COMMUNICATIONS

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DETERMINATION OF THE APPROPRIATE VEHICLE OPERATING IN PARTICULAR URBAN TRAFFIC CONDITIONS

This paper presents selection of the most appropriate vehicle intended to operate on a particular urban territory, using the specific methods of multi-criteria analysis. For selecting the suitable vehicle, it is necessary to determine a number of specific criteria. In the paper, the desired vehicle is selected from five vehicles, while, each of them has a different product brand. To determine the weights of criteria, the Saaty pairwise comparison method is applied, and subsequently, the multi-criteria evaluation of alternatives is utilized for a research problem.

***Keywords:** Operation, supply, urban traffic, City logistics, vehicle, decision-making.*

1. Introduction

Utility vehicle, i.e. vehicle used for the cargo supply in urban area, is an important factor and limitation for the customers' services in regard to the urban style of the city, city built-up area, the deployment of customers, etc. Generally, customers or distribution centers do not have any specific requirements for the transport means and are supplied by conventional freight vehicles.

However, each of the vehicles has distinct fuel consumption and their individual parameters differ. The deployment of the optimal vehicle can significantly facilitate the activities of the supply in a given territory. Thus, determining the appropriate vehicle for operating in a particular territory in the context of City logistics undoubtedly represents an essential aspect for individual enterprises [1 - 3].

2. Issues of decision-making

Determination of the weights and making the subsequent multi-criteria evaluation of alternatives can be considered to be a decision-making issue in which the final result is influenced by a group of external aspects [4 and 5].

For the purpose of solving the decision-making issues, the individual methods of multi-criteria analysis may be utilized [6, 7 and 8]. It is important to have a list of alternatives from which to select. Cases where a clearly defined list of potential alternatives is known are more or less the exception than the rule [7 and 9].

General procedure for the multi-criteria evaluation of alternatives includes six basic phases: (1) Identification of alternatives, (2) Determination of the specific criteria, (3) Determination of the weights of criteria, (4) Determination of the criteria examples, (5) Partial evaluation of alternatives and (6) Selection of the most appropriate alternative.

The analysis of existing methods utilized for dealing with the multi-criteria analysis has been carried out. Some of these methods do not take into consideration the weights of criteria. And since, among the criteria which influence the individual factors of the multi-criteria evaluation of alternatives, significant distinctions in the importance of criteria exist, these methods are not suitable for our particular research problem [7 and 10 - 14].

2.1. Methods for determination of the weights of criteria

Methods for determining the weights (see Table 1) can be divided according to the information that we have about the criteria significance [5 - 8, 13 and 14]:
- no information,
- ordinal information,
- cardinal information.

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No information - The researchers are not able to decide about the level of significance of the criteria. It is supposed that there is a criteria matrix quantified by the cardinal values.

Ordinal information - These methods suppose that the researcher may express the significance of each criterion by assigning to all criteria their special numbers or when comparing all criteria pairs, they may decide which criterion, from the current pair, is more important compared to another. In both cases, it is permissible to determine two or more criteria as equal.

Cardinal information - These methods suppose that the researcher may not only determine the order of criteria significance, but also the significance of the relationships among all criteria.

Methods for determination of the weights of criteria   Table 1

Information about significance among the criteria pairs		
No information	Ordinal information	Cardinal information
Method of equal weights	Method of ranking	Scoring method
Entropy method	Fuller method	Saaty method

Source: [10]

2.2. Methods for the multi-criteria evaluation of alternatives

Methods for the multi-criteria evaluation of alternatives (selection of the most suitable alternative) are divided according to the information about the significance between the criteria pairs that is required. The information may be [5 and 10]:

- maximizing the benefits,
- minimizing the distance from the ideal variant,
- regarding the preferential relationship.

Specific methods for the multi-criteria evaluation of alternatives include: Simple method of scoring or Simple method of ranking, Lexicographical method, Permutation method, ORESTE method, TOPSIS method, Weighted Sum

Approach - WSA method, Analytic Hierarchy Process - AHP method, Entropy method and many others [5 and 8 - 11].

3. Research problem and outcomes

This part of the paper deals with the research problem and obtained outcomes, i.e., the shortened and modified version of the general procedure for multi-criteria evaluation of alternatives. This version specifically consists of: (1) Determination of the specific criteria, (2) Identification of alternatives, (3) Determination of the weights of criteria and (4) Selection of the most appropriate alternative.

3.1. Determination of the specific criteria

Phase one of our modified procedure of multi-criteria evaluation of alternatives includes the decision about the specific criteria which influence the final evaluation process [8, 9 and 12].

Among the specific criteria regarding the selection of the most appropriate vehicle for the cargo supply in urban area, five of them, primarily due to the vehicles utility purposes, were defined. For these criteria, required data, concerning the parameters of further identified alternatives, were obtained [10 and 13].

For the purpose of the appropriate vehicle selection, the following criteria were therefore included: $K1$ - the fuel consumption (engine diesel) of the vehicle in the city (l / 100km), $K2$ - the price of the vehicle (CZK), $K3$ - the vehicle loading length (mm), $K4$ - the cargo space volume of the vehicle (m³) and $K5$ - the gross vehicle weight (kg).

3.2. Identification of alternatives

Among the selected alternatives (utility vehicles - Di), commonly used means of transport for operation on the city territory produced by different manufacturers may be

Identified alternatives (vehicles) with respect to the specific criteria   Table 2

Criteria (Ki) / Vehicle (Di)	$K1$ - Fuel consumption (l/100 km)	$K2$ - Price (CZK)	$K3$ - Length (mm)	$K4$ - Cargo space volume (m³)	$K5$ - Gross weight (kg)
D1	9.1	489 900	5 048	10.80	2 950
D2	7.8	328 000	3 450	7.05	1 970
D3	8.5	724 200	5 998	14.00	3 223
D4	9.5	505 000	3 250	9.50	2 810
D5	13.5	547 676	3 400	8.70	2 087

Source: authors

included. For the purpose of this paper, the following vehicles are chosen and with respect to the above-identified criteria, are characterized in the subsequent table (see Table 2): *D1* - Vehicle 1, *D2* - Vehicle 2, *D3* - Vehicle 3, *D4* - Vehicle 4 and *D5* - Vehicle 5.

3.3. Determination of the weights of criteria using the particular method

To determine the weights of criteria, *Saaty pairwise comparison method* was selected. A number of specific criteria have lesser or greater effect on vehicle determination. Thus, it was important to select such a method which enables the expert´s judgment in order to decide about the relationship of significance among the criteria pairs. Furthermore, Saaty method enables the detailed distribution of these significances [12 - 14].

For the evaluation of the relationship of significance among the criteria pairs, Saaty method a nine point scale utilizes [5, 6 and 13]. 1 - equal criteria i and j, 3 - slightly preferred criterion i above j, 5 - strongly preferred criterion i above j, 7 - very strongly preferred criterion i above j, 9 - absolutely preferred criterion i above j [5, 6 and 13].

It is possible to use intermediate values (2, 4, 6, 8) as well. Matrix elements $S = (s_{ij})$ are interpreted as estimates of the fraction of the weights of the *i-th* and *j-th* criteria. The expert compares each pair of the criteria and writes the significance values of *i-th* in the relation to the *j-th* criterion in the Saaty matrix $S = (s_{ij})$. In case that *j-th* criterion is preferred above the *i-th* criterion, inverse values are written in the Saaty matrix (s_{ij} = 1/3 for low preference, s_{ij} = 1/5 for strong preference, etc.) [10, 15 and 16].

Weight vector values are denoted as $v = (v_1, v_2, ...,v_k)$. The normalized geometric mean represents the most preferred method of the weight calculation. This process is generally called "logarithmic least squares method [14 - 16]." The normalized weights are calculated for each criterion when utilizing the geometric mean of each row in the matrix divided by the sum of the geometric means of all the criteria [10 and 14].

Calculation of the geometric mean of each row of the matrix S is expressed in the following formula (1):

$$g_i = \sqrt[k]{\prod_{j=1}^{k} s_{ij}} \dots\dots i,j = 1, 2, \dots, k \qquad (1)$$

where g_i is the geometric mean; s_{ij} are elements of Saaty matrix; $\prod$ represents the product of values of Saaty matrix elements.

Normalization of the geometric mean is shown in the formula (2):

$$v_i = \frac{g_i}{\sum_{i=1}^{k} g_i}, \dots\dots i,j = 1, 2, \dots, k \qquad (2)$$

where v_i is the normalized (weighted) geometric mean, g_i is the geometric mean, $\sum$ represents the sum of geometric mean values.

The individual values of the weights of criteria are summarized in Table 3.

Completed Saaty matrix (table)　　　　　　　　　　Table 3

Criteria (Ki) \ Criteria (Ki)	K1	K2	K3	K4	K5
K1	1	3	5	1/2	5
K2	1/3	1	4	1/3	7
K3	1/5	1/4	1	1/7	7
K4	2	3	7	1	9
K5	1/5	1/7	1/7	1/9	1

Source: authors

Subsequently, individual values of the Saaty method were utilized for further calculations. The values obtained for the individual criteria in the intermediate calculations and the resulting values of the weighted geometric mean are shown in Table 4.

Values calculated by the Saaty method　　　　　　Table 4

Criterion	Multiples of preferences	Geometric mean (g_i)	Weighted geometric mean (v_i)
K1	37.5000	2.0640	0.2810
K2	3.1110	1.2550	0.1710
K3	0.0500	0.5490	0.0750
K4	3780.0000	3.2770	0.4460
K5	0.0004	0.2090	0.0270
$\sum$	418.6614	7.3540	1.0000

Source: authors

3.4. Selection of the most appropriate alternative using the particular method

There are a lot of distinct methods to solve the multi-criteria evaluation issues that can be utilized for the matter of particular alternative selection. However, a significant number of them cannot be applied, since they do not allow taking into consideration the entire complexity of these issues.

From the foregoing, it was decided to apply the Weighted Sum Approach method - WSA, which is suitable for the comprehensive issue of vehicle choice. The WSA method requires cardinal information, criteria matrix Y and criteria weight vector *v*.

The WSA method is able to create the overall rating for each of the alternatives and therefore, it can be utilized for selecting the most appropriate vehicle as well as for scaling the vehicles from best to worst [10, 14 and 17].

Regarding this method, the weight of each criterion, i.e. $s_v = (v_p, v_2,...,v_k)$ for k of maximization criteria, is taken into consideration.

The WSA method then maximizes the weighted sum (see formula 3):

$$u(A_i) = \sum\nolimits_{j=1}^{k} v_i r_{ij}. \tag{3}$$

where $u(A_i)$ is the aggregated utility function for each alternative, v_i is the criteria weight vector (normalized geometric mean), r_{ij} are the elements of the normalized criteria matrix. Hence, the value of the weighted sum for each alternative can be calculated and as a compromise alternative, the particular one with the greatest weighted sum can be selected [10, 11 and 18].

In the next step, it is necessary to create the criteria matrix. The rows of the criteria matrix are formed by the individual alternatives. The columns of the criteria matrix correspond to the individual criteria. In our case, the criteria matrix looks the same as Table 2.

Subsequently, it is inevitable to carry out the following steps:

1) <u>Transformation of the criteria to the same type</u> - it is important for all the criteria to be of the same type (minimization or maximization) [10 and 16].

2) <u>Ideal and basal alternative</u> - ideal alternative is the best option which may be practically achieved and basal alternative represents the worst possible alternative [5, 17 and 18].

3) <u>Criteria matrix normalization</u> - if the ideal and basal alternatives are known, the normalization of the criteria matrix may be simply carried out. In the criteria matrix, all the values are in the interval <0, 1>, the ideal value of the criteria matrix is represented by the number 1 and the basal by the number 0. A lot of studies on criteria matrix normalization are shown, for instance, in literature [5, 6, 11 and 19].

After creating the normalized criteria matrix, the aggregated utility function for each alternative "$u(A_i)$" is calculated and alternatives are ranked from best to worst (see Table 5) [7 - 9, 20 - 22].

4. Conclusions

After completing the Saaty method, the greatest weight was assigned to the cargo space volume and the fuel consumption of the particular utility vehicle. After creating the criteria matrix with regard to the multi-criteria evaluation of alternatives, the individual vehicles were ranked from best to worst.

And therefore, on the basis of performed calculations, it may be concluded that the optimal vehicle type for cargo supply in particular urban traffic conditions seems to be an **alternative D3**. On the other hand, alternative D5 appears to be the least suitable selection that has the high fuel consumption and, compared to alternative D3 has insufficient cargo space volume [20 and 23].

Achieved results   Table 5

Criterion / Alternative	K1	K2	K3	K4	K5	$u(A_i)$	Order
D1	0.772	0.591	0.654	0.540	0.218	0.614	2.
D2	1.000	1.000	0.073	0.000	1.000	0.484	3.
D3	0.877	0.000	1.000	1.000	0.000	0.767	**1.**
D4	0.702	0.553	0.000	0.353	0.330	0.458	4.
D5	0.000	0.445	0.055	0.237	0.907	0.210	5.
Weightings	0.281	0.171	0.075	0.446	0.027		

Source: authors

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