A HYBRID MULTI-CRITERIA DECISION MAKING MODEL FOR THE VEHICLE SERVICE CENTER SELECTION WITH THE AIM TO INCREASE THE VEHICLE FLEET ENERGY EFFICIENCY

by

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In this paper is researched how to achieve an effective fleet maintenance planning in transport companies, which contributes in increasing the fleet energy efficiency and in achieving the companies' goal. Within the fleet maintenance planning, managers have to make the right decisions on the selection of vehicle service centers in the region where the maintenance work will be realized. The mentioned decision is affected by a number of different interdependent factors (criteria). Based on a survey, relevant factors (criteria) were defined. As defined factors are interdependent and differently influence the mentioned decision, an approach of decision making trial and evaluation laboratory (DEMATEL)-based analytic network process called DANP was applied. In this respect, authors propose a hybrid multi-criteria decision making model. The proposed model was applied in the companies to demonstrate how effective their managers are in the maintenance planning and how this effectiveness influences the fleet energy efficiency and fulfilment of companies' goal.

Key words: *maintenance planning, fleet's energy efficiency, vehicle service center, multi-criteria decision making, DEMATEL-based ANP (DANP)*

Introduction

The research presented in this paper deals with companies owning road vehicle fleet for freight transportation. The companies' profit is primarily affected by transportation and vehicle maintenance costs. The observed companies have a goal to carry out all the planned transport tasks in certain period, alongside minimizing the mentioned costs. One way to achieve defined company goal is the implementation of an effective fleet maintenance planning, which provides vehicles from the most suitable construction-operation group for transportation tasks realization. It influences the increase in fleet's energy efficiency and reduction of the transportation and maintenance costs. For an effective fleet maintenance planning, maintenance managers have to make a right decision on the selection of suitable vehicle service center in the region, per vehicle maintenance request. The mentioned decision is affected by a number of different interdependent factors (criteria). In this sense, the problem treated in this paper is how to determine the intensity of interdependence and relative weights of the relevant factors, in order to increase the fleet energy efficiency and to achieve defined company goal.

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Many authors have proposed traditional mathematical models for an effective maintenance planning and scheduling in the transportation system [1, 2]. But, these models are not useful for solving the problems where exist relationships between more interdependent factors (criteria) and clusters (dimensions). These problems are successfully solved by implementation of multi-criteria decision making (MCDM) [3-5]. Such a problem is decision making about selection of a suitable vehicle service center in the region. In this respect, a MCDM model is recommended in this paper. In order to obtain the MCDM model, an approach of decision making trial and evaluation laboratory (DEMATEL)-based analytic network process (ANP) called DANP is applied. By jointly usage of DEMATEL and ANP methods, the impacts of clusters' interdependence are not equally taken into calculation, which contributes to better description of the real system [6]. In addition, a comprehensive unweighted supermatrix is formed, where the pairwise comparisons of total impact matrix are carried out for the whole system [7].

The novelty in this paper is the hybrid MCDM model for the vehicle service center selection by using DANP approach. It makes the fleet maintenance planning more effective. With the use of MCDM model, maintenance managers can better recognize all relevant factors and their relative weights while making the observed decision. This affects the greater vehicle availability. In this sense, fleet managers can better dispose of vehicles of the most suitable construction-operation group for transportation tasks realization, which increases the vehicle cargo capacity utilization [8]. This leads to the fleet energy efficiency increasing [9]. With the use of MCDM model the number of backup vehicles can be reduced, which leads to the total fleet size decreasing and lower transportation and maintenance costs [10]. Thus, the MCDM model finds application as a tool to evaluate the effectiveness of managers in fleet maintenance planning.

Factors (criteria) for the vehicle service center selection

During the fleet maintenance planning, maintenance managers make a decision on the location of the maintenance work realization (in the company's own facilities, or in a vehicle service center in the region), among other. However, when companies do not own maintenance facilities or when there is deficiency or unavailability of adequate maintenance capacity (equipment, workspace), managers make a decision on the selection of an appropriate vehicle service center in the region. According to paper [11], about 78.6% of companies with own truck fleets in the Republic of Serbia had significantly higher share of maintenance work performed in vehicle service centers in the region, compared to the maintenance workload in their own facilities.

To make the fleet maintenance planning more effective, it is indispensable that managers make right decision about the selection of a suitable vehicle service center in the region, in which a planned maintenance work will be realized. This decision is affected by different interdependent factors (criteria). According to many authors [1, 12-14], maintenance costs represent a significant dimension (cluster) that impacts the maintenance planning and scheduling. In this sense, maintenance labor cost has an important role [1, 13], and together with the spare parts' cost represent the *Maintenance service realization costs*. Authors in paper [15], observed the price for maintenance service as an important factor for the vehicle service center selection. In paper [16], author proposed a mathematical model for vehicle replacement which includes the highway tolls and vehicle fuel costs. Highway tolls, vehicle fuel costs and vehicle towing costs as well represent the *Vehicle travel costs to the service center*. According to authors [17], maintenance quality is an important dimension that has an impact on company's competitiveness. The authors observed the maintenance quality through the number of repeated jobs caused by human error, and through the work order accuracy, among others. Some of leading indicators for maintenance process are *Quality of execution* (*Rework*) and *Schedule compliance* [14]. The quality of repair work, the service done within the agreed time schedule, and the time waiting for an appointment as well are important expectations (demands) of consumers for the vehicle service center selection [15]. In paper [18], authors presented an approach for the planned maintenance of geographically distributed equipment in which the important factors are equipment locations and travel time between equipment locations. The size of maintenance department also affects the improvement of maintenance planning and scheduling [1, 2].

Besides a literature review, an expert opinion questionnaire was conducted in March 2016 with the aim to determine the other relevant factors that influence the mentioned decision making. A group of 78 experts with an experience in the field of fleet operation and maintenance were involved. They were asked to define factors which in their opinion have an important role in the selection of vehicle service center in the region. Based on the analysis of questionnaire responses, the literature review and the personal experience of authors as well, 11 relevant factors (criteria) were defined (tab. 1). As shown in tab. 1, factors belong to the following clusters (dimensions): maintenance cost, maintenance quality, location of the vehicle service center, and properties of the vehicle service center.

Table 1. Preview of relevant factors and clusters affecting the vehicle service center selection

Factors (Criteria)	Description of factors	Clusters (Dimensions)
Maintenance service realization costs – C_1	Price that the company pays to the service center for performing maintenance interventions on vehicle	Maintenance cost – C
Vehicle travel costs to the vehicle service center – C_2	Consists of the fuel cost, tolls (optional) and vehicle towing costs (optional)	
Payment amenities for maintenance service – C_3	Approved deadlines for deferred payment for performed maintenance interventions by service center	
Performed maintenance interventions' quality – Q_1	Company's experience regarding to erroneous or inadequately realized maintenance interventions by service center	Maintenance quality – Q
Respecting agreed timeframe – Q_2	Company's experience regarding to disrespect of agreed terms of vehicle admission and/or release by service center	
Performed maintenance interventions' speed – Q_3	Company's experience regarding to readiness of the service center to provide vehicle return to the operational condition, according to company requests	
Position of the vehicle service center (distance) – L_1	Required time for vehicle to arrive at the location of service center	Location of the vehicle service center – L
Accessibility of the vehicle service center – L_2	Required additional time for vehicle to access a location of service center due to unexpected conditions of terrain configuration, traffic control or road infrastructure	
Level of the service network development – P_1	Mutual assistance of service centers in the region (of the same owner) aiming a better utilization of workers, equipment or spare parts	Properties of the vehicle service center – P
Size of the vehicle service center – P_2	Size of working spaces and workforce capacity in a service center	
Specialization and facility equipment – P_3	Existing maintenance interventions and quantity of available modern equipment and machinery in a service center	

In order to effectively plan the fleet maintenance, maintenance managers should take into consideration all relevant factors (tab. 1) while making the decision about the selection of a suitable vehicle service center in the region. By respecting factors Q_2, Q_3, L_1, L_2, and P_1, the required vehicles will be ready to operate in the required timeframes, according to requirements of the transportation process and the environment as well. This allows fleet managers to dispose of vehicles of the most suitable construction-operation group for transportation tasks realization, thus increasing the vehicle cargo capacity utilization per realized transportation volume [8]. Better usage of the vehicle cargo capacity has an impact on the fleet energy efficiency increase [9]. It affects lower transportation costs. By taking into consideration factors Q_1, Q_2, P_1, P_2, and P_3, the number of backup vehicles (as substitute for the vehicles held in maintenance) can be reduced. By reducing the number of backup vehicles, the total fleet size decreases, making it more rational [1, 10]. This allows fleet managers to realize all planned transportation tasks in observation period with a smaller fleet size. It ultimately affects lower transportation and maintenance costs. Respecting the factors C_1, C_2, and C_3 directly affects maintenance costs. As all factors don't have the same importance to the mentioned decision and between factors exist interdependencies, it is necessary to establish which factor influences more the accomplishment of company goal.

Building a hybrid MCDM model for the vehicle service center selection

This research uses the DANP method to explore the interdependencies and feedbacks that exist between relevant factors and clusters (tab. 1) and to establish a hybrid MCDM model for the vehicle service center selection. The model procedure of this research is presented in fig. 1.

DANP (DEMATEL-based ANP) method

The DANP is a hybrid approach that combines the DEMATEL method [19] with the basics of ANP method [20]. The main purpose of DANP is to calculate the caused and received effects, as well as the relative weights of each defined factor, according to the established goal. DANP is successfully applied in many fields, [7, 21, 22]. DANP consists of following steps [7].

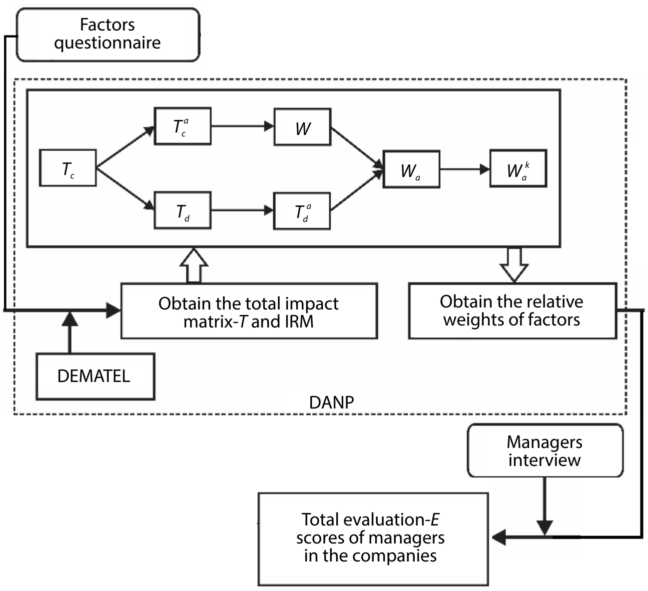

Figure 1. Procedure of the research model

Step 1. Determining the factors, clusters and measuring scale. An expert opinion survey and the support of literature overview are applied in order to define the factors and clusters which have an influence on the considered system. The measuring scales by DANP approach can be usually established from 3-point scale up to 10-point scale.

Step 2. Obtaining the initial direct-relation matrix – A. Assuming that there is a decision problem with n factors, and H experts are involved in the survey. The pairwise comparison of factor pair i and j by the expert k is denoted by p_{ij}^k. The expression $P^k = [p_{ij}^k]_{n\times n}$ is an integer non-negative matrix of rank $n \times n$ and represents the answer of expert k. The initial direct-relation matrix A is calculated by averaging all experts' opinions for each element of the matrix-A as follows:

$$A = [a_{ij}]_{n\times n} = \frac{1}{H}\sum_{k=1}^{H}\left[p_{ij}^k\right], \quad 1\le i,j\le n; \quad 1\le k\le H \tag{1}$$

Step 3. Calculating the normalized initial direct-relation matrix – X. The normalized initial direct-relation matrix – X is calculated according to expression (2):

$$X = [x_{ij}]_{n\times n} = gA, \quad 0\le x_{ij}; \quad 1\le i, \quad j\le n \tag{2}$$

where g is the normalization factor calculated:

$$g = \min\left(\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}}, \frac{1}{\max 1\le j\le n \sum_{i=1}^{n} a_{ij}}\right) \tag{3}$$

Step 4. Computing the total impact matrix – T. The total impact matrix T is obtained by using expression (4), in which matrix I is denoted as the identity matrix of rank $n\times n$:

$$\mathrm{T} = [t_{ij}]_{n\times n} = X + X^2 ... + X^k = X(I-X)^{-1}, \ 1\le i, \ j\le n; \ \lim_{k\to\infty} X^k = [0]_{n\times n} \tag{4}$$

Step 5. Setting a threshold value – q. The threshold value q is set on the basis of expert opinion to ignore the relationships that have minor or small impacts in the matrix T.

Step 6. Measuring the factors' influence and obtaining the IRM. Based on the adopted threshold value q, the sum of the row and column values of the matrix T can be calculated:

$$r = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1}, \ 1\le i\le n; \quad s = [s_l]'_{1xn} = \left[\sum_{i}^{n} t_{ij}\right]'_{1xn}, \ 1\le j\le n \tag{5}$$

where sign represents a transposed matrix. A sum of the row values r indicates the overall influence of a given factor on other factors and a sum of the column values s indicates the overall influence of other factors on a given factor. The $(r + s)$ values named *Prominence* reveal how important the factors and clusters are. The $(r – s)$ values named *Relation* allow factors and clusters to be sorted into cause and receive groups. If the $(r – s)$ value is positive, the factor (or cluster) is grouped into the cause group. Otherwise, the factor (or cluster) is grouped into the receive group.

Step 7. Obtaining the unweighted super-matrix – W. In this step, the total impact matrix for factors $\mathrm{T_c}$ is applied, as shown in the expression (6):

$$\mathrm{T_c} = \begin{array}{cc} & \\ D_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1n_1} \end{array} \\ D_2 & \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2n_2} \end{array} \\ \vdots & \vdots \\ D_m & \begin{array}{c} c_{m1} \\ c_{m2} \\ \vdots \\ c_{mn_m} \end{array} \end{array} \overset{\begin{array}{cccc} D_1 & D_2 & \cdots & D_m \\ c_{11}\cdots c_{1n_1} & c_{21}\cdots c_{2n_2} & \cdots & c_{m1}\cdots c_{mn_m} \end{array}}{\begin{bmatrix} \mathrm{T_c^{11}} & \mathrm{T_c^{12}} & \cdots & \mathrm{T_c^{1m}} \\ \mathrm{T_c^{21}} & \mathrm{T_c^{22}} & \cdots & \mathrm{T_c^{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{T_c^{m1}} & \mathrm{T_c^{m2}} & \cdots & \mathrm{T_c^{mm}} \end{bmatrix}} \tag{6}$$

where D_m denotes the m-th cluster and denotes the n-th factor in the m-th cluster. The matrix indicates the sub-matrix of the matrix T_c and contains the factor impacts in the cluster D_1. The row sum values for each sub-matrix in the matrix T_c are obtained in order to carry out the process of normalization.

After normalization process of total impact matrix for factors, the normalized total impact matrix for factors is calculated, as given in expression (7):

$$T_c^{\alpha} = \begin{array}{c c} & \begin{array}{cccc} D_1 & D_2 & \cdots & D_m \\ c_{11}\ldots c_{1n_1} & c_{21}\ldots c_{2n_2} & \cdots & c_{m1}\ldots c_{mn_m} \end{array} \\ \begin{array}{cc} D_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1n_1} \end{array} \\ D_2 & \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2n_2} \end{array} \\ \vdots & \vdots \\ D_m & \begin{array}{c} c_{m1} \\ c_{m2} \\ \vdots \\ c_{mn_m} \end{array} \end{array} & \begin{bmatrix} T_c^{\alpha 11} & T_c^{\alpha 12} & \cdots & T_c^{\alpha 1m} \\ T_c^{\alpha 21} & T_c^{\alpha 22} & \cdots & T_c^{\alpha 2m} \\ \vdots & \vdots & \ddots & \vdots \\ T_c^{\alpha m1} & T_c^{\alpha m2} & \cdots & T_c^{\alpha mm} \end{bmatrix} \end{array} \tag{7}$$

The unweighted super-matrix – W is obtained by using the transposition of the each cluster in the normalized total impact matrix for factors, as shown in expression (8):

$$W = (T_c^{\alpha})' = \begin{array}{c c} & \begin{array}{cccc} D_1 & D_2 & \cdots & D_m \\ c_{11}\ldots c_{1n_1} & c_{21}\ldots c_{2n_2} & \cdots & c_{m1}\ldots c_{mn_m} \end{array} \\ \begin{array}{cc} D_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1n_1} \end{array} \\ D_2 & \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2n_2} \end{array} \\ \vdots & \vdots \\ D_m & \begin{array}{c} c_{m1} \\ c_{m2} \\ \vdots \\ c_{mn_m} \end{array} \end{array} & \begin{bmatrix} W^{11} & W^{12} & \cdots & W^{1m} \\ W^{21} & W^{22} & \cdots & W^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W^{m1} & W^{m2} & \cdots & W^{mm} \end{bmatrix} \end{array} \tag{8}$$

where $W^{ij} = (T_c^{\alpha ji})'$, $i = 1, 2,\ldots m$; $j = 1, 2,\ldots m$. The vectors of factor impacts with value zero show independent relationship between the clusters or factors.

Step 8. Obtaining the weighted super-matrix – W_α. In this step, the total impact matrix for clusters T_D is used to show the sum of impacts for each cluster, as given in expression (9):

$$T_D = \begin{bmatrix} t_D^{11} & \cdots & t_D^{1j} & \cdots & t_D^{1m} \\ \vdots & & \vdots & & \vdots \\ t_D^{i1} & \cdots & t_D^{ij} & \cdots & t_D^{im} \\ \vdots & & \vdots & & \vdots \\ t_D^{m1} & \cdots & t_D^{mj} & \cdots & t_D^{mm} \end{bmatrix} \begin{array}{l} \rightarrow d_1 = \sum_{j=1}^{m} t_D^{1j} \\ \vdots \\ \rightarrow d_i = \sum_{j=1}^{m} t_D^{ij} \\ \vdots \\ \rightarrow d_m = \sum_{j=1}^{m} t_D^{mj} \end{array} \tag{9}$$

where t_D^{ij} represents the sum of all impacts from the matrix T_c^{ij}, *i. e.* represents the degree of impact that the cluster i exerts on the cluster j and where denotes the sum of i-th row in the matrix T_D, while $i = 1, 2,\dots, m$. The row sums are applied to calculate the normalized total impact matrix for clusters, according to expression (10):

$$T_D^\alpha = \begin{bmatrix} t_D^{11}/d_1 & \cdots & t_D^{1j}/d_1 & \cdots & t_D^{1m}/d_1 \\ \vdots & & \vdots & & \vdots \\ t_D^{i1}/d_i & \cdots & t_D^{ij}/d_i & \cdots & t_D^{im}/d_i \\ \vdots & & \vdots & & \vdots \\ t_D^{m1}/d_m & \cdots & t_D^{mj}/d_m & \cdots & t_D^{mm}/d_m \end{bmatrix} = \begin{bmatrix} t_D^{\alpha 11} & \cdots & t_D^{\alpha 1j} & \cdots & t_D^{\alpha 1m} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha i1} & \cdots & t_D^{\alpha ij} & \cdots & t_D^{\alpha im} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha m1} & \cdots & t_D^{\alpha mj} & \cdots & t_D^{\alpha mm} \end{bmatrix} \tag{10}$$

The normalized total impact matrix for clusters T_D^α is used to weight the unweighted super-matrix – W. As result, the weighted super-matrix – W_α is obtained in line with expression (11):

$$W_\alpha = T_D^\alpha \cdot W = \begin{bmatrix} t_D^{\alpha 11} \cdot W^{11} & t_D^{\alpha 21} \cdot W^{12} & \cdots & \cdots & t_D^{\alpha m1} \cdot W^{1m} \\ t_D^{\alpha 12} \cdot W^{21} & t_D^{\alpha 22} \cdot W^{22} & \vdots & & \vdots \\ \vdots & \cdots & t_D^{\alpha ji} \cdot W^{ij} & \cdots & t_D^{\alpha mi} \cdot W^{im} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1m} \cdot W^{m1} & t_D^{\alpha 2m} \cdot W^{m2} & \cdots & \cdots & t_D^{\alpha mm} \cdot W^{mm} \end{bmatrix} \tag{11}$$

Step 9. Calculating the relative importance of factors. The weighted super-matrix W_α is multiplied by itself multiple times to calculate the limited weighted super-matrix-W_α^k with a stable convergence value, as presented in expression (12):

$$\lim_{k\to\infty} (W_\alpha)^k = W_\alpha^k \tag{12}$$

where the number k represents a positive integer number which tends to infinity. Vectors of the limited super-matrix represent relative weights of each factor in relation to the defined goal.

Accomplished results

According to the DANP, an expert opinion survey was conducted to find the interdependencies between defined factors. This survey involved the same 78 experts who participated in the questionnaire defining the relevant factors. From the experts, 8% are professors from the Faculty of Transportation and Traffic Engineering, University of Belgrade, and 92% are managers in the transport companies. Experts had a task in the survey to estimate the interdependencies for 11 defined factors with a score from 0 to 4 (from *no influence* to *very high influence*). The measuring scale from 0 to 4 is very often in use by jointly implementation of DEMATEL and ANP methods and it is good enough to describe the observed system. The expressions were manually calculated.

According to expressions (1-4), the total impact matrix T is calculated, (tab. 2). The experts established the threshold value to $q = 0.15$. Factors with the highest values of the term $(r + s)$ are the most important factors as follows (tab. 2): *performed maintenance interventions' quality* (Q_1), *maintenance service realization costs* (C_1), and *respecting agreed timeframe* (Q_2). Factor *Level of the service network development* (P_1) with the highest value of the term $(r – s)$ influences the most the remaining factors. Factor *respecting agreed timeframe* (Q_2) is under the greatest influence of all remaining factors. According to expression (9), the total impact matrix of clusters T_D is obtained (tab. 3). As shown in tab. 3, the most important total impacts are from the cluster *maintenance quality* (Q) with the highest value of the term ($r+s$). Table 3 also shows that the cluster *properties of the vehicle service center* (P) cause the most important effects to remaining clusters. Cluster *maintenance quality* (Q) with the lowest value of term ($r-s$) for the most part is subject to the influence of remaining clusters.

Table 2. Total impact matrix of factors with caused and received effects

Factors	C_1	C_2	C_3	Q_1	Q_2	Q_3	L_1	L_2	P_1	P_2	P_3
C_1	0.49	0.33	0.35	0.61	0.62	0.57	0.39	0.27	0.42	0.41	0.54
C_2	0.29	0.20	0.17	0.31	0.33	0.32	0.33	0.21	0.27	0.22	0.32
C_3	0.41	0.23	0.16	0.35	0.36	0.33	0.25	0.18	0.26	0.25	0.30
Q_1	0.65	0.37	0.32	0.51	0.65	0.58	0.38	0.27	0.43	0.43	0.56
Q_2	0.56	0.34	0.28	0.58	0.46	0.53	0.36	0.25	0.38	0.39	0.48
Q_3	0.61	0.34	0.27	0.61	0.62	0.45	0.36	0.27	0.41	0.39	0.52
L_1	0.37	0.37	0.20	0.38	0.40	0.39	0.24	0.24	0.29	0.28	0.37
L_2	0.28	0.30	0.00	0.28	0.28	0.28	0.28	0.00	0.23	0.21	0.26
P_1	0.54	0.39	0.32	0.58	0.59	0.55	0.43	0.31	0.33	0.38	0.50
P_2	0.49	0.27	0.27	0.51	0.51	0.49	0.33	0.24	0.34	0.28	0.49
P_3	0.64	0.35	0.31	0.66	0.63	0.60	0.41	0.28	0.44	0.44	0.46
($r+s$)	10.32	6.45	5.74	10.52	10.05	9.94	7.29	4.94	8.73	7.91	10.02
($r-s$)	–0.31	–0.51	0.43	–0.21	–0.84	–0.23	–0.23	–0.15	1.12	0.52	0.42

Table 3. Total impact matrix of clusters with caused and received effects

Clusters	Maintenance costs – C	Maintenance quality – Q	Location of the V. service center – L	Properties of the service center – P
Maintenance costs – C	2.63	3.80	1.64	2.99
Maintenance quality – Q	3.74	4.98	1.89	4.01
Location of the V. service center – L	1.51	2.01	0.77	1.64
Properties of the service center – P	3.58	5.12	2.00	3.66
Prominence: ($r+s$)	22.51	30.51	12.22	26.66
Relation**:** *($r-s$)*	–0.40	–1.28	–0.38	2.06

For better understanding the relationships between factors and clusters, IRM is obtained (fig. 2), based on the calculated total caused and received effects (tabs. 2 and 3). As shown in fig. 2, cluster P has an impact on clusters L, C, and Q. In the same way, cluster L impacts the clusters C, and Q. Finally, cluster C also influences the cluster Q (fig. 2). Within the cluster of Maintenance cost, factor C_3 has an impact on factors C_1 and C_2, but also factor C_1 has an impact on factor C_2 (fig. 2).

Finally, the limited super-matrix W_α^k is calculated by using the expression (12). The obtained vectors of the limited super-matrix are relative weights of the relevant factors influencing the selection of vehicle service center in the region (tab. 4). According to the results shown in tab. 4, it is evident that the factor *respecting agreed timeframe* (Q_2) has the greatest influence for the selection of a suitable vehicle service center in the region, *i. e.* for an effective maintenance planning. In addition to this factor, very important factors are *performed maintenance*

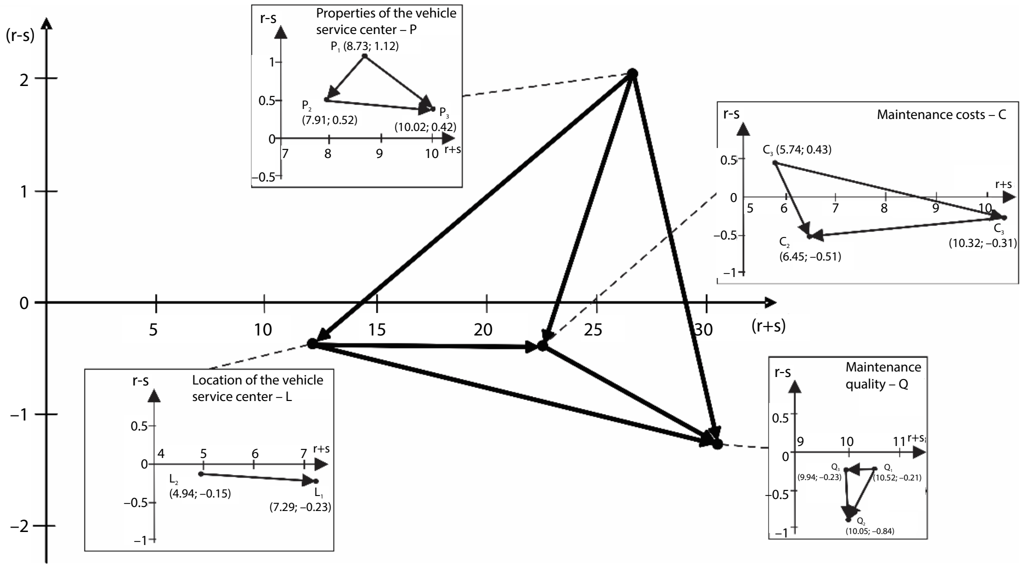

Figure 2. Influence relation map (IRM) for the vehicle service center selection

interventions' quality (Q_1), *maintenance service realization costs* (C_1) and *performed maintenance interventions' speed* (Q_3). The most important cluster is the *maintenance quality* (Q).

Table 4. MCDM model with the relative weights of factors

Factors	C_1	C_2	C_3	Q_1	Q_2	Q_3	L_1	L_2	P_1	P_2	P_3
Relative weights	0.1157	0.0761	0.0576	0.1165	0.1181	0.1106	0.0821	0.0547	0.0833	0.0807	0.1046
Local weights	0.4639	0.3051	0.2310	0.3375	0.3421	0.3204	0.6001	0.3999	0.3101	0.3005	0.3894
Ranking	3	9	10	2	1	4	7	11	6	8	5
Clusters	Maintenance cost – C			Maintenance quality – Q			Location of the vehicle service center – L		Properties of the vehicle service center – P		
Local weights	0.2494			0.3452			0.1368		0.2686		
Ranking	3			1			4		2		

Application of the MCDM model in companies

The developed MCDM model was applied in the following companies: Company A, Company B, Company C, Company D, Company E. In April 2016 the average fleet size in these 5 companies was 186 vehicles. All maintenance work on their vehicles is planned for realization in the vehicle service centers in the region. The conducted survey consisted in interviews. The managers were asked to give their opinion on the importance of each of the relevant factors when making a decision on the selection of a vehicle service center in the region. For this purpose, managers assessed each of the 11 relevant factors with a score from 1-5 (rating 1 meaning of no importance; while rating 5 meant an extremely important factor). The measuring scale from 1-5 is used only for the factor assessments by managers in the observed companies. Based on managers' responses as well as on MCDM model implementation, the Total evaluation-*E* in each of five companies was calculated (tab. 5), according to expression (13):

$$E = M_{C1} g_{C1} + M_{C2} g_{C2} + M_{C3} g_{C3} + M_{Q1} g_{Q1} + M_{Q2} g_{Q2} + M_{Q3} g_{Q3} + M_{L1} g_{L1} + \\ + M_{L2} g_{L2} + M_{P1} g_{P1} + M_{P2} g_{P2} + M_{P3} g_{P3} \quad (13)$$

where M_{C1}, M_{C2}, M_{C3},…M_{P3} are the middle score of managers' responses for each factor and g_{C1}, g_{C2}, g_{C3},...g_{P3} are the relative weights of each factor. Total evaluation – *E* represents the degree of managers' effectiveness in fleet maintenance planning, with the aim to increase the fleet energy efficiency and to achieve defined company goal.

The highest score of the Total Evaluation realized managers of the Company A (tab. 5). They substantially recognize the importance of fleet maintenance effective planning for increasing the fleet energy efficiency and achieving the primary company goal. Managers of this company are very sensitive to the top 5 of the factors, but also do not neglect the factors with lower ranking in the model. Managers of the Company C achieved the lowest score of the Total Evaluation, being the least effective in the maintenance planning due primarily to the non-recognition of factors P_1, P_2 and C_3.

Table 5. Total Evaluation-*E* scores of managers in the considered companies, based on model

Factors (criteria)	C_1	C_2	C_3	Q_1	Q_2	Q_3	L_1	L_2	P_1	P_2	P_3
Relative weights	0.1157	0.0761	0.0576	0.1165	0.1181	0.1106	0.0821	0.0547	0.0833	0.0807	0.1046
Company name	Company A										
Middle score	4.00	3.50	2.00	5.00	4.50	5.00	3.00	3.00	3.00	3.00	4.50
E	3.8845										
Company name	Company B										
Middle score	4.00	3.50	2.50	4.50	5.00	5.00	4.00	3.00	2.50	1.00	2.50
E	3.5840										
Company name	Company C										
Middle score	4.00	3.00	1.50	4.50	4.00	5.00	3.00	2.00	1.00	1.50	3.00
E	3.2011										
Company name	Company D										
Middle score	3.50	3.50	3.00	5.00	3.75	4.00	4.00	2.25	3.25	3.50	4.00
E	3.7351										
Company name	Company E										
Middle score	4.00	3.00	2.00	5.00	5.00	4.00	3.00	3.00	3.50	3.00	3.00
E	3.6796										

Table 6 shows the total evaluation scores of managers when all factors have the equal relative weights, *i. e.* when the model is not applied. As can be seen from tab. 6, total evaluation scores of each company are lower, compared to the scores when the model is implemented (tab. 5). This fact shows that managers in observed companies recognize and respect to a greater degree the factors with higher relative weights such as Q_2, Q_1, C_1, and Q_3, compared to factors with lesser importance in the developed model. When choosing a suitable vehicle service center in the region, managers should also more respect the factors of lesser importance, such as L_2, C_3, C_2, P_2, and P_1. This leads to the effective fleet maintenance planning.

Table 6. Total evaluation-*E* scores of managers in the considered companies, based on implementation of equal relative weights of factors

Factors (criteria)	C_1	C_2	C_3	Q_1	Q_2	Q_3	L_1	L_2	P_1	P_2	P_3
Relative weights	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909
Company name	Company A										
Middle score	4.00	3.50	2.00	5.00	4.50	5.00	3.00	3.00	3.00	3.00	4.50
E	3.6816										
Company name	Company B										
Middle score	4.00	3.50	2.50	4.50	5.00	5.00	4.00	3.00	2.50	1.00	2.50
E	3.4090										
Company name	Company C										
Middle score	4.00	3.00	1.50	4.50	4.00	5.00	3.00	2.00	1.00	1.50	3.00
E	2.9544										
Company name	Company D										
Middle score	3.50	3.50	3.00	5.00	3.75	4.00	4.00	2.25	3.25	3.50	4.00
E	3.6135										
Company name	Company E										
Middle score	4.00	3.00	2.00	5.00	5.00	4.00	3.00	3.00	3.50	3.00	3.00
E	3.4997										

Conclusion

As a part of fleet maintenance planning, managers often make a decision on the selection of suitable vehicle service center in the region, in which they need to carry out planned maintenance work. The mentioned decision is affected by 11 relevant factors (criteria), based on the literature review, the analysis of questionnaire responses and the personal experience of authors as well. In order to determine the intensity of interdependence of factors and calculating their influence on the mentioned decision, the DANP method was applied. As a result, a hybrid MCDM model was developed.

According to the MCDM model, factor *respecting agreed timeframe* (Q_2) is of the utmost importance for the decision on the managers' selection of suitable vehicle service centers in the region. In this respect, factor Q_2 largely contributes to fleet maintenance effective planning in order to increase the fleet energy efficiency and to realize the company goal. Besides factor Q_2, significantly affecting factors are: *performed maintenance interventions' quality* (Q_1), *maintenance service realization costs* (C_1), *performed maintenance interventions' speed* (Q_3), and *specialization and facility equipment* (P_3).

The developed MCDM model was applied in transport companies with the aim to evaluate the effectiveness of managers in fleet maintenance planning. Results of the model application show that managers of considered companies recognize and respect to a greater degree the factors with higher relative weights such as Q_2, Q_1, C_1 and Q_3, compared to factors with lesser importance. Less effective managers do not recognize or they do not respect enough the factors of lesser importance in the model, such as L_2, C_3, C_2, P_2 and P_1. In order to become more effective in fleet maintenance planning, managers should involve more into consideration the factors with lesser importance in the model while making a decision on the selection of vehicle service center in the region.

In this sense, managers in the companies with a large vehicle fleet should take into consideration all defined factors in the MCDM model with their relative weights, while making a decision on the selection of vehicle service center in the region. This affect the greater vehicle availability and allows managers to dispose of vehicles of the most suitable construction-operation group for transportation tasks realization, thus increasing the vehicle cargo capacity utilization, *i. e*. transport energy efficiency. Additionally, this allows managers to realize all planned transportation tasks in observation period with lower transportation and maintenance costs.

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Nomenclature

C_1 – factor maintenance service realization costs, [–]
C_2 – factor *vehicle travel costs to the vehicle service center*, [–]
C_3 – factor *payment amenities for maintenance service*, [–]
C_{mn_m} – the n^{th} factor in theth cluster of matrix, [–]
D_m – the m^{th} cluster of matrix, [–]
E – total evaluation score of managers' effectiveness, [–]
$g_{C1}, g_{C2},..., g_{P3}$ – relative weights of each factor, [–]
H – number of experts, [–]
L – cluster *location of the vehicle service center*, [–]
L_1 – factor *position of the vehicle service center* (*distanc*e), [–]
L_2 – factor *accessibility of the vehicle service center*, [–]
$M_{C1}, M_{C2},..., M_{P3}$ – the middle score of managers' responses for each factor, [–]
p_{ij}^{k} – the answer of expert *k,* [–]
P_1 – factor *level of the service network development*, [–]
P_2 – factor *size of the vehicle service center*, [–]
P_3 – factor *specialization and facility equipment*, [–]
q – the threshold value, [–]
Q_1 – factor *performed maintenance interventions' quality*, [–]
Q_2 – factor *respecting agreed timeframe*, [–]
Q_3 – factor *performed maintenance interventions' speed*, [–]
r – overall influence of a given factor on other factors, [–]
s – overall influence of other factors on a given factor, [–]

Acronyms

ANP – analytic network process
DANP – DEMATEL-based ANP
DEMATEL – decision making trial and evaluation laboratory
IRM – influence relation map
MCDM – multi-criteria decision making

Subscripts

m – number of clusters
n – number of factors

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