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A Multi Criteria Decision Making Based Novel Model For Supplier Selection

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Abstract: Supplier selection and measurement of supplier performance are multi-criteria decision making (MCDM) problems and have strategic importance for all industries. The study contains analyzed factors that are affecting the process of the supply chain concerning supplier performance. Supplier performance measures is a tool to determine whether suppliers are doing their job as expected. The importance of supplier performance measurement should not be underestimated due to direct and indirect productivity-related consequences. Supplier evaluation is a complex multiple criteria decision-making problem that is affected by several conflicting factors. Therefore, the measurement of supplier performance has been becoming crucial and critical throughout the world. The purpose of this paper is to investigate the MCDM methods and propose a novel method to check how the performance of suppliers is being measured using three different methods. Qualification and final selection of the supplier can be done with a proposed novel model. In the study, the criteria are weighted with the Analytical Hierarchy Process, while TOPSIS and VIKOR methods are used to evaluate and rank the suppliers. Evaluating supplier performance, derive the importance of the main criteria and sub-criteria applied in decision-matrix to sort the suppliers according to the measurement of supplier performance criteria.

Keywords: Analytical Hierarchy Process, Multi Criteria Decision Making, Supplier Selection, TOPSIS, VIKOR

Tedarikçi Seçiminde Çok Kriterli Karar Verme Tabanlı Yeni Bir Model

Öz: Tedarikçi seçimi ve performansının ölçülmesi tüm endüstriler için stratejik öneme sahip çok kriterli karar verme (ÇKKV) problemleridir. Çalışma, tedarik zinciri sürecini etkileyen, analiz edilmiş faktörlerin tedarikçi performansına dayalı şekilde ölçümlenmesini içermektedir. Tedarikçi performans ölçütleri, tedarikçilerin işlerini beklendiği ve istenilen formatta yapıp yapmadıklarını belirleyen bir araçtır. Tedarikçi performans ölçümü verimlilikle alakalı doğrudan ve dolaylı sonuçları sebebiyle hafife alınmamalıdır. Tedarikçi değerlendirmesi, çeşitli ve karmaşık faktörlerden etkilenen yapıda, çok kriterli bir karar verme problemidir. Bu nedenle, tedarikçi performansının ölçülmesi giderek daha önemli ve kritik hale gelmektedir. Bu çalışmanın amacı, tedarikçilerin performansının ölçümlenmesini ÇKKV yöntemleriyle incelemek ve üç yöntemi barındıran yeni bir metodolojisi önermektir. Çalışmada Analitik Hiyerarşi Süreci yöntemi ile kriterlerin ağırlandırılması yapılırken TOPSIS ve VIKOR yöntemleri ile tedarikçilerin değerlendirilmesi ve sıralanması sağlanmaktadır. Tedarikçi yeterliliğinin testi ve nihai seçimi önerilen yeni modelle yapılabilir. Tedarikçi performansının değerlendirilmesi, tedarikçi performansı için belirlenen ana ve alt kriterlere göre ölçümlenmekte ve karar matrisi ile alternatiflerin sıralanmasını sağlamaktadır.

Anahtar kelimeler: Analitik Hiyerarşi Süreci, Çok Kriterli Karar Vereme, Tedarikçi Seçimi, TOPSIS, VIKOR

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1. Introduction

Nowadays, the supply chain process has been made easier and traceable for companies to be carried out through enterprise resource planning systems such as processes logistics, inventory management, customer relationship management, supplier performance measurements. According to the previous study [1] as defined, the supply chain is a global network covering the process from raw material to final product delivery to meet customer demand [2]. The supply chain is a whole that covers almost all areas of a company such as purchasing, quality, finance, logistics, and production. The supply chain is like the rings of the chain that interact. In the supply chain, each ring is the customer of the next ring. The problem is one of the rings affects all jobs that are connected. In this sense, accurate and proper reporting in the supply chain is very important. Reporting and analyzing processes, using forecasting methods are valuable tools and methods used to create strategies in the supply chain method. In this way, more efficient production for companies will be realized and the costs will be reduced to a lesser extent.

The supplier evaluation systems are an evaluation system in which the companies have the opportunity to measure and monitor the performance of their suppliers according to the criteria defined by companies. The measurement of Supplier performance is a measure of achieving results based on quality, on-time delivery accurate product or service at the right price. Companies are involved in the purchasing department to conduct transactions with suppliers. Purchasing specialists are interested in buying products, that is, the product is being valuable. Companies choose the most suitable suppliers with measurement of supplier performance.

This study aims to measure supplier performance to increase the efficiency of the supply chain process by using a novel MCDM method. In the study, the measurement of performance criterion for the company by using multi-criteria decision-making methods will be weighted by creating a decision matrix with the Analytic Hierarchy Process (AHP). AHP method is used for determining the importance of the main criteria and sub-criteria, the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods are used to sort the suppliers according to the measurement of supplier performance criteria.

A variety of methodologies and studies have been suggested for the supplier selection problem in the literature. A case study is conducted in the automobile manufacturing company to evaluate green suppliers' performance using with fuzzy multi criteria approach [3], [4] examined the problem of identifying an effective model based on the Triple Bottom Line (TBL) approach for measuring sustainability performance of a supplier. [5] conducted a case study in a railway company to cope with SSP (Supplier Selection Problem) by implementing AHP-based approaches for supplier evaluation. [6] proposed an integrated approach in SSP to make clustering and multi-criteria decision-making methods. Another study [7] has used the benefit of fuzzy logic with the application in AHP to determine the weights of criteria with the aim of prioritization of the alternative groups in manufacturing. On the other study [8] multi criteria decision making methods are used to identify risks with the help of fuzzy logic while [9] used parameters of FMEA to determine the preference of cause failures.

Multiple criteria decision making (MCDM) is a process evaluating the alternatives for selected criteria. It is under operations research. There are two types of Multiple criteria decision making approaches. One of them is Multi-Attribute Decision Making, and the other is Multiple-Objective Decision Making. Multi-Attribute Decision Making is used when we are evaluating the criteria to select the best alternative, however, Multiple-Objective Decision Making is used when you select the best alternative by evaluating the conflicting criteria. In this study, we will use the Multi-Criteria Decision Making, since we aimed to find the weights of each criterion.

MCDM helps the decision maker to give a rational decision and, select the best alternative concerning criteria. The main purpose is from the view of all the criteria, determining the alternative that satisfies all of them. It is applicable in many topics, in our daily lives we evaluate the criteria, to make a decision.

MCDM methods are used to find the best option for feasible alternatives. It is the most effective and useful methodology to evaluate and rank the alternatives. Therefore, methods of multi-criteria decisions making methods such as AHP, VIKOR, and TOPSIS are used to find the best alternative.

AHP is one of the most widely used quantitative methods for ranking weights and the importance of each alternative based on expert decisions. Using hierarchy methodology percentage of each main and sub-criteria are obtained using pairwise comparisons. Superdecision, Microsoft Excel, Expertchoice are some tools to use the AHP algorithm. In this study, the Superdecision program is selected to use it. AHP is based on pair-wise comparisons on a decision hierarchy, using a 1-9 comparison scale. AHP method is carried out by a measurable process and it is a form of multiple scale structure. Multiple scale structure supplies boundary conditions to make comparisons [9]-[10].

In recent years, although there are many articles on the evaluation of supplier performance and supplier selection; very few of them involve a holistic examination of multi-criteria decision-making methods [10]-[11]. According to Cengiza and Thiruchelvam [12]-[13], supplier selection problem requires basic of multi criteria decision making methodologies and consists of both qualitative and quantitative criteria. Recently business environment has been changing and the level of competitiveness depends on multiple more factors than before [14]. Selecting the best supplier is a multi-dimensional problem and requires a systematic perspective. Method selection and criteria set are two important parts of SSP.

In this study, multi criteria decision making based model has been proposed with the most important indicators to be considered in SSP. First of all, several alternatives of MCDM are analyzed and three of them are selected in the application. This paper concentrates on the criteria set determination and their application examples using MCDM methods. Thus, the objective of this paper is to present a three method methodology to increase consistency about supplier selection problem.

2. Methods

In this part proposed three methods are explained in detail. Firstly, the AHP method is used to find each criteria’s weights and it is explained with 5 steps and then VIKOR and TOPSIS methods are explained to rank suppliers.

2.1. Analytical Hierarchy Process

AHP model can be used in the SSP by considering the main objectives of the supply chain process. Thomas L. Saaty developed AHP in 1980 as a measurement theory of intangible criteria [15]. AHP exposes relevant priority vector when interpreting information preferred by decision makers based on a set of pairwise comparison values of objects. The AHP is based on the hierarchical structure and it is a kind of MCDM method. Goal, criteria, and alternatives are 3 important elements of AHP. The goal shows the aim of the problem. Criteria are problem-related elements that can be used for the decision process. Saaty's scale of 1–9 has been used for each hierarchical level. The scale is used for pairwise comparisons which are made with judgments using numerical values.

Decision making has two criteria. The first is called single criteria decision making, where the criteria are made according to one determination, and the second is called multi-criteria decision

making, which is evaluated by many criteria. Multi-criteria decision making is a set of concepts, approaches, models, and methods that help decision makers define, evaluate, rank, select or reject options based on many criteria. Decision making problem can be expressed as choosing the most correct option by looking at a specific target or criterion from the set of options. AHP aims to conclude the problem with its hierarchical analysis and applicability consisting of goals, criteria, sub-criteria, and options.

AHP can evaluate hierarchical structure as a whole of both quantitative and qualitative criteria. The pairwise comparisons are organized with using matrix and priorities are derived from the matrix as its principal eigenvector. The consistency of decision makers can be checked in AHP with the help of a consistency ratio(CR). 0.1 value is the maximum limit to ensure that judgment is adequately done. Steps of AHP are shown below: [16]-[18]

Step 1: Definition of the problem and identifying the target of the problem.

In the first stage, the decision making problem is defined. Options (decision points) are determined to define the decision making problem. It is determined how many results of the decision will be evaluated. Then the main criteria that affect the options are determined.

Step 2: Criteria, sub-criteria, and alternatives are determined by creating a hierarchical structure.

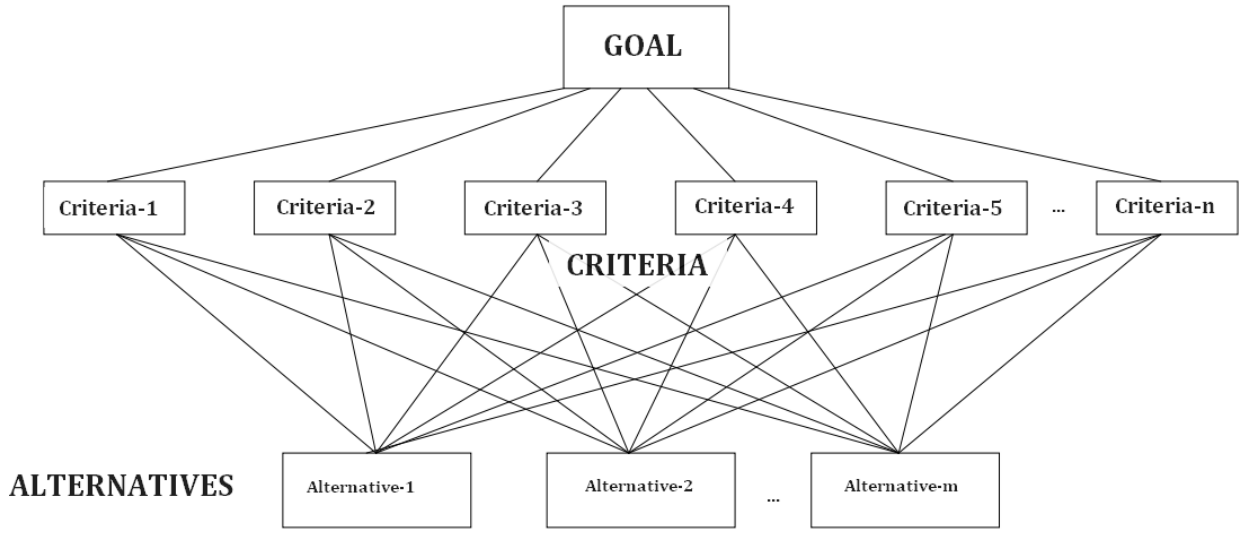

Figure 1: An example of three-level AHP

In the second stage, the problem is defined as a hierarchy as shown in Figure.1

Step 3: The pairwise comparison matrix is created concerning experts.

Each expert makes pairwise comparisons for all hierarchical criteria and alternatives.

Step 4: Computation of λmax(average) of values from the previous step.

Criteria weights are determined by λmax value

Step 5: Computation of consistency index,

(1)

where n: total number of items being compared.

Step 6: Estimation of CR and CI and obtaining random index (RI)

The final stage is to the calculation of a Consistency Ratio (CR) to measure how consistent the judgments.

2.2 Vlse Criterion Optimization And Compromise Solution

VIKOR is one of the most common MCDM methods. It is developed by Opricovic in 1998 for compromise solutions and related multi-objective optimization problems and The VIKOR method deals with the selection of one set of alternatives or the sequencing of alternatives in the case of conflicting criteria. Under the assumption that each alternative is evaluated for each criterion, the closest values are reached by comparing the proximity values to the ideal alternative. It allows to determine the minimum sequence and to reach the immediate solution under specified weights. VIKOR also helps to reach a final solution with a solution that has conflicting criteria. Determining the ordering of alternatives between conflicting criteria allows you to choose the most appropriate option. Ranking of alternatives and determination of compromise solution can be done with VIKOR. The solution shows the "ideal" which means closest to the optimal solution. This method focuses on selecting and sorting alternatives.

To get appropriate results and decision making process, VIKOR methods require consensus to be acceptable to resolve the disputes. The decision maker should accept the closest value to the ideal solution. The relationship between benefits and criteria for decision-makers should be linear. Alternatives are evaluated for all criteria. The choices determined by the decision maker should be expressed in weight. The VIKOR method begins without the interaction of the decision maker, then the decision maker is responsible for approving the final solution. It is based on proximity to the ideal solution. It is defined as the ranking index. VIKOR method steps are shown below:

Step 1: Creating alternatives and determining criteria
Step 2: Create a decision matrix: where A_i represents ith alternative, $i = 1,2,3, \dots m$; Cx_j represents the jth criterion, j =1, 2,..n; and x_{ij} separate performance of an alternative .
Step 3: The normalized decision matrix can be expressed as follows:

$$F = [f_{ij}]_{m \times n} \tag{2}$$

Here,

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{3}$$

$i = 1,2,3, \dots m$; x_{ij} is the performance of A_i alternative for the jth criterion.
Step 4: Determination of the best and worst (f_j^* , f_j^-, respectively) values of all criterion functions $j = 1,2, \dots . n$. If the jth function represents a benefit, then:

$$f_j^* = \max_i f_{ij} \, , f_j^- = \min_i f_{ij} \tag{4}$$

Step 5: Estimation of utility measure (S) and regret measure (R): S and R for each alternative are calculated as :

$$S_{ij} = w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \tag{5}$$

$$S_i = \sum_{j=1}^{n} w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \tag{6}$$

$$R_i = \max_j (S_{ij}) = \max_j \left(w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \right) \tag{7}$$

where, S_i represents the utility measure and also R_i represents the regret measure, besides w_j indicates the weight of the jth criterion, expressing the relative importance of each criterion. w_j can be calculated by the AHP or Entropy method.

Step 6: Computation of VIKOR index (Q_i) for ith alternative by the following relation:

$$Q_i = \frac{v(S_i - S^-)}{(S^* - S^-)} + \frac{(1-v)(R_i - R^*)}{(R^* - R^-)} \tag{8}$$

where: Q_i represents the ith alternative VIKOR value, $i = 1,2,3, \ldots m$;

$$S^* = \max_i S_i, S^- = \min_i S_i \tag{9}$$

$$R^* = \max_i R_i, R^- = \min_i R_i \tag{10}$$

where "v" denotes: the weight of the maximum group utility. It ranges between 0 and 1 and is based on the level of compromise among decision makers. The higher the term v, the compromise is greater. In most cases, it is to be set to 0.5 (v =0.50).

Step 7: Using 3 parameters S, R and Q, rank the alternatives. The minimum to a maximum ranking procedure is followed.

Step 8: A_1 and A_2 are two different alternatives respectively, the alternative with first position (minimum) and second positions in the ranking list by the measure Q (Minimum) if the following two conditions are satisfied:

The first condition (C1) shows that A_1 must be the best ranked by values of S or R

The second condition (C2) is an acceptable advantage which is shown below

$$Q(A_2) - Q(A_1) \geq DQ \tag{11}$$

where DQ=1/(m-1); m is the number of alternatives.

2.3 Technique for Order Preference by Similarity to Ideal Solution

TOPSIS is another MCDM method which is used for The proximity of the decision points to the ideal solution is based on the main principle. TOPSIS aims to find the best selection among the criteria. The method provides the opportunity for decision makers to make the best choice between alternatives.

Step 1: Creation of Decision Matrix

A= (12)

m is an integer from a decision in the decision matrix,
n gives the number of evaluation factors

Step 2: Creating of Standard Decision Matrix(R)

The Standard Decision Matrix is calculated using the elements of matrix A.

(13)

R decision matrix is obtained as a result of the calculation above.

R= (14)

Step 3: Formation of Weighted(V) Standard Decision Matrix

After calculating the wi values, multiplied by the value of rij, V decision matrix is created.

R= $\begin{bmatrix} w_1 \\ w_1 \\ \\ w_1 \end{bmatrix}$ (15)

Step 4: Determine the ideal and a negative ideal solutions.

It is assumed that each evaluation factor has a monotonous increasing or decreasing tendency

A* stands for ideal solution and A- stands for a negative ideal solution

A*= $\{(\max_i$ (16)

A-= $\{(\min_i$ (17)

Step 5: Calculation of Discrimination Measures

The deviation values for the decision points obtained from the following equations are called the Ideal Separation (S_i^*) and Negative Ideal Discrimination (S_i^-).

=)2 (18)

Positive Ideal Separation function is given above.

=)2 (19)

Negative Ideal Separation function is given above.

Step 6: Calculation of Relative Proximity to Ideal Solution
The ideal and a negative ideal separation measures using equation 20

*= (20)

It takes the value C_i* in the range of values 0<=C_i*<=1 and shows the absolute closeness of the relevant decision point C_i*=1 to the ideal solution, the corresponding decision point C_i*=0 to a negative ideal solution.

3. Application of Proposed Model

AHP, VIKOR and TOPSIS are three important MCDM methods to find each SSP criteria to increase productivity. Criteria set is defined and determined with the help of 10 experts who have experience in supply chain process and with the help of literature review for SSP.

Main and subcriteria of them can be seen in Table 1.

Table 1: Main and Sub Criteria Set of SSP.

Criteria	Sub-Criteria
Management Capabilities-(MC1)	Management and Organization (S1), Financial position(S2), Customer relation(S3), Reputation(S4)
Production Capabilities (MC2)	Production capacity(S5), Product diversity(S6), Quality(S7), R&D(S8)
Collaboration Capabilities (MC3)	Deliver reliability(S9), Warranties and claim policies(S10), Collaboration with partners(S11)
Cost (MC4)	Discount(S12), Terms of Payment(S13), Transportation cost(S14), Unit Product Cost(S15)
Agility (MC5)	Delivery flexibility(S16), Delivery speed(S17), Make Flexibility(S18), Source flexibility(S19)

MC: Main criteria S: Sub criteria

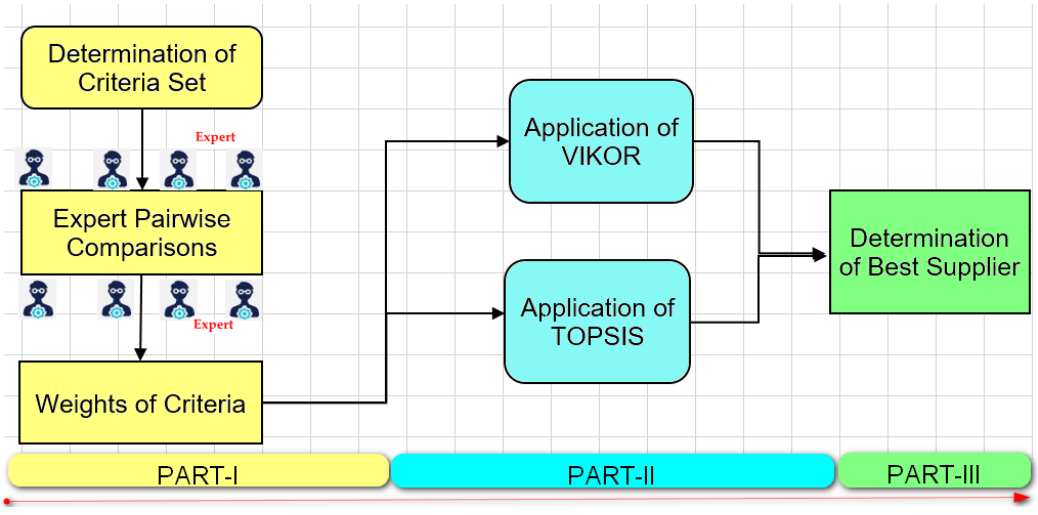

Figure 2: The flowchart of the proposed approach for supplier selection

In this study each criterion weights have been found with using AHP, ranking and prioritization of alternatives have been done with the help of VIKOR and TOPSIS method.

Subjective weights of Main Criteria set can be seen in Table-2

Table 2: Subjective weights of Criteria

Main Criteria	Weight
MC1	0.25
MC2	0.23
MC3	0.2
MC4	0.13
MC5	0.19

According to the AHP application, evaluations of the 10 experts in 9 scale matrixes are used to evaluate the relative weights of each group by pairwise comparisons. Table 2 shows the obtained results. After determining the weights of five SSP parameters by AHP, the evaluations of each sub criteria is done. The obtained results are showing in Figure 3-6.

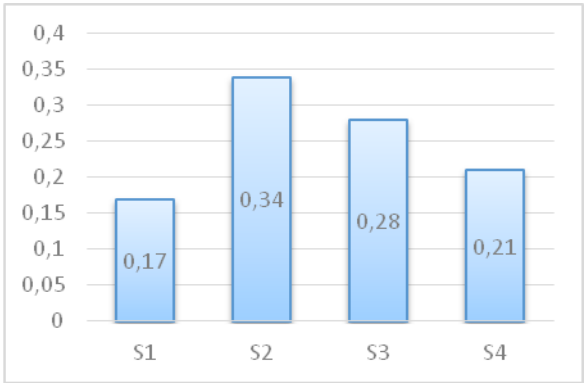

Figure 3: Weights of Management Capabilities.

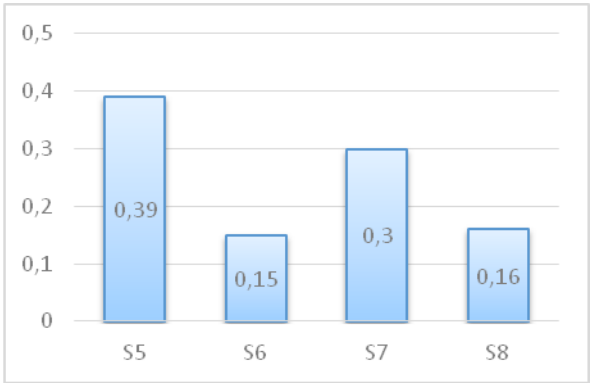

Figure 4.a: Weights of Production Capabilities.

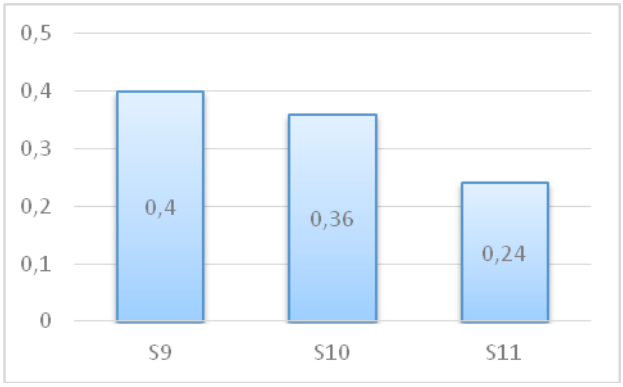

Figure 4.b: Weights of Collaboration Capabilities.

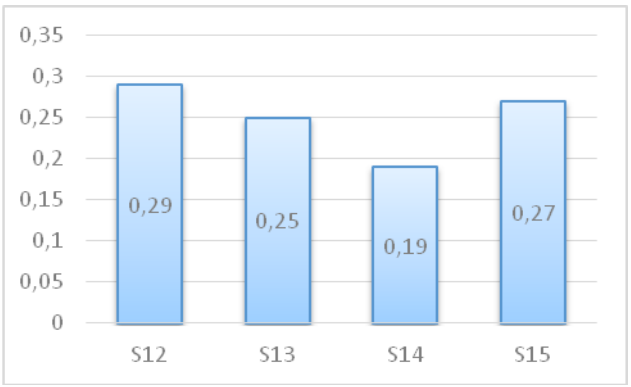

Figure 5: Weights of Main Criteria: Cost.

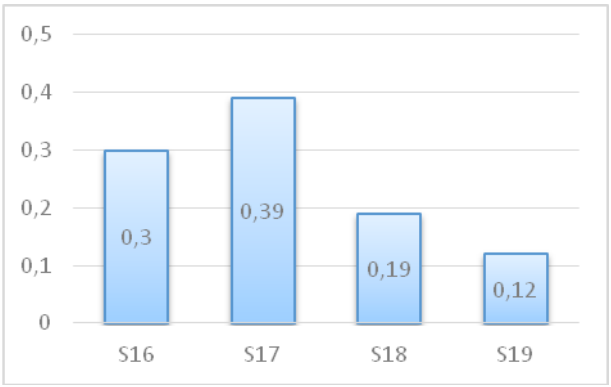

Figure 6: Weights of Main Criteria: Agility.

To rank 5 suppliers, VIKOR and TOPSIS methods are used as follows.

By using the selection criteria weights obtained, VIKOR and TOPSIS method were used to rank the suppliers and determine the best supplier.

Table 3: Decision Matrix

	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary	N.Beneficiary	N.Beneficiary	Beneficiary	Beneficiary	Beneficiary	Beneficiary
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	**S14**	**S15**	S16	S17	S18	S19
Weights	0.0425	0.085	0.07	0.0525	0.0897	0.0345	0.069	0.0368	0.08	0.072	0.048	0.0377	0.0325	0.0247	0.0351	0.057	0.0741	0.0361	0.0228
SUPPLIER-1	9	8	9	7	3	7	9	7	3	7	4	9	7	4	7	4	8	3	7
SUPPLIER-2	7	5	7	9	5	5	7	9	8	5	6	6	5	8	8	5	5	4	7
SUPPLIER-3	8	8	8	5	8	4	8	5	5	4	9	8	8	7	6	3	8	8	9
SUPPLIER-4	5	4	5	7	4	6	5	7	9	6	7	7	5	6	3	5	4	4	5
SUPPLIER-5	6	5	6	6	9	7	6	6	7	7	5	8	6	4	2	6	5	9	6
Fj*	9	8	9	9	9	7	9	9	9	7	9	9	8	4	2	6	8	9	9
Fj-	5	4	5	5	3	4	5	5	3	4	4	6	5	8	8	3	4	3	5

Fj^* and $F\ j^-$ indicate the best and worst value for the given criteria. For beneficiary variables, the maximum value is given with Fj^* while the non-beneficiary variable is minimum with Fj^*

Table 4: Normalize Unweighted Decision Matrix

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	**S14**	**S15**	S16	S17	S18	S19
Weights	0.0425	0.085	0.07	0.0525	0.0897	0.0345	0.069	0.0368	0.08	0.072	0.048	0.0377	0.0325	0.0247	0.0351	0.057	0.0741	0.0361	0.0228
SUPPLIER-1	0	0.25	0	0.5	1.5	0.5	0	0.5	1.5	0.5	1.25	0	0.5	1.25	0.5	1.25	0.25	1.5	0.5
SUPPLIER-2	0.5	1	0.5	0	1	1	0.5	0	0.25	1	0.75	0.75	1	0.25	0.25	1	1	1.25	0.5
SUPPLIER-3	0.25	0.25	0.25	1	0.25	1.25	0.25	1	1	1.25	0	0.25	0.25	0.5	0.75	1.5	0.25	0.25	0
SUPPLIER-4	1	1.25	1	0.5	1.25	0.75	1	0.5	0	0.75	0.5	0.5	1	0.75	1.5	1	1.25	1.25	1
SUPPLIER-5	0.75	1	0.75	0.75	0	0.5	0.75	0.75	0.5	0.5	1	0.25	0.75	1.25	1.75	0.75	1	0	0.75

The decision matrix in which alternatives are evaluated for each criterion is formed in this stage. This matrix is converted to normalize weighted decision matrix with the multiplication of each alternative with its weights.

Table 5: Normalize Weighted Decision Matrix

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	**S14**	**S15**	S16	S17	S18	S19
SUPPLIER-1	0	0.02125	0	0.02625	0.13455	0.01725	0	0.0184	0.12	0.036	0.06	0	0.01625	0.030875	0.01755	0.07125	0.018525	0.05415	0.0114
SUPPLIER-2	0.02125	0.085	0.035	0	0.0897	0.0345	0.0345	0	0.02	0.072	0.036	0.028275	0.0325	0.006175	0.008775	0.057	0.0741	0.045125	0.0114
SUPPLIER-3	0.010625	0.02125	0.0175	0.0525	0.022425	0.043125	0.01725	0.0368	0.08	0.09	0	0.009425	0.008125	0.01235	0.026325	0.0855	0.018525	0.009025	0
SUPPLIER-4	0.0425	0.10625	0.07	0.02625	0.112125	0.025875	0.069	0.0184	0	0.054	0.024	0.01885	0.0325	0.018525	0.05265	0.057	0.092625	0.045125	0.0228
SUPPLIER-5	0.031875	0.085	0.0525	0.039375	0	0.01725	0.05175	0.0276	0.04	0.036	0.048	0.009425	0.024375	0.030875	0.061425	0.04275	0.0741	0	0.0171

The weighted normalized decision matrix is constructed by multiplying the criteria weight calculated by AHP of elements in each column of the normalized decision matrix.

Table 6: VIKOR Results

	Ranking		
	Si	**Ri**	**Q**
SUPPLIER-1	2	5	4
SUPPLIER-2	4	2	3
SUPPLIER-3	1	3	1
SUPPLIER-4	5	4	5
SUPPLIER-5	3	1	2

The following calculations show that C1 (Acceptable advantage) and C2 (Acceptable stability) conditions are satisfied since

(1) Q (A2)- Q (A1)= 0.269189 and DQ=0.25. Q (A2)- Q (A1) > DQ
(2) Supplier-3 is in the first rank for S_i. So acceptable stability condition is satisfied.

After VIKOR application, TOPSIS methods are applied to check whether it will give the same results and consistency or not.

Table 7: Normalize Unweighted Decision Matrix

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	**S14**	**S15**	S16	S17	S18	S19
Weights	0.0425	0.085	0.07	0.0525	0.0897	0.0345	0.069	0.0368	0.08	0.072	0.048	0.0377	0.0325	0.0247	0.0351	0.057	0.0741	0.0361	0.0228
SUPPLIER-1	0.5636019	0.574367	0.563602	0.451848	0.21483446	0.52915	0.563602	0.451848	0.1986799	0.52915	0.278019	0.524891	0.496217	0.297318	0.549972	0.379663	0.574367	0.219971	0.451848
SUPPLIER-2	0.438357	0.358979	0.438357	0.580948	0.35805744	0.377964	0.438357	0.580948	0.5298129	0.377964	0.417029	0.349927	0.354441	0.594635	0.628539	0.474579	0.358979	0.293294	0.451848
SUPPLIER-3	0.5009794	0.574367	0.500979	0.322749	0.5728919	0.302372	0.500979	0.322749	0.3311331	0.302372	0.625543	0.466569	0.567105	0.520306	0.471405	0.284747	0.574367	0.586588	0.580948
SUPPLIER-4	0.3131121	0.287183	0.313112	0.451848	0.28644595	0.453557	0.313112	0.451848	0.5960396	0.453557	0.486534	0.408248	0.354441	0.445976	0.235702	0.474579	0.287183	0.293294	0.322749
SUPPLIER-5	0.3757346	0.358979	0.375735	0.387298	0.64450339	0.52915	0.375735	0.387298	0.4635863	0.52915	0.347524	0.466569	0.425329	0.297318	0.157135	0.569495	0.358979	0.659912	0.387298

Table 8: Normalize Weighted Decision Matrix

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	**S14**	**S15**	S16	S17	S18	S19
SUPPLIER-1	0.0239531	0.048821	0.039452	0.023722	0.01927065	0.018256	0.038889	0.016628	0.0158944	0.038099	0.013345	0.019788	0.016127	0.007344	0.019304	0.021641	0.042561	0.007941	0.010302
SUPPLIER-2	0.0186302	0.030513	0.030685	0.0305	0.03211775	0.01304	0.030247	0.021379	0.042385	0.027213	0.020017	0.013192	0.011519	0.014687	0.022062	0.027051	0.0266	0.010588	0.010302
SUPPLIER-3	0.0212916	0.048821	0.035069	0.016944	0.0513884	0.010432	0.034568	0.011877	0.0264906	0.021771	0.030026	0.01759	0.018431	0.012852	0.016546	0.016231	0.042561	0.021176	0.013246
SUPPLIER-4	0.0133073	0.024411	0.021918	0.023722	0.0256942	0.015648	0.021605	0.016628	0.0476832	0.032656	0.023354	0.015391	0.011519	0.011016	0.008273	0.027051	0.02128	0.010588	0.007359
SUPPLIER-5	0.0159687	0.030513	0.026301	0.020333	0.05781195	0.018256	0.025926	0.014253	0.0370869	0.038099	0.016681	0.01759	0.013823	0.007344	0.005515	0.032461	0.0266	0.023823	0.00883
V+	0.0239531	0.048821	0.039452	0.0305	0.05781195	0.018256	0.038889	0.021379	0.0476832	0.038099	0.030026	0.019788	0.018431	0.007344	0.005515	0.032461	0.042561	0.023823	0.013246
V-	0.0133073	0.024411	0.021918	0.016944	0.01927065	0.010432	0.021605	0.011877	0.0158944	0.021771	0.013345	0.013192	0.011519	0.014687	0.022062	0.016231	0.02128	0.007941	0.007359

V+ and V- indicate the best and worst value for the given criteria. For beneficiary variables, the maximum value is given with V+ while the non-beneficiary variable is minimum with V+.

Determining positive ideal and negative ideal points of each criterion, distances of each alternative to a positive ideal (Si+) and a negative ideal (Si-) points are calculated. At the last stage relative closeness to a positive ideal solution is calculated and alternatives are ranked according to these values. Supplier-5 is the best alternative for the performance score.

Table 9: TOPSIS Results

	Si+	**Si-**	**Pi**	**Rank**
SUPPLIER-1	0.058448	0.048257	0.45224998	4
SUPPLIER-2	0.048332	0.039999	0.45283235	3
SUPPLIER-3	0.039554	0.056447	0.58798522	2
SUPPLIER-4	0.057241	0.041215	0.41861502	5
SUPPLIER-5	0.038532	0.057196	0.59748352	1

4. Results and Discussion

After the MCDM methods application has been determined to deal with SSP and avoid direct and indirect disadvantages of them. It can be easily set up production planning according to obtained results with an extended version of MCDM. AHP application of SSP comes up with benefits of productivity and easiness of planning. Since the supply chain has significant importance for each company and each product production process productivity of it can be improved and planning could be taking into account more properly. At this point, the advantages of AHP and MCDM can be seen and the supplier selection strategy of any company can be revised. Using the AHP criteria set is weighted. After the determination and calculation of each criteria weight, TOPSIS and VIKOR methods were used to rank suppliers. Optimization of supplier selection problem with proper methods and methodologies could set comparative advantage for any country. More research and development studies should be done and implemented systematically in the supply chain process especially each case could be considered with its own MCDM model. Results indicated that the ranking of alternatives seems different due to the normalization difference between VIKOR and TOPSIS. Decision makers will be able to achieve the same result by eliminating this problem by changing the weight of their priorities at this stage. The ranking difference in the results is based on the normalization process and priority difference.

This study contributes to the context of SSP from two sides. From a methodological point of view; (1) an AHP-based method that avoids shortcomings of the inconsistency in decision-making is proposed. Apart from classical SSP alternatives risk assessment methods, decision-makers assign criteria weights in a pairwise comparison manner of AHP. (2) Different from classic methods this paper considers the three-stage decision making process which is the determination of alternatives and their weights with AHP, the ranking of suppliers with VIKOR and TOPSIS, determination of

best supplier alternative(s) to AHP-VIKOR-TOPSIS integrated model. In the previous studies [21]-[24] AHP method was preferred to select the best alternatives for SSP.

In this study supplier selection problem of companies considered and analyzed with AHP-VIKOR-TOPSIS integrated methodology and have been proposed. This paper reviewed multi-criteria decision-making approaches for supplier performance evaluation and MCDM methods application of it is proposed. Criteria weights were determined by performing AHP analysis. Utilizing these weights, TOPSIS and VIKOR methods are applied and alternatives were listed. When comparing the results, it was seen that Supplier-3 and Supplier-5 are the most important alternatives in both methods. For future work, more detailed criteria set and extended MCDM application could be applied for each specific industry to increase the effectiveness and efficiency of the supply chain process. Criteria weights were determined by performing AHP analysis. Utilizing these weights, TOPSIS and VIKOR methods are applied and alternatives were listed.

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