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Using ANP and ELECTRE Methods for Supplier Selection: Cable Industry Application

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ABSTRACT

Business has to perform their activities in increasingly competitive environment due to emerging technologies and globalization. To be successful in this competitive environment, they have to make decisions to ensure superiority over its competitors. One of the important decisions for the future of the business is the selection of right suppliers. The right selection of suppliers that will provide the necessary resources will be an advantage to businesses. Choosing the right supplier will lead to increase in product quality, decrease in costs, to increase customer satisfaction and production flexibility. Therefore, accurate and impartial manner in the selection of suppliers is a necessity. In this study, supplier selection problem is discussed for business operating in the cable industry.

Supplier selection, due to the excess of the criteria for effective decision-making and the alternative, is defined as "Multi-Criteria Decision Making Problem". Different methods have been developed to solve the multi-criteria decision making problem. In this study, “Analytic Network Process (ANP)” and “Elimination Et Choix Traduisant La Realité (ELECTRE)” methods were used to complement each other and this integrated method as applied to the selection of suppliers for a cable manufacturing company operating in Samsun. Supplier selection criteria used in the study have been identified as the 6 main criteria and 19 sub-criteria in accordance with the literature. These criteria may be both qualitative and quantitative. The weight of criteria were determined by taking into account the opinions of experts. The information obtained from them were used as input for Super Decision program for ANP approach. Then weights of the criteria and the performance of seven suppliers for each criteria have been used as input for ELECTRE method. The required calculations were made for the application of ELECTRE method using Microsoft Excel 2010 program. As a result of these calculations suppliers were evaluated and ranked. Thus it was determined the best supplier for business.

Keywords: multi-criteria decision making, ANP, ELECTRE, supplier selection

1. INTRODUCTION

The companies have to make some decisions in order to survive in today's competitive markets, to be superior to their competitors, to reduce their costs and to increase their profits. One of these decisions is the choice of the suppliers that they co-ordinate in the production phase. The problem of supplier selection can be defined as the determination of who and how much of the raw materials, semi-finished products and other materials required for production are taken. Working with appropriate suppliers has a

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significant impact on the competitiveness of the company [1].

It is one of the major problems handled by supplier selection due to the large number and diversity of the expectations of the enterprises working with the suppliers, due to the large number of suppliers that can provide the same service and satisfy the expectations differently. With the supplier selection, it is aimed to determine the suppliers who can continuously supply the demands at the appropriate price, in the required quantity, on time and in quality [2], [3], [4], [5]. The companies need to work with the most appropriate suppliers in order to achieve their goals. This goal is about the supplying of PVC raw material.

Several methods have been used in the literature in order to solve the problems of supplier evaluation [6]. The highlights among these approaches are clustering analysis [7], mathematical programming models [8] - [12], artificial intelligence and network-based methods [13] - [16] and MCDM methods [17] - [21].

If the studies about supplier selection are examined, it can be seen that different criteria are used. These criteria are summarized as follows: price, quality, delivery, past performance, guarantees and obligations, financial situation, technical support, response to customer requests, references, risk factor, speed, quality system, information technology, sector type, technology, geographical location, service, flexibility, just in time delivery, delivery time, bilateral agreements, management organization, technical capacity, supplier profile, resources, human resources, packaging ability, impression, production capacity, storage capability, experience, cycle time, e-commerce capability, green production, product development, product variety, application control, problem solving ability, manufacturing, communication and technical personel [22].

In this study, a problem was handled for supplier selection for the PVC raw material industry in a company operated in cable industry. This company was established in 1984 and employs more than 2000 people. It also operates with 15 companies in many different sectors. It has been produced copper wire and PVC granules with a capacity of 1,200 tons of copper smelting capacity per month.

There is no any scientific method for selection of suppliers in the related company. Besides, the supplier selection is made by considering the experience of the purchasing department and competent people in the current situation. Because of that, it is necessary to make the selection of suppliers in technical and mathematical basis. A Multi-Criteri Decison Making model was conducted for this purpose.

When the literature is examined, it can be seen that many MCDM methods are used purely or integrated with other methods. ANP integrated ELECTRE method was used in our study. ANP reflects the relationships and interactions between the selection criteria at a good level, and ELECTRE is applied to get the superiority of alternatives. There are a few works about this hybrit method in literature [23], [24]. For this reason, our model has progressed in this direction.

Within the scope of the study, it was firstly determined the weights of the criteria for PVC raw material suppliers by ANP method and then by using these weights in the ELECTRE method, 7 different alternative suppliers were evaluated and the suppliers were ranked in the decreasing order.

In the first stage of this study, the basic knowledge about supplier selection were introduced, the description of the problem and its purpose was presented, and the literature about the methods and criteria used in supplier evaluation were summarized. In the second stage, the solution steps of ANP and ELECTRE methods used to solve the problem were explained. The study was applied in the third stage. In the last stage, the results obtained were discussed and suggestions were presented.

2. METHOD

In this part of the study, the steps of ANP and ELECTRE were briefly mentioned.

2.1. ANP

The ANP (Analytic Network Process) method was developed by Thomas L. Saaty and specifies the importance weights of the alternatives. In literature, it can be seen many papers which has evaluated some alternatives with ANP method [25], [26]. The steps in the implementation of the method can be summarized as follows [22], [27]:

Step 1. At this stage, the problem is defined and a decision model is established. Objective, criteria,

sub-criteria and alternatives related to the problem are expressed clearly.

Step 2. The relationships between the criteria of the problem and its sub-criteria are determined.

Step 3. Priority vectors are calculated from pairwise comparisons between the criteria. The pairwise comparison matrix is obtained from experts in related company.

Step 4. Consistency analyzes of comparison matrices are performed. To determine if the compared comparisons are consistent, the consistency ratio (TO) for each matrix should be calculated after the comparison matrices have been constructed. TO is obtained by dividing the consistency index (TI) by the Randomized Consistency Index (RTI). If the value of TO is less than 0.10, binary comparisons can be said to be consistent. If the values are greater than 0.10, there is inconsistency in the comparison. In this case, the decision-making expert group should repeat the comparisons made.

Step 5. Supermatris is created. A new matrix is formed by multiplied by all of the values in unweighted supermatrix and the weights of the cluster. This matrix can be expressed as a weighted supermatrix. All the columns of the matrix are identical and each gives the relative priorities of the elements from which the priorities of the elements in each cluster are normalized to one. In order to equalize the priorities at one point, the supermatrix is taken to sufficiently large power. This obtained matrix is called as the limit supermatrix. [28].

Step 6. The best alternative is chosen. With the obtained limit super matrix, the importance weights related to the each criterion are determined. The best alternative in the selection problem is the alternative which is the most important alternative and h has the highest importance in the decision process.

2.2. ELECTRE

The ELECTRE method was first proposed by Benayoun in 1966 and developed in 1968 as a result of Bernard Roy's decision-making studies. The ELECTRE method is suitable for assessing some alternatives in any major sector [29], [30], [31]. The ELECTRE method is based on a comparison of the pairwise superiority between alternatives for each criterion. The steps of the ELECTRE method are described below [32], [33].

Step 1. Create the decision matrix (A): while the alternatives are settled in the row, the criteria are settled in the column. The matrix A is the initial matrix generated by the decision maker's opinion. The decision matrix is shown as follows:

$$A_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \quad (1)$$

Step 2. Normalization of matrix A: The matrix A needs to be normalized to remove the diversity of units. The normalization formula depens on the cost and benefit of the criteria which is used in the decision making process.

If the criteria indicates the cost;

$$x_{ij} = \frac{\frac{1}{r_{ij}}}{\sqrt{\sum_{i=1}^{m}\left(\frac{1}{r_{ij}}\right)^2}} \quad (2)$$

i= 1, 2… m j=1, 2… n

If the criteria indicates the benefits;

$$x_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}} \quad (3)$$

$$i = 1,2,\dots,m \text{ and } \qquad j = 1,2,\dots,n$$

Step 3. Obtain the weighted normalized matrix: Decision maker has to assign the weights of each criterion (w_j). ($\sum_{i=1}^{n} w_j = 1$). The weighted normalized matrix is obtained by multiplying by the weights of the normalized matrix criteria.

$$v_{ij} = w_j x\, X_{ij} \quad (4)$$

Step 4. Establish the compliance and the divergence clusters: A sets of compliance and divergence clusters are established. The criteria are divided into two separate sets for each alternative pairwise. A_p and A_q (1, 2… m and p≠q).

The alternative A_p is preferred to A_q in the compliance cluster.

$$C(p,q) = \{j,\ v_{pj} \geq v_{qj}\} \quad (5)$$

If A_p is the worse alternative than A_q, the divergence cluster must be created.

$$D(p,q) = \{j,\ v_{pj} < v_{qj}\} \quad (6)$$

Step 5. Calculate the compliance and divergence indexes: Compliance sets are used to establish the compliance matrix (C).

$$C_{pq} = \sum_{j^*} w_{j^*} \quad (7)$$

j^* is a factor in the compliance matrix C(p,q).

$$D_{pq} = \frac{(\sum_{j^0} \left| v_{pj^0} - v_{qj^0} \right|)}{(\sum_{j} \left| v_{pj} - v_{qj} \right|)} \quad (8)$$

The divergence (D) matrix is obtained from the following formula.

j^0 is a factor in the compliance matrix D (p,q).

Step 6. Compare the superiorities: The average of C ve D values ($\bar{C}, \bar{D}$) are calculated. If $C_{pq} \geq \bar{C}$ and $D_{pq} \leq \bar{D}$, then $A_p \rightarrow A_q$. On the other hands, p^{th} element is superior to q^{th}. The alternatives selected by ELECTRE method occurs a Kernel. The Kernel K is constructed by the following two states:
A point in K (alternative) is not more dominant than another (alternative).

A point outside of K is behind at least one point in K (alternative) in the order of preference.

Step 7. Net compliance and divergence indices are calculated: Cp's are ordered by decreasing and Dp's are ordered by increasing. Then, the final ranking can be obtained.

$$C_p = \sum_{k=1\ k\neq p}^{m} C_{pk} - \sum_{k=1\ k\neq p}^{m} C_{kp} \quad (9)$$

$$D_p = \sum_{k=1\ k\neq p}^{m} D_{pk} - \sum_{k=1\ k\neq p}^{m} D_{kp} \quad (10)$$

3. AN APPLICATION: SUPPLIER SELECTION PROBLEM

The problem of supplier selection was handled for a cable manufacturing operation operating in the province of Samsun. 7 suppliers were identified which is suitable for company's business purposes. The main criteria and sub-criteria for the selection process were determined. The weights of these criteria were determined by the ANP method, and then these weights were used as input in the ELECTRE method.

3.1. Determination of supplier selection criteria

The literature was examined firstly to determine the criterion to be used in the selection of suppliers. The criteria which are frequently used in supplier selection were selected. In addition to literature review, the criteria were selected by consulting with the opinions of the experts employed in the related company. In this study, individual questionnaires were prepared for the three experts in the management department, and binary comparisons were made by considering the effects of the main criteria on the supplier selection. Besides, the sub criteria of these criteria were determined in line with the opinions of the same team. In this direction, 6 main criteria which are named as quality, price, delivery, flexibility, technology and relationship, and 19 sub-criteria related to these main criteria were determined as seen Table 1.

The description of the main criteria was presented in following paragraph.

Quality: a measure of defects, deficiencies and significant variations.

Price: ability of the payback and effectiveness of the reducing cost for each firms.

Delivery: the action of delivering products just in time and in the appropriate amount.

Flexibility: the ability of offering appropriate options.

Technology: technological features of each supplier firms.

Association: the features of the communications between supplier firms and manufacturer.

Table 1. The weights obtained from limit supermatrix.

Main Criteria	The Weights of the Main Criteria	Sub-Criteria	The Weights of the Criteria in the Cluster	The Overall Weights of the Criteria
Quality	0.253	Percent of defective products (DP)	0.352	0.065
		The product quality (PQ)	0.583	0.105
		Having the quality certificates (HQC)	0.065	0.083
Price	0.142	Payment term (PT)	0.689	0.045
		Activity on cost reducing (OCR)	0.238	0.046
		Option duration (OD)	0.073	0.051
Delivery	0.126	Delivery just in time (DJT)	0.368	0.037
		The right amount of delivery (RAD)	0.216	0.029
		Packaged delivery (PD)	0.069	0.025
		Delivery to right destination (DRD)	0.347	0,035
Flexibilty	0.149	Shortness of preparation time (SPT)	0.182	0.027
		Ability on solving problems (ASP)	0.147	0.049
		Service competence (SC)	0.671	0.073
Technology	0.226	Technological Compatibility (TC)	0.700	0.092
		Assessment of future manufacturing capabilities (AFM)	0.107	0.067
		Speed of the supplier's development (SSD)	0.193	0.067
Association	0.104	Association on long term (ALT)	0.644	0.036
		Clarity in communication (CC)	0.177	0.026
		Closeness of the communication (COC)	0.179	0.042

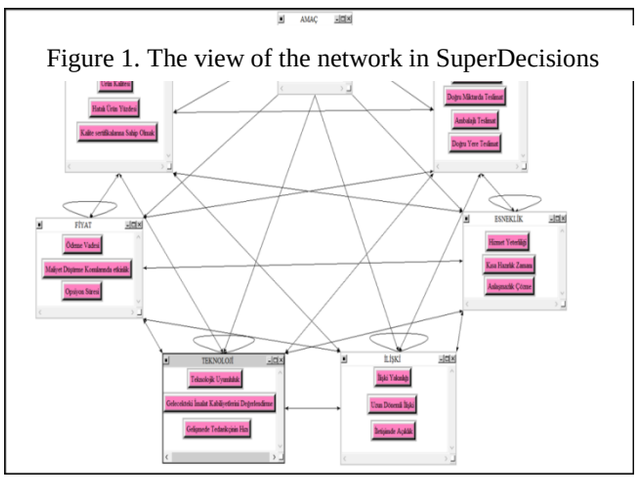

Figure 1. The view of the network in SuperDecisions

3.2. Determination of the relation between criteria

After selecting the supplier selection criteria, the internal and external dependencies between the criteria and sub-criteria were determined along with the team of purchasing managers. The network structure was created using these dependencies in SuperDecisions 2.8 program. The network structure is given in Fig 1.

3.3. Determine the weights of the criteria with ANP

After the network structure is established, the binary comparisons of related criteria were performed. For this purpose, a questionnaire has been conducted for 3 persons in the decision making team and each decision maker has been provided to fill in the questionnaires. The questionnaires has the some comparison questions such as two groups of subcategories related to each other, the binary comparison of the main criteria related to each other and the comparison of the main criteria and the subcriteria according to the effect of the supplier choice. The geometric mean of the answers given by each person to the questions was used to construct the pairwise comparison matrices.

The initial supermatrix, the weighted supermatrix and the limit supermatrix were obtained. The weighted supermatrix was obtained by multiplication of the initial supermatrix and the priority values for each cluster.

Tablo 2. ELECTRE matrix.

CRITERIA	QUALITY			PRICE			DELIVERY				FLEXIBILITY			ASSOCIATION			TECHNOLOGY		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SUPPLIERS	DP (%)	PQ (1-10)	HQC (amount)	PT (day)	OCR (1-10)	OD (day)	DJT (1-10)	RAD (%)	PD (%)	DRD (1-10)	SPT (1-10)	ASP (1-10)	SC (1-10)	ALT (1-10)	CC (1-10)	COC (1-10)	TC (1-10)	AFM (1-10)	SSD (1-10)
Supplier 1	0	10	6	90	10	2	10	99	99	10	10	10	10	10	10	10	10	10	10
Supplier 2	1	9	4	90	10	2	10	98	99	10	10	10	9	10	9	9	9	9	9
Supplier 3	1	10	4	45	10	2	9	98	98	10	10	10	10	10	9	9	9	9	9
Supplier 4	2	9	6	45	9	2	9	96	98	10	10	9	10	9	8	8	8	8	8
Supplier 5	0	9	6	15	9	2	9	94	97	10	9	8	8	10	9	8	9	9	8
Supplier 6	5	9	5	30	9	2	8	96	96	10	9	7	8	9	8	7	8	7	8
Supplier 7	0	9	5	15	9	2	8	95	98	10	9	9	8	9	7	8	8	8	7
WEIGHTS	0.065	0.105	0.083	0.045	0.046	0.051	0.037	0.029	0.025	0.035	0.073	0.027	0.049	0.042	0.036	0.026	0.092	0.067	0.067

The limit supermatrix was obtained by taking a number of exponents of the weighted super matrix. The importance ratings of the criteria obtained with the limit supermatrix were shown in Table 1.

According to the ANP method's results, the most important sub-criterion for supplier selection was "Product Quality" with 10.5%. Following the sub-criteria of "Product Quality", "Technological Compliance" with 9.2%, "Having Quality Certificates" with 8.3% and "Service Qualification" with 7.3% is followed.

Qualitative and quantitative criteria were used together in the ELECTRE matrix. Since quantitative variables such as "having a quality certificate" and "payment valuation" were available numerically, the related data were used without any preprocess. Since qualitative criteria such as "Relationship Relevance" and "Product Quality" were not quantifiable, they have to be converted into a numerical expression. Based on this, 1-10 scale was used for these criteria. Each supplier was evaluated by a 3-person team of purchasing managers with the help of a scale of 1-10 according to each criterion. The arithmetic mean of these scores was used in the matrix.

After the decision matrix was constructed, the decision matrix was normalized. Then weighted normalization decision matrix was formed by multiplication of the values obtained by ANP method and the values in normalization decision matrix. Using this matrix, the alternatives were compared with each other according to each criterion, and sets of Compliance (Cp) and Divergence (Dp) were established. Then, these indices were calculated by using these clusters.

After the weights of criteria were analyzed with ANP, the ordering of the suppliers would be performed with ELECTRE method.

3.4. Selection of the best supplier with ELECTRE method

Criteria obtained from Analytical Network Process method were compared and the weights of criteria were determined with SuperDecisions program. Then, the ELECTRE matrix was created for the evaluation of the suppliers. ELECTRE matrix is given in Table 2.

The average values of Compliance and Divergence were found to compare the partial superiority of suppliers. As a result, the net Compliance and Divergence values were calculated and the values can be seen in Table 3.

After calculation of the net Compliance (C_p) and Divergence (D_p) indices, the C_p values were sorted by increasing and the D_p values were sorted by decreasing to find the final ranking. The final ranking was given in Table 4. And the supplier has been identified as the best supplier in which the C_p value was the largest, the D_p value was the smallest.

Table 3.The net compliance (C_p) and divergence (D_p) indices.

	C_p	D_p
Supplier 1	3.794	-3.537
Supplier 2	1.618	-2.285
Supplier 3	1.944	-2.824
Supplier 4	-0.446	-1.516
Supplier 5	-1.118	1.830
Supplier 6	-2.679	2.242
Supplier 7	-3.131	5.090

Table 4. Final ranking.

Ranking to C_p	Ranking to D_p
Supplier 1 (3.794)	Supplier 1 (-3.537)
Supplier 3 (1.944)	Supplier 3 (-2.824)
Supplier 2 (1.618)	Supplier 2 (-2.285)
Supplier 4 (-0.446)	Supplier 4 (-1.516)
Supplier 5 (-1.118)	Supplier 5 (1.830)
Supplier 6 (-2.679)	Supplier 6 (2.242)
Supplier 7 (-3.131)	Supplier 7 (5.090)

As seen in Table 4, the final ranking is founded as consecutively Supplier 1, Supplier 3, Supplier 2, Supplier 4, Supplier 5, Supplier 6 and Supplier 7. According to the obtained ranking, it might be seen that Supplier 1 is the best supplier for the company. This is followed by Supplier 3 and Supplier 2. Supplier 6 and Supplier 7 have lower performance to other supplier firms, and can not fully respond to the requirements of the company.

4. CONCLUSIONS

In this study, the supplier selection problem was handled for the company operating in the cable sector in Samsun province. A hybrit model with ANP and ELECTRE methods was proposed for that selection problem. The ANP method provided the weights for each criterion on supplier selection. Then the ELECTRE method was used to sort the alternatives.

The ANP method is an effective method that allows the ease of usage of the qualitative and quantitative data together. The ELECTRE method has the disadvantages of determining the criteria weights randomly or subjectively, and not calculating the performance scores of the alternatives in spite of the advantages of examining the superiority relation of the alternatives. When a new alternative is added to the model, it must be compared again with all other alternatives.

Based on literature view, ANP and ELECTRE can be used alone or in combination with other MCDM methods. This application was conducted due to lack of the studies in which

both methods were used together (ANP and ELECTRE) in literature. The AHP method could be used instead of ANP. However, the ANP method was used because it takes into account the relationships between the criteria and therefore offers more realistic solutions.

According to the ANP results, the most important sub-criterion was "Product Quality" with 10,5%. Following "Product Quality" sub-criteria, "Technological Compliance" with 9,2%, "Having Quality Certificates" with 8,3% and "Service Qualification" with 7,3% were followed. It was considered as an interesting result that the sub-criteria of the Price main criterion are not in the upper order.

As a result of the proposed ANP-ELECTRE integrated method, Supplier 1 became the best supplier. This is followed by Supplier 3 and Supplier 2. Accordingly, the firm can compensate the raw materials from Supplier 1 as the best alternative. Other than this alternative, it would be advantageous to work with Suppliers 3 and Suppliers 2 among other suppliers.

Since this study was conducted in a company operating in the cable sector in Samsun, the generalization of the results may not be a very correct approach. When the used criteria in the application are changed or the application is conducted in a different sector than the cable sector, the results may vary. For future work, new solution models can be developed using fuzzy ANP and fuzzy ELECTRE methods. In addition, except the proposed hybrit methos, many new hybrit methods can be used alone or as an integrated, and the results can be compared with this study.

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