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A New Comprehensive Approach for Efficient Road Vehicle Procurement Using Hybrid DANP-TOPSIS Method

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Abstract: The efficient vehicle procurement is an important business segment of different companies with their own vehicle fleet. It has a significant influence on reducing transport and maintenance costs and on increasing the fleet's energy efficiency. It is indispensable that managers consider various criteria from several aspects when procuring a vehicle. In that sense, we defined 13 relevant criteria and divided them into four multidisciplinary aspects: Construction-technical, financial, operational, and environmental. Decision-Making Trial and Evaluation Laboratory-Based Analytic Network Process (DANP) method was applied to evaluate the significance of defined criteria and aspects and their interdependency. It is established that the three most important criteria for vehicle procurement are vehicle price, vehicle maintenance, and vehicle selling price. The most important aspect is construction technical aspect, while the aspect of the environment is the least important. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was used to rank eight different vehicles, which were considered by vehicle fleet manager at the observed company. This model assists fleet managers in the selection of the most suitable vehicle for procurement, while significantly reducing decision-making time and simultaneously observing all necessary criteria and their weights. Moreover, we have considered 10 different scenarios to establish whether and how the rank of the observed alternatives would change.

Keywords: vehicle procurement; MCDM; fleet energy efficiency; transport costs; maintenance costs; alternative fuel vehicles

1. Introduction

The vehicle procurement represents one of the significant activities of the fleet managers [1]. Transport and logistics companies often have a heterogeneous vehicle fleet, composed of different vehicle types and different construction-operation characteristics [2]. One of the main goals of the observed companies is to reduce transport and maintenance costs, as well as to increase the fleet's energy efficiency in order to increase profit [3]. This paper analyzes the road vehicles procurement as one of the factors which contribute to the achievement of the defined goal. Besides choosing the right vehicle type during the procurement, an additional potential for achieving the defined goal is to choose the appropriate vehicle model within the selected type. However, the problem is that the managers during vehicle procurement often observe only certain criteria of certain aspects that they consider important, while other criteria and aspects that they insufficiently know about are neglected and considered insignificant. An additional problem is that managers evaluate the importance of observed criteria according to their (subjective) perceptions. All of the above leads to higher transport and maintenance costs and lower fleet's energy efficiency, and thereby, to lower profit.

Vehicle procurement has been often covered in the literature as part of solving the fleet renewal or fleet replacement problem [4–6]. Some authors propose various models of integer programming to achieve efficient road vehicle fleet renewal or replacement [7–9]. Although the authors observed many different criteria, there is a lack of criteria that indirectly have an impact on transport and maintenance costs and energy efficiency. Moreover, the interdependent influences between criteria are not taken into account even though they exist in managers' decision-making during the vehicle procurement process. The task of fleet renewal consists of defining the number and type of vehicles that are added to the fleet by procurement or that are removed from the fleet by selling [10], but there are only a few papers that deal with the decision which type and model of vehicle to procure. This is especially important for road vehicles since there are many different models of the same vehicle type (e.g., various models of van with gross vehicle weight up to 3.5 t) where each model has different characteristics which have an impact on transport and maintenance costs and energy efficiency. Besides that, although it gives good results, the integer programming is not commonly used by vehicle fleet managers, and it is not how they make a decision during the road vehicle procurement process. Considering the above-mentioned, the observed problem belongs to the Multi-Criteria Decision Making (MCDM).

In order to determine criteria weights, we used the Decision-Making Trial and Evaluation Laboratory-Based Analytic Network Process (DANP) method because the interdependent effects of the vehicle procurement criteria are non-reciprocal values. DANP method calculates non-weighted supermatrices by applying pairwise comparisons to the total impact matrix within the whole system, which better describes the real system [11]. The integration of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP) method is still widely used for solving different problems. The authors of [12] used integration of these two methods to establish the relationship between six important performance criteria and eighteen key performance indicators that describe the performance measurement system of any food supply chain, as well as to determine their ranking. Gudiel Pineda et al. [13] used the DANP method to obtain relative weights of the criteria important to evaluate the financial and operational performance of airlines. Hsu et al. [14], in their paper, observe multiple criteria regarding the quality of service for bike-sharing systems, as well as the relationships between them in order to better reflect the real-world situation and thus they used DANP method to determine the observed criteria relative weights. The authors of [15] have researched the inhibitors in the intermodal freight transport system, and they used grey-DEMATEL and ANP (gDANP) method to establish relationships between these inhibitors, as well as their relative weights. DANP method was used in [16] in order to determine relative weights and interdependency of 11 criteria from four clusters with an aim to support vehicle fleet managers in decision making on the selection of vehicle service centers. After that, we used the well-known Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to rank the observed vehicles. This method is one of the best in addressing the rank reversal problem [17]. The TOPSIS method as MCDM method was applied in [18], where authors used this method to integrate environmental, economic, and social dimensions in order to assess the sustainability of battery electric vehicles and to compare it with the sustainability of internal combustion engine vehicles. TOPSIS method was used in [19] for problem-solving in urban public transportation by ranking observed alternatives (electric buses) and evaluating them through seven different criteria. Additionally it was used in the selection of Brazilian furniture industry suppliers [20], an egg supplier for a Thai restaurant [21], evaluation of different fuel characteristics [22], vehicle manufacturer evaluation [23], performance evaluation of seven Indian industries based on financial ratio analysis taking into account 15 criteria [24], selection of the best railroad container terminal location out of 11 potential ones observing seven different criteria [25], etc.

We are not aware of a model that selects the most suitable road vehicle while taking into account construction-technical, financial, operational, and environmental aspects of road vehicle, simultaneously from three points of view: Transport costs, maintenance costs, and energy efficiency. Thus, the main contribution of this paper is such a developed model for efficient vehicle procurement.

This model is easily understandable for vehicle fleet managers since it describes better their perception in case there are multiple interdependent criteria. It significantly reduces decision making time, observing all necessary criteria and their weights. The aim of the model is to increase companies' profit through a comprehensive and multidisciplinary approach. Additionally, we have conducted a literature review and engaged 50 experts to define relevant criteria for road vehicle procurement and their relative weights. Finally, this model is applicable for the selection of alternative fuel vehicles (AFVs) as well as for conventional (diesel) vehicles.

The paper is structured as follows. Section 2 comprises a literature review with the aim of defining the relevant vehicle procurement criteria. The developed model methodology is presented step-by-step in Section 3. The model implementation, obtained results, and discussion are presented in Sections 4 and 5, while the conclusions are given in Section 6.

2. Vehicle Procurement Criteria

In this chapter, a literature review was conducted to identify significant aspects and criteria for vehicle procurement within the developed model that have a direct and indirect impact on transport and maintenance costs and fleet's energy efficiency.

Many authors, while researching efficient fleet renewal/replacement, consider criteria such as the existence of new vehicle technologies, which includes vehicle equipment regarding safety and technical systems [26]. The same author points out the vehicle comfort and vehicle technical condition (age) as relevant criteria in order to increase the competitiveness of companies in the market. The older vehicles contribute to increased transport and maintenance costs [27], as well as to increased environmental costs [2]. The vehicle technical condition concerning the vehicle mileage is important in the calculation of the expected costs [6]. In order to increase a vehicle's energy efficiency and reduce CO₂ emission, vehicle manufacturers endeavor to reduce engine capacity [28,29]. It is established that the homogeneous fleet in air traffic has an influence on reducing transport and maintenance costs, pilots and technicians training costs, spare parts stock costs, and other costs [30]. Since this can be applied for road vehicles, the criterion compatibility with the existing vehicle fleet is also significant for our model. Vehicle price is considered in solving strategic fleet renewal in shipping and depends on the size, age and vessel technical condition [27]. This criterion is also used to calculate the life cycle costs of vehicles in [18]. For example, the electric commercial vehicles (ECVs) have approximately three times higher procurement costs in relation to conventional vehicles, and because of that, the fleet managers should not plan ECV procurement if the vehicle life cycle is shorter than 12 years [8]. Thus, government subsidies as a form of financing options when buying a vehicle are necessary for the electric vehicles to become more competitive [7]. The national and local financial subsidies were observed in taken into account in [18]. The criterion financing options when buying a vehicle in the form of vehicle leasing was taken into consideration in the developed model for fleet renewal with the aim to minimize AFVs' expected and risk costs [9]. The discounted value of vehicle price, also as a form of financing options, should be contained within economic factors in the model for fleet replacement [8]. As the vehicle ages and its' technical condition degrades, vehicle selling price decreases as well, while transport and maintenance costs tend to increase [31]. One of the factors that influence transport (operating) costs is fuel/energy consumption [18]. Fuel/energy consumption is the key parameter in stochastic processes because it depends on vehicle operation conditions and drivers' skills [6]. With a decrease in fuel efficiency with diesel-fueled commercial vehicles, ECVs become much more competitive [8]. The fuel (energy) costs are about 62% lower for electric vans, about 37% lower for compressed natural gas (CNG) vans, and about 2% higher for biodiesel B30 vans, compared to diesel vans [32]. Some vehicle manufacturers and distributors, with a longer period of vehicle maintenance at their service centers, provide certain discounts on vehicle price [33]. In this way, fleet managers obtain lower initial vehicle procurement costs, but the overall maintenance costs are higher (due to the contracted extended maintenance in authorized service centers). While considering the AFVs, it is important to take into account the preventive maintenance costs since the electric vehicles have lower

maintenance costs than conventional [8]. The maintenance costs are about 30% lower for electric vans and about 11% higher for biodiesel B30 and CNG vans compared to diesel vans [32]. This criterion is also observed in [18] for comparing battery electric vehicles and internal combustion engine vehicles. Besides all, legislation requirements, competition, and clients themselves play a remarkable role when procuring vehicles [33]. In that sense, in order to be in compliance with legislation requirements and to conduct efficient vehicle procurement, it is necessary to consider vehicle's CO₂ emissions. The CO₂ emissions depend directly on the vehicle age and weight, so older or heavier vehicles emit more CO₂ than newer or lighter vehicles [34]. The AFVs, such as electric vehicles, can significantly reduce harmful gas emissions, but only if electricity is generated from renewable energy sources [35]. CO₂ emission is 50%-70% lower for electric vans, 28% lower for biodiesel B30, and about 5% lower for CNG vans compared to diesel vans [32]. The vehicle dimensions and weight sometimes represent a limitation for vehicle access to the transportation network, especially in dense urban environments [2]. In this sense, it is also necessary to take into account the criterion of vehicle's compliance with the road-traffic infrastructure requirements on the transport network. This criterion can be quantified and measured through the vehicle turning diameter, which is of great importance in urban areas where diameters of road curves are smaller, and traffic lanes' width is usually narrower. A potential to increase the fleet's energy efficiency is much greater if managers optimize vehicle utilization and choose the right size and type of vehicle according to transport operations [36]. In that sense, we will observe vehicle's compliance with the customers' transport requirements as a criterion in our model.

Based on the literature review and authors' own experience, we defined 13 relevant criteria and divided them into the four multidisciplinary aspects: Construction-technical, financial, operational, and environment (Table 1).

Table 1. Preview of relevant criteria and aspects related to vehicle procurement.

Aspects/Criteria	Criteria Description	Criteria Parameter
CONSTRUCTION-TECHNICAL ASPECT (CT)		
<i>CT1</i> —Vehicle equipment regarding safety and technical systems	Existence of advanced onboard systems: ABA, Cruise Control with Variable Speed Limiter, Active Distance Assist Distronic, Blind Spot Assist Mirror, Rear View Camera, Stop&Start System, TSR, LGS, TPMS, HSA.	Number of safety-technical systems: <i>CT1_p</i>
<i>CT2</i> —Engine characteristics	Engine capacity	Engine capacity (cm ³): <i>CT2_p</i>
<i>CT3</i> —Vehicle comfort	Existence of further devices and equipment on the vehicle: Automatic air condition, driver's armrest, Electric windows, Rain sensors, LCD display with navigation, Bluetooth connection, Automatic transmission, Seat heating, Seat cooling, Seat massagers	Number of on-board devices/equipment: <i>CT3_p</i>
<i>CT4</i> —Vehicle's compatibility with the existing vehicle fleet	Number of the observed vehicle model in the existing vehicle fleet	Percentage of the observed vehicle model (%): <i>CT4_p</i>
<i>CT5</i> —Vehicle's technical condition	$1 + \frac{\text{Vehicle current mileage at the moment of procurement}}{\text{Average vehicle annual mileage in observed company}}$	Vehicle mileage coefficient: <i>CT5_p</i>
FINANCIAL ASPECT (F)		
<i>F1</i> —Vehicle price	The price of the observed vehicle model on the market	Vehicle price (£): <i>F1_p</i>
<i>F2</i> —Financing options when buying a vehicle	Existence of further options: Leasing, government subsidies, discounts on the vehicle price	Number of options: <i>F2_p</i>
<i>F3</i> —Vehicle selling price	The residual value of the observed vehicle model on the market with the certain number of years and miles traveled	Vehicle selling price (£): <i>F3_p</i>
OPERATIONAL ASPECT (O)		
<i>O1</i> —Fuel/energy costs	Specific fuel (energy) consumption multiplied by fuel/energy price	Fuel (energy) costs (£/100 km): <i>O1_p</i>

Table 1. Cont.

Aspects/Criteria	Criteria Description	Criteria Parameter
O2–Vehicle maintenance	Price of preventive maintenance multiplied by the number of obligatory annual preventive maintenance services (vehicle manufacturer requirements during warranty period)	Preventive maintenance costs (£/year): $O2_p$
ASPECT OF THE ENVIRONMENT (E)		
E1–Environmental protection requirements	Amount of CO ₂ emission from the observed vehicle model	CO ₂ emission (g/km): $E1_p$
E2–Vehicle’s compliance with the road-traffic infrastructure requirements on the transport network	Compliance of vehicle turning diameter with the characteristics of the road infrastructure on the transport network (road curve diameter, curves frequency, traffic lane width, etc.)	Vehicle turning diameter “curb to curb” (m): $E2_p$
E3–Vehicle’s compliance with customers’ transport requirements	Compliance of the vehicle’s payload capacity with the cargo amount that should be carried	Utilization of vehicle’s payload capacity (%): $E3_p$
Note: ABA: Active Brake Assist; TSR: Traffic Sign Recognition; LGS: Lane Guard System; TPMS: Tire Pressure Monitoring System; HSA: Hill Start Assist.		

3. Building an Evaluation Model for Vehicle Procurement

The procedure of the developed model for efficient vehicle procurement is shown in Figure 1. There are six phases that are described in the following subchapters.

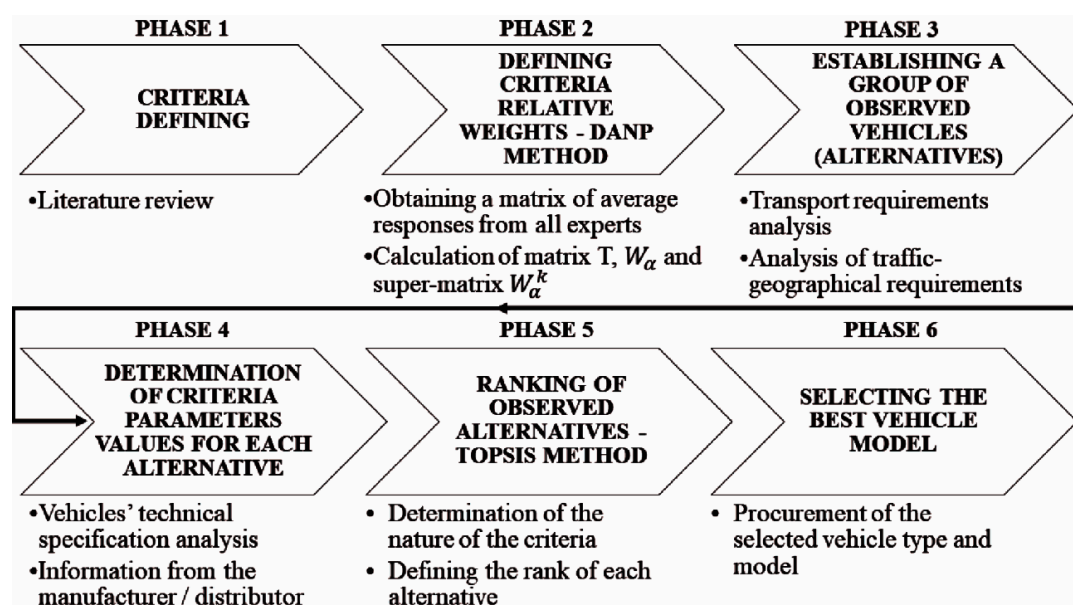


Figure 1. The procedure of the Multi-Criteria Decision Making (MCDM) model for efficient vehicle procurement.

3.1. Defining Criteria Relative Weights with DANP Method

DANP was used to determine the intensity of relevant criteria interdependencies, as well as to calculate the criteria significance to attaining the main goal of the observed companies. DANP shows the criteria interdependent effects as non-reciprocal values and calculates non-weighted supermatrices by applying pairwise comparisons (comparison of impact pairs) to the total impact matrix within the whole system, which better describes the real system [11]. The basic steps of DANP are [11]:

Step 1: Defining criteria (factors) and aspects (dimensions). In order to define the relevant criteria and aspects, it is necessary to conduct a scientific literature review in the considered area and conduct a survey.

Step 2: Calculation of direct-relation matrix-**B**. Matrix **B** represents the matrix of average responses of all H experts as follows:

$$B=[b_{ij}]_{n \times n} = \frac{1}{H} \sum_{k=1}^H [p_{ij}^k]; 1 \leq i, j \leq n; 1 \leq k \leq H \quad (1)$$

where $P^k = [p_{ij}^k]_{n \times n}$ represents the answers of the expert k on the interaction of the i^{th} and j^{th} factors in the form of integer non-negative numbers within the $n \times n$ rank matrix.

Step 3: Calculation of normalized direct-relation matrix- X . Matrix X is calculated as follows:

$$X=[x_{ij}]_{n \times n} = g \cdot B; 0 \leq x_{ij} \leq 1; 1 \leq i, j \leq n \quad (2)$$

where g is the normalization factor which is calculated as follows:

$$g = \min \left(\frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n b_{ij}}, \frac{1}{\max_{1 \leq j \leq n} \sum_{i=1}^n b_{ij}} \right) \quad (3)$$

Step 4: Determining the total impact matrix- T . In order to determine the total impact matrix T , it is used the identity matrix I of rank $n \times n$, as follows:

$$T=[t_{ij}]_{n \times n} = X(I-X)^{-1}; 1 \leq i, j \leq n; \lim_{k \rightarrow \infty} X^k = [0]_{n \times n} \quad (4)$$

Step 5: Adjusting a threshold value- q . According to expert opinion, the threshold value q can be adjusted in order to disregard the criteria relationships with small impacts in the matrix T .

Step 6: Calculating the criteria influence and making the Influence Relation Map-IRM. On the basis of adopted threshold value q , the row and column sum values of the matrix T are calculated as follows

$$r=[r_i]_{n \times 1} = \left[\sum_{j=1}^n t_{ij} \right]_{n \times 1}; 1 \leq i \leq n; s=[s_j]_{1 \times n}' = \left[\sum_{i=1}^n t_{ij} \right]_{1 \times n}'; 1 \leq j \leq n \quad (5)$$

where a row sum values r indicates the overall influence of a given criterion on other criteria, and a column sum values s indicates the overall influence of other criteria on a given criterion. A sign ' indicates a transposed matrix. The expression $(r + s)$ shows the importance of criteria and aspects. The expression $(r - s)$ sorts the criteria and aspects into cause and receive groups. With positive $(r - s)$ value, a criterion (or aspect) is into the cause group. Otherwise, criterion (or cluster) is into the receive group.

Step 7: Obtaining the unweighted super-matrix- W . For this purpose, the total impact matrix- T is used. The matrix T actually represents the total impact matrix for criteria- T_c . The normalized total impact matrix for criteria T_c^α is calculated, according to Expression (6):

$$T_c^\alpha = \begin{matrix} & & \begin{matrix} D_1 \\ c_{11} \dots c_{1n_1} \end{matrix} & \begin{matrix} D_2 \\ c_{21} \dots c_{2n_2} \end{matrix} & \dots & \begin{matrix} D_m \\ c_{m1} \dots c_{mn_m} \end{matrix} \\ \begin{matrix} D_1 \\ c_{11} \\ c_{12} \\ \vdots \\ c_{1n_1} \end{matrix} & \left[\begin{array}{cccc} T_c^{\alpha 11} & T_c^{\alpha 12} & \dots & T_c^{\alpha 1m} \\ T_c^{\alpha 21} & T_c^{\alpha 22} & \dots & T_c^{\alpha 2m} \\ \vdots & \vdots & \ddots & \vdots \\ T_c^{\alpha m1} & T_c^{\alpha m2} & \dots & T_c^{\alpha mm} \end{array} \right] & & & & \\ \vdots & & & & & \\ \begin{matrix} D_2 \\ c_{21} \\ c_{22} \\ \vdots \\ c_{2n_2} \end{matrix} & & & & & \\ \vdots & & & & & \\ \begin{matrix} D_m \\ c_{m1} \\ c_{m2} \\ \vdots \\ c_{mn_m} \end{matrix} & & & & & \end{matrix} \quad (6)$$

where D_m indicates the m^{th} aspect and c_{mn_m} marks the n^{th} criterion in the m^{th} aspect. The matrix $T_c^{\alpha 11}$ shows the normalized sub-matrix of the matrix T_c^α with criteria impacts in the aspect D_1 .

The super-matrix W is calculated, as shown in Expression (7):

$$W = (T_c^\alpha)' = \begin{matrix} & & & D_1 & D_2 & \dots & D_m \\ & & & c_{11} \dots c_{1n_1} & c_{21} \dots c_{2n_2} & \dots & c_{m1} \dots c_{mn_m} \\ \begin{matrix} D_1 \\ \vdots \\ D_2 \\ \vdots \\ D_m \end{matrix} & \begin{matrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1n_1} \\ \vdots \\ c_{21} \\ c_{22} \\ \vdots \\ c_{2n_2} \\ \vdots \\ c_{m1} \\ c_{m2} \\ \vdots \\ c_{mn_m} \end{matrix} & \left[\begin{array}{cccc} W^{11} & W^{12} & \dots & W^{1m} \\ W^{21} & W^{22} & \dots & W^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W^{m1} & W^{m2} & \dots & W^{mm} \end{array} \right] \end{matrix} \quad (7)$$

where $W^{ij} = (T_c^{\alpha ji})'$ indicates a transposition of the sub-matrix $T_c^{\alpha ji}$ in the normalized total impact matrix for criteria T_c^α , while $i = 1, 2, \dots, m; j = 1, 2, \dots, m$.

Step 8: Calculating the weighted super-matrix- W_α . For this purpose, the total impact matrix for aspects T_D is used. The matrix T_D represents the sum of all impacts of every aspect in the matrix T_c . The normalized total impact matrix for aspects T_D^α is calculated, as shown in Expression (8)

$$T_D^\alpha = \left[\begin{array}{cccc} t_D^{11}/d_1 & \dots & t_D^{1j}/d_1 & \dots & t_D^{1m}/d_1 \\ \vdots & & \vdots & & \vdots \\ t_D^{i1}/d_i & \dots & t_D^{ij}/d_i & \dots & t_D^{im}/d_i \\ \vdots & & \vdots & & \vdots \\ t_D^{m1}/d_m & \dots & t_D^{mj}/d_m & \dots & t_D^{mm}/d_m \end{array} \right] = \left[\begin{array}{cccc} t_D^{\alpha 11} & \dots & t_D^{\alpha 1j} & \dots & t_D^{\alpha 1m} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha i1} & \dots & t_D^{\alpha ij} & \dots & t_D^{\alpha im} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha m1} & \dots & t_D^{\alpha mj} & \dots & t_D^{\alpha mm} \end{array} \right] \quad (8)$$

where t_D^{ij} indicates the sum of all impacts from the sub-matrix T_c^{ij} of the total impact matrix for criteria and where d_i denotes the sum of i^{th} row in the super-matrix for aspects T_D , while $i = 1, 2, \dots, m$.

The super-matrix W_α is calculated according to Expression (9):

$$W_\alpha = T_D^\alpha \cdot W = \left[\begin{array}{cccc} t_D^{\alpha 11} \cdot W^{11} & t_D^{\alpha 21} \cdot W^{12} & \dots & \dots & t_D^{\alpha m1} \cdot W^{1m} \\ t_D^{\alpha 12} \cdot W^{21} & t_D^{\alpha 22} \cdot W^{22} & \vdots & & \vdots \\ \vdots & \dots & t_D^{\alpha ji} \cdot W^{ij} & \dots & t_D^{\alpha mi} \cdot W^{im} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1m} \cdot W^{m1} & t_D^{\alpha 2m} \cdot W^{m2} & \dots & \dots & t_D^{\alpha mm} \cdot W^{mm} \end{array} \right] \quad (9)$$

Step 9: Obtaining the criteria relative weights. It is necessary to multiply the super-matrix W_α by itself multiple times in order to calculate the limited weighted super-matrix W_α^k with a stable convergence value, as shown in Expression (10):

$$\lim_{k \rightarrow \infty} (W_\alpha)^k = W_\alpha^k \quad (10)$$

where the number k denotes a positive integer number, which tends to infinity. Every vector of the limited super-matrix W_α^k represents the relative weight of each criterion in relation to the defined goal.

3.2. Establishing a Group of Observed Vehicles—Defining Alternatives

Within this phase, the suitable vehicle types and models necessary for the realization of the transport process are defined. Since the observed companies are different regarding their characteristics, when defining a set of considered vehicles (alternatives) for procurement, it is necessary to take into account the following elements: The available company budget, the transport network specifics, the characteristics of the customers' transport requirements, and legislation requirements.

Road characteristics (road curve diameter, traffic lanes width, existing traffic regulations, etc.) can be limiting factors for certain vehicle types and models. This is especially the case in urban areas with small road curve diameters and lane widths, with traffic restrictions for certain vehicles, such as trucks over 7.5 t gross vehicle weight (GVW) and vehicles with lower Euro standard than it is prescribed. Based on the analysis of customers' transport requirements, the quantities and types of cargo most often transported by the company have to be determined, and therefore, the suitable types and models of vehicles are established (by type of vehicle's cargo compartment, vehicle's payload capacity). Legislation requirements (vehicle emission, noise, etc.) also represent limiting factors for certain vehicle categories when defining the vehicles set, especially for vehicles that operate in urban areas.

3.3. Determination of Criteria Parameters Values for Each Alternative

After defining a set of considered vehicles, it is necessary to determine for each vehicle the parameter values that quantitatively express each of the defined criteria, as noted in Table 1. These values of parameters are determined on the basis of the vehicles' technical and operational data using vehicle specifications, available scientific and professional literature, information obtained from vehicle distributors, as well as from vehicle service centers. After determining the parameter value of the defined criteria for each vehicle, it is necessary to rank the considered vehicles by applying the TOPSIS method.

3.4. Ranking of Observed Alternatives with TOPSIS Method

TOPSIS method [37] was applied in order to rank the considered vehicles (alternatives) within the procuring process. The basic steps of the TOPSIS method are [37]:

Step 1: Construct the normalized decision matrix. Starting matrix $X_T = [x_{ij}]_{m \times n}$ is transformed into a normalized matrix $R_T = [r_{ij}]_{m \times n}$, where r_{ij} are normalized values obtained by normalization. i represents i^{th} alternative considered A_i ($1 \leq i \leq m$) and j represents j^{th} criterion K_j ($1 \leq j \leq n$). Normalization of starting matrix is carried out by vector normalization based on Equations (11) and (12):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}; \forall K_j \in K'; \text{ for benefit criteria} \quad (11)$$

$$r_{ij} = \frac{\frac{1}{x_{ij}}}{\sqrt{\sum_{i=1}^m (\frac{1}{x_{ij}})^2}}; \forall K_j \in K''; \text{ for cost criteria} \quad (12)$$

Step 2: Construct the weighted normalized decision matrix. This step involves incorporating the relative weights of the criteria $W_j = [w_j]_{1 \times n}$ obtained with the DANP method on the basis of W_α^k matrix, where j represents j^{th} criterion and $j = 1, \dots, n$. Criteria relative weights are included in the decision matrix, which transforms the matrix R_T into a weighted matrix V_T based on Equation (13):

$$V_T = [v_{ij}]_{m \times n} = [W_j \cdot r_{ij}]_{m \times n}; i = 1, \dots, m; j = 1, \dots, n \quad (13)$$

Step 3: Determine the ideal and anti-ideal solution. Ideal (A^+) and anti-ideal (A^-) solutions are vectors that are calculated, as shown in Equations (14) and (15):

$$A^+ = \left(\left(\max_i v_{ij} \mid \forall K_j \in K' \right), \left(\min_i v_{ij} \mid \forall K_j \in K'' \right) \right) = (v_1^+, v_2^+, \dots, v_j^+, \dots, v_n^+), i = 1, \dots, m; i = 1, \dots, n \quad (14)$$

$$A^- = \left(\left(\min_i v_{ij} \mid \forall K_j \in K' \right), \left(\max_i v_{ij} \mid \forall K_j \in K'' \right) \right) = (v_1^-, v_2^-, \dots, v_j^-, \dots, v_n^-), i = 1, \dots, m; i = 1, \dots, n \quad (15)$$

Step 4: Calculate the separation measure. The alternative distance from ideal (S_i^+) and anti-ideal (S_i^-) solution is calculated by Euclidean distance in n -dimensional space of criteria as shown in Equation (16):

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2}; S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}; i = 1, \dots, m; j = 1, \dots, n \quad (16)$$

Step 5: Calculate the relative closeness to the ideal solution. This is calculated as follows (17):

$$C_i = \frac{S_i^-}{S_i^- + S_i^+}, i = 1, \dots, m \quad (17)$$

where $0 \leq C_i \leq 1$. The closer C_i is to 1 the alternative is relatively closer to A^+ .

Step 6: Rank the preference order. A compromise solution is one or more alternatives that make the set A^* determined in accordance with (18):

$$C_i = \frac{S_i^-}{S_i^- + S_i^+}, i = 1, \dots, m \quad (18)$$

where the rank of alternatives A_i (from best to worst) corresponds to the order of C_i values ranked in descending order.

3.5. Selecting The Best Vehicle Model

After obtaining the best vehicle model for procurement, an analysis of the obtained results is carried out according to defined criteria. It is considered by which criteria the chosen alternative takes precedence over the other alternatives. In addition, the expected effects and losses of other alternatives are analyzed. Fleet managers consider the obtained results and make a decision on the choice of an appropriate vehicle for procurement. The presented model is a support for fleet managers in the road vehicle procurement process in order to reduce the transport and maintenance costs and increase the fleet's energy efficiency.

4. Model Application

The developed model was applied at a company that owns a vehicle fleet for automotive spare parts distribution. According to the model's second phase (Figure 1), the relative weights of the vehicle procurement criteria were calculated. In accordance with the other phases of the model, a set of vehicles

(alternatives) was determined, as well as values of the observed parameters. Afterwards, the observed alternatives were ranked.

4.1. Calculating Criteria Relative Weights

Within Phase 2 of the developed model, a survey was conducted to gather experts' opinions on the interdependencies between the defined criteria. The survey included 50 opinions of experts in this field. The demographic information of experts is shown in Table 2. The survey was conducted during the period from January to March 2019. The experts were informed about the model idea and therefore tasked to determine the interdependencies of 13 defined criteria with a score from 0 to 4 (from “no impact” to “very strong impact”). The inconsistent rate of 50 responses was less than 5%.

Table 2. Demographic information of survey participants.

Demographic Information		Frequency	Percentage
Age	25–34	10	20%
	35–44	26	52%
	45–54	12	24%
	55–65	2	4%
Education level	High school	1	2%
	College	5	10%
	Bachelor of Science	7	14%
	Master of Science	16	32%
	Doctor of Science	21	42%

Based on the results of the survey and Equations (1)–(4), the total impact matrix-T was calculated, which simultaneously represents the total impact matrix for criteria – T_c (Table 3). As can be seen from Table 3, the more important criteria are those with higher value of $(r + c)$: Vehicle procurement price (F1), Vehicle maintenance (O2), and Engine characteristics (CT2). The criterion that influences the other criteria the most has the highest value of $(r - s)$, and that is Environmental protection requirements (E1). The criterion with the lowest value of $(r - s)$ is influenced the most by the other criteria, and that is Vehicle procurement price (F1).

Table 3. Total impact matrix of criteria T_c and effects.

Criteria.	CT1	CT2	CT3	CT4	CT5	F1	F2	F3	O1	O2	E1	E2	E3
CT1	0.0477	0.0850	0.0699	0.0874	0.1196	0.2012	0.0712	0.1582	0.1463	0.1732	0.0591	0.0784	0.0876
CT2	0.0790	0.0724	0.0773	0.1055	0.1165	0.2133	0.0865	0.1603	0.1800	0.1709	0.0978	0.1184	0.1486
CT3	0.0614	0.0673	0.0301	0.0639	0.0621	0.1554	0.0575	0.1175	0.1140	0.1130	0.0525	0.0675	0.0745
CT4	0.0800	0.1090	0.0600	0.0456	0.0800	0.1345	0.0641	0.0888	0.1077	0.1539	0.0514	0.0920	0.1038
CT5	0.0987	0.1078	0.0955	0.0773	0.0644	0.2096	0.0829	0.1548	0.1599	0.1737	0.0888	0.0747	0.0880
F1	0.0959	0.0969	0.0812	0.0745	0.0981	0.0928	0.0949	0.1293	0.1050	0.1222	0.0621	0.0697	0.0869
F2	0.0757	0.0757	0.0587	0.0690	0.0648	0.1596	0.0315	0.0877	0.0629	0.0985	0.0436	0.0438	0.0592
F3	0.0552	0.0782	0.0526	0.0586	0.0857	0.1450	0.0733	0.0566	0.0955	0.1078	0.0540	0.0420	0.0714
O1	0.0483	0.0812	0.0339	0.0492	0.0693	0.1204	0.0555	0.1169	0.0548	0.0903	0.0771	0.0618	0.0851
O2	0.0764	0.0927	0.0565	0.0910	0.1133	0.1585	0.0695	0.1427	0.1325	0.0741	0.0788	0.0510	0.0759
E1	0.1010	0.1469	0.0901	0.1033	0.1513	0.2068	0.0927	0.1605	0.1557	0.1775	0.0510	0.1004	0.1152
E2	0.0922	0.1222	0.0740	0.1200	0.0977	0.1881	0.0675	0.1351	0.1682	0.1494	0.0717	0.0492	0.1314
E3	0.0522	0.1088	0.0591	0.1134	0.0966	0.1704	0.0591	0.1202	0.1586	0.1418	0.0575	0.0878	0.0548
($r + s$)	2.3484	2.8704	1.8756	2.2296	2.6957	3.3649	1.8370	2.6045	2.5846	2.9593	2.4977	2.4035	2.4628
($r - s$)	0.4211	0.3824	0.1979	0.1120	0.2567	−0.9462	0.0246	−0.6528	−0.6973	−0.5334	0.8070	0.5299	0.0981

In order to show the interdependencies of aspects, the total impact matrix of aspects $-T_D$ was calculated (Table 4). As can be seen in Table 4, the Construction-technical aspect (CT) is very important. The aspect of the environment (E) has the most influence on other aspects, while the Financial aspect (F) is influenced the most by the other aspects.

Table 4. Total impact matrix of aspects T_D and effects.

Aspects	Construction-Technical CT	Financial F	Operational O	Environment E
Construction technical-CT	1.9634	1.9558	1.4926	1.2831
Financial-F	1.1208	0.8707	0.5918	0.5327
Operational-O	0.7118	0.6635	0.3516	0.4297
Environment-E	1.5288	1.2004	0.9513	0.7189
$(r + s)$	12.020	7.8064	5.5439	7.3639
$(r - s)$	1.3701	−1.5744	−1.2307	1.4350

Based on the calculated total caused and received effects, Figure 2 shows the Influence Relation Map (IRM), in order to clarify the relationships between defined criteria and aspects. As can be seen in Figure 2, aspect E has the highest value of $(r - s)$, so it affects all other aspects. Aspect CT influences aspects O and F, while aspect F has the most received effects from the other aspects (Figure 2). When considering the impacts of criteria within one aspect such as e.g., CT aspect, the CT1 criterion affects all other criteria within CT aspect because it has the highest value of $(r - c)$, while the CT4 criterion with the lowest value of $(r - c)$ receives the most effects from the other criteria of CT aspect.

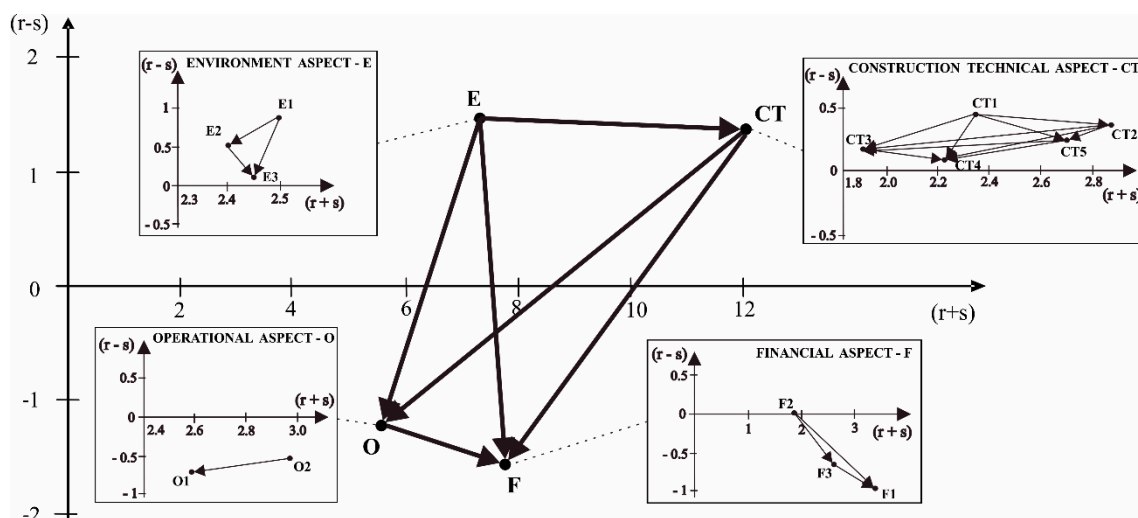


Figure 2. Influence Relation Map (IRM) for vehicle procurement.

Based on Equation (10), a limited weighted super-matrix W_{α}^k was calculated (Table 5). The vectors in super-matrix W_{α}^k represent the relative weights of vehicle procurement criteria W_j . As it is shown in Table 5, the criterion Vehicle procurement price (F1) has the highest relative weight, i.e., has the highest importance for the procurement of vehicles, in achieving the defined goal. Other significant criteria for vehicle procurement are: Vehicle maintenance (O2), Vehicle selling price (F3), and Fuel/energy Cost (O1). The most important vehicle procurement aspect is construction-technical aspect (CT), followed by financial (F), operational (O) and aspect of the environment (E), which has the least significance for the vehicle procurement process (Table 5).

Table 5. Relative weights of criteria and aspects.

Criteria	CT1	CT2	CT3	CT4	CT5	F1	F2	F3	O1	O2	E1	E2	E3
Relative weights- W_j	0.0603	0.0773	0.0516	0.0643	0.0762	0.1291	0.0588	0.1002	0.0963	0.1039	0.0544	0.0562	0.0715
Rank	9	5	13	8	6	1	10	3	4	2	12	11	7
Aspects	Construction technical CT					Financial F			Operational O		Environment E		
Local weights	0.3296					0.2881			0.2002		0.1821		
Rank	1					2			3		4		

4.2. Establishing and Ranking the Vehicles and Selecting the Best Vehicle for Procurement

The observed company (Delmax Ltd.) has a heterogeneous fleet of 66 vehicles, with small pickup vehicles (GVW up to 2.5 t), vans (GVW up to 3.5 t), and trucks (GVW up to 15 t). The analysis of the operation data shows that the vehicles' average annual mileage is 55,000 km. Based on the analysis of transport routes and history of customers' transport requirements in the observed company, it was found that more than 90% of the transport routes pass through urban areas, and the weight of the transported cargo is between 800 and 1300 kg in more than 80% cases. According to the obtained results of conducted analyses, it was determined that possible vehicle types that can meet transportation requirements are: Vans with GVW up to 3.5 t and trucks with GVW up to 7.5 t. Regarding this, different types and models of vehicles from different manufacturers were considered in order to determine which vehicle model contributes the most to achieving the company's goal. For the purpose of calculating the rank of alternatives, we have used the adjusted program code written in Python 3.7 [38].

Alternative A5 is a truck with a GVW up to 7.5 t, and the other alternatives are vans with a GVW up to 3.5 t (Table 6). Alternatives A1, A2, A3, and A4 are conventional (diesel) vans from different manufacturers, while the alternative A6 is an electric van. The alternatives A7 and A8 are a variation of the alternative A2 that use different alternative fuel CNG and biodiesel B30, respectively. Criteria values of the observed alternatives were determined based on the brochures from vehicle manufacturers' websites and websites that advertise used vehicles, as well as from authorized maintenance services and vehicle dealers. These values were also determined based on the characteristics of the observed companies' vehicle fleet and their transport requirements, considered the price of diesel is £1.08/lit and the price of electricity is £0.11/kWh. After determining the nature of each criterion (min./max.) the relative closeness of the observed alternatives to the ideal solution (C_i) was calculated on the basis of Equations (11)–(18), and the rank of each alternative was determined (Table 6).

Table 6. Criteria values and rank of alternatives.

Criteria	CT1	CT2	CT3	CT4	CT5	F1	F2	F3	O1	O2	E1	E2	E3	C_i	Rank
A1 diesel	6	2179	5	10.61	1	38801	1	7600	10.42	495	159	12.6	84	0.485	4
A2 diesel	2	2300	4	24.24	1	36693	1	8000	8.21	243	186	12.8	84	0.570	1
A3 diesel	1	2298	4	12.12	1	38331	1	7500	7.45	248	182	13.6	89	0.489	3
A4 diesel	3	2143	1	3.03	1	39852	1	11500	8.75	288	213	13.6	100	0.459	5
A5 diesel	2	4580	1	0	1	59605	1	21150	15.34	471	375	13.2	33	0.315	8
A6 electric	1	0	4	0	1	66373	1	11445	3.63	174	55	13.6	94	0.522	2
A7 CNG	2	3000	4	0	1	43901	1	5832	5.18	270	177	12.8	84	0.413	7
A8 B30	2	2300	4	0	1	36693	1	8000	8.40	269	134	12.8	84	0.432	6
max/min	max	min	max	max	min	min	max	max	min	min	min	min	max		
Crit. W_j	0.0603	0.0773	0.0516	0.0643	0.0762	0.1291	0.0588	0.1002	0.0963	0.1039	0.0544	0.0562	0.0715		

5. Results and Discussion

As it is shown in Table 6 the A2 (diesel van) is the first ranked alternative, while the A6 (electric van) is the second one. This vehicle has the lowest procurement price (about £30,000 lower than A6 and more than £1600 lower than the third ranked alternative, i.e., A3), which is the most important criterion. If a period of five years in operation (275,000 km) is observed, it can be seen that the sum of fuel/energy and maintenance costs is the lowest for the observed electric van (about £10,800), which is

almost £13,000 less than for A2, about £11,000 less than for A3 and £4700 for CNG van. Regarding CO₂ emission, it can be seen that A6 is the best alternative since it emits about 15 t of CO₂ during a period of five years (well to wheel emission), which is 36 t less than the first ranked alternative and 88 t less than A5. However, if we observe overall transport and maintenance costs (sum of vehicle price, fuel/energy, and maintenance costs minus vehicle selling price) we can see that A2 has about £13,300 lower costs than A6. Besides the higher procurement price of alternative A3, the first ranked vehicle has one additional safety/technical system, twice as good compatibility with the existing vehicle fleet, higher vehicle selling price, as well as smaller vehicle turning diameter (which is very important in dense urban environments). Despite the fact that alternative A1 has the most safety-technical systems and equipment regarding vehicle comfort, it has very high maintenance costs (£495/year), which is the second most important criterion. Some of the reasons why the alternative A5 is the worst ranked are very high procurement, fuel/energy, and maintenance costs, as well as low payload utilization (33% of payload utilization means that this vehicle has 67% of free space while transporting goods, which means about 725,800 tonne-kilometer of loss compared to full payload utilization observed over a period of five years and 275,000 km traveled). It can be seen that electric van (A6) is second ranked mostly due to its high procurement price, zero compatibility with the existing vehicle fleet, and very low importance of criterion related to CO₂ emission. Thus, we have considered different scenarios to establish whether and how the rank of the alternatives would change.

Scenario S-0 represents the existing scenario, while the S-1 represents the ranking of observed alternatives if the electric power is produced from renewable sources (zero emission of CO₂ from well to wheel). S-2 and S-3 represent scenarios where there are subsidies of £15,000 and £20,000, whereby the use of renewable sources is significantly increased, respectively. Additionally, we have observed scenarios where the relative weights of criteria vehicle price (F1) and CO₂ emission (E1) are the same (S-4), they have the same weights but the electric van emission is zero (S-5), where the importance of E1 criterion is twice as high as the importance of F1 (S-6), and where the relative weights of criteria F1 and E1 switch places (S-7). We have researched the rank of alternatives when the compatibility with the existing vehicle fleet of all alternatives is the same (S-8). Scenario S-9 represents the case where the number of safety technical systems is the same for all vehicles. Since the maintenance costs for alternative A1 are very high, in scenario S-10 we examined what would happen if these costs were the same as for the alternative A2. The ranks of alternatives for all of these scenarios are shown in Figure 3.

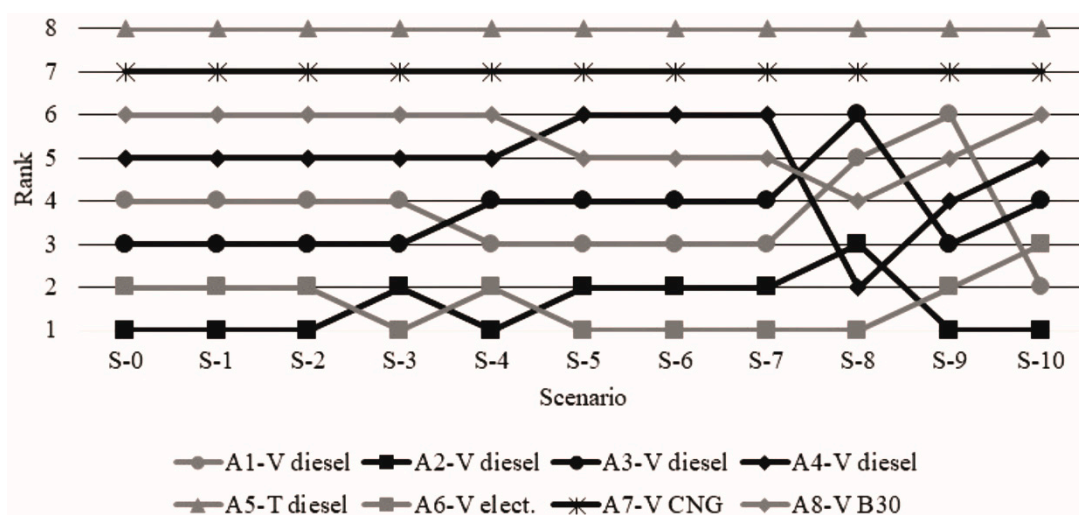


Figure 3. Ranks of alternatives in different scenarios.

As can be seen from Figure 3, in our case study, scenarios S-1 and S-2 are the same as the basic scenario. If there are subsidies of £20,000 (about 30% of new electric vehicle price) and the electric energy production is mostly from renewable sources (S-3), A6 is the first ranked alternative. In scenario

S-4 the only change is between alternatives A1 and A3. Scenarios S-5, S-6, and S-7 show that there are changes in rank between alternatives A2 and A6 (which is first ranked alternative in this case), between A1 and A3, as well as between A8 and A4. If the compatibility with the existing vehicle fleet of all alternatives is the same (S-8), then electric van is the first ranked alternative, and the second one is A4, while the first ranked alternative from the basic scenario (A2) is now the third ranked. The rank of alternatives A4 and A8 in scenario S-9 has improved, while the rank of alternative A1 has gone down from fourth to sixth. In the final scenario (S-10) it can be seen that the alternative A1 would be second ranked if its' maintenance costs were lower, such as for the alternative A2. The rank of alternatives A5 and A7 is the same for all scenarios.

6. Conclusions

Vehicle procurement as a factor that contributes to making more profit in companies with their own vehicle fleet has been researched in this paper. We developed a model that selects the most suitable road vehicle while taking into account construction-technical, financial, operational, and environmental aspects of a road vehicle, simultaneously from three points of view: Transport costs, maintenance costs, and energy efficiency. Using the DANP method and engaging 50 experts from this field, we determined the criteria relative weights and their interdependency, which was ignored in most previous studies. The most important criteria for vehicle procurement are vehicle price (F1), vehicle maintenance (O2), vehicle selling price (F3), and fuel/energy costs (O1), while environmental protection requirements (E1) and vehicle comfort (CT3) are the least significant criteria. The TOPSIS method was used to rank the observed vehicles by their suitability. Besides the basic scenario, we have considered 10 more different scenarios to establish whether and how the rank of the observed alternatives would change.

On the basis of collected criteria parameter values observing five-year period and annual mileage of 55,000 km, the first ranked alternative (diesel van) has lower overall transport and maintenance costs (fuel/energy costs, maintenance costs, vehicle price and vehicle selling price) for £13,300 than second ranked alternative (electric van). In our case (observed company) the electric vehicle price should be about 30% lower (there should be subsidies) in order for this alternative to become the first ranked. We think there should be government subsidies, as well as the increase in usage of renewable energy sources, which will together encourage vehicle fleet managers to procure electric vehicles. For example, this difference in the vehicle price can be used to train the maintenance technicians and drivers, as well as to buy some spare parts and equipment to maintain electric vehicles. We can see that the sum of fuel/energy costs and vehicle maintenance costs of electric van are almost £15,000 lower, on average, than for diesel vans (observing five-year period). However, if overall transport and maintenance costs of electric van are observed, it can be seen that these costs are about £10,000 higher, on average, for five years in operation than for diesel vans.

This model is evaluated by road vehicle fleet managers as easy to understand and operate, while it gives extremely satisfying results in a short period of time. The managers said that without the model they were not aware of all criteria, and they did not observe all of them in previous vehicle procurements. Moreover, it was almost impossible for them to simultaneously observe all relevant criteria necessary for vehicle procurement, as well as their weights and parameters (vehicle data). With the model, the only thing managers should do is to provide vehicles' data and import them into the model. Managers in the observed company during the vehicle procurement process have replaced two old, less suitable vans, with two new ones of the same manufacturer and the same model as the A2 alternative, based on the obtained results of the model. By choosing this alternative instead of second ranked alternative, this company saved about 20% of overall transport and maintenance costs. Moreover, this alternative has proven to be a better choice than all of the other ones as well, taking into account transport and maintenance costs and energy efficiency.

Since the criteria values of the observed alternatives should be determined based on the brochures from vehicle manufacturers' websites and websites that advertise used vehicles, as well as from

authorized maintenance services and vehicle dealers, the accuracy of the obtained information could affect the accuracy of derived results. Additionally, the limitation could represent the non-existence of parameter information that is needed for the model (e.g., vehicle CO₂ emission), as well as a little longer time to collect all necessary data compared to the time when managers observed only a few criteria.

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