Agile Supplier Evaluation Using Hierarchical TOPSIS Method

MEHTAP DURSUN, OSMAN OGUNCLU
Industrial Engineering Department
Galatasaray University
Ciragan Caddesi No: 36, Ortakoy, Istanbul
TURKEY

Abstract: - 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. This study addresses agile supplier selection problem. Hierarchical fuzzy technique for order preference by similarity to ideal solution approach (TOPSIS) is proposed for agile supplier selection problem in an airline company.

Key-Words: - Agility, Decision support system, Hierarchical TOPSIS, Multi-criteria decision making, Supply chain management, Supplier selection.

Received: June 20, 2019. Revised: January 14, 2021. Accepted: February 2, 2021. Published: February 27, 2021.

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 [1]. 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. Many firms aim to cooperate with the suppliers they work with to improve their management effectiveness and competitive power [2]. 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 [3].

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 [1].

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.

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. [4] formed a concept for supply chain agility as the capability for quickly reacting to changes, occurred in business environment and customer requirements, however; Ismail and Sharifi [5] 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. [6] 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.

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 paper.

2 Fuzzy Set Theory

Fuzzy set theory, introduced by Zadeh [7] 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.

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 [8].

Zimmerman [9] 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 $\widetilde{\mathrm{A}}$ 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 [8].

A triangular fuzzy number $\widetilde{\mathrm{A}}$ can be defined by a triplet (a, b, c) as illustrated in Figure 1.

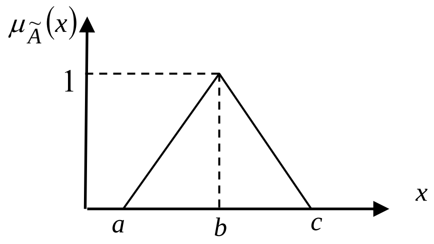

Fig. 1. A triangular fuzzy number $\widetilde{A}$

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

$$\mu_{\widetilde{\mathrm{A}}}(x) = \begin{cases} \frac{x-a}{b-a}, & a \leq x < b \\ \frac{x-b}{b-c}, & b \leq x \leq c \\ 0, & otherwise \end{cases} \quad (1)$$

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:

$$A_1 \oplus A_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (2)$$
$$A_1 \ominus A_2 = (a_1 - a_2, b_1 - b_2, c_1 - c_2) \quad (3)$$

If k is a scalar,

$$k \otimes A_1 = \begin{cases} (ka_1, kb_1, kc_1), & k > 0 \\ (kc_1, kb_1, ka_1), & k < 0 \end{cases} \quad (4)$$

$$A_1 \otimes A_2 = (a_1 a_2, b_1 b_2, c_1 c_2), \text{if } a_1 \geq 0, a_2 \geq 0 \quad (5)$$

$$A_1 \phi A_2 \cong \left(\frac{a_1}{c_2}, \frac{b_1}{b_2}, \frac{c_1}{a_2}\right), \quad \text{if } a_1 \geq 0, a_2 > 0 \quad (6)$$

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.

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 [10].

3 Hierarchical Fuzzy TOPSIS

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a widely used method, introduced by Hwang and Yoon [11]. 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 multi-criteria decision making (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 performances 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. [12] introduced hierarchical fuzzy TOPSIS method in which the sub-criteria are considered within the same layer which damages hierarchical structure.

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;

$$y'_{ijk} = \begin{cases} \dfrac{y_{ijk} - y^-_{jk}}{y^*_{jk} - y^-_{jk}}, & k \in CB_j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \\ \dfrac{y^*_{jk} - y_{ijk}}{y^*_{jk} - y^-_{jk}}, & k \in CC_j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \end{cases} \quad (7)$$

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;

$$\tilde{w}_j = \frac{\tilde{w}_j^1 + \tilde{w}_j^2 + \cdots + \tilde{w}_j^N}{N}, \forall j \quad (8)$$

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.

$$\tilde{w}_{jk} = \frac{\tilde{w}_{jk}^1 + \tilde{w}_{jk}^2 + \cdots + \tilde{w}_{jk}^N}{N}, \forall j \quad (9)$$

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:

$$\widetilde{W}_{jk} = \tilde{w}_j \otimes \tilde{w}_{jk}, \forall j \quad (10)$$

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:

$$\tilde{v}_{ijk} = y'_{ijk} \otimes \widetilde{W}_{jk}, \forall i, j, k \quad (11)$$

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

$$\tilde{v}_{ij} = \sum_{k=1}^{r_j} \tilde{v}_{ijk}, \forall i, j \quad (12)$$

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:

$$M(\tilde{v}_{ij}) \frac{-a_{ij}^2+c_{ij}^2-a_{ij}b_{ij}+b_{ij}c_{ij}}{[3(-a_{ij}+c_{ij})]} \quad (13)$$

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:

$$\tilde{S}_i^* = \sum_{j=1}^{n} \widetilde{D}_{ij}^*, \forall i \quad (14)$$
$$\tilde{S}_i^- = \sum_{j=1}^{n} \widetilde{D}_{ij}^-, \forall i \quad (15)$$

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

$$\widetilde{D}_{ij}^* = \begin{cases} 1 - \frac{c_{ij}-a^*}{b^*+c_{ij}-a^*-b_{ij}}, & b_{ij} < b^*, \\ 1 - \frac{c^*-a_{ij}}{b_{ij}+c^*-a_{ij}-b^*}, & b^* < b_{ij}, \end{cases} \quad \forall i,j \ (16)$$

$$\widetilde{D}_{ij}^- = \begin{cases} 1 - \frac{c^--a_{ij}}{b_{ij}+c^--a_{ij}-b^-}, & b^- < b_{ij}, \\ 1 - \frac{c_{ij}-a^{*-}}{b^-+c_{ij}-a^--b_{ij}}, & b_{ij} < b^-, \end{cases} \quad \forall i,j \ (17)$$

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.

$$C_i = \frac{\tilde{S}_i^*}{\tilde{S}_i^*+\tilde{S}_i^-} \quad (18)$$

***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.

3 Case Study

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. First, experts evaluated the importance of the criteria and the related sub-criteria independent from each other. Eight suppliers are assessed in terms of performances observed by experts through the main criteria and sub-criteria. The criteria and sub-criteria diagram is shown in the Table …

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 2.

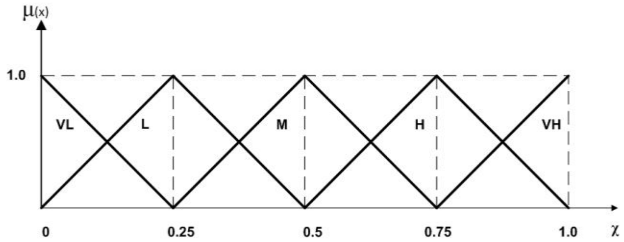

Figure 2. The linguistic term set

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)

The evaluations of the importance of the criteria and sub-criteria by four experts is represented in Table 1 and Table 2.

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.

Data related to agile supplier selection problem is normalized by using Eq. (7). The weighted importance of the main criteria and sub-criteria and the weighted normalized performance ratings of suppliers, in terms of the sub-criteria are calculated.

Table 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 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
Insuriance 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

Generalized mean of each alternative based on each criterion is computed by using Eq. (13). The results are represented in Table 3. Each alternative's closeness to ideal solution is computed by using Eqs. (14-18) and ranked accordingly. The results are represented in Table 4.

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.

Table 3. 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 C1	1.41	1.84	2.87	2.63	3.14	3.18	1.54	2.42
Production capabilities C2	0.82	0.86	1.41	1.27	1.48	1.62	0.86	1.20
Collaboration capabilities C3	0.67	0.90	1.59	1.48	1.47	1.44	1.16	1.51
Agility C4	1.11	1.32	1.68	1.61	1.88	1.92	1.34	1.66
Cost C5	1.73	1.96	2.42	2.41	2.49	2.25	0.92	1.93

Table 4. 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

4 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 TOPSIS method is proposed in the corresponding agile supplier selection problem. This method provides 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. Further studies might focus on the application of different hierarchical MCDM methods to the case problem.

Acknowledgment

This study has been financially supported by Galatasaray University Research Fund FBA-2020-1024.

References:

[1] Chen, I.J., Paulraj, A., Towards a theory of supply chain management, *Journal of Operations Management*, Vol.22, No.2, 2004, pp.119-150.

[2] Shin, H., Collier, D.E., Wilson, D.D. Supply management orientation and supplier/buyer performance, *Journal of Operations Management*, Vol.18, No.3, 2000, pp.317-333.

[3] Chen, C.T., Lin, C.T., Huang, S.F., A fuzzy approach for supplier evaluation and selection in supply chain management, *International Journal of Production Economics*, Vol.102, No.2, 2006, pp.289-301.

[4] Sharp, J.M., Irani, Z. and Desai, S., Working towards agile manufacturing in the UK industry, *International Journal of Production Economics*, Vol.62, No.1/2, 1999, pp.155-169.

[5] Ismail, H.S. and Sharifi, H., A balanced approach to building agile supply chains., *International Journal of Physical Distribution & Logistics Management*, Vol.36, No.6, 2006, pp.431-444.

[6] Li, X., Chung, C., Goldsby, T.J. and Holsapple, C.W., A unified model of supply chain agility: the work-design perspective, *International*

Journal of Logistics Management, Vol.19, No.3, 2008, pp.408-435.
[7] Zadeh, L.A., Fuzzy Sets, *Information and control*, Vol. 8, 1965, pp.199-249.
[8] Klir, G., Yuan, B., *Fuzzy sets and fuzzy logic* Vol. 4, New Jersey: Prentice hall.
[9] Zimmermann, H.J. 2011 *Fuzzy set theory—and its applications*. Springer Science & Business Media.
[10] Zadeh, L.A., The Concept of a Linguistic Variable and its Application to Approximate Reasoning-I. *Information sciences*, Vol.8, 1975, pp.199-249.
[11] Hwang, C.L., Yoon, K., Multiple Attribute Decision Making: Methods and Applications Springer-Verlag, Berlin, Heidelberg, New York, 1981.
[12] Ateş, N.Y., Çevik S., Kahraman, C., Gülbay, M., Erdoğan, S.A., Multi attribute performance evaluation using a hierarchical fuzzy TOPSIS method, studies in fuzziness and soft computing, *Fuzzy Applications in Industrial Engineering*, Vol. 201, 2006, pp. 537-572.