DOI 10.20544/HORIZONS.B.03.1.16.P37
UDC 658.86/.87:303.22

MODELLING OF PROCUREMENT PROCESSESUSING MULTICRITERIA ANALYSIS[1]

Željko Stević[1] Ilija Tanackov[2] Marko Vasiljević [1] Kire Dimanoski[3]
[1]University of East Sarajevo
Faculty of Transport and Traffic Engineering Doboj, Vojvode Mišića 52
Doboj, Bosnia and Herzegovina
zeljkostevic88@yahoo.com

[2]University of Novi Sad
Faculty of Technical Sciences, Trg Dositeja Obradovića 6
Novi Sad, Serbia
[3]Macedonian Railway Transport JSC
III Makedonska brigada No. 66, 1000
Skopje, Macedonia

Abstract

Logistics sub-system of purchase causes certain expenses with significant influence on complete supply chain. Therefore, optimisation is necessary in the first phase of logistics, ie. purchase, in order to make possible the total operation's efficiency. The aim of this paper is indeed optimisation of purchasing process by usage of multi-criteria analysis method. Model is being done based on nine quantitative and qualitative criteria, using the AHP method, TOPSIS method, and combination for these two, where the AHP is used for determination of weighting values, and TOPSIS method for choosing the best out of group of potential solutions. Also, comparative analysis of results obtained by applying these methods is shown.

Keywords–Multi-criteria analysis; procurement; AHP; TOPSIS

INTRODUCTION

Literature and various publications dealing with these or issues similar to ones from this paper, there can be found great number of criteria for supplier evaluation. However, one question arises: how to make right selection from certain group, which will assist in finding the best solution. Some authors

---
[1] Original scientific paper

in[1] tried to answer this question at the end of last century, so they examined criteria for selection of supplier in production and retail trade surrounding. Criteria's were given in 74 documents published between 1966 and 1991. Group of authors came to conclusion that following criteria are dominant: quality, delivery and price; while geographic location, financial status and production capacities belong to secondary group of factors. Then, [2] commenced examination among big number of managers with the aim to examine in which way to make compromise during supplier selection. Their research pointed out that managers are paying the most attention to the quality as the most important suppliers' attribute, before delivery and price. Research about influence of criteria in the supply chain is continuing on during the beginning of this century as well, so authors in [3] took reliability of delivery as a criteria for choice making while authors in [4] used four criteria for evaluation of suppliers: price, quality, technology and service. In [5] for optimization of the import also used four criteria: material price, quality, and transport distance and delivery time.

In this study is using nine criterion for ranking five alternatives which explained in chapter numerical example.

AHP METHOD

The Analytic Hierarchy Process (AHP) developed by[6] and, AHP is a theory of measurement by pairwise comparisons and relies on the opinion of experts to derive priority scales.Saatyin [7]defined the axioms which the AHP is based on: the reciprocity axiom. If the element A is n times more significant than the element B, then element B is 1/n times more significant than the element A; Homogeneity axiom. The comparison makes sense only if the elements are comparable, e.g. weight of a mosquito and an elephant may not be compared; Dependency axiom. The comparison is granted among a group of elements of one level in relation to an element of a higher level, i.e. comparisons at a lower level depend on the elements of a higher level; Expectation axiom. Any change in the structure of the hierarchy requires re-computation of priorities in the new hierarchy.

Some of the key and basic steps in the AHP methodology according to [8] are as follows: to define the problem, expand the problem taking into account all the actors, the objective and the outcome, identification of criteria that influence the outcome, to structure the problem previously explained hierarchy, to compare each element among them at the appropriate level, where the total of nx(n-1)/2 comparisons is necessary, to calculate the maximum value of own vector, the consistency index and the degree of consistency.

Let $\{A_1, A_2, ..., A_n\}$ be n alternatives, and $\{w_1, w_2,...,w_n\}$ be their current weights. The pairwise comparison is conducted by usage the scale (1–9), [6]
A pairwise comparison matrix that is defined as follows:

$$W = \left[\frac{w_i}{w_j}\right] = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} \cdots & \frac{w_n}{w_n} \end{bmatrix} \quad (1)$$

This matrix $A=[a_{ij}]$ represents the value of the expert's preference among individual pairs of alternatives (A_i versus A_j for all i, j = 1,2,...,n).
After this, the decision-maker compares pairs of alternatives for all the possible pairs. Based on that, the comparison matrix A is obtained, where the element a_{ij} shows the preference weight of A_i obtained by comparison with A_j.

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 \cdots & a_{2n} \\ \cdots & \cdots \cdots & \cdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} \cdots & 1 \end{bmatrix} (2)$$

The a_{ij} elements estimate the ratios w_i / w_j, where w is the vector of current weights of the alternative.
The matrix has reciprocal properties, which are $a_{ji}=1/a_{ij}$.
The matrices are formed after all pairwise comparison and the vector of weights $w= [w_1,w_2, . . . ,w_n]$ is computed on the basis of Satty's eigenvector procedure in two steps. First, the pair-wise comparison matrix, $A = [a_{ij}]_{nxn}$, is normalized, and then the weights are computed.

Normalization:

$$a_{ij}^* = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (3)$$

for all j = 1,2,..., n.

Weight calculation:

$$w_i = \frac{\sum_{i=1}^{n} a_{ij}^*}{n} \qquad (4)$$

for all j = 1,2,..., n.

The consistency of the pairwise matrix (*CI*) is checked for a valid comparison.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (5)$$

where λ_{max} is an important validating parameter in AHP and is used as a reference index to screen information by calculating the Consistency Ratio (CR) of the estimated vector. CR is calculated by using the following equation:

$$CR = \frac{CI}{RI} \quad (6)$$

where RI is the random consistency index obtained from a randomly generated pairwise comparison matrix.

This coefficient is recommended depending on the size of the matrix, so we may find in the papers [9, 10]. that the maximum allowed level of consistency for the matrices 3x3 is 0.05, 0.08 for matrices 4x4 and 0.1 for the larger matrices. If the calculated CR is not of the satisfactory value, it is necessary to repeat the comparison to have it within the target range [11].

TOPSIS METHOD

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was first proposed by [12]. The basic idea for this method is to choose the alternative, which is as close to the positive ideal solution as possible and as far from the negative ideal solution as possible. The positive ideal solution is a solution with maximized benefit criteria and minimized cost criteria. The negative ideal solution is a solution, where the cost criteria are maximized and benefit criteria are minimized.

The following are the steps of the algorithm for solving the multi-criteria tasks of TOPSIS method:

Initial matrix $X = \|x_{ij}\|_{m \times n}$ (7)

Step 1 - normalization of the initial matrix:

$$\|X\| \to \|R\| \quad (8)$$

$$R = \|r_{ij}\|_{m \times n} \quad (9)$$

$$Rij = \frac{Xij}{\sqrt{\sum_{i-1}^{m} Xij^2}} \quad (10)$$

Step 2 - weighting of the normalized matrix:

$$\|R\| \rightarrow \|V\| \quad (11)$$

$$V = \|v_{ij}\| = \|W_j^{'} \cdot r_{ij}\| \quad (12)$$

Step 3 - forming the positive ideal and negative ideal solution:
A^+ - the positive ideal solution, which has all best features regarding all criteria:

$$A^+ = \left\{ \left(\max_i v_{ij} \mid j \in K' \right) i \left(\min_i v_{ij} \mid j \in K'' \right) \right\} = \left\{ v_1^+, v_2^+, ..., v_j^+, ..., v_n^+ \right\}, \quad i = \overline{1, m} \quad (13)$$

$K' \subseteq K \rightarrow K'$ is a subset of K consisting of *max* type criteria.
$K'' \subseteq K \rightarrow K''$ is a subset of K consisting of *min* type criteria.
A^- - the negative ideal solution, which has all worst features regarding all criteria:

$$A^- = \left\{ \left(\min_i v_{ij} \mid j \in K' \right) i \left(\max_i v_{ij} \mid j \in K'' \right) \right\} = \left\{ v_1^-, v_2^-, ..., v_j^-, ..., v_n^- \right\}, \quad (i = \overline{1, m}) \quad (14)$$

Step 4 - calculating the distance (Euclidean distance) of each alternative from the positive ideal and negative ideal solution:
S_1^+ - distance of an alternative from the positive ideal solution

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad (15)$$

S_1^- - distance of an alternative from the negative ideal solution

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (16)$$

Step 5 - calculating the relative closeness of an alternative to the ideal solution:

$$C_i = \frac{S_i^-}{S_i^- + S_i^+} \quad (17)$$

$$0 \le C_i \le 1. \quad (18)$$

Step 6 - ranking of alternatives:
Ranking of Ci values arranged in descending order (from the highest to lowest value) corresponds to the ranking of Ai alternatives (from the best to worst).

NUMERICAL EXAMPLE

Criteria applied in this study are: price of materials, pipe length, delivery time, way of payment, transport distance, quality, reliability, flexibility and communications system that are still in operation are marked with C_1-C_9 respectively. Therefore, there are three criteria, quantitatively expressed and five criteria which are qualitative. Prices of materials, pipe length, delivery time are the quantitative criteria that are easily expressed as they represent stabile measures, i.e. specific values.

Price of materials indicates the money value of goods established by the supplier based on investment in the form of materials, energy, labor, etc.

Pipe length is a parameter that is expressed in meters and which in this case plays an important role due to the fact that customers often require delivery of pre-insulated pipes with precisely defined length, which allows easier use.

Delivery time is the time interval between the moment of getting the order and the time of availability of goods to the customer. It is most commonly expressed in days, but can be in other time units as well.

In contrast to the above, the remaining criteria are qualitative, they represent soft measurers and are not so easy to express, so they should be presented by a descriptive mark.

Payment represent compensation in money for delivered goods as determined between the contract parties. During research, it was established that payment can be done as advance, postponed with bank guarantee, or percentage of total amount as advance, and the rest is paid postponed, what can be shown in following way: bad, acceptable, good and excellent.

Way of delivery represents a qualitative criteria that can be expressed as good, average and bad, depending of the fact whether the transport is calculated in the price of material – is it free of charge, or delivery of goods is to be done by vehicles of examined company. If it is the second option distances of suppliers must be taken into consideration, as well as expenses caused by that.

The quality of materials is the level of fulfilling the requirements of regulations and standards, on the one hand and the level of fulfilling customer's expectations on the other side. It can be described as good, very good, excellent and outstanding.

Reliability is probability of the established time for delivery. Any failure to comply with previously agreed terms of delivery may cause some confusion to the customer for example: disruption of production due to lack of materials, cost increase, etc. It can be described as satisfactory, good and excellent.

Flexibility means the ability of delivery systems to respond to customer-specific requirements, which include: the amount of goods to be taken over, the moment of delivery, method of delivery, a variant of transport, the possibility of delivery by invitation. It is expressed as poor, average and good.

Communications system is represented by kindness of the staff, the ability to provide the necessary information, and can be acceptable, average, good, very good and excellent.

After comparison criteria and calculation with software Expert Choice we obtained following results which presented on the figure 1.

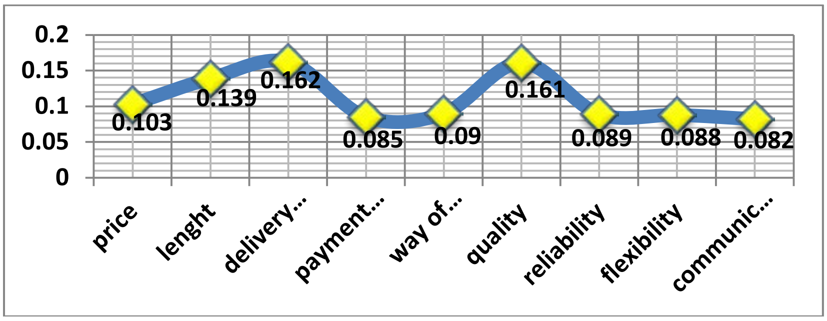

Fig. 1. Weight of criteria

The most important criterion for the decision on the selection of suppliers is a third criterion: delivery time with a relative importance of 16.2%, and sixth criterion quality with importance 16.1% while pipe length have importance 13.9 % and follow immediately after the time of delivery, while the other criteria have a somewhat lower value. The delivery time and quality criteria in great number of practical researches dealing with similar issues are of great importance. However, pipe length as a criterion is rarely used and even more rarely is of great importance as it is the case in this study. Consistency Ratioregarding the comparison of criteriais0.00, which means that the results arevalidbecause itislowerthan0.10 and no subjectivity in decision making.

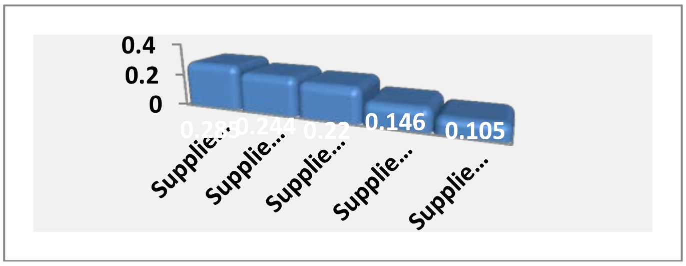

Fig. 2. Ranking alternatives using AHP method

After comparing the alternatives per criterion by applying the described methodology in chapter AHP method, the calculation for each alternative is performed and, based on the obtained results, the ranking is made, i.e. the selection of the optimal alternative (supplier). The figure 2. shows the ranking alternatives and their values. In this case supplier A is optimal solution.

For Topsis method, first it is required to determine the orientation of criteria, so thatthey need to beminimized ormaximized. The first and thirdcriterionneeds to be minimized, since it ispriceanddelivery time, while theothercriterianeedto be maximized. The first three criteria are quantitative, while the other must be quantified. Quantification is performed on thescale from one tofiveand theyshould also bemaximized, for example, the aimforpayment methodcriteria is “delayed”aslonger as possibleperiod.

Table 1. Initial matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	78.3	12	0	0.9	0.6	5	2.5	2.5	5
A_2	88.5	12	0	5	0.6	1.7	2.5	2.5	2.9
A_3	89.6	11.6	6	1.7	5	3	5	5	2.9
A_4	91	6	3	0.9	4.5	1.7	2.5	1.3	1.5
A_5	95.5	11	30	3.2	1.2	1	1.3	1.3	0.8
W_j	5	7	9	3.5	4	9	4	4	3
	min	max	min	max	max	max	max	max	max
W_j'	**0.10**	**0.15**	**0.19**	**0.07**	**0.08**	**0.19**	**0.08**	**0.08**	**0.06**

By applying previously described steps of Topsis method, results represented by the following figure were obtained.

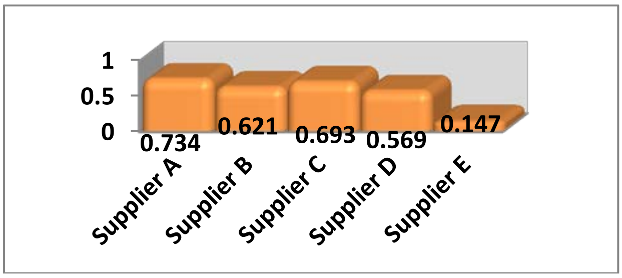

Fig. 3. Ranking alternatives using TOPSIS method

On figure 3, it is visible that the alternative, ie. supplier no. 1 has the highest value and represent the best solution according to previously conducted steps. In contrast to ranking alternatives using AHP method in this case where for ranking using Topsis method supplier no. 3 is on second place.

Many publication in this area using combination of this two methods, AHP method for determination of weight criteria and TOPSIS method for ranking alternatives. Results obtained using combination AHP-Topsis is presented in figure 4.

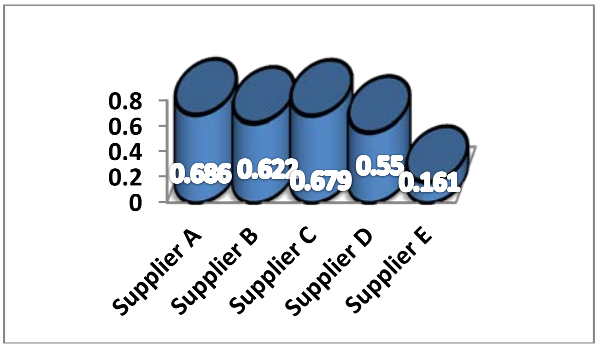

Fig. 4. Ranking alternatives using combined AHP-TOPSIS method

After all calculation obtained in this paper using three different way of method multicriteria analysis supplier no. 1 is optimal solution for company which needs material for production. In table 2 presented all results.

Table 2. Ranking alternatives using different methods

Rank			
	AHP	**TOPSIS**	**AHP-TOPSIS**
Supplier A	1	1	1
Supplier B	2	3	3
Supplier C	3	2	2
Supplier D	4	4	4
Supplier E	5	5	5

CONCLUSION

In day-to-day business, making decisions which will, on one side lessen the expenses, and on the other side fulfill user's needs, certainly represents a challenge. Accordingly, decision makers are bearing great responsibility when modeling supply chain which includes the above mentioned.

Company must strive to enlarge the quality of product itself, so the end user is satisfied with provides services, what would make him a loyal user. Due to above mentioned, it is necessary, during the first phase of logistics, ie. purchasing logistics, to commit good evaluation and choice of supplier, what can largely influence the forming of product's final price and in that way accomplish significant effect in complete supply chain.

Depending on market demands, changes of criteria importance, as well as company's needs, current rank of alternatives could change, even in near future; what requires constant monitoring of own performances and performances of potential suppliers.

REFERENCES

[1] Weber, C. A et. al. Vendor selection criteria and methods. *European journal of operational research*, 50(1), (1991), pp. 2-18.

[2] Verma, R.and Pullman, M. E. An analysis of the supplier selection process. *Omega*, 26(6), (1998), pp. 739-750.

[3] Karpak, B. et. al. Purchasing materials in the supply chain: managing a multi-objective task. *European Journal of Purchasing & Supply Management*, 7(3), (2001), pp. 209-216.

[4] Bhutta, K. S. and Huq, F. Supplier selection problem: a comparison of the total cost of ownership and analytic hierarchy process approaches. *Supply Chain Management: An International Journal*, 7(3), (2002), pp. 126-135.

[5] Stević et al., Optimization of the Import of Chipboard - a case study: *International Journal of Engineering, Business and Enterprise Applications*, 14(1), September-November, 2015, pp. 19-23

[6] Saaty, T. L. “The Analytic Hierarchy Process”, Mc Graw-Hill, NewYork 1980.

[7] Saaty, T. L. Axiomatic foundation of the analytic hierarchy process. *Management science*, 32(7), (1986), pp. 841-855.

[8] Vaidya, Omkarprasad S., and Sushil Kumar. "Analytic hierarchy process: An overview of applications." *European Journal of operational research* 169.1 (2006): 1-29.

[9] Lee, A. H. et. al. A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan. *Expert systems with applications*, (2008). *34*(1), 96-107.

[10] Anagnostopoulos, K. P. et. al. "Using the fuzzy analytic hierarchy process for selecting wastewater facilities at prefecture level."*European Water* 19.20 (2007): 15-24.

[11] Saaty, T. L. Decision-making with the AHP: Why is the principal eigenvector necessary. *European journal of operational research*, (2003). *145*(1), 85-91.

[12] Hwang, C. L. and Yoon, K. Multiple attributes decision making methods and applications. (1981) Berlin: Springer.