process. As a methodology, analytic hierarchy process (AHP), which is an extensive method for evaluation of qualitative data. In the corresponding method, it

is quite possible to convert the qualitative data to information ranking or pairwise comparison data. Technical capability, Performance of the supplier, Reputation, Supplier quality system, Geographical location, Financial status, Price and cost are considered as main criteria Consequently; a result is achieved that the most important criteria is identified as a set in which high quality, low costs and customer responsiveness are included.

Beikkhakhian et al. (2016) leveled the suppliers' evaluation criteria thorough ISM as methodology, afterwards, each criterion is weighed with fuzzy AHP and the suppliers are ranked through TOPSIS method. In this study, first, crucial factors for supplier selection are specified and next, using ISM model the factors are leveled. Finally, the AHP and fuzzy TOPSIS methods are conducted in order to rank the suppliers. Uncertainty minimization, Customer satisfaction, Lead time minimization, Data accuracy, Cost minimization, Information technology tools, Delivery speed, Price, Transportation, Quality improvement are the main criteria in selection. The results provided that it is possible for institutions to implement the given methodology for supplier selection and address on interpretive structural model in which derives driving power variables to grow the efficiency and agility of suppliers.

Sellitto et al. (2015) proposed a model for supply chain performance measurement application in the footwear industry. The model provides an aggregate value of the extension level of strategies implemented and succeeded in terms of agile concept and concluded that cost, flexibility and delivery time need to be considered as main criteria and the revision and improvement through these criteria inevitably results in development in performance ratings of the suppliers.

Lee et al. (2015) represented a framework for supplier selectors, with possessing a decision support system including the Pareto fronts, which are a group of the most successful, providing high-quality standards suppliers with a perfectly planned and implemented business activity levels from these qualified suppliers. Furthermore; it is quantified that the agility criterion's significance and the sub-criteria in the progress of evaluation and selection of the agile suppliers by determining the importance of inventory costs and bullwhip effect. Fuzzy TOPSIS and Fuzzy AHP are conducted to successful determination of the priority weights of multiple criteria and selection of the most appropriate suppliers in consideration of the imprecision and vagueness of human assessments with representing result of the supplier chains for varied priority weights of the agility criterion and its sub-criteria. This representation is accomplished by Pareto fronts approximately. Four perspectives are examined as main criteria in the study, Manufacturing capability, general management capability, Collaboration capability and Agility. It is presented that Pareto fronts of agile and non-agile supply chains to anticipate fluctuations in business efficiency levels measured in the degree of bullwhip effect and inventory cost as the weight of agility criterion variation. The Pareto fronts under consideration, supports the decision makers for determination of an adequate degree in terms of agility in their supply chains arrangement in regard of the fact that the business efficiency improvement at a decreasing rate as a higher level of agility is desired. Moreover, a variety of Pareto fronts, belong to sub-criteria in agility criterion resulted in a recommendation that, it is essential for decision makers to comprehend the corresponding influences of sub-criteria and avoid from significant variations on priority weights of sub-criteria from values recommended by authorities.

Abdollahi et al. (2015) provided a demonstration for supplier selection based on the features related to product and organizational characteristics of the suppliers to gain competitive advantage in business environment and increase the level of flexibility against possible fluctuations in supplies, demand and so on. Since the criteria interact each other, analytical network process (ANP) is implemented to determine each candidate supplier’s criteria weights. It is followed by data envelopment analysis (DEA) for ranking process. Since the proposed criteria are accurately interdependent, a fuzzy decision making trial and evaluation laboratory (DEMATEL) is conducted in order to resolve the interdependency. The proposed criteria which are Technological capability, Human capability, Managerial systems capability and Cultural capability. The paper possesses to present a structure for both supplier evaluation and selection in view of agile and lean criteria. Examination depends on a DEMATEL–ANP–DEA model which enhances to incorporate various suppliers in determination of the efficiencies respectively. Performance scores are integrated into the determined efficiency scores. The developed combination is used for classification of suppliers through four proposed criteria. The Criteria are found effective to increase the efficiency of the operations belong to unsatisfactory suppliers. The few beneficial administrative experiences and suggestions from the review are additionally discussed are accommodated enhancing the operations of inadequately performing suppliers.

N. Viswanadham & A. Samvedi (2013) determined decision criteria which based on both performance risk, both criteria are crucial to the supply chain. AHP and fuzzy technique, including order of preference by closeness to ideal solution were implemented for MCDM and strengthened with a numerical example. Performance and Risk perspectives are assumed two main criteria in this survey. The proposed study enhances to examine risk and performance criteria simultaneously with equal importance.

Wu & Barnes, (2012) conducted a study includes a dynamic feedback model consist of four-phases for supplier selection in agile supply chains (ASCs) which works efficiently and responsive in rapidly changing markets. Nevertheless, selection partners in ASCs is innately more complicated and challenging under uncertain and ambiguous conditions of as supply chains need to organize or re-organize by itself. The proposed model focuses on techniques involving quantitative and qualitative methods such as analytic network process-mixed integer multi-objective programming (ANP-MIMOP), radial basis function artificial neural networks (RBF-ANN), the Dempster-Shafer and optimization theories, Complexity-fit and Costs-benefits are the main criteria and other queries
exist below these two criteria. The model enhances decision makers to make effective and efficient abstraction and utilization of the largely spread data that is available and it provides an inclusive and accurate approach to a complicated case.

Luo et al. (2009) studied on a model that supports a possibility for coping with the difficulties of information-processing occurs in examining a large number of candidate suppliers in the very beginning moments of the selection procedure. The model enhances to examine candidate suppliers against multiple criteria based on artificial neural network (RBF-ANN) using both qualitative and quantitative criteria. The main criteria includes, financial quality, management and technology ability, Company resources and quality and relevant sub-criteria. The most important acquisition of the proposed model stated in this paper about the usage of the classification matrix, which enhances visualization of strength and weakness of each potential supplier's during the evaluation procedure. This leads to enhance decision makers make more rational decisions on potential suppliers.

Table 2.1 represents the methodology implemented in agile supplier selection problems in the literature.

Table 2.1: Implemented Methodology for Agile Supplier Selection Problems

Author	Year	Title	Methodology
Matawale et al.	2016	Supplier selection in agile supply chain: Application potential of FMLMCDM approach in comparison with Fuzzy-TOPSIS and Fuzzy-MOORA.	FMLMCDM, TOPSIS,and Fuzzy-MOORA
Matawale et al.	2016	Supplier/partner selection in agile supply chain: Application of vague set as a decision making tool.	Vague Set Theory
Sahu et al.	2016	Application of integrated TOPSIS in ASC index: partners benchmarking perspective.	TOPSIS
Felice et al.	2015	Performance Measurement Model for the Supplier Selection Based on AHP.	AHP
Beikkhakhian et al.	2015	The application of ISM model in evaluating agile suppliers selection criteria and ranking suppliers using fuzzy TOPSIS-AHP methods.	Fuzzy TOPSIS and AHP
Sellitto et al.	2015	A SCOR-based model for supply chain performance measurement: application in the footwear industry.	SCOR and AHP
Lee et al.	2015	Assessing business impacts of agility criterion and order allocation strategy in multi-criteria supplier selection	Fuzzy AHP and Fuzzy TOPSIS
Abdollahi et al.	2015	An integrated approach for supplier portfolio selection: Lean or agile?	ANP,DEA andDEMATEL
Li Qian	2014	Market-based supplier selection with price, delivery time, and service level dependent demand.	General Analytical Mocel
N. Viswanadham & A. Samvedi	2013	A. Supplier selection based on supply chain ecosystem, performance and risk criteria	Fuzzy AHP and Fuzzy TOPSIS
Wu & Barnes	2011	A dynamic feedback model for partner selection in agile supply chains	ANP-MIMOP
Luo et al.	2009	Supplier selection in agile supply chains: An information-processing model and an illustration	RBF-ANN

3. MULTI CRITERIA DECISION MAKING

MCDM (multi-criteria decision-making) or MCDA (multi-criteria decision analysis) are acclaimed branch for decision making. This methodological framework refer to knowledgeable recommendation in the presence of multiple alternatives and in consideration of generally conflicting multiple criteria. In MCDM problems, there is a finite set of alternatives, called actions, solutions, objects or candidates. The alternatives are taken into consideration through multiple criteria, known as attributes, objectives or features (Balteiro, L.D. & Romero, C., 2008). The criteria may include both qualitative and quantitative factors. Alternatives, including a product, an organization or an action plan of any kind, is possibly be assessed on the roots of attributes. An attribute is a feature, quality or property of alternatives in question. A part of the attributes may divide into further into sub-attributes. A criterion is set up for each attribute for evaluation of an alternative. Since the objectives in MCDM problems conflict each other, the decision resolved is strongly dependent on the decision-maker's preferences. Therefore, the process usually involves a variety of groups of decision-makers. Each group comes up with different criteria and perspective. This variation must be resolved within structural framework of understanding and consensus. (Pohekar,S.D. & Ramachandran, M., 2004) MCDM has been developed as a branch of operations research, based on designing computational and mathematical tools for dealing with the subjective and imprecise evaluation of performance criteria by decision-makers (Mardani et al., 2015).

The major concept of MCDM is further divided into two sub-concepts that multi-attribute decision making (MADM) and multi-objective decision making (MODM) (Pohekar S.D, and Ramachandran, M., 2004). This division occurs from having a finite or infinite number of alternative solutions. Generally, in problems related to selection and evaluation, a limited number of alternative solutions exist. However; in problems associated with design, the value of an attribute may be varied in a wide interval which results in an infinite number of the potential alternative solutions. In this case; the problem is categorized as to as multiple objective optimization problems. Otherwise; the problem is named as multiple attribute decision problems.

MCDM is an effective way for working in hybrid nature. It enhances to make decision through incommensurable units. Attributes may be non-quantitative or a combination of quantitative and qualitative attributes in many decision problems. Moreover; mixture of probabilistic and deterministic attributes is also considered.

The decision-making process starts with the identification of the objective/goal of the decision-making process. It is followed by the selection of the Criteria / Parameters / Factors / Decider. The criteria must be selected coherently with the decision, represented in same scale, independent of each other, measurable and related with the alternatives. The next step is selection of the alternatives. In this case, it is important to consider that alternatives must be comparable, available, practical / feasible and real instead of ideal. After an adequate number of alternatives are selected, representation of importance is essentially be made with a proper basis of the weighing methods. The weight determination methods can be either compensatory or non-compensatory. Tradeoffs between attributes are not permitted in Non-compensatory methods. It is not possible to compensate an unsatisfactory value in one attribute by a satisfactory value in other attributes. In other words; each attribute must survive by itself. Therefore; attribute-by-attribute comparisons are made. The main reason for the MCDM methods are credited in this category is the simplicity they provide. Tradeoffs are allowed between attributes in compensatory methods. A minor drop in one of the attributes can be accepted if the possible enhancements in other attributes is compensates it. After the selection of the weighing methods, an aggregation method is determined. It can be a product, average or function and finally; As a consequence of the aggregation, the best alternative will eventually be separated from the other available options.

Some of the fundamental techniques in compensatory methods are, dominance method, Maxmax and Maxmin methods, conjunctive and disjunctive constraint methods. Dominance method stands for eliminating alternatives dominated by others and it is possible to reach multiple solutions with this method. The Maxmax method selects the most satisfactory alternative in terms of attribute values. However; comparable attributes is necessary to apply the Maxmax method. In contrast to Maxmax method, Maxmin method aims to determine the attribute with the least satisfactory value of each alternative and then based on the comparison of the weakest attribute value of all alternatives, best alternative is chosen. Like Maxmax method, this method can be applied if only attribute values are comparable each other. Conjunctive constraint method first determines a minimum expected value for each attribute, afterwards; the alternative which has an unsatisfactory attribute compared to the minimum expected value, is eliminated. In the disjunctive constraint method an alternative is evaluated with only its best attribute is focused. Although it is possible to implement these techniques in some areas, it is considerably restricted. Generally, they are not very useful in decision making.

Compensatory methods can be classified into the following four subgroups which are scoring methods, compromising methods, concordance methods and evidential reasoning approach. Scoring method makes utility based selections or evaluations on an alternative. The preferences of decision makers are expressed by utility or score. Attribute values are transformed into a common preference scale enhances to compare different attributes. Another well-known branch in compensatory methods is the Simple Additive Weighting method in which the overall score of a candidate is calculated as the weighted sum of scores or utilities of an attribute. The Analytical Hierarchy Process (AHP) is another spread implemented method in Simple Additive Weighting methods. In this methodology, scores for each alternative are calculated based on pairwise comparisons. Compromising method is also commonly used in which the closes alternative to ideal solution is selected. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method occurs a strong illustration for this category. This method begins with normalization of the decision matrix in a MCDM problem. It is followed by calculation of the weighed distances of each alternative to ideal solution based on the normalized matrix.

Stewart (1991) concluded that some of these approaches are considerably unjustified on theoretical or empirical aspects. While selecting appropriate method, the inputs determined by decision maker should be clearly defined and purified from ambiguities. Furthermore; corresponding inputs should necessarily be translated into complete or partial recommendations with reasonable assumptions and should be as possible as transparent to decision maker. Finally, the method should be efficient and simple to implement.

4. FUZZY SET THEORY

Most of the classical methods for formal modelling, in which the reality is not reflected adequately, are crisp. Crispness is a structure in which a binary, yes or no type data are conceptualized. In this logic, a statement must be true or false and there is not such a possibility for belonging in between. In set theory, it must be precisely identified that an element can either be a member of a set or not. Precision as mentioned, does not allow any ambiguity.

Certainty implies all the parameters and structures of the model are absolutely known and their values and occurrences are definite. The certainty is more valid for formal models including arbitrary assumptions, made by model builder. In this case, the model is builder free to choose model characteristics as he desires. However; if the model reflects the reality, drawn from facts rather than the assumptions, then the model characteristics must be suited to the current, real situation appropriately. (Zimmermann, 1980). For the factual models two major complexities appear; The former, the real situations are usually imprecise, not deterministic and crisp. The latter, it is required a more detailed data to describe the real system adequately.

If the features of the real-world systems are considered, the first remarkable characteristic is the mentioned system is usually uncertain and vague in various aspects. The future state of the system might not be precisely known due to lack of information about the elements or structure of the system. It is possible to deal with this stochastic character by probability theory and statistics. However, in this methodology, the statements or the elements of sets are defined precisely. This type of vagueness or uncertainty is named as stochastic uncertainty. The source of vagueness might also be the description of the semantic meaning of elements of the set or statements which is named as fuzziness.

Fuzziness can possibly be observed in many areas, such as manufacturing, engineering, medicine, meteorology and others. All the areas, include fuzziness have a feature in common, which is the importance of human judgement, evaluation and decision. These areas enforce the authorities for making the relevant evaluations reasoning and most importantly, decisions. While deciding, or evaluating an element or a statement, some standards, characteristics in meaning of words becomes subjective due to the structure of the natural language, which raises the vagueness. Even the meaning of a word is well defined, when using the word for description of a set as a label, the set's boundaries, determine the issue which elements is or is not a member of the set becomes vague or fuzzy. These boundaries are fuzzy since not only meaning of the word or dependency on the context, but also the subjectivity of the evaluators. In other words; fuzziness depends on the application area and the measurement methodology.

Fuzzy set theory, introduced by Zadeh (1965) to provide a methodology to deal with the problems, including imprecision caused by vagueness rather than knowledge about a value of a parameter for the class membership. The theory has been applied for incorporation of the imprecise data into the decision framework.

4.1. Basic Definitions & Operations

The crisp set is defined in such a way as a collection of elements to and the elements are dichotomized in some given universe of discourse into two groups: members and nonmembers. (Klir & Yuan ,1995). Zimmerman (2011) defined the member elements with a function. In crisp sets this function has a binary characteristic in which 1 indicates membership and 0 indicates non-membership. For the fuzzy set, it is possible to value the function in the interval [0,1] which means grade of membership. A fuzzy set $\widetilde{A}$ defined mathematically by assigning to each elements or objects in the universe of discourse a value indicating its grade of membership with a membership function in the fuzzy set (Klir & Yuan ,1995).

A triangular fuzzy number $\tilde{A}$ can be defined by a triplet (a, b, c) as illustrated in Fig. 4.1.1.

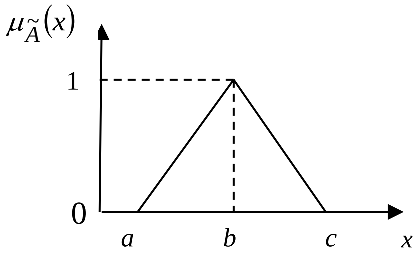

Figure 4.1.1: A triangular fuzzy number

The membership function $\mu_{\tilde{A}}(x)$ is defined as

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-a}{b-a}, & a \leq x < b \\ \frac{x-b}{b-c}, & b \leq x \leq c \\ 0, & otherwise \end{cases} \tag{4.1.1}$$

Preliminary arithmetic operations on triangular fuzzy numbers $A_1 = (a_1, b_1, c_1)$, where $a_1 \leq b_1 \leq c_1$, and $A_2 = (a_2, b_2, c_2)$, where $a_2 \leq b_2 \leq c_2$, can be shown as follows:

Addition: $$A_1 \oplus A_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \tag{4.1.2}$$

Subtraction: $$A_1 \ominus A_2 = (a_1 - a_2, b_1 - b_2, c_1 - c_2) \tag{4.1.3}$$

Multiplication: If k is a scalar,

$$k \otimes A_1 = \begin{cases} (ka_1, kb_1, kc_1), & k > 0 \\ (kc_1, kb_1, ka_1), & k < 0 \end{cases} \tag{4.1.4a}$$

$$A_1 \otimes A_2 = (a_1a_2, b_1b_2, c_1c_2), \quad \text{if } a_1 \geq 0, a_2 \geq 0 \tag{4.1.4b}$$

Division: $$A_1 \phi A_2 \cong \left(\frac{a_1}{c_2}, \frac{b_1}{b_2}, \frac{c_1}{a_2}\right), \quad \text{if } a_1 \geq 0, a_2 > 0 \tag{4.1.5}$$

For the multiplication and division operations, it is possible to use triangular fuzzy number approximation practically, although the output of these operations on triangular fuzzy numbers, does not represent a fuzzy number. The main reason for the spread use of triangular fuzzy numbers to quantify the vagueness, that they are enabled to be represent intuitively and computational efficiently (Karsak, 2002).

The definition of a Linguistic variable is a variable in which the values are not assigned numerically but verbally in natural and artificial language in consideration of achievement to a precise representation of the conditions or situations under excessively complex environments.

A linguistic variable can be featured by a quintuple $(x, T(x), U, G, \widetilde{M})$ where x is labeled as name of the variable: $T(x)$ is defined as the set of x, in which carries the linguistic values of x, the values are fuzzy variables denoted by X and ranged through a universe of discourse U with the base variable u, G is a syntactic rule, generally defined in grammar form for identification of name of X and values of x, M is a semantic rule in relation with each X its meaning, $\widetilde{M}(X)$ occurs a fuzzy subset which belongs to U. Linguistic value of X ‘s meaning is determined by the definition of a compatibility function, $c: U \rightarrow [0,1]$. The corresponding function associates the compatibility each u in U with X. For instance, age 33 has a compatibility of with “young”, valued as 0.2, while the compatibility of 27 might be 0.7. The linguistic variable conceptually presents approximately characterized means of complex or ill-defined phenomena. The phenomena refers to something known through senses, however, it is quite challenging to describe it quantitatively. For instance, examination of the phenomena “truth” in terms of a linguistic variable with values such as completely true, very true, true, not very true etc., results in a rationalization of fuzzy logic by approximate reasoning (Zadeh,1975).

5. METHODOLOGY

5.1 Hierarchical Fuzzy MCDM Approach

While dealing with real-life decision problems in industry, including supplier selection in which requires a profound evaluation of alternatives in consideration of many performance attributes, a practical fuzzy logic based decision-making method, acknowledged as hierarchical distance-based fuzzy multi-criteria group decision making approach introduced by Karsak and Ahiska (2005) in evaluation of agile suppliers. The fuzzy multi-criteria group decision making approach is focused on the decision problems, structured within a multi-level hierarchy, including qualitative performance attributes. The multi-level hierarchy is required for organization in case of existence of a large number of performance attributes. The corresponding methodology, reinforces the decision-maker with improved identification of discrepancies and similarities of their judgments. (Yekta et al.,2015). This methodology is constructed based on the closeness to the ideal solution concept with an alternative and it gives an opportunity to include both crisp and fuzzy data within the performance of alternatives.

The following consecutive steps describes the implementation of the hierarchical DBF-MCDM approach:

***Step* 1.** The decision matrix is constructed, including the fuzzy assessments by linguistic variables related to qualitative criteria and sub-criteria and crisp values related to quantitative criteria and sub-criteria.

***Step* 2.** Both crisp and fuzzy data are normalized to acquire sub-criteria values which are comparable and free from units. The normalized values may not only benefit-based, but cost-based quantitative or qualitative criteria and sub-criteria are estimated by a linear scale transformation as;

$$y'_{ijk} = \begin{cases} \dfrac{y_{ijk} - y^{-}_{jk}}{y^{*}_{jk} - y^{-}_{jk}}, & k \in CB_j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \\ \dfrac{y^{*}_{jk} - y_{ijk}}{y^{*}_{jk} - y^{-}_{jk}}, & k \in CC_j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \end{cases} \tag{5.1.1}$$

Where y'_{ijk} represents the normalized value of y_{ijk}, in which is the crisp value assigned to alternative *i* with respect to the sub-criterion *k* of criterion *j*. Moreover; *m* denotes the number of alternatives; *n* identifies the number of criteria. CB_j is the set of benefit-related crisp sub-criteria of criterion *j* for which the higher the efficiency value the more performance of it and CC_j is the set of cost-related crisp sub-criteria of criterion *j* for which the higher the efficiency value the more performance of it, $y^{*}_{jk} = \max_i y_{ijk}$ and $y^{-}_{jk} = \min_i y_{ijk}$. The normalized values for crisp data can be represented as $\tilde{y}_{ijk} = (y'_{aijk}, y'_{bijk}, y'_{cijk})$ in triangular fuzzy number format, where $y'_{aijk} = y'_{bijk} = y'_{cijk} = y'_{ijk}$.

***Step* 3.** The performance ratings of alternatives are aggregated at the sub-criteria stage to criteria stage to figure out the aggregate performance ratings as follows:

$$\tilde{x}_{ij} = (x_{aij}, x_{bij}, x_{cij}) = \frac{\sum_k \tilde{w}^{1}_{jk} \otimes \tilde{y}_{ijk}}{\sum_k \tilde{w}^{1}_{jk}}, \forall i, j \tag{5.1.2}$$

where $\tilde{x}_{ij}$ indicates the aggregate performance rating of alternative *i* in relation with criterion *j*, the average importance weight assigned to sub-criterion *k* of criterion *j* is represented by $\tilde{w}^{1}_{jk}$ and $\otimes$ is the multiplication operator in fuzzy logic.

***Step* 4.** The aggregate performance ratings are normalized at criteria stage corresponding to a linear normalization method. Based on this method and it is possible to figure out from the following equation, the best result receive value equal to 1 and the worst one acquire equal to 0.

$$\tilde{r}_{ij} = (r_{aij}, r_{bij}, r_{cij}) = \left(\frac{x_{aij} - x_{aj}^{-}}{x_{cj}^{*} - x_{aj}^{-}}, \frac{x_{bij} - x_{aj}^{-}}{x_{cj}^{*} - x_{aj}^{-}}, \frac{x_{cij} - x_{aj}^{-}}{x_{cj}^{*} - x_{aj}^{-}} \right), \forall i, j \qquad (5.1.3)$$

where $\tilde{r}_{ij}$ denotes the normalized aggregate performance rating of alternative *i* with respect to criterion *j* and $x_{cj}^{*} = \max_{i} x_{cij}$, $x_{aj}^{-} = \min_{i} x_{aij}$.

***Step* 5.** The ideal solution $A^{*} = (r_1^{*}, r_2^{*}, \ldots, r_n^{*})$ and the anti-ideal solution $A^{-} = (r_1^{-}, r_2^{-}, \ldots, r_n^{-})$ are defined, where $r_j^{*} = (1,1,1)$ and $r_j^{-} = (0,0,0)$ for $j = 1, 2, \ldots, n$

***Step* 6.** Weighted distances from ideal solution and anti-ideal solution are computed as D_i^{*} and D_i^{-}, respectively. The weighted distances for each alternative are calculated as follows:

$$D_i^{*} = \sum_j 1/2 \left\{ \max(w_{aj}^{1} \left| r_{aij} - 1 \right|, w_{cj}^{1} \left| r_{cij} - 1 \right|) + w_{bj}^{1} \left| r_{bij} - 1 \right| \right\}, i = 1,2,...,m \qquad (5.1.4)$$

$$D_i^{-} = \sum_j 1/2 \left\{ \max(w_{aj}^{1} \left| r_{aij} - 0 \right|, w_{cj}^{1} \left| r_{cij} - 0 \right|) + w_{bj}^{1} \left| r_{bij} - 0 \right| \right\}, i = 1,2,...,m. \qquad (5.1.5)$$

***Step* 7.** Proximity of the alternatives to the ideal solution is represented with P_i^* and calculated by considering the distances from ideal and anti-ideal solutions as

$$P_i^* = D_i^- \Big/ \left(D_i^* + D_i^-\right), \; i = 1,2,...,m. \tag{5.1.6}$$

Step 8. Alternatives are ranked based on P_i^* values in descending order. The alternative with the highest P_i^* is identified as the best alternative.

5.2 Hierarchical Fuzzy TOPSIS

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a widely used method, introduced by Hwang and Yoon (1984). Conceptually; it is based on the choosing the alternative having the shortest distance to positive ideal solution (PIS) and the longest distance to negative ideal solution (NIS). These distances are the composition of the best and the worst performance ratings. The measurement of the proximity of the each alternative is computed through the Euclidean sense with the weight of criteria.

Since the fuzziness is often involved in MCDM problems, application of the classical TOPSIS method leads to problems related to dealing with the qualitative data. Fuzzy set theory is included in extension to fuzzy TOPSIS method which improves the rationality and comprehensiveness of the decision making process.

Since evaluation of the performance and decision making processes have become more complex, not only the experts' knowledge is considered, but also the information or indicators on criteria and their hierarchical structures through sub-criteria should be evaluated as well. Ateş et al. (2006) and Kahraman et al. (2007) introduced a sort of hierarchical fuzzy TOPSIS method in which the sub-criteria are considered within the same layer which damages hierarchical structure. Bao et al. (2012) followed the corresponding studies with designing a hierarchical fuzzy hierarchical TOPSIS model which enhances to respond the layered hierarchy of all criteria.

The proposed hierarchical fuzzy TOPSIS method can be described as follows:

***Step* 1.** The decision matrix is constructed, including the fuzzy assessments by linguistic variables related to qualitative criteria and sub-criteria and crisp values related to quantitative criteria and sub-criteria.

***Step* 2.** Both crisp and fuzzy data are normalized to acquire sub-criteria values which are comparable and free from units. The normalized values may not only benefit-based, but also cost-based quantitative or qualitative criteria and sub-criteria are estimated by a linear scale transformation as;

$$y'_{ijk} = \begin{cases} \dfrac{y_{ijk} - y^{-}_{jk}}{y^{*}_{jk} - y^{-}_{jk}}, & k \in CB_j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \\ \dfrac{y^{*}_{jk} - y_{ijk}}{y^{*}_{jk} - y^{-}_{jk}}, & k \in CC_j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \end{cases} \tag{5.2.1}$$

Where y'_{ijk} represents the normalized value of y_{ijk}, in which assigned to alternative *i* with respect to the sub-criterion *k* of criterion *j*. Moreover; *m* denotes the number of alternatives; *n* identifies the number of criteria. CB_j is the set of benefit-related crisp sub-criteria of criterion *j* for which the higher the efficiency value the more performance of it and CC_j is the set of cost-related crisp sub-criteria of criterion *j* for which the higher the efficiency value the more performance of it, $y^{*}_{jk} = \max_i y_{ijk}$ and $y^{-}_{jk} = \min_i y_{ijk}$. The normalized values for crisp data can be represented as $\tilde{y}_{ijk} = (y'_{aijk}, y'_{bijk}, y'_{cijk})$ in triangular fuzzy number format, where $y'_{aijk} = y'_{bijk} = y'_{cijk} = y'_{ijk}$.

***Step* 3.** The importance of the main criteria is determined by taking the arithmetic average of the weights of importance assigned to each criteria *j* by *N* experts as follows;

$$\tilde{w}_j = \frac{\tilde{w}_j^1 + \tilde{w}_j^2 + \cdots + \tilde{w}_j^N}{N}, \forall j \tag{5.2.2}$$

Where $\tilde{w}_j^N$ indicates the weight of importance in terms of linguistic variables assigned to criterion j by the *N*th decision maker.

***Step* 4.** Sub-criteria importance within the corresponding main criteria is determined based on the same method in *Step* 3.

$$\tilde{w}_{jk} = \frac{\tilde{w}_{jk}^1 + \tilde{w}_{jk}^2 + \cdots + \tilde{w}_{jk}^N}{N}, \forall j \tag{5.2.3}$$

Where $\tilde{w}_{jk}^N$ indicates the weight of importance in terms of linguistic variables assigned to sub-criterion *k* belongs to criterion *j* by the *N*th decision maker.

***Step* 5.** Final weight of importance for each sub-criterion is calculated with the product of the weighted importance of the main criteria ($\tilde{w}_j$) and the weighted importance of the sub-criteria ($\tilde{w}_{jk}$) within the corresponding main criterion respectively:

$$\widetilde{W}_{jk} = \tilde{w}_j \otimes \tilde{w}_{jk}, \forall j \tag{5.2.4}$$

Where $\widetilde{W}_{jk}$ indicates the finalized importance weight of the sub-criterion *k* within the main criterion *j*.

***Step* 6.** Weighted normalized decision matrix is obtained with the product of the normalized fuzzy performance ratings of each sub-criterion *k* of each alternative *i by* its corresponding final weight of importance:

$$\tilde{v}_{ijk} = y'_{ijk} \otimes \widetilde{W}_{jk} \ , \forall i, j, k \tag{5.2.5}$$

The obtained weighted normalized decision values ($\tilde{v}_{ijk}$) are aggregated with the fuzzy addition principle:

$$\tilde{v}_{ij} = \sum_{k=1}^{r_j} \tilde{v}_{ijk} \ , \forall i, j \tag{5.2.6}$$

Where $\tilde{v}_{ij}$ represents the aggregate performance rating of alternative *i* with respect to criterion *j* and r_j indicates the number of sub-criteria belongs to criterion *j*.

***Step* 7.** Fuzzy positive ideal solution (FPIS), $\tilde{A}^*$ and fuzzy negative ideal solution (FNIS), $\tilde{A}^-$ are defined as $\tilde{A}^* = [\tilde{v}_1^*, \ldots\ldots, \tilde{v}_n^*]$ for FPIS and $\tilde{A}^- = [\tilde{v}_1^-, \ldots\ldots, \tilde{v}_n^-]$ for NPIS. The $\tilde{v}_j^*$ and $\tilde{v}_j^-$ are consisted of the fuzzy numbers in which the largest and the smallest generalized mean is calculated respectively. The generalized mean for $\tilde{v}_{ij} = (a_{ij}, b_{ij}, c_{ij}), \forall j$ is defined as:

$$M(\tilde{v}_{ij}) \frac{-a_{ij}^2 + c_{ij}^2 - a_{ij}b_{ij} + b_{ij}c_{ij}}{[3(-a_{ij} + c_{ij})]} \tag{5.2.7}$$

For each criterion *j*, the largest and lowest generalized means are calculated as $\tilde{v}_j^*$ and $\tilde{v}_j^-$ respectively which leads to derivation of the FPIS ($\tilde{A}^*$) and FNIS ($\tilde{A}^-$).

***Step* 8.** Separation measures $\tilde{S}_i^*$ and $\tilde{S}_i^-$ are computed as follows:

$$\tilde{S}_i^* = \sum_{j=1}^{n} \widetilde{D}_{ij}^*, \forall i \qquad (5.2.8)$$

$$\tilde{S}_i^- = \sum_{j=1}^{n} \widetilde{D}_{ij}^-, \forall i \qquad (5.2.9)$$

Where the Euclidean distances $\widetilde{D}_{ij}^*$ and $\widetilde{D}_{ij}^-$ are defined as:

$$\widetilde{D}_{ij}^* = \begin{cases} 1 - \dfrac{c_{ij} - a^*}{b^* + c_{ij} - a^* - b_{ij}}, & b_{ij} < b^*, \\ 1 - \dfrac{c^* - a_{ij}}{b_{ij} + c^* - a_{ij} - b^*}, & b^* < b_{ij}, \end{cases} \quad \forall i, j \qquad (5.2.10)$$

$$\widetilde{D}_{ij}^- = \begin{cases} 1 - \dfrac{c^- - a_{ij}}{b_{ij} + c^- - a_{ij} - b^-}, & b^- < b_{ij}, \\ 1 - \dfrac{c_{ij} - a^{*-}}{b^- + c_{ij} - a^- - b_{ij}}, & b_{ij} < b^-, \end{cases} \quad \forall i, j \qquad (5.2.11)$$

Where $\tilde{v}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ indicates an arbitrary element of aggregate performance table, created as a result of *Step* 6. However; $\tilde{v}_j^* = (a^*, b^*, c^*)$ and $\tilde{v}_j^- = (a^-, b^-, c^-)$ correspond to the largest and smallest generalized mean, respectively.

***Step* 9.** Relative closeness to ideal (C_i) for each alternative is obtained for combining the separation measures $\tilde{S}_i^*$ and $\tilde{S}_i^-$ computed in previous step.

$$C_i = \frac{\tilde{S}_i^*}{\tilde{S}_i^* + \tilde{S}_i^-} \tag{5.2.12}$$

***Step* 10.** The alternatives are ranked based on C_i values in descending order. The alternative with the greatest C_i , identified as the best solution.

6. APPLICATION OF THE FUZZY MCDM METHODS TO AGILE SUPPLIER SELECTION

6.1. Agility in Airline Industry

Airline companies contributes extremely high profits and loss in their business environment. Many firms deal with the crisis by adopting agile business models. However; these business models achieves success would result in the firms in to contentment directed by profits in the short and medium period. Consequently; developing a long term situation is essential for further agility in the future.

Most business practices in the airline industry use a stable approach characterized as illustrates the business model at a point in time. If the profitability of an examined model is considered, it would be realized that it i under risk because of regulatory changes, technology innovations, competition, and customer preferences. The business model needs to be include constitutional features which enables it to give responses to declining business performance and uncertainty by modifying the underlying elements with obtaining or adapting the factors that resulted in an inefficient model. Moreover; the corresponding adaptation needs be sustainable and it is enhanced by agile business models which are adjusted and bolstered the obtained features continuously.

It is essential for an agile business model to perform in an environment with uncertainty regard of concern about minimizing decline in performance ratings over time. It is possible to achieve this establishment of a constitutional course of adaptability and flexibility in the model that will continuously be utilized to acquire analyze, strengthen, and benchmark the appropriate features needed to sustain the airline’s business performance. In most business practices, dramatic decreases in performance ratings are observed and possibly result in unsuccessful circumstances if the uncertainty emerges from environmental and internal existential threats and from external competitor.

However; in an agile business model, the performance ratings declines when uncertainty increases, but not dramatically since the corresponding uncertainty stage is defeated by sustainable agile practices and to a flowing adaptation stage by the obtain of necessary features which enhances the business model to deal with the uncertainty. The performance ratings rises when the obtained characteristics are enhanced and adjusted in to the business model.

The agile model to execute comes up with the requirements of the analyzing the core competencies of the airline company, and findings of the weaknesses by comparison with the industry standards. This sort of never-ending evaluation requires a mentality spreads companywide in which is based on people rather than systems planning. Service orientation plays a crucial role at this point with continuous observation for identifying customer needs and providing the best quality services for the customers will lead to such a model to be developed. In order to achieve this agile model required by the airline industry, airlines have attempted to gain required competencies. The corresponding process includes an adaptation stage in which will only ensure preventing the imitation by rivals appeal to the market success as uniqueness can go away rapidly.
It is possible to modify, enhance and continuously renovate the competencies that only if the firm comes up with a comprehensive principle of agility built in to the philosophy of its existence. This can be accomplished by a business model based on notion of agility and continuous evolution throughout the model.

6.2 Application Background

The methodology, mentioned is implemented in jet-fuel supplier selection in an airline company. Four experts form the purchasing department are consulted as decision makers. These experts are experienced in this sector for two to three years. Since the market leader suppliers are the most preferred companies by the airline company are quite successful not adequately differentiated each other in terms of performance ratings evaluated by experts, the case study focuses on the second degree preferred suppliers make business with the airline company. Based on the review accomplished through the existing literature and the suggestions provided by the experts of the company, five main criteria are defined and corresponding sub-criteria are selected accordingly. Afterwards, experts evaluated the importance of the criteria and the related sub-criteria independent from each other. Eight suppliers are assessed in terms of performance observed by experts through the main criteria and sub-criteria. The criteria and sub-criteria diagram with sample references from the literature is shown in the Table 6.2.1 below.

Table 6.2.1 Criteria and Sub-Criteria related to agile supplier selection problem

Indicator	Criteria / Sub-criteria	Sample References
C_1	**Management capabilities**	Felice et al.(2015)
C_{11}	Management and Organization	Matawale et al.(2016), Lee et al.(2015)
C_{12}	Financial position	Lee et al.(2015)
C_{13}	Customer relation	Lee et al.(2015)
C_{14}	Training Aids	Felice et al.(2015)
C_{15}	Reputation	Sahu et al. (2016)
C_{16}	Insurance policy and budget	Suggested by Experts
C_2	**Production capabilities**	Lee et al.(2015)
C_{21}	Production capacity	Sahu et al. (2016)
C_{22}	Product diversity	Lee et al.(2015)
C_{23}	R&D	Lee et al.(2015), Luo et al.(2009)
C_{24}	Quality	Matawale et al.(2016)
C_3	**Collaboration capabilities**	Lee et al.(2015)
C_{31}	Deliver reliability	Felice et al.(2015)
C_{32}	Warranties and claim policies	Felice et al.(2015)
C_{33}	Collaboration with partners	Sahu et al. (2016)
C_4	**Agility**	Lee et al.(2015)
C_{41}	Delivery speed	Beikkhakhian et al.(2015)
C_{42}	Delivery flexibility	Matawale et al.(2016)
C_{43}	Agile customer responsiveness	Lee et al.(2015)
C_{44}	Make Flexibility	Lee et al.(2015)
C_{45}	Source flexibility	Lee et al.(2015)
C_5	**Cost**	N. Viswanadham (2013)
C_{51}	Discount	Felice et al.(2015)
C_{52}	Terms of Payment	Felice et al.(2015)
C_{53}	Transportation cost	Felice et al.(2015)
C_{54}	Unit Product Cost	Felice et al.(2015)
C_{55}	Acceptance of local currency payment based on the country, where the fuel is purchased	Suggested by Experts

6.3 Application of the Hierarchical Fuzzy MCDM Method

The importance of main criteria and related sub-criteria in terms of qualitative values of both experts' judgements and performance evaluations of suppliers are represented by linguistic variables. It is possible to transform these linguistic variables into triangular fuzzy numbers in order to make quantitative evaluations. The structure of the triangular fuzzy numbers is represented in figure 6.3.1.

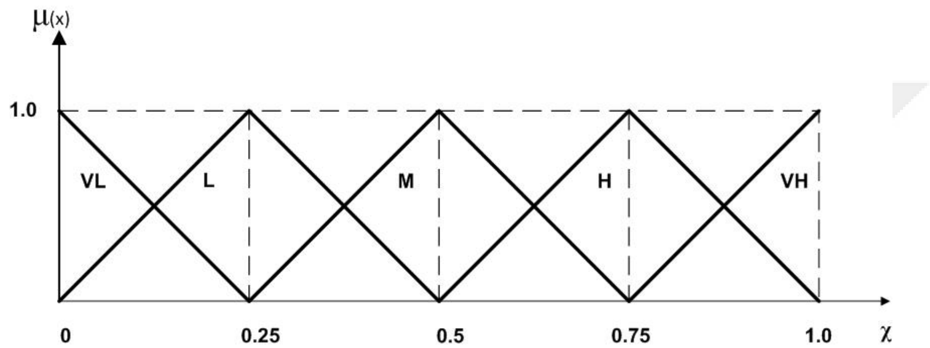

Figure 6.3.1 : The Linguistic term set

It is stated in the linguistic term set above that VL= (0, 0, 0.25), L= (0, 0.25, 0.5), M= (0.25, 0.5, 0.75), H= (0.5, 0.75, 1) and VH= (0.75, 1, 1)

***Step* 1.** The linguistic variables considered as expressions by experts' evaluations on the importance of criteria and performance of the suppliers in terms of criteria. In this case; five level is considered in which VL stands for "very low", L for "low", M for "moderate", H for "high" and VH for "high". The evaluations of the importance of the criteria and sub-criteria by four experts is represented in Table 6.3.1 and Table 6.3.2;

Table 6.3.1: Importance weights of main criteria

Criteria	**Importance Weight by Experts**			
	Exp1	**Exp2**	**Exp3**	**Exp4**
Management capabilities *C_1*	H	H	H	H
Production capabilities *C_2*	H	H	H	H
Collaboration capabilities *C_3*	H	M	H	H
Agility *C_4*	H	M	M	H
Cost *C_5*	H	H	M	H

Table 6.3.2: Importance weights of sub-criteria

Sub-Criteria	Importance Weight by Experts			
	Exp1	Exp2	Exp3	Exp4
Management and Organization C_{11}	M	H	M	M
Financial position C_{12}	H	H	H	H
Customer relation C_{13}	H	H	M	H
Training Aids C_{14}	M	M	M	M
Reputation C_{15}	M	H	H	H
Insurance policy and budget C_{16}	H	H	H	H
Production capacity C_{21}	H	H	M	H
Product diversity C_{22}	VL	M	L	L
R&D C_{23}	VL	L	VL	M
Quality C_{24}	H	M	H	H
Deliver reliability C_{31}	H	H	H	H
Warranties and claim policies C_{32}	H	H	H	H
Collaboration with partners C_{33}	H	M	M	H
Delivery speed C_{41}	H	H	H	H
Delivery flexibility C_{42}	H	H	H	H
Agile customer responsiveness C_{43}	H	H	M	H
Make Flexibility C_{44}	VL	L	M	M
Source flexibility C_{45}	L	M	M	M
Discount C_{51}	H	H	H	H
Terms of Payment C_{52}	H	H	H	H
Transportation cost C_{53}	M	H	H	H
Unit Product Cost C_{54}	H	H	H	H
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	H	H	M	H

The corresponding linguistic variables in the importance tables related to criteria and sub-criteria are transformed into fuzzy triangular numbers in Table 6.3.3 and Table 6.3.4 below:

Table 6.3.3: Fuzzy importance weights of criteria

Criteria	Importance Weight by Experts			
	Exp1	Exp2	Exp3	Exp4
Management capabilities C_1	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Production capabilities C_2	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Collaboration capabilities C_3	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Agility C_4	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
Cost C_5	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)

Table 6.3.4: Fuzzy importance weights of sub-criteria

Sub-Criteria	Importance Weight by Experts			
	Exp1	Exp2	Exp3	Exp4
Management and Organization C_{11}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Financial position C_{12}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Customer relation C_{13}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Training Aids C_{14}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Reputation C_{15}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Insurance policy and budget C_{16}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Production capacity C_{21}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Product diversity C_{22}	(0,0,0.25)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)
R&D C_{23}	(0,0,0.25)	(0,0.25,0.5)	(0,0,0.25)	(0.25,0.5,0.75)
Quality C_{24}	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Deliver reliability C_{31}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Warranties and claim policies C_{32}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Collaboration with partners C_{33}	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
Delivery speed C_{41}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Delivery flexibility C_{42}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Agile customer responsiveness C_{43}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Make Flexibility C_{44}	(0,0,0.25)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Source flexibility C_{45}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Discount C_{51}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Terms of Payment C_{52}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Transportation cost C_{53}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Unit Product CostC_{54}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Acceptance of local currency payment based or the country, where the fuel is purchased C_{55}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)

Since experts judgements are differentiated each other, the arithmetic average weights of importance in terms of fuzzy values are determined by considering each expert has the similar level of experience and knowledge, represented in Table 6.3.5 and Table 6.3.6

Table 6.3.5: Average weighted fuzzy importance of criteria

Criteria	Average Weighted Fuzzy Importance
Management capabilities C_1	(0.69,0.94,1)
Production capabilities C_2	(0.69,0.94,1)
Collaboration capabilities C_3	(0.63,0.88,0.94)
Agility C_4	(0.44,0.69,0.88)
Cost C_5	(0.57,0.82,0.94)

Table 6.3.6: Average weighted fuzzy importance of sub-criteria

Sub-Criteria	**Average Weighted Fuzzy Importance**
Management and Organization C_{11}	(0.32,0.57,0.82)
Financial position C_{12}	(0.57,0.82,1)
Customer relation C_{13}	(0.5,0.75,0.94)
Training Aids C_{14}	(0.25,0.5,0.75)
Reputation C_{15}	(0.44,0.69,0.94)
Insurance policy and budget C_{16}	(0.57,0.82,1)
Production capacity C_{21}	(0.44,0.69,0.94)
Product diversity C_{22}	(0.07,0.25,0.5)
R&D C_{23}	(0.07,0.19,0.44)
Quality C_{24}	(0.63,0.88,0.94)
Deliver reliability C_{31}	(0.63,0.88,1)
Warranties and claim policies C_{32}	(0.57,0.82,1)
Collaboration with partners C_{33}	(0.44,0.69,0.88)
Delivery speed C_{41}	(0.75,1,1)
Delivery flexibility C_{42}	(0.69,0.94,1)
Agile customer responsiveness C_{43}	(0.5,0.75,0.94)
Make Flexibility C_{44}	(0.13,0.32,0.57)
Source flexibility C_{45}	(0.19,0.44,0.69)
Discount C_{51}	(0.69,0.94,1)
Terms of Payment C_{52}	(0.69,0.94,1)
Transportation cost C_{53}	(0.5,0.75,0.94)
Unit Product Cost C_{54}	(0.63,0.88,1)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.57,0.82,0.94)

Self-evaluations of candidate suppliers are evaluated by four experts represented in Table 6.3.7, Table 6.3.8, Table 6.3.9 and Table 6.3.10.

Table 6.3.7: Self Evaluation for performance ratings of suppliers by Expert 1

Expert 1 Self Evaluation for performance ratings of suppliers				
Sub-Criteria	**S_1**	**S_2**	**S_3**	**S_4**
Management and Organization C_{11}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Financial position C_{12}	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.5,0.75,1)	(0.5,0.75,1)
Customer relation C_{13}	(0,0,0.25)	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)
Training Aids C_{14}	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Reputation C_{15}	(0,0,0.25)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Insurance policy and budget C_{16}	(0.25,0.5,0.75)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)
Production capacity C_{21}	(0,0,0.25)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Product diversity C_{22}	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)
R&D C_{23}	(0,0,0.25)	(0,0,0.25)	(0,0.25,0.5)	(0,0,0.25)
Quality C_{24}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Deliver reliability C_{31}	(0,0,0.25)	(0,0.25,0.5)	(0.5,0.75,1)	(0.5,0.75,1)
Warranties and claim policies C_{32}	(0,0,0.25)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)
Collaboration with partners C_{33}	(0,0,0.25)	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)
Delivery speed C_{41}	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Delivery flexibility C_{42}	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Agile customer responsiveness C_{43}	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Make Flexibility C_{44}	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Source flexibility C_{45}	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)
Discount C_{51}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)
Terms of Payment C_{52}	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.75,1,1)	(0.25,0.5,0.75)
Transportation cost C_{53}	(160.1,160.1,160.1)	(144.9,144.9,144.9)	(51.4,51.4,51.4)	(27,27,27)
Unit Product Cost C_{54}	(651.8,651.8,651.8)	(540.5,540.5,540.5)	(638.4,638.4,638.4)	(458.4,458.4,458.4)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.75,1,1)	(0.25,0.5,0.75)	(0.75,1,1)	(0,0.25,0.5)

Table 6.3.7(continued): Self Evaluation for performance ratings of suppliers by Expert 1

Expert 1 Self Evaluation for performance ratings of suppliers				
Sub-Criteria	**S_5**	**S_6**	**S_7**	**S_8**
Management and Organization C_{11}	(0.75,1,1)	(0.25,0.5,0.75)	(0,0,0.25)	(0.25,0.5,0.75)
Financial position C_{12}	(0.75,1,1)	(0.75,1,1)	(0,0.25,0.5)	(0.5,0.75,1)
Customer relation C_{13}	(0.5,0.75,1)	(0.75,1,1)	(0,0.25,0.5)	(0.5,0.75,1)
Training Aids C_{14}	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)	(0.5,0.75,1)
Reputation C_{15}	(0.75,1,1)	(0.75,1,1)	(0,0,0.25)	(0.25,0.5,0.75)
Insurance policy and budget C_{16}	(0.5,0.75,1)	(0.75,1,1)	(0,0.25,0.5)	(0.25,0.5,0.75)
Production capacity C_{21}	(0.75,1,1)	(0.75,1,1)	(0,0.25,0.5)	(0.5,0.75,1)
Product diversity C_{22}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)
R&D C_{23}	(0.5,0.75,1)	(0.5,0.75,1)	(0,0.25,0.5)	(0,0,0.25)
Quality C_{24}	(0.75,1,1)	(0.75,1,1)	(0,0.25,0.5)	(0.5,0.75,1)
Deliver reliability C_{31}	(0.75,1,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Warranties and claim policies C_{32}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Collaboration with partners C_{33}	(0.5,0.75,1)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)
Delivery speed C_{41}	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.75,1,1)
Delivery flexibility C_{42}	(0.5,0.75,1)	(0.5,0.75,1)	(0,0.25,0.5)	(0.75,1,1)
Agile customer responsiveness C_{43}	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)
Make Flexibility C_{44}	(0.75,1,1)	(0.75,1,1)	(0,0.25,0.5)	(0.5,0.75,1)
Source flexibility C_{45}	(0.75,1,1)	(0.75,1,1)	(0,0.25,0.5)	(0.25,0.5,0.75)
Discount C_{51}	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)	(0.5,0.75,1)
Terms of Payment C_{52}	(0.5,0.75,1)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)
Transportation cost C_{53}	(10.9,10.9,10.9)	(29.4,29.4,29.4)	(232.7,232.7,232.7)	(111,111,111)
Unit Product Cost C_{54}	(454.8,454.8,454.8)	(450.8,450.8,450.8)	(726.8,726.8,726.8)	(548.9,548.9,548.9)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)

Table 6.3.8: Self Evaluation for performance ratings of suppliers by Expert 2

Expert 2 Self Evaluation for performance ratings of suppliers				
Sub-Criteria	**S_1**	**S_2**	**S_3**	**S_4**
Management and Organization C_{11}	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Financial position C_{12}	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Customer relation C_{13}	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Training Aids C_{14}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
Reputation C_{15}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
Insurance policy and budget C_{16}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Production capacity C_{21}	(0,0.25,0.5)	(0,0.25,0.5)	(0.5,0.75,1)	(0.25,0.5,0.75)
Product diversity C_{22}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
R&D C_{23}	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)
Quality C_{24}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Deliver reliability C_{31}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Warranties and claim policies C_{32}	(0,0,0.25)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)
Collaboration with partners C_{33}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Delivery speed C_{41}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Delivery flexibility C_{42}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
Agile customer responsiveness C_{43}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
Make Flexibility C_{44}	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Source flexibility C_{45}	(0,0,0.25)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.25,0.5,0.75)
Discount C_{51}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Terms of Payment C_{52}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Transportation cost C_{53}	(0.33,0.33,0.33)	(0.40,0.40,0.40)	(0.82,0.82,0.82)	(0.93,0.93,0.93)
Unit Product Cost C_{54}	(0.93,0.93,0.93)	(0.67,0.67,0.67)	(0.32,0.32,0.32)	(0.97,0.97,0.97)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)

Table 6.3.8(continued): Self Evaluation for performance ratings of suppliers by Expert 2

Expert 2 Self Evaluation for performance ratings of suppliers				
Sub-Criteria	**S_5**	**S_6**	**S_7**	**S_8**
Management and Organization C_{11}	(0.5,0.75,1)	(0.5,0.75,1)	(0,0.25,0.5)	(0.25,0.5,0.75)
Financial position C_{12}	(0.5,0.75,1)	(0.5,0.75,1)	(0,0.25,0.5)	(0.25,0.5,0.75)
Customer relation C_{13}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Training Aids C_{14}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Reputation C_{15}	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Insurance policy and budget C_{16}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Production capacity C_{21}	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Product diversity C_{22}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
R&D C_{23}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0.25,0.5)	(0.25,0.5,0.75)
Quality C_{24}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Deliver reliability C_{31}	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Warranties and claim policies C_{32}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Collaboration with partners C_{33}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Delivery speed C_{41}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Delivery flexibility C_{42}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Agile customer responsiveness C_{43}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Make Flexibility C_{44}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Source flexibility C_{45}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Discount C_{51}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Terms of Payment C_{52}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Transportation cost C_{53}	(1,1,1)	(0.92,0.92,0.92)	(0,0,0)	(0.55,0.55,0.55)
Unit Product Cost C_{54}	(0.99,0.99,0.99)	(1,1,1)	(0,0,0)	(548.9,548.9,548.9)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0.5,0.75,1)

Table 6.3.9: Self Evaluation for performance ratings of suppliers by Expert 3

Expert 3 Self Evaluation for performance ratings of suppliers				
Sub-Criteria	**S_1**	**S_2**	**S_3**	**S_4**
Management and Organization C_{11}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)
Financial position C_{12}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)
Customer relation C_{13}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)
Training Aids C_{14}	(0,0.25,0.5)	(0.5,0.75,1)	(0.75,1,1)	(0,0.25,0.5)
Reputation C_{15}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)
Insurance policy and budget C_{16}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)
Production capacity C_{21}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)
Product diversity C_{22}	(0,0.25,0.5)	(0,0.25,0.5)	(0.75,1,1)	(0,0.25,0.5)
R&D C_{23}	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)
Quality C_{24}	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0.5,0.75,1)
Deliver reliability C_{31}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)	(0.5,0.75,1)
Warranties and claim policies C_{32}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)
Collaboration with partners C_{33}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)
Delivery speed C_{41}	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0.5,0.75,1)
Delivery flexibility C_{42}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.75,1,1)	(0.25,0.5,0.75)
Agile customer responsiveness C_{43}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)
Make Flexibility C_{44}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)
Source flexibility C_{45}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)
Discount C_{51}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Terms of Payment C_{52}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Transportation cost C_{53}	(160.1,160.1,160.1)	(144.9,144.9,144.9)	(51.4,51.4,51.4)	(27,27,27)
Unit Product Cost C_{54}	(651.8,651.8,651.8)	(540.5,540.5,540.5)	(638.4,638.4,638.4)	(458.4,458.4,458.4)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)

Table 6.3.9(continued): Self Evaluation for performance ratings of suppliers by Expert 3

Expert 3 Self Evaluation for performance ratings of suppliers				
Sub-Criteria	**S_5**	**S_6**	**S_7**	**S_8**
Management and Organization C_{11}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Financial position C_{12}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Customer relation C_{13}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Training Aids C_{14}	(0.5,0.75,1)	(0.5,0.75,1)	(0,0.25,0.5)	(0,0.25,0.5)
Reputation C_{15}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Insurance policy and budget C_{16}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Production capacity C_{21}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Product diversity C_{22}	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)
R&D C_{23}	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)	(0,0.25,0.5)
Quality C_{24}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Deliver reliability C_{31}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Warranties and claim policies C_{32}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Collaboration with partners C_{33}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Delivery speed C_{41}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Delivery flexibility C_{42}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Agile customer responsiveness C_{43}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Make Flexibility C_{44}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Source flexibility C_{45}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Discount C_{51}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Terms of Payment C_{52}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Transportation cost C_{53}	(10.9,10.9,10.9)	(29.4,29.4,29.4)	(232.7,232.7,232.7)	(111,111,111)
Unit Product Cost C_{54}	(454.8,454.8,454.8)	(450.8,450.8,450.8)	(726.8,726.8,726.8)	(548.9,548.9,548.9)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)

Table 6.3.10: Self Evaluation for performance ratings of suppliers by Expert 4

Expert 4 Self Evaluation for performance ratings of suppliers **Sub-Criteria**	**S_1**	**S_2**	**S_3**	**S_4**
Management and Organization C_{11}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)
Financial position C_{12}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)
Customer relation C_{13}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Training Aids C_{14}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
Reputation C_{15}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)
Insurance policy and budget C_{16}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)
Production capacity C_{21}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Product diversity C_{22}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
R&D C_{23}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)
Quality C_{24}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)
Deliver reliability C_{31}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)
Warranties and claim policies C_{32}	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Collaboration with partners C_{33}	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Delivery speed C_{41}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.75,1,1)
Delivery flexibility C_{42}	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)
Agile customer responsiveness C_{43}	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)
Make Flexibility C_{44}	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)
Source flexibility C_{45}	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)
Discount C_{51}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Terms of Payment C_{52}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1)	(0,0.25,0.5)
Transportation cost C_{53}	(160.1,160.1,160.1)	(144.9,144.9,144.9)	(51.4,51.4,51.4)	(27,27,27)
Unit Product Cost C_{54}	(651.8,651.8,651.8)	(540.5,540.5,540.5)	(638.4,638.4,638.4)	(458.4,458.4,458.4)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.5,0.75,1)	(0,0.25,0.5)	(0.5,0.75,1)	(0,0.25,0.5)

Table 6.3.10(continued):Self Evaluation for performance ratings of suppliers by Expert 4

Expert 4 Self Evaluation for performance ratings of suppliers **Sub-Criteria**	**S_5**	**S_6**	**S_7**	**S_8**
Management and Organization C_{11}	(0.75,1,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Financial position C_{12}	(0.75,1,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Customer relation C_{13}	(0.75,1,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Training Aids C_{14}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Reputation C_{15}	(0.75,1,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Insurance policy and budget C_{16}	(0.75,1,1)	(0.75,1,1)	(0.5,0.75,1)	(0.5,0.75,1)
Production capacity C_{21}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Product diversity C_{22}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
R&D C_{23}	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Quality C_{24}	(0.75,1,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Deliver reliability C_{31}	(0.5,0.75,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.75,1,1)
Warranties and claim policies C_{32}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)
Collaboration with partners C_{33}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Delivery speed C_{41}	(0.75,1,1)	(0.75,1,1)	(0.25,0.5,0.75)	(0.5,0.75,1)
Delivery flexibility C_{42}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Agile customer responsiveness C_{43}	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.25,0.5,0.75)
Make Flexibility C_{44}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Source flexibility C_{45}	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)
Discount C_{51}	(0.5,0.75,1)	(0.5,0.75,1)	(0,0.25,0.5)	(0.5,0.75,1)
Terms of Payment C_{52}	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.5,0.75,1)
Transportation cost C_{53}	(10.9,10.9,10.9)	(29.4,29.4,29.4)	(232.7,232.7,232.7)	(111,111,111)
Unit Product Cost C_{54}	(454.8,454.8,454.8)	(450.8,450.8,450.8)	(726.8,726.8,726.8)	(548.9,548.9,548.9)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0,0.25,0.5)	(0,0.25,0.5)	(0.5,0.75,1)	(0.5,0.75,1)

As it was implemented in determination of the importance weight of sub-criteria, the arithmetic average of performance ratings evaluated by experts in terms of fuzzy values are determined by considering each expert has the similar level of experience and knowledge. Finally; the data related to agile supplier selection problem, is created within this procedure, represented in Table 6.3.11 below;

Table 6.3.11: Data related to Agile Supplier Selection Problem

Data related to Agile Supplier Selection Problem				
Sub-Criteria	**S_1**	**S_2**	**S_3**	**S_4**
Management and Organization C_{11}	(0.13,0.38,0.63)	(0.25,0.5,0.75)	(0.44,0.69,0.94)	(0.44,0.69,0.88)
Financial position C_{12}	(0.19,0.44,0.69)	(0.13,0.38,0.63)	(0.5,0.75,0.94)	(0.44,0.69,0.88)
Customer relation C_{13}	(0.13,0.25,0.5)	(0.19,0.44,0.69)	(0.57,0.82,1)	(0.38,0.63,0.88)
Training Aids C_{14}	(0.13,0.32,0.57)	(0.32,0.57,0.82)	(0.38,0.63,0.82)	(0.32,0.57,0.82)
Reputation C_{15}	(0.13,0.32,0.57)	(0.25,0.5,0.75)	(0.44,0.69,0.88)	(0.44,0.69,0.88)
Insurance policy and budget C_{16}	(0.25,0.5,0.75)	(0.32,0.5,0.75)	(0.44,0.69,0.88)	(0.44,0.69,0.88)
Production capacity C_{21}	(0.13,0.32,0.57)	(0.13,0.38,0.63)	(0.5,0.75,0.94)	(0.32,0.57,0.82)
Product diversity C_{22}	(0.13,0.32,0.57)	(0.13,0.32,0.57)	(0.32,0.5,0.69)	(0.25,0.5,0.75)
R&D C_{23}	(0.07,0.25,0.5)	(0.07,0.25,0.5)	(0.19,0.44,0.69)	(0.13,0.32,0.57)
Quality C_{24}	(0.32,0.57,0.82)	(0.32,0.57,0.82)	(0.5,0.75,0.94)	(0.5,0.75,0.94)
Deliver reliability C_{31}	(0.19,0.38,0.63)	(0.32,0.57,0.82)	(0.57,0.82,1)	(0.57,0.82,1)
Warranties and claim policies C_{32}	(0.19,0.32,0.57)	(0.13,0.38,0.63)	(0.44,0.69,0.88)	(0.44,0.69,0.94)
Collaboration with partners C_{33}	(0.19,0.38,0.63)	(0.19,0.44,0.69)	(0.5,0.75,0.94)	(0.32,0.57,0.82)
Delivery speed C_{41}	(0.25,0.5,0.75)	(0.38,0.63,0.88)	(0.5,0.75,0.94)	(0.5,0.75,0.94)
Delivery flexibility C_{42}	(0.25,0.5,0.75)	(0.19,0.44,0.69)	(0.44,0.69,0.88)	(0.38,0.63,0.88)
Agile customer responsiveness C_{43}	(0.19,0.44,0.69)	(0.38,0.63,0.88)	(0.38,0.63,0.82)	(0.44,0.69,0.94)
Make Flexibility C_{44}	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.44,0.69,0.88)	(0.25,0.5,0.75)
Source flexibility C_{45}	(0.19,0.38,0.63)	(0.19,0.44,0.69)	(0.32,0.57,0.82)	(0.19,0.44,0.69)
Discount C_{51}	(0.32,0.57,0.82)	(0.44,0.69,0.94)	(0.44,0.69,0.88)	(0.38,0.63,0.88)
Terms of Payment C_{52}	(0.32,0.57,0.82)	(0.25,0.5,0.75)	(0.5,0.75,0.94)	(0.25,0.5,0.75)
Transportation cost C_{53}	(160.1,160.1,160.1)	(144.9,144.9,144.9)	(51.4,51.4,51.4)	(27,27,27)
Unit Product Cost C_{54}	(651.8,651.8,651.8)	(540.5,540.5,540.5)	(638.4,638.4,638.4)	(458.4,458.4,458.4)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.5,0.75,0.94)	(0.25,0.5,0.75)	(0.57,0.82,1)	(0.19,0.44,0.69)

Table 6.3.11(continued): Data related to Agile Supplier Selection Problem

Data related to Agile Supplier Selection Problem				
Sub-Criteria	**S_5**	**S_6**	**S_7**	**S_8**
Management and Organization C_{11}	(0.57,0.82,0.94)	(0.44,0.69,0.88)	(0.13,0.32,0.57)	(0.32,0.57,0.82)
Financial position C_{12}	(0.57,0.82,0.94)	(0.57,0.82,0.94)	(0.13,0.38,0.63)	(0.38,0.63,0.88)
Customer relation C_{13}	(0.5,0.75,0.94)	(0.5,0.75,0.94)	(0.25,0.5,0.75)	(0.44,0.69,0.94)
Training Aids C_{14}	(0.44,0.69,0.94)	(0.38,0.63,0.88)	(0.13,0.32,0.57)	(0.25,0.5,0.75)
Reputation C_{15}	(0.63,0.88,1)	(0.69,0.94,1)	(0.19,0.38,0.63)	(0.38,0.63,0.88)
Insurance policy and budget C_{16}	(0.5,0.75,0.94)	(0.63,0.88,1)	(0.25,0.5,0.75)	(0.32,0.57,0.82)
Production capacity C_{21}	(0.5,0.75,0.94)	(0.57,0.82,0.94)	(0.19,0.44,0.69)	(0.38,0.63,0.88)
Product diversity C_{22}	(0.19,0.44,0.69)	(0.25,0.5,0.75)	(0.13,0.32,0.57)	(0.13,0.32,0.57)
R&D C_{23}	(0.32,0.57,0.82)	(0.38,0.63,0.88)	(0.07,0.32,0.57)	(0.13,0.32,0.57)
Quality C_{24}	(0.57,0.82,0.94)	(0.63,0.88,1)	(0.25,0.5,0.75)	(0.44,0.69,0.94)
Deliver reliability C_{31}	(0.57,0.82,1)	(0.69,0.94,1)	(0.32,0.57,0.82)	(0.57,0.82,1)
Warranties and claim policies C_{32}	(0.38,0.63,0.88)	(0.38,0.63,0.88)	(0.38,0.63,0.88)	(0.5,0.75,0.94)
Collaboration with partners C_{33}	(0.38,0.63,0.88)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.32,0.57,0.82)
Delivery speed C_{41}	(0.57,0.82,1)	(0.63,0.88,1)	(0.32,0.57,0.82)	(0.57,0.82,1)
Delivery flexibility C_{42}	(0.44,0.69,0.94)	(0.44,0.69,0.94)	(0.25,0.5,0.75)	(0.44,0.69,0.88)
Agile customer responsiveness C_{43}	(0.44,0.69,0.94)	(0.38,0.63,0.88)	(0.38,0.63,0.88)	(0.25,0.5,0.75)
Make Flexibility C_{44}	(0.5,0.75,0.94)	(0.57,0.82,1)	(0.25,0.5,0.75)	(0.38,0.63,0.88)
Source flexibility C_{45}	(0.44,0.69,0.88)	(0.5,0.75,0.94)	(0.25,0.5,0.75)	(0.32,0.57,0.82)
Discount C_{51}	(0.38,0.63,0.88)	(0.32,0.57,0.82)	(0.19,0.44,0.69)	(0.44,0.69,0.94)
Terms of Payment C_{52}	(0.32,0.57,0.82)	(0.19,0.44,0.69)	(0.25,0.5,0.75)	(0.32,0.57,0.82)
Transportation cost C_{53}	(10.9,10.9,10.9)	(29.4, 29.4, 29.4)	(232.7,232.7,232.7)	(111,111,111)
Unit Product Cost C_{54}	(454.8,454.8,454.8)	(450.8,450.8,450.8)	(726.8,726.8,726.8)	(548.9,548.9,548.9)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.13,0.38,0.63)	(0.13,0.38,0.63)	(0.19,0.44,0.69)	(0.32,0.57,0.82)

***Step* 2.** Data related to Agile Supplier Selection Problem is n normalized by using equation 5.1.1. Only two of the sub-criteria are considered as cost related attributes which are Transportation cost C_{53} and Unit Product cost C_{54}. Additionally; these two are the only crisp data given in the study. Result of the normalization is represented in Table 6.3.12.

Table 6.3.12: Normalized Data related to Agile Supplier Selection Problem

Normalized Data related to problem **Sub-Criteria**	**S_1**	**S_2**	**S_3**	**S_4**
Management and Organization C_{11}	(0,0.31,0.62)	(0.16,0.47,0.77)	(0.39,0.7,1)	(0.39,0.7,0.93)
Financial position C_{12}	(0.08,0.39,0.7)	(0,0.31,0.62)	(0.47,0.77,1)	(0.39,0.7,0.93)
Customer relation C_{13}	(0,0.15,0.43)	(0.08,0.36,0.65)	(0.5,0.79,1)	(0.29,0.58,0.86)
Training Aids C_{14}	(0,0.24,0.54)	(0.24,0.54,0.85)	(0.31,0.62,0.85)	(0.24,0.54,0.85)
Reputation C_{15}	(0,0.22,0.5)	(0.15,0.43,0.72)	(0.36,0.65,0.86)	(0.36,0.65,0.86)
Insurance policy and budget C_{16}	(0,0.34,0.67)	(0.09,0.34,0.67)	(0.25,0.59,0.84)	(0.25,0.59,0.84)
Production capacity C_{21}	(0,0.24,0.54)	(0,0.31,0.62)	(0.47,0.77,1)	(0.24,0.54,0.85)
Product diversity C_{22}	(0,0.3,0.7)	(0,0.3,0.7)	(0.3,0.6,0.9)	(0.2,0.6,1)
R&D C_{23}	(0,0.24,0.54)	(0,0.24,0.54)	(0.16,0.47,0.77)	(0.08,0.31,0.62)
Quality C_{24}	(0.09,0.42,0.75)	(0.09,0.42,0.75)	(0.34,0.67,0.92)	(0.34,0.67,0.92)
Deliver reliability C_{31}	(0,0.24,0.54)	(0.16,0.47,0.77)	(0.47,0.77,1)	(0.47,0.77,1)
Warranties and claim policies C_{32}	(0.08,0.24,0.54)	(0,0.31,0.62)	(0.39,0.7,0.93)	(0.39,0.7,1)
Collaboration with partners C_{33}	(0,0.25,0.59)	(0,0.34,0.67)	(0.42,0.75,1)	(0.17,0.5,0.84)
Delivery speed C_{41}	(0,0.34,0.67)	(0.17,0.5,0.84)	(0.34,0.67,0.92)	(0.34,0.67,0.92)
Delivery flexibility C_{42}	(0.09,0.42,0.75)	(0,0.34,0.67)	(0.34,0.67,0.92)	(0.25,0.59,0.92)
Agile customer responsiveness C_{43}	(0,0.34,0.67)	(0.25,0.59,0.92)	(0.25,0.59,0.84)	(0.34,0.67,1)
Make Flexibility C_{44}	(0,0.34,0.67)	(0,0.34,0.67)	(0.25,0.59,0.84)	(0,0.34,0.67)
Source flexibility C_{45}	(0,0.25,0.59)	(0,0.34,0.67)	(0.17,0.5,0.84)	(0,0.34,0.67)
Discount C_{51}	(0.17,0.5,0.84)	(0.34,0.67,1)	(0.34,0.67,0.92)	(0.25,0.59,0.92)
Terms of Payment C_{52}	(0.17,0.5,0.84)	(0.09,0.42,0.75)	(0.42,0.75,1)	(0.09,0.42,0.75)
Transportation cost C_{53}	(0.33,0.33,0.33)	(0.4,0.4,0.4)	(0.82,0.82,0.82)	(0.93,0.93,0.93)
Unit Product Cost C_{54}	(0.28,0.28,0.28)	(0.68,0.68,0.68)	(0.32,0.32,0.32)	(0.98,0.98,0.98)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.43,0.72,0.93)	(0.15,0.43,0.72)	(0.5,0.79,1)	(0.08,0.36,0.65)

Table 6.3.12(continued): Normalized Data related to Agile Supplier Selection Problem

Normalized data related to problem **Sub-Criteria**	**S_5**	**S_6**	**S_7**	**S_8**
Management and Organization C_{11}	(0.54,0.85,1)	(0.39,0.7,0.93)	(0,0.24,0.54)	(0.24,0.54,0.85)
Financial position C_{12}	(0.54,0.85,1)	(0.54,0.85,1)	(0,0.31,0.62)	(0.31,0.62,0.93)
Customer relation C_{13}	(0.43,0.72,0.93)	(0.43,0.72,0.93)	(0.15,0.43,0.72)	(0.36,0.65,0.93)
Training Aids C_{14}	(0.39,0.7,1)	(0.31,0.62,0.93)	(0,0.24,0.54)	(0.16,0.47,0.77)
Reputation C_{15}	(0.58,0.86,1)	(0.65,0.93,1)	(0.08,0.29,0.58)	(0.29,0.58,0.86)
Insurance policy and budget C_{16}	(0.34,0.67,0.92)	(0.5,0.84,1)	(0,0.34,0.67)	(0.09,0.42,0.75)
Production capacity C_{21}	(0.47,0.77,1)	(0.54,0.85,1)	(0.08,0.39,0.7)	(0.31,0.62,0.93)
Product diversity C_{22}	(0.1,0.5,0.9)	(0.2,0.6,1)	(0,0.3,0.7)	(0,0.3,0.7)
R&D C_{23}	(0.31,0.62,0.93)	(0.39,0.7,1)	(0,0.31,0.62)	(0.08,0.31,0.62)
Quality C_{24}	(0.42,0.75,0.92)	(0.5,0.84,1)	(0,0.34,0.67)	(0.25,0.59,0.92)
Deliver reliability C_{31}	(0.47,0.77,1)	(0.62,0.93,1)	(0.16,0.47,0.77)	(0.47,0.77,1)
Warranties and claim policies C_{32}	(0.31,0.62,0.93)	(0.31,0.62,0.93)	(0.31,0.62,0.93)	(0.47,0.77,1)
Collaboration with partners C_{33}	(0.25,0.59,0.92)	(0.09,0.42,0.75)	(0.09,0.42,0.75)	(0.17,0.5,0.84)
Delivery speed C_{41}	(0.42,0.75,1)	(0.5,0.84,1)	(0.09,0.42,0.75)	(0.42,0.75,1)
Delivery flexibility C_{42}	(0.34,0.67,1)	(0.34,0.67,1)	(0.09,0.42,0.75)	(0.34,0.67,0.92)
Agile customer responsiveness C_{43}	(0.34,0.67,1)	(0.25,0.59,0.92)	(0.25,0.59,0.92)	(0.09,0.42,0.75)
Make Flexibility C_{44}	(0.34,0.67,0.92)	(0.42,0.75,1)	(0,0.34,0.67)	(0.17,0.5,0.84)
Source flexibility C_{45}	(0.34,0.67,0.92)	(0.42,0.75,1)	(0.09,0.42,0.75)	(0.17,0.5,0.84)
Discount C_{51}	(0.25,0.59,0.92)	(0.17,0.5,0.84)	(0,0.34,0.67)	(0.34,0.67,1)
Terms of Payment C_{52}	(0.17,0.5,0.84)	(0,0.34,0.67)	(0.09,0.42,0.75)	(0.17,0.5,0.84)
Transportation cost C_{53}	(1,1,1)	(0.92,0.92,0.92)	(0,0,0)	(0.55,0.55,0.55)
Unit Product Cost C_{54}	(0.99,0.99,0.99)	(1,1,1)	(0,0,0)	(0.36,0.36,0.36)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0,0.29,0.58)	(0,0.29,0.58)	(0.08,0.36,0.65)	(0.22,0.5,0.79)

***Step* 3.** The normalized sub-criteria values belong to each supplier are transformed into aggregated values for criteria level by using equation 5.1.2 and the result is represented in Table 6.3.13

Table 6.3.13: Criteria level aggregated values

Criteria level aggregated performance ratings **Criteria**	**S_1**	**S_2**	**S_3**	**S_4**
Management capabilities *C_1*	(0.02,0.28,0.58)	(0.1,0.4,0.71)	(0.39,0.69,0.93)	(0.32,0.63,0.88)
Production capabilities *C_2*	(0.05,0.33,0.64)	(0.05,0.35,0.67)	(0.37,0.68,0.92)	(0.28,0.59,0.87)
Collaboration capabilities *C_3*	(0.03,0.24,0.56)	(0.06,0.38,0.69)	(0.43,0.74,0.98)	(0.36,0.67,0.95)
Agility *C_4*	(0.03,0.35,0.68)	(0.12,0.44,0.77)	(0.3,0.62,0.88)	(0.27,0.58,0.87)
Cost *C_5*	(0.27,0.47,0.65)	(0.31,0.52,0.72)	(0.49,0.69,0.83)	(0.43,0.64,0.84)

Table 6.3.13(continued): Criteria level aggregated values

Criteria level aggregated performance ratings **Criteria**	**S_5**	**S_6**	**S_7**	**S_8**
Management capabilities *C_1*	(0.47,0.78,0.98)	(0.49,0.79,0.97)	(0.04,0.32,0.62)	(0.25,0.55,0.85)
Production capabilities *C_2*	(0.42,0.72,0.95)	(0.5,0.8,1)	(0.03,0.35,0.68)	(0.25,0.54,0.84)
Collaboration capabilities *C_3*	(0.36,0.67,0.95)	(0.37,0.68,0.9)	(0.19,0.51,0.82)	(0.39,0.7,0.95)
Agility *C_4*	(0.37,0.7,0.98)	(0.39,0.72,0.99)	(0.12,0.45,0.78)	(0.29,0.6,0.88)
Cost *C_5*	(0.45,0.66,0.87)	(0.38,0.59,0.8)	(0.04,0.24,0.43)	(0.33,0.53,0.72)

***Step* 4.** Computation of the corresponding performance ratings belong to main criteria by using equation 5.1.3 resulted in normalized values and represented in Table 6.3.14, in which the worst value and the best value are indicated by 0 and 1 respectively.

Table 6.3.14: Normalized values of aggregated performance ratings

Normalized values of aggregated performance ratings **Criteria**	**S_1**	**S_2**	**S_3**	**S_4**
Management capabilities *C_1*	(0,0.27,0.59)	(0.09,0.4,0.72)	(0.39,0.7,0.95)	(0.32,0.64,0.9)
Production capabilities *C_2*	(0.02,0.31,0.63)	(0.02,0.33,0.66)	(0.36,0.67,0.92)	(0.26,0.57,0.86)
Collaboration capabilities *C_3*	(0,0.23,0.56)	(0.04,0.37,0.7)	(0.42,0.76,1)	(0.35,0.68,0.98)
Agility *C_4*	(0,0.34,0.68)	(0.09,0.43,0.78)	(0.29,0.63,0.89)	(0.25,0.58,0.88)
Cost *C_5*	(0.29,0.53,0.75)	(0.33,0.58,0.83)	(0.55,0.79,0.96)	(0.48,0.74,0.98)

Table 6.3.14(continued): Normalized values of aggregated performance ratings

Normalized values of aggregated performance ratings **Criteria**	**S_5**	**S_6**	**S_7**	**S_8**
Management capabilities *C_1*	(0.47,0.79,1)	(0.5,0.81,1)	(0.03,0.31,0.63)	(0.24,0.56,0.88)
Production capabilities *C_2*	(0.4,0.71,0.95)	(0.48,0.79,1)	(0,0.33,0.67)	(0.23,0.52,0.83)
Collaboration capabilities *C_3*	(0.35,0.68,0.98)	(0.36,0.69,0.92)	(0.18,0.51,0.84)	(0.38,0.71,0.98)
Agility *C_4*	(0.36,0.7,1)	(0.38,0.73,1)	(0.1,0.44,0.79)	(0.27,0.61,0.89)
Cost *C_5*	(0.51,0.76,1)	(0.42,0.68,0.92)	(0,0.25,0.48)	(0.35,0.6,0.83)

***Step* 5.** The ideal solution and the anti-ideal solution as:

$A^* = ((1,1,1),(1,1,1),(1,1,1))$,

$A^- = ((0,0,0),(0,0,0),(0,0,0))$.

***Step* 6.** Weighted distances from ideal solution and anti-ideal solution for each alternative are calculated by using equation 5.1.4 and 5.1.5 and result is represented in Table 6.3.15:

Table 6.3.15: Weighted distances from ideal and anti-ideal solutions

Weighted distances from ideal and anti-ideal solutions							
S_1	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
2.85	2.59	1.53	1.79	1.47	1.42	2.78	1.94
2.21	2.62	3.74	3.53	3.88	3.88	2.37	3.34

***Step* 7.** Proximity of the alternatives to ideal solution is calculated by using equation 5.1.6 and represented in Table 6.3.16.

Table 6.3.16: Proximity of alternatives to ideal solution

Proximity of alternatives to ideal solution							
S_1	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
0.4364	0.5023	0.7101	0.6642	0.7257	0.7317	0.4602	0.6332

Step 8. The results are represented in Table 6.3.17.

Table 6.3.17: Ranking of Agile Supplier alternatives

Supplier	**Proximity**	**Ranking**
1	0.4364	8
2	0.5023	6
3	0.7101	3
4	0.6642	4
5	0.7257	2
6	0.7317	1
7	0.4602	7
8	0.6332	5

Table 6.3.17 represents that supplier 6 is the best alternative performed within the related criteria and sub-criteria with its highest value of proximity while supplier 1 is the worst alternative with the lowest proximity value.

6.4 Application of the Hierarchical Fuzzy TOPSIS Method

The corresponding methodology is implemented through the steps as follows:

***Step* 1.** Initialization procedure of the Hierarchical Fuzzy TOPSIS method is similar to Distance Based Hierarchical Fuzzy MCDM methodology. The decision matrix is constructed with the utilization of the arithmetic averages of the importance of the criteria and sub-criteria resulted in Table 6.3.5 and Table 6.3.6 and obtaining the data related to agile supplier selection problem stated in Table 13 based on the arithmetic average of the self-evaluation of the experts through the performance ratings stated in Table 6.3.7, Table 6.3.8, Table 6.3.9 and Table 6.3.10.

***Step* 2.** The Normalization procedure is exactly same as in the Distance Based Hierarchical Fuzzy MCDM methodology. By using the equation 5.2.1 the data related to agile supplier selection problem is normalized as represented in Table 14.

***Step* 3.** The weighted importance of the main criteria is composed by using equation 5.2.2 and represented in Table 6.3.5.

***Step* 4.** The weighted importance of the sub-criteria is composed by using equation 5.2.3 and represented in Table 6.3.6.

***Step* 5.** Final weight of importance of each sub-criterion is computed by using equation 5.2.4 and the results are represented in Table 6.4.1.

Table 6.4.1: Final weighted fuzzy importance of sub-criteria

Sub-Criteria	**Final Weighted Fuzzy Importance**
Management and Organization C_{11}	(0.22,0.53,0.82)
Financial position C_{12}	(0.39,0.77,1)
Customer relation C_{13}	(0.35,0.71,0.94)
Training Aids C_{14}	(0.18,0.47,0.75)
Reputation C_{15}	(0.31,0.65,0.94)
Insurance policy and budget C_{16}	(0.39,0.77,1)
Production capacity C_{21}	(0.31,0.65,0.94)
Product diversity C_{22}	(0.05,0.24,0.5)
R&D C_{23}	(0.05,0.18,0.44)
Quality C_{24}	(0.43,0.83,0.94)
Deliver reliability C_{31}	(0.4,0.77,0.94)
Warranties and claim policies C_{32}	(0.36,0.72,0.94)
Collaboration with partners C_{33}	(0.28,0.61,0.83)
Delivery speed C_{41}	(0.33,0.69,0.88)
Delivery flexibility C_{42}	(0.31,0.65,0.88)
Agile customer responsiveness C_{43}	(0.22,0.52,0.83)
Make Flexibility C_{44}	(0.06,0.22,0.5)
Source flexibility C_{45}	(0.09,0.31,0.61)
Discount C_{51}	(0.39,0.77,0.94)
Terms of Payment C_{52}	(0.39,0.77,0.94)
Transportation cost C_{53}	(0.29,0.61,0.88)
Unit Product Cost C_{54}	(0.36,0.72,0.94)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.32,0.67,0.88)

***Step* 6.** Weighted normalized performance ratings of suppliers, in terms of the sub-criteria are obtained by using equation 5.2.5. The results are represented in Table 6.4.2.

Table 6.4.2: Weighted Normalized Performance Ratings

Weighted Normalized Performance Ratings				
Sub-Criteria	**S_1**	**S_2**	**S_3**	**S_4**
Management and Organization C_{11}	(0,0.31,0.62)	(0.16,0.47,0.77)	(0.39,0.7,1)	(0.39,0.7,0.93)
Financial position C_{12}	(0.08,0.39,0.7)	(0,0.31,0.62)	(0.47,0.77,1)	(0.39,0.7,0.93)
Customer relation C_{13}	(0,0.15,0.43)	(0.08,0.36,0.65)	(0.5,0.79,1)	(0.29,0.58,0.86)
Training Aids C_{14}	(0,0.24,0.54)	(0.24,0.54,0.85)	(0.31,0.62,0.85)	(0.24,0.54,0.85)
Reputation C_{15}	(0,0.22,0.5)	(0.15,0.43,0.72)	(0.36,0.65,0.86)	(0.36,0.65,0.86)
Insurance policy and budget C_{16}	(0,0.34,0.67)	(0.09,0.34,0.67)	(0.25,0.59,0.84)	(0.25,0.59,0.84)
Production capacity C_{21}	(0,0.24,0.54)	(0,0.31,0.62)	(0.47,0.77,1)	(0.24,0.54,0.85)
Product diversity C_{22}	(0,0.3,0.7)	(0,0.3,0.7)	(0.3,0.6,0.9)	(0.2,0.6,1)
R&D C_{23}	(0,0.24,0.54)	(0,0.24,0.54)	(0.16,0.47,0.77)	(0.08,0.31,0.62)
Quality C_{24}	(0.09,0.42,0.75)	(0.09,0.42,0.75)	(0.34,0.67,0.92)	(0.34,0.67,0.92)
Deliver reliability C_{31}	(0,0.24,0.54)	(0.16,0.47,0.77)	(0.47,0.77,1)	(0.47,0.77,1)
Warranties and claim policies C_{32}	(0.08,0.24,0.54)	(0,0.31,0.62)	(0.39,0.7,0.93)	(0.39,0.7,1)
Collaboration with partners C_{33}	(0,0.25,0.59)	(0,0.34,0.67)	(0.42,0.75,1)	(0.17,0.5,0.84)
Delivery speed C_{41}	(0,0.34,0.67)	(0.17,0.5,0.84)	(0.34,0.67,0.92)	(0.34,0.67,0.92)
Delivery flexibility C_{42}	(0.09,0.42,0.75)	(0,0.34,0.67)	(0.34,0.67,0.92)	(0.25,0.59,0.92)
Agile customer responsiveness C_{43}	(0,0.34,0.67)	(0.25,0.59,0.92)	(0.25,0.59,0.84)	(0.34,0.67,1)
Make Flexibility C_{44}	(0,0.34,0.67)	(0,0.34,0.67)	(0.25,0.59,0.84)	(0,0.34,0.67)
Source flexibility C_{45}	(0,0.25,0.59)	(0,0.34,0.67)	(0.17,0.5,0.84)	(0,0.34,0.67)
Discount C_{51}	(0.17,0.5,0.84)	(0.34,0.67,1)	(0.34,0.67,0.92)	(0.25,0.59,0.92)
Terms of Payment C_{52}	(0.17,0.5,0.84)	(0.09,0.42,0.75)	(0.42,0.75,1)	(0.09,0.42,0.75)
Transportation cost C_{53}	(0.33,0.33,0.33)	(0.4,0.4,0.4)	(0.82,0.82,0.82)	(0.93,0.93,0.93)
Unit Product Cost C_{54}	(0.28,0.28,0.28)	(0.68,0.68,0.68)	(0.32,0.32,0.32)	(0.98,0.98,0.98)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0.43,0.72,0.93)	(0.15,0.43,0.72)	(0.5,0.79,1)	(0.08,0.36,0.65)

Table 6.4.2(continued): Weighted Normalized Performance Ratings

Weighted Normalized Performance Ratings				
Sub-Criteria	**S_5**	**S_6**	**S_7**	**S_8**
Management and Organization C_{11}	(0.54,0.85,1)	(0.39,0.7,0.93)	(0,0.24,0.54)	(0.24,0.54,0.85)
Financial position C_{12}	(0.54,0.85,1)	(0.54,0.85,1)	(0,0.31,0.62)	(0.31,0.62,0.93)
Customer relation C_{13}	(0.43,0.72,0.93)	(0.43,0.72,0.93)	(0.15,0.43,0.72)	(0.36,0.65,0.93)
Training Aids C_{14}	(0.39,0.7,1)	(0.31,0.62,0.93)	(0,0.24,0.54)	(0.16,0.47,0.77)
Reputation C_{15}	(0.58,0.86,1)	(0.65,0.93,1)	(0.08,0.29,0.58)	(0.29,0.58,0.86)
Insurance policy and budget C_{16}	(0.34,0.67,0.92)	(0.5,0.84,1)	(0,0.34,0.67)	(0.09,0.42,0.75)
Production capacity C_{21}	(0.47,0.77,1)	(0.54,0.85,1)	(0.08,0.39,0.7)	(0.31,0.62,0.93)
Product diversity C_{22}	(0.1,0.5,0.9)	(0.2,0.6,1)	(0,0.3,0.7)	(0,0.3,0.7)
R&D C_{23}	(0.31,0.62,0.93)	(0.39,0.7,1)	(0,0.31,0.62)	(0.08,0.31,0.62)
Quality C_{24}	(0.42,0.75,0.92)	(0.5,0.84,1)	(0,0.34,0.67)	(0.25,0.59,0.92)
Deliver reliability C_{31}	(0.47,0.77,1)	(0.62,0.93,1)	(0.16,0.47,0.77)	(0.47,0.77,1)
Warranties and claim policies C_{32}	(0.31,0.62,0.93)	(0.31,0.62,0.93)	(0.31,0.62,0.93)	(0.47,0.77,1)
Collaboration with partners C_{33}	(0.25,0.59,0.92)	(0.09,0.42,0.75)	(0.09,0.42,0.75)	(0.17,0.5,0.84)
Delivery speed C_{41}	(0.42,0.75,1)	(0.5,0.84,1)	(0.09,0.42,0.75)	(0.42,0.75,1)
Delivery flexibility C_{42}	(0.34,0.67,1)	(0.34,0.67,1)	(0.09,0.42,0.75)	(0.34,0.67,0.92)
Agile customer responsiveness C_{43}	(0.34,0.67,1)	(0.25,0.59,0.92)	(0.25,0.59,0.92)	(0.09,0.42,0.75)
Make Flexibility C_{44}	(0.34,0.67,0.92)	(0.42,0.75,1)	(0,0.34,0.67)	(0.17,0.5,0.84)
Source flexibility C_{45}	(0.34,0.67,0.92)	(0.42,0.75,1)	(0.09,0.42,0.75)	(0.17,0.5,0.84)
Discount C_{51}	(0.25,0.59,0.92)	(0.17,0.5,0.84)	(0,0.34,0.67)	(0.34,0.67,1)
Terms of Payment C_{52}	(0.17,0.5,0.84)	(0,0.34,0.67)	(0.09,0.42,0.75)	(0.17,0.5,0.84)
Transportation cost C_{53}	(1,1,1)	(0.92,0.92,0.92)	(0,0,0)	(0.55,0.55,0.55)
Unit Product Cost C_{54}	(0.99,0.99,0.99)	(1,1,1)	(0,0,0)	(0.36,0.36,0.36)
Acceptance of local currency payment based on the country, where the fuel is purchased C_{55}	(0,0.29,0.58)	(0,0.29,0.58)	(0.08,0.36,0.65)	(0.22,0.5,0.79)

The obtained weighted normalized decision values are aggregated with using equation 5.2.6.The results are represented in Table 6.4.3.

Table 6.4.3: Aggregated Normalized Performance Ratings

Aggregated Performance ratings of the alternatives				
Criteria	**S_1**	**S_2**	**S_3**	**S_4**
Management capabilities *C_1*	(0.03,1.06,3.14)	(0.18,1.52,3.82)	(0.69,2.66,5.03)	(0.58,2.41,4.75)
Production capabilities *C_2*	(0.04,0.61,1.8)	(0.04,0.66,1.87)	(0.31,1.27,2.59)	(0.23,1.09,2.43)
Collaboration capabilities *C_3*	(0.03,0.5,1.49)	(0.07,0.78,1.85)	(0.43,1.54,2.63)	(0.37,1.39,2.56)
Agility *C_4*	(0.03,0.82,2.47)	(0.11,1.04,2.8)	(0.3,1.47,3.2)	(0.26,1.35,3.16)
Cost *C_5*	(0.46,1.63,2.93)	(0.56,1.83,3.25)	(0.8,2.33,3.7)	(0.76,2.26,3.86)

Table 6.4.3(continued): Aggregated Normalized Performance Ratings

Aggregated Performance ratings of the alternatives				
Criteria	**S_5**	**S_6**	**S_7**	**S_8**
Management capabilities *C_1*	(0.84,2.98,5.29)	(0.88,3.04,5.26)	(0.08,1.21,3.33)	(0.44,2.11,4.62)
Production capabilities *C_2*	(0.34,1.34,2.66)	(0.41,1.5,2.82)	(0.03,0.65,1.9)	(0.21,1,2.35)
Collaboration capabilities *C_3*	(0.36,1.38,2.56)	(0.38,1.4,2.42)	(0.2,1.05,2.21)	(0.39,1.44,2.56)
Agility *C_4*	(0.36,1.64,3.58)	(0.38,1.7,3.6)	(0.12,1.06,2.85)	(0.28,1.42,3.21)
Cost *C_5*	(0.79,2.33,3.95)	(0.68,2.1,2.1)	(0.06,0.81,1.9)	(0.55,1.81,3.23)

***Step* 7.** Generalized mean of each alternative based on each criterion is computed by using equation 5.2.7. The results are represented in Table 6.4.4.

Table 6.4.4: Generalized Mean of Alternatives

Generalized Mean of Alternatives								
Criteria	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
Management capabilities *C_1*	1.41	1.84	2.87	2.63	3.14	3.18	1.54	2.42
Production capabilities *C_2*	0.82	0.86	1.41	1.27	1.48	1.62	0.86	1.20
Collaboration capabilities *C_3*	0.67	0.90	1.59	1.48	1.47	1.44	1.16	1.51
Agility *C_4*	1.11	1.32	1.68	1.61	1.88	1.92	1.34	1.66
Cost *C_5*	1.73	1.96	2.42	2.41	2.49	2.25	0.92	1.93

Regard of maximum and minimum generalized means in each criteria, FPIS and FNIS are determined for each criterion which are represented in Table 6.4.5.

Table 6.4.5: FPIS and FNIS of Criteria

FPIS and FNIS of Criteria		
Criteria	**FPIS**	**FNIS**
Management capabilities *C_1*	(0.88,3.04,5.26)	(0.03,1.06,3.14)
Production capabilities *C_2*	(0.41,1.5,2.88)	(0.04,0.61,1.8)
Collaboration capabilities *C_3*	(0.43,1.54,2.63)	(0.03,0.5,1.49)
Agility *C_4*	(0.38,1.7,3.6)	(0.03,0.82,2.47)
Cost *C_5*	(0.79,2.33,3.95)	(0.06,0.81,1.9)

***Step* 8.** Euclidean distances for each criterion of each aggregated performance rating of alternatives to FPIS and FNIS are obtained by using equation 5.2.10 and 5.2.11. The results are represented in Table 6.4.6 and Table 6.4.7.

Table 6.4.6: Euclidean Distances to FPIS

Distances to FPIS								
Criteria	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
Management capabilities *C_1*	0.47	0.35	0.09	0.14	0.02	0	0.43	0.2
Production capabilities *C_2*	0.4	0.37	0.1	0.17	0.07	0	0.37	0.21
Collaboration capabilities *C_3*	0.5	0.35	0	0.07	0.07	0.07	0.22	0.05
Agility *C_4*	0.3	0.22	0.08	0.11	0.02	0	0.21	0.09
Cost *C_5*	0.25	0.17	0	0.03	0.01	0.08	0.58	0.18

Table 6.4.7: Euclidean Distances to NPIS

Distances to NPIS								
Criteria	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
Management capabilities *C_1*	0	0.14	0.4	0.35	0.46	0.47	0.05	0.29
Production capabilities *C_2*	0	0.03	0.31	0.24	0.34	0.4	0.03	0.21
Collaboration capabilities *C_3*	0	0.17	0.5	0.45	0.44	0.45	0.3	0.47
Agility *C_4*	0	0.09	0.23	0.2	0.28	0.3	0.1	0.22
Cost *C_5*	0.37	0.44	0.58	0.56	0.58	0.52	0	0.43

***Step* 9.** Separation measures for FPIS and FNIS are computed by using equation 5.2.12. Results are represented in Table 6.4.8.

Table 6.4.8: Separation measures of alternatives

Separation Measures	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
PIS	1.9	1.44	0.26	0.51	0.17	0,14	1.8	0.71
NIS	0.37	0.85	2.01	1.78	2.09	2.12	0.46	1.59

***Step* 10.** Each alternative's closeness to ideal solution is computed by using equation 5.2.13 and ranked accordingly. The results are represented in Table 6.4.9

Table 6.4.9: Rank order of the alternatives

Supplier	**Closeness to Ideal**	**Ranking**
1	0.1606	8
2	0.3695	6
3	0.8882	3
4	0.7794	4
5	0.9278	2
6	0.9382	1
7	0.2044	7
8	0.6913	5

Final rankings indicates that the best alternative satisfies the criteria and related sub-criteria is Supplier 6 while the worst alternative is the Supplier 1. Moreover; It is possible to observe that from the distances to FPIS and NPIS in which Supplier 6 comes up with the closest distance to FPIS in three of the main criteria while Supplier 1 comes up with the closest distance to FNIS in four of the main criteria. The ranking of the suppliers did not change through the both methods.

7. CONCLUSION

The competition of the market have become extremely challenging and the structure of the business environment is considerably complex recently. In this competitive and complex environment, acquiring competitive power with responding the rapidly fluctuating situations of the environment. In order to achieve this enhancement agility concept creates a great opportunity to adapt firms to give quick responses to market changes. It is essential for not only the manufacturing firms, but also but also service firms adapting themselves through the agile concept. Implementation of agility on manufacturing or service aspects is not adequate by itself. Both kind of firms are required to have an agile supplier chain. The significance of agile supplier selection rises at this level.

Fuzzy Hierarchical MCDM and Fuzzy Hierarchical TOPSIS methodologies has proposed in the corresponding agile supplier selection problem. These methodologies provide feasibility for incorporation of about numerous factors in multi-level hierarchical structure. The conducted study is enriched by a case study for agile supplier selection in an airline company. Moreover; the proposed methodologies enhances decision makers knowledge from the experts regard of linguistic terms to represent to evaluations of factors' importance and performance of the alternatives in terms of qualitative and quantitative elements. The success of the of the methodology relies on its capability of assessing the imprecision innate in decision maker's evaluations and ease of structured programming.

Novelty of this thesis is mainly based on its field of application. Airline Industry requires agility, however; existing studies are not providing an satisfactory background to enlighten the field. Furthermore; experts are satisfied with the resulted rankings of the candidate suppliers since they claimed cost is the only preference element when they were select the supplier through the agile perspective. During the study they are also encouraged to make developments in the corresponding selection procedure and they participated with two specific criteria and consequently it is observed that rankings of the candidate suppliers are not directly dependent on the cost criteria which means other criteria have also an effect on selection of the supplier.

In conclusion, the proposed methodologies provides a reliable decision making process for comprehensive analysis of multi-level hierarchical agile supplier selection problems.

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BIOGRAPHICAL SKETCH

Osman Öğünçlü was born in Muş in 1990. He participated Denizli Anatolian High School in 2009. After graduation, He participated Industrial Systems Engineering Program at Izmir University of Economics. Throughout the study period of the program, he was awarded with a Merit Scholarship given by the Trustee Committee due to academic success in his freshman, junior and sophomore ages. In the meantime, He was enrolled in Double Major Program on Business Administration as weld and graduate his B.A. degree. Afterwards, he was accepted as a graduate student in Industrial Engineering at Galatasaray University. Moreover, he is currently working as a research assistant in Industrial Engineering Department at Istanbul Bilgi University. His interested research areas are mainly Multi-Criteria Decision Making, Optimization Techniques, Production Planning and Scheduling.

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- Dursun, M., Goker, N., Ogunclu, O. (2017). A Fuzzy Group Decision Making Approach for Agility Evaluation in Aviation Industry, *Proceedings of the World Congress on Engineering,* WCE’2017, London, United Kingdom.
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