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Using a multi-criteria decision making approach (ANP-TOPSIS) to evaluate suppliers in Iran's auto industry

K. Shahroudi*, H. Rouydel

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Abstract Supplier selection is a multi-criteria problem which includes both tangible and intangible factors in these problems if suppliers have capacity or other different constraints two problems will exist: which suppliers are the best and how much should be purchased from each selected supplier? The objective of this paper is to present an integrated model and a supporting approach for effective supplier selection decisions and determined optimum order allocation. Therefore, an integrated approach of ANP- TOPSIS (Analytic Network Process and Technique for Order Preference by Similarity to Ideal Solution) is proposed in choosing the best suppliers and defined the optimum quantities order among selected suppliers by using a mathematical model (Multi-Objective Linear Programming). Hence, after library studies and interview with experts, managers and specialists in supply chain management filed, decision criterion was identified through brain storming contains of seven main criteria for suppliers selection process. Then in the second section for order allocation to every selected suppliers in first section; we used a (MOLP) Multi-Objective Linear Programming model. Therefore objectives and subjective of suppliers and Automotive Company were identified in this section. Results show that applying a two phase ANP-TOPSIS methodology causes to some important advantages such as: Long-term relationship, consist quality, lower cost, special attention and etc.

Keywords Supplier Evaluation, TOPSIS, ANP, Order Allocation.

1 Introduction

Quality, flexibility, diversity, quick response and competition in the global environment have become important for the manufactures in regard to customer satisfaction in today's competition environment [1]. Therefore, the success of a company is determined to a greater degree by the abilities of its suppliers [2]. The suppliers' selection is one of the most critical activities of a company and a strategic purchasing decision that commits significant resources (40-80 percent of total product cost) and impacts the total performance of the firm [3]. Suppliers are an integral part of the supply chain of an Organization. Supply chain management integrates suppliers, manufactures and distribution centers to get the right products to the right place at the right time and in the right condition [4]. Generally the primary goal of supply chain management will be to reduce supply chain risk, reduce

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*** Corresponding Author.** (✉)
E-mail: shahroudi@iaurasht.ac.ir (K. Shahroudi)

K. Shahroudi
Assistant professor, Department of Industrial Management, Islamic Azad University, Rasht Brunch, Rasht, Iran.

H. Rouydel
Young Researchers Club, Islamic Azad University, Rasht Brunch, Rasht, Iran.

production costs, make the maximum revenue, improve customer service, optimize inventory levels, improve business processes which ends in increasing competitiveness, customer satisfaction and profitability [5].

The remainder of the paper is organized into five sections. Section 2 represents the main research's problem, Section 3 reviews previous work on supplier selection and order allocation. Section 3 lays out research methods, processes, and data sources in five steps. Finally, conclusions are presented in Section 5.

2 Problem statement

Basically the issues related to supplier selection are two types. The first type (single sourcing), in which a supplier is able to meet all buyers' needs including demand rate, quality, and delivery time. In this condition the management should just decide which supplier is the best? In type II (multiple sourcing) a supplier alone is not able to meet all needs of buyer and buyer must meet their demands through several suppliers. In this case, management should take two types of decisions: first, which suppliers are the best? And second, how much should be purchased from each supplier? [6,7].

In many cases, organizations usually choose more than one supplier for their products, until facing with non-competence of one supplier to ensure continuity of supply. They can also compare prices and services from various suppliers during the period of time. Hence, in present study we discuss solving the selection of supplier in the state of multiple sourcing.

Increasingly importance of selecting appropriate supplier, as a critical decision in supply chain management, leads organizations in different industries to use systematically formed models to choose suppliers and allocate orders to them. One of these industries is automotive manufacturing industry which had been significant progress in Iran during the recent years. The study is doing at an automotive manufacturing company which despite spending energy, time and cost to select the appropriate suppliers, unfortunately is facing with deficiencies and drawbacks in its supply chain. Therefore, the present study using the suggested model is done to remove these deficiencies and to answer two main research questions:
Which suppliers are the best and how much should be purchased from each selected supplier?

3 Review of the supplier selection methods

The problem of supplier selection is not new. Selection of appropriate suppliers is one of the fundamental strategies for enhancing the quality of output of any organization, which has a direct influence on the company's reputation [8]. Nowadays, supply chain management tries to obtain the long-term participation with suppliers and use fewer numbers but more reliable suppliers [9]. Therefore, to choose appropriate suppliers is something more than just looking at the list of suppliers' suggested prices and suppliers selection depends on to many qualitative and quantitative factors [10]. Hence several methods have been proposed for solving supplier selection problem such as: Analytic Hierarchy Process (AHP), Analytical Network Process (ANP), Artificial Neural Networks (ANN), Case-Based Reasoning (CBR), Data Envelopment Analysis (DEA), Genetic Algorithm (GA), Fuzzy Set Theory, Mathematical Programming (MP), Simple Multi–Attribute Rating Technique (SMART) and mixed technique.

At least four journal articles have already reviewed the literature related to suppliers' evaluation and selection models [11,12,13,14].

There are many studies about the supplier selection process. Traditional methodologies of the supplier selection process in research literature include the cost-ratio method, the categorical method, weighted-point evaluations, mathematical programming models and statistical or probabilistic approaches [15]. Table 1 shows various decision making approaches have been proposed to tackle the supplier selection problem.

Table 1 Category of approaches of supplier selection [14]

	Approaches	Techniques	Authors
1	**Individual approaches**	Data Envelopment Analysis (DEA)	Liu et al, (2000)- Narasimhan et al, (2001)- Talluri and Sarkis, (2002), Sedel, (2006), Saen, (2007)
		Mathematical Programming	
		• Linear Programming	Talluri and Narasimhan, (2003 & 2005)- Ng, (2008)
		• Integer Liner Programming	Talluri, (2002)- Hong et al, (2005)
		• Integer Non-Liner Programming	Ghodsypour and O'Brien, (2001)
		• Goal Programming	Karpak et al, (2001)
		• Multi-Objective Programming	Narasimhan et al, (2006)- Wadhwa and Ravindran, (2007)
		Analytic Hierarchy Process (AHP)	Chan, (2003)- Liu and Hai, (2005)- Chan et al, (2007)- Hou and Su, (2007)
		Case Based Reason (CBR)	Choy and Lee, (2002)- Choy et al, (2005)
		Analytic Network Process (ANP)	Sarkis and Talluri, (2002)- Bayzit, (2006)- Gencer and Gurpinar, (2007)
		Fuzzy Set Theory (FST)	Sarkis and Mohapatra, (2006)- Florez Lopez, (2007)
		Generic Algorithm (GA)	Ding et al, (2005)
2	**Integrated approaches**	AHP-DEA	Ramanathan, (2007)- Saen, (2007)- Sevkil et al, (2007)
		AHP-DEA- Artificial Neural Network (ANN)	Ha and Krishnan, (2008)
		AHP-GP	Cebi and Bayraktar, (2003)- Percin, (2006)- Kull and Talluri, (2008)- Mendoza et al, (2008)
		AHP-Multi-Objective Programming	Xia and Wu, (2007)
		ANN-CBR	Choy et al, (2003, 2004)
		ANN-GA	Lau et al, (2006)
		ANN- Multi-Objective Programming	Demirtas and Ustun, (2008)
		DEA- Multi-Objective Programming	Weber et al, (2000)- Talluri et al, (2008)

4 Methodology

The research was carried out in automotive industry. Overall, this study is doing in five steps. In the first steps, after reviewing the research literature, interview with the experts, and survey the managers, in a company custodian to automotive supply chain management group, decision-making criteria were identified, through the brainstorming method including seven criteria affecting on suppliers selection. Then, the degree of interdependent relationship between different criteria is determined by the expert group in second steps. In third and forth steps in order to calculate the weight of each indices and final ranking of desired parts suppliers, integrated ANP-TOPSIS techniques were used. hence we answered the first question of the research: how to select best suppliers. In the fifth steps, in order to answer the second question of the research concerning allocation quantity of orders to each supplier, multi-objective linear programming model (MOLP) was used. First, the multi-objectives of the company were identified then suppliers' and buyers' constraints were considered. Finally the equations solved by LINGO software and the optimum amount of order to each supplier identified. Fig. 1 shows the process of the research.

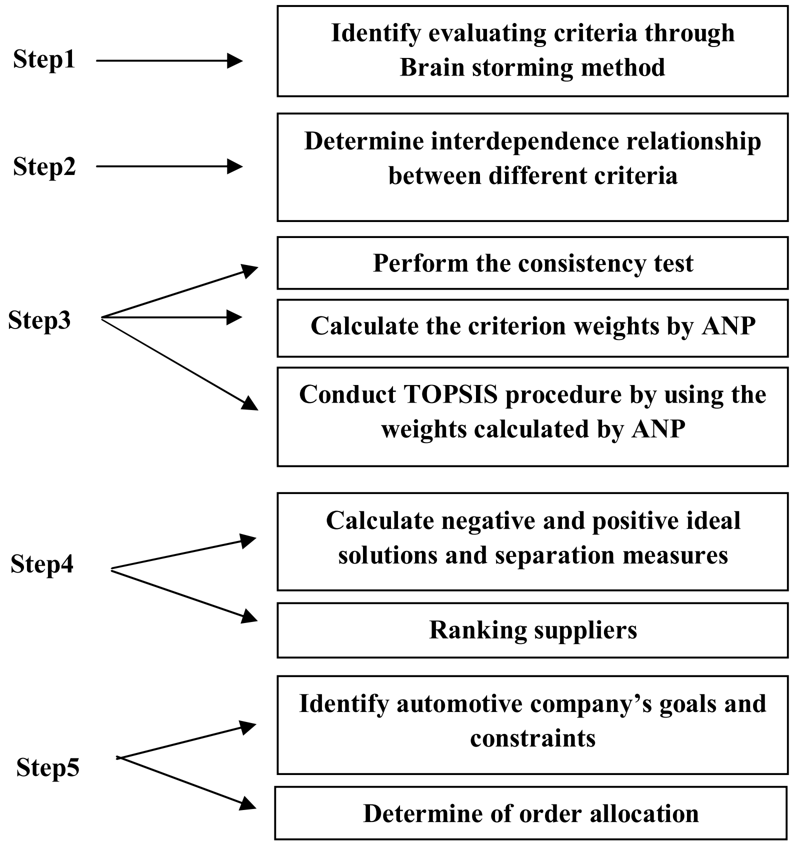

Fig. 1 The overall research processes

Step 1: Identification of necessary criteria for supplier selection

In decision-making models, one of the most important parts is to determine the criteria and measuring indicators. Selecting criteria and indicators is for this purpose that the important aspects and characteristics of suppliers being measured. In fact, suppliers' selection indices indicate the present status and present/future supplier's performance. Therefore, the design and selection of indices as the input of decision-making model have a direct impact on model efficiency [16]. As in companies and organizations the criteria and sub-criteria affecting on suppliers' selection processes differ based on their objectives, in our case study, automotive company used brainstorming in order to identify criteria, with regard to their strategic goals. Therefore, the automotive company–in a meeting consists of 32 managers, experts and

specialists in supply chain area identified the criteria influencing on the process of appropriate suppliers selection due to their industry targets by using brain-storming method. The criteria were identified as follows:
(C1) **PPM (Part Per Million) customers**: measuring the number of returned parts per million delivered parts which is returned by automobile-maker.
(C2) **Quality**: The quality of goods provided by the suppliers.
(C3) **Price/ cost**: The amount paid by the enterprise to buy goods from its suppliers.
(C4) **standardization**: to standardize the maker production process, as the first step to improve production process and to form process control program.
(C5) **Service**: The after-sales service and support provided by a supplier.
(C6) **Flexibility**: The ability of a supplier to accommodate changes in the enterprise's production plans.
(C7) **On time delivery**: How well a supplier succeeds in delivering goods according to schedule?

Step 2: Recognition of the interdependence between criteria

Next, in order to reflect the interdependence property between the criteria, we need to identify the exact relationship in a network structure of ANP. Another brainstorming process is taken to construct the relationship based on the following two recognitions:
 Price/cost may be influenced by the quality of products and the on time delivery.
 Product quality may be influenced by standardization.
Fig. 2 represents the relationship of interdependency.

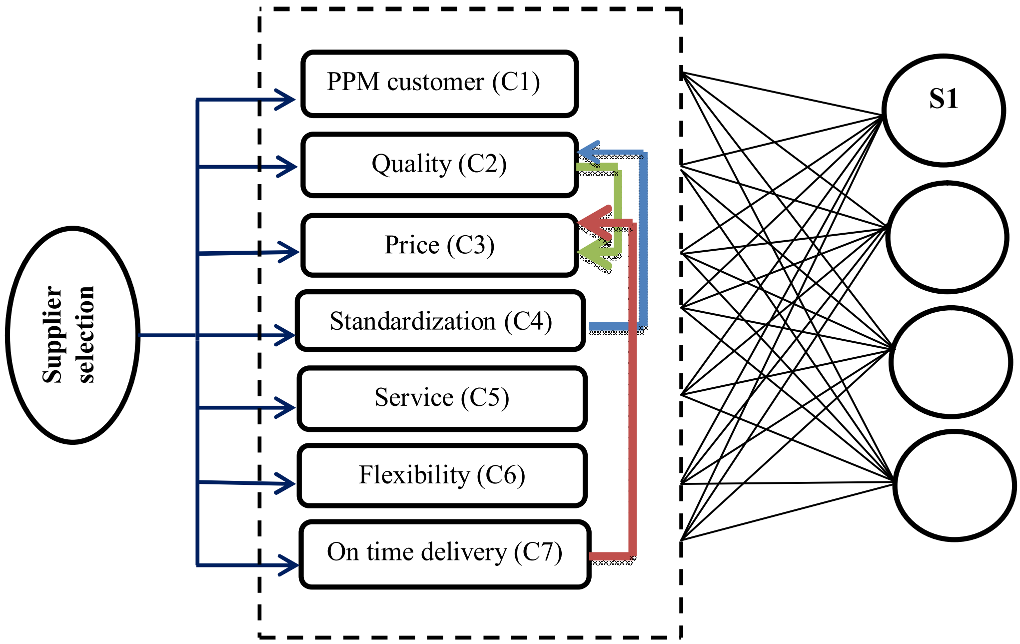

Fig. 2 The interdependent relationship among the selected criteria

Step 3: Determination of the weights of criteria by ANP technique

To determine the relationship of the degree of interdependence, the ANP technique, which is an extension of AHP, is used to address the relative importance of the criteria. ANP is developed to generate priorities for decisions without making assumptions about a unidirectional hierarchy relationship between decision levels [17]. To take the place of a linear top-to-bottom form of strict hierarchy, the ANP model provides a looser network structure and possibly represents any decision problem. The relative importance or strength of the impacts on a given element is measured on a ratio scale, which is similar to AHP. In comparison to AHP, ANP is capable of handling interrelationships between the decision levels and attributes by obtaining the composite weights through the development of a "supermatrix". The supermatrix is a partitioned matrix, where each submatrix is composed of a set of relationships between two components or clusters in a connection network structure [18].

It should be noted that despite the frequency of the number of suppliers and parts, in order to test the model, some parts makers (suppliers) who had the highest evaluation (grade A) and were able to produce four parts with codes A, B, C, and D were selected.

After the hierarchical structure drew; in order to determine the criteria, and sub-criteria weights, a questionnaire concerning to pair-wise comparisons matrix was given to 42 managers, experts, and specialists in the field of supply chain management. Then the data gathered from them, entered into specialized software of Supper Decision to calculate the weight of suppliers indices and to ensure the accuracy of judged and inconsistency rate. Because of smaller inconsistency rate from 0.1 the accuracy of judgments was confirmed.

Three steps will be done with three activites described as follows:

First, Without assuming the interdependence among criteria, the decision makers or experts are asked to evaluate all proposed criteria pair-wise. Table 2 shows the weights obtained for each of the criteria.

Table 2 The pair-wise comparison matrix for criteria

	C1	C2	C3	C4	C5	C6	C7	**Vector weights**
C1	1	4	4	2	5	6	4	0.361
C2	1/4	1	3	1/2	2	4	2	0.142
C3	1/4	1/3	1	1/3	1/2	2	1/4	0.055
C4	1/2	2	2	1	4	4	2	0.207
C5	1/5	1/2	1/2	1/4	1	2	1/2	0.070
C6	1/6	1/4	1/4	1/4	1/2	1	1/5	0.037
C7	1/4	1/2	1/2	1/2	2	5	1	0.128

Next, the effects of the interdependence among the criteria are resolved. The group members will examine the impact of all criteria on each other by pair-wise comparisons too, as shown in table 3.

Table 3 Degree of relative impact for evaluation criteria

	C1	C2	C3	C4	C5	C6	C7
C1	1	0	0	0	0	0	0
C2	0	0.657	0.865	0	0	0	0
C3	0	0.325	0	0	0	0	0.633
C4	0	0	0.135	1	0	0	0
C5	0	0	0	0	1	0	0
C6	0	0.018	0	0	0	1	0.367
C7	0	0	0	0	0	0	0

Now we can obtain the interdependence priorities of the criteria by synthesizing the results from the previous two steps as follows:

$$w_c = \begin{bmatrix} c1 \\ c2 \\ c3 \\ c4 \\ c5 \\ c6 \\ c7 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.657 & 0.865 & 0 & 0 & 0 & 0 \\ 0 & 0.325 & 0 & 0 & 0 & 0 & 0.633 \\ 0 & 0 & 0.135 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0.018 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.367 \end{bmatrix} \times \begin{bmatrix} 0.361 \\ 0.142 \\ 0.055 \\ 0.207 \\ 0.070 \\ 0.037 \\ 0.128 \end{bmatrix} = \begin{bmatrix} 0.361 \\ 0.141 \\ 0.127 \\ 0.214 \\ 0.070 \\ 0.040 \\ 0.046 \end{bmatrix}$$

According to the vector from decision maker, C1, C2, C4 and C3 (in series: PPM Customer, Quality, Standardaization, Price) are four of the most important factors related to the evaluation supplier selection process.

Finally, decision makers are asked to establish the decision matrix by comparing candidates under each criterion separately. Table 4 shows the result of performance of each alternative with respect to each criterion.

Table 4 Performance of each alternative with respect to each criterion

	C1	C2	C3	C4	C5	C6	C7
S1	0.475	0.435	0.479	0.542	0.379	0.571	0.600
S2	0.425	0.446	0.524	0.475	0.525	0.452	0.585
S3	0.552	0.543	0.325	0.313	0.500	0.452	0.432
S4	0.535	0.396	0.463	0.570	0.422	0.356	0.596

Step 3: Ranking suppliers by TOPSIS technique

TOPSIS is a widely accepted model that proposed by Huang and Yoon in 1981, and then in 1992 was developed by Chen and Huang. In this method, alternatives are ranking based shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution.

In this step, TOPSIS technique played its role. The weight obtained by the AHP technique using equations (1) and (2) As Table 5 is shown converted to normalized weighted matrix.

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \qquad (1)$$

$$V = N_D \times w_{n \times n} \qquad (2)$$

Table 5 The weighted normalized decision matrix

	C1	C2	C3	C4	C5	C6	C7
S1	0.700	1.658	3.771	3.397	0.231	7.316	1.564
S2	0.310	0.131	1.118	0.523	8.106	1.948	0.689
S3	0.113	0.589	0.202	6.898	4.645	0.560	3.272
S4	0.052	0.131	1.118	0.532	1.154	3.482	0.294

Then, using equations (3) and (4) positive and negative ideal solutions are obtained the results obtained are shown in Table (6).

$$A^{+} = \{(\max V_{ij} \left| j \in J), (\min V_{ij} \right| j = \in J^{`})\} = \{V_1^{+}, V_2^{+}, ..., V_n^{+}\} \quad (3)$$

$$A^{-} = \{(\min V_{ij} \left| j \in J), (\max V_{ij} \right| j = \in J')\} = \{V_1^{-}, V_2^{-}, ..., V_n^{-}\} \quad (4)$$

Table 6 The ideal solution and negative solution

	C1	C2	C3	C4	C5	C6	C7
A^{+}	0.052	0.131	0.202	6/896	0.231	0.560	1.564
A^{-}	0.814	1.658	3.771	0.523	8.106	7.419	0.294

The next step of TOPSIS technique, as shown in Table 7 is to calculate the Euclidean distance of each alternative. The positive and negative ideals, using equations (5) and (6).

$$d_i^{+} = \{\sum_{j=1}^{n} (V_{ij} - V_j^{+})^2\}^{0.5} \quad (5)$$

$$d_i^{-} = \{\sum_{j=1}^{n} (V_{ij} - V_j^{-})^2\}^{0.5} \quad (6)$$

Table 7 Separation of each alternative to positive and negative solution

	S1	S2	S3	S4
d_i^{+}	13.176	10.035	11.123	13.854
d_i^{-}	7.224	12.569	14.566	7.136

In the final stage, relative closeness of suppliers to ideal solution using equation (7) obtained and ranked according to relative approximately descending order of suppliers. Table 8 represents the ranking of suppliers based on combining two techniques of AHP and TOPSIS.

$$CL_i^{+} = \frac{d_i^{-}}{(d_i^{+} + d_i^{-})} \qquad 0 \le CL_i^{+} \le 1 \qquad i = 1, 2, ..., m \quad (7)$$

Table 8 Final ranking in two-phase ANP-TOPSIS approaches

Alternatives	S1	S2	S3	S4
C_j^+	0.313	0.515	0.329	0.460
Ranking	4	1	3	2

Step 5: Mathematical Modeling

As observed, in the first phase of this study using two techniques of ANP and TOPSIS in integrated form, suppliers were classified with regard to selected criteria.While in the step five, using a mathematical model it was identified that how much order should be allocated to each supplier. Thus, these steps are included designing a multi-objective linear programming model. Table 9 is briefly described the symbols used in equations.

Table 9 Introducing mathematical parameters model

Decision variables	**Definition**
x_{ij}	Order quantity of the jth part from the ith supplier
parameters	
d_{ij}	Average defect rate of jth part from the ith supplier
t_{ij}	Average delivery delay of the jth part from the ith supplier
p_{ij}	The price of jth part that be suggested by ith supplier to automotive company
B_j	Purchasing budget for the jth part
D_j	demand for jth part
S_{ij}	Lowest quantity supply of jth part from the ith supplier
S'_{ij}	Highest quantity supply of jth part from the ith supplier
z_i	Objective function
K_j	capacity of a vehicle for carried the jth part in terms of kg
U_{ij}	Weight of the jth part that bought from the ith supplier

Multi-objective linear programming model was designed this way, that at first, automotive company multiple targets are formulated as three objectives function that includes:

The first objective function (Z_1): purchase costs

$$Min \quad Z_1 = \sum_{i}^{m} \sum_{j}^{n} p_{ij} * X_{ij}$$

The first objective function (Z_1) which is expressed as a minimum, indicates the minimizing of costs to buy its pieces which are from its supplier.

The second objective function (Z_2): Quality

$$Min \;\; z_2 = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij}\, x_{ij}$$

The second objective function (Z_2) expressed minimizing of the amount due to defects and disadvantages in the parts.

The third objective function (Z_3): Delivery

$$Min \;\; z_3 = \sum_{i=1}^{m}\sum_{j=1}^{n} t_{ij}\, x_{ij}$$

The third objective function (Z_3) expressed the minimizing of total deviation from the delivery date which is determined according to the contract.

Then the limitation of company's suppliers and automotive company are specified in seven constraints as follows.

First limitation: shopping budget

$$\sum_{i=1}^{m} p_{ij}\, x_{ij} \le B_j \qquad j = A, B, C, D \qquad i = 1,2,3,4$$

The first limitation represents budget constraints of purchase by the automotive company. This limitation is as ≤ because the total payments to buy parts to suppliers should not be higher from the set budget.

Second limitation: product demand (pieces)

$$\sum_{i=1}^{n} X_{ij} \ge D_j \qquad j = A, B, C, D$$

The second restriction indicated limits of demand for the product by automotive company.

The third limitation: production capacity

$$S_{ij} \le x_{ij} \le S'_{ij} \qquad j = A, B, C, D \qquad i = 1,2,3,4,5$$

This restriction shows that how much the highest and lowest production which supplier is able to meet it.

Fourth limitation: vehicle weight capacity

$$\sum_{i=1}^{m} u_{ij}\, x_{ij} \le K_j \qquad j = A, B, C, D \qquad i = 1,2,3,4,5$$

This restriction indicates constraints in available transportation capacity. In the above limitation, KJ is expressed in terms of kg, so weight of customized parts should be less than or equal to vehicle capacity in terms of kg.

Fifth limitation: non-zero limit (integer)

$$X_{ij} = Integer \qquad j = A, B, C, D \qquad i = 1,2,3,4,5$$

After gathering data about decision variables and parameters of mathematical model, the information obtained to resolve was entered into software (LINGO). Table 10 shows that automotive company in order to minimize the purchase costs, returned rate from defects, and delivery time, must buy from any supplier in the amount specified by the model.

Table 10 The order quantity allocation

Alternative Part	A	B	C	D	Total
Supplier 1	–	1500	5300	–	6800
Supplier 2	5500	3700	6800	4100	20100
Supplier 3	1100	2200	4800	3600	11700
Supplier 4	2100	2500	3500	4500	12600
Z1= 581262300		Z2= 86		Z3= 13	

5 Conclution

Supplier selection and evaluation are very important to the success of a manufacturing firm. This is because of the cost and quality of goods and services sold are directly related to the cost and quality of goods and services purchased. Therefore, purchasing and supplier selection play an important role in supply chain management. Therefore, the selection of appropriate suppliers is a very important problem for any organization, and requires consideration of a multitude of factors, some of which can be quantitative, while some can be qualitative. Results show that applying a two phase ANP-TOPSIS methodology causes to some important advantages such as: Long-term relationship, consist quality, lower cost, special attention and etc.

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