Expert Systems with Applications 39 (2012) 10552–10563

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Evaluation of vehicle fleet maintenance management indicators by application of DEMATEL and ANP

Davor Vujanović *, Vladimir Momčilović, Nebojša Bojović, Vladimir Papić

University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, Belgrade, Serbia

ARTICLE INFO

Keywords:
Maintenance management
Vehicle fleets
Energy efficiency
Multiple Criteria Decision-Making (MCDM)
Decision Making Trial and Evaluation Laboratory (DEMATEL)
Analytic Network Process (ANP)

ABSTRACT

The paper refers to the importance of maintenance management to increase the vehicle fleet energy efficiency. The fleet maintenance management influences as the vehicle maintenance process itself as well as the primary transport process but also their environment. In order to increase fleet energy efficiency by means of a more efficient maintenance management, it is indispensable to observe maintenance process, transport process and the environment. Since the implementation effects of such measures can be measured by different indicators, this paper analyses the influence of indicators in all three mentioned areas on management decision-making. In this sense, appropriate indicators have been defined and subsequently used in fleet maintenance management. To determine levels and intensities of interdependence as well as relative weight of selected indicators two methods have been combined: Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP). A model was proposed with indicators' interdependence whose relative weights were calculated. The proposed model has been implemented in several companies with road vehicle fleets. Collected results show the perceived evaluation by company managers in view of maintenance management process influence onto their fleet energy efficiency. Besides, by proposed model implementation we have obtained equally managers' evaluation upon effectiveness and efficiency of the maintenance management within studied companies.

1. Introduction

Companies with own road vehicle fleets attain profit by performing transport services. The amount of profit is significantly influenced among other things, by the costs incurred by transport and vehicle maintenance processes. Considered companies seek to accomplish all the planned transport tasks while minimising transport and maintenance costs.

More efficient fleet maintenance management could affect rational transport process realisation, i.e. reduction in incurred costs. Efficient maintenance management facilitates vehicles of best suited construction–operation (CO) groups in a state "ready for operation" for transport tasks realisation during the required time periods. This certainly influences the increase in energy efficiency of the fleet and transport and maintenance costs reduction, meanwhile company's core performance is not jeopardised i.e. all planned transport tasks are to be accomplished.

In order to attain an efficient maintenance management, it is necessary to coordinate the primary (core) process with maintenance, which has been researched mostly in the field of industrial production (Ashayeri, Teelen, & Selen, 1996; Nikolopoulos, Metaxiotis, Lekatis, & Assimakopoulos, 2003; Waeyenbergh & Pintelon, 2002). In these papers different models and systems have been proposed, all with the objective of increasing efficiency and productivity of industrial machines.

However, vehicle operation and maintenance processes differ from those related to industrial machines. The fact that vehicles are mobile assets, further affected by a large number of external environmental factors imposes the need for a different approach in their maintenance management, compared to other static machines.

In this sense, for an efficient fleet maintenance management it is necessary to observe jointly: (1) the transport process as a primary (core) process that brings profit to the company; (2) the vehicle maintenance, as logistical support to the core transport process, which by means of maintenance interventions transforms vehicle condition from the state of "unready for operation" to the state "ready for operation"; (3) the environment, associated to safety and environmental protection from the maintenance impact, which is monitored via technical inspections. For an integrated approach to maintenance management an important concept is the "Process based maintenance" (Zhu, Gelders, & Pintelon, 2002) and (Zhu & Pintelon, 2001). This concept, among other things, involves the definition of necessary indicators which allow measuring the implementation effects of specific measures during maintenance

* Corresponding author. Tel.: +381 11 309 12 66; fax: +381 11 309 67 04.
E-mail address: d.vujanovic@sf.bg.ac.rs (D. Vujanović).

0957-4174/$ - see front matter
http://dx.doi.org/10.1016/j.eswa.2012.02.159

management, monitoring the value of indicators in relation to the adopted thresholds and management decision making in the event of unauthorized indicator values deviation from threshold values.

However, in case of several indicators for measuring the implemented measures effects and for management decision making, it is necessary to determine which of the indicators is more significant for achieving a defined objective. Moreover, large number of observed indicators have interdependent impact. Implementing certain measures within management, could improve an indicator value, but impact differently a number of other indicators' values. The considered issue represents a classic example of Multiple Criteria Decision Making (MCDM).

Therefore, the problem under consideration in this paper is to determine the level of interdependences of indicators and determine their significance and their relative weight in the maintenance management causing an increase in the fleet energy efficiency, provided that planned transport tasks are realised. As a solution, a model with ranked indicators upon their impact onto the fleet energy efficiency is obtained. The resulting model should point out to managers which indicators should be given more attention in measuring the implemented measures effects and in maintenance management decision-making. The proposed model can be used to evaluate the managers' perception of the importance of maintenance management to increase the fleet energy efficiency. Also, managers can be evaluated by means of the model upon their effectiveness and efficiency in the fleet maintenance management.

To calculate the level of interdependences and determine the level of significance of indicators in relation to the accomplishment of a defined objective, a combination of two methods DEMATEL and ANP will be used as tools for Multiple Criteria Decision Making (MCDM).

DEMATEL method has been developed by "Science and Human Affairs Program of the Battelle Memorial Institute of Geneva" between 1972 and 1976 and used for research and solving several groups of complicated and interdependent problems (Fontela & Gabus, 1974) and (Fontela & Gabus, 1976). This method has been applied in various fields most recently (Li & Tzeng, 2009; Lin, Chen, & Tzeng, 2009; Lin, Yang, Kang, & Yu, 2011; Tzeng, Chiang, & Li, 2007). As a result, total direct and indirect influences of each factor (indicator) are obtained as each factor's (indicator) influence given to other factors, but as well influence received from other factors. This interdependence is visually depicted by a Network Relation Map (NRM).

ANP method represents a more developed version of Analytic Hierarchy Process (AHP) method. Proposed by Saaty in (Saaty, 1996) and (Saaty & Vargas, 1998), in order to avoid hierarchical constraints that exist in the AHP method (Saaty, 1980). It is a relatively new MCDM method used to calculate the interdependences of factors and determine their relative weights. This method has been applied in many areas (Chung, Lee, & Pearn, 2005).

However, treatment of factors' interdependences in ANP method is not objectively addressed in relation to the actual system. This lack is covered by using the DEMATEL method, where interdependences between groups (sets) of factors are determined more objectively and based on the NRM form a structure of the observed system is created, which is subsequently used to calculate the relative weight of factors by using the ANP method (Yang et al., 2008). Combined use of these two methods has been recently implemented for solving MCDM problems in different fields (Yang & Tzeng, 2011; Wu, 2008; Lin, Hsieh, & Tzeng, 2010). In the paper (Lee, Huang, Chang, & Cheng, 2011), the authors go a step further and propose a new hybrid method, which is a developed version of the method compared to the paper by (Ou Yang et al., 2008). According to (Lee et al., 2011), DEMATEL method is used not only as a more objective view of interdependences of groups (sets) of factors, but its total-influence matrix – T is normalised and incorporated into an unweighted supermatrix by the AHP method.

A combination of DEMATEL and ANP methods has been used in this research with same approach as in the paper by (Lee et al., 2011). By literature review and based on authors' personal experience, appropriate indicators were defined in the fleet maintenance management. A model which contains three interdependent groups or fields: transport and maintenance processes and their environment has been developed. In each field there are interdependent factors (indicators). Based on a conducted research of perceptions of field-related professors and other relevant experts from the Faculty of Transport and Traffic engineering in Belgrade, the interdependences among indicators, as well as interdependences between observed fields have been established. Afterwards, the relative weights of indicators and of each observed field are calculated within the developed model using the above mentioned methods. By surveys of managers in several transport companies and by the proposed model implementation, an evaluation of perception on maintenance management impact on the enhancement of the fleet energy efficiency was made, as well as evaluation of managers' efficiency in the maintenance management within each studied company.

In the following Section 2, the concept of fleet maintenance management has been presented in detail, together with a description of selected indicators. Section 3 describes the DEMATEL and ANP methods. Based on survey results, relative weights of indicators and observed fields were obtained in the developed model. In the Section 4 the results of proposed model implementation in several companies with road fleets were addressed. In Section 5 the results were thoroughly analysed, while in the last section the main conclusions and future research topics were drawn up.

2. Fleet maintenance management

2.1. Interdependence of transport and maintenance processes and their environment

Studied transport companies most often own heterogeneous fleets composed of different construction–operation (CO) vehicle groups, especially from the point of view of their available cargo capacity. The set of all planned transport tasks that vehicles have to accomplish in certain time period is defined by the Operation Plan (OP) (Milosavljević, Teodorović, Papić, & Pavković, 1996) and (Momčilović, Papić, & Vujanović, 2007). In this sense, it can be assumed that fleets in observed transport companies operate according to the predefined OP.

During transport task realisation, i.e. during the transport process, vehicles are undergoing more or less important deterioration of their technical condition (Fig. 1). As a consequence of such deterioration, vehicles are initiating maintenance requests. During realisation of maintenance interventions vehicles are in a state "unready for operation" and such vehicles therefore will not be available for transport tasks realisation according to OP requirements. The moments and durations of those periods depend mainly on fleet maintenance management effectiveness and efficiency. After completion of required maintenance interventions, vehicles turn into the state "ready for operation" and become available for further transport tasks realisation.

In this sense, vehicle maintenance process represents a logistic support for the transport process, which on the other hand should provide for the transport service in order to satisfy client requests. The objective of vehicle maintenance process is to allow the accomplishment of Transport Company's objective through ensuring the required number of vehicles in the state "ready for operation" in the exact moment when and the entire period during

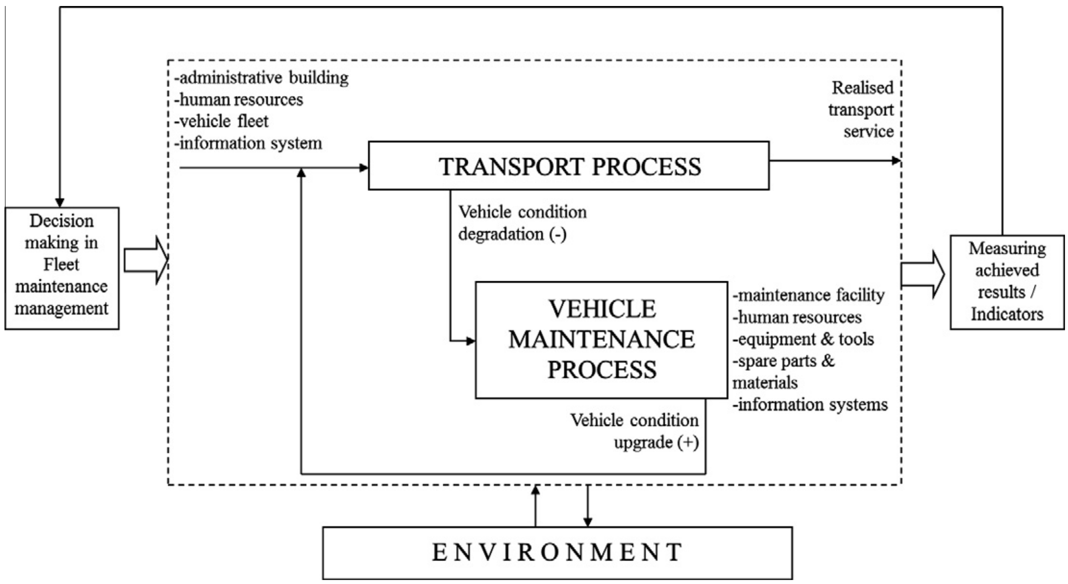

Fig. 1. Interdependence of the environment, transport and maintenance processes.

which they are needed with certain level of reliability (Papić, Medar, & Pejčić Tarle, 1999). This illustrates the interdependence and influence of transport and maintenance processes.

On the other hand, maintenance process impacts the environment through realisation of maintenance interventions on vehicles. The latter could reflect on vehicle functionality, i.e. its reliability and safety, as well as on harmful exhaust gas emissions, fuel and oil consumption, etc. (Yamamoto, Madre, & Kitamura, 2004). Therefore, the objective of vehicle maintenance process is to decrease its environmental impact through superior quality of maintenance interventions. From the other side, as to limit the environmental impact of maintenance, vehicles must remain in correct technical condition (faultless operation) throughout the entire transport process realisation, after completing maintenance interventions. In order to keep the environmental impact under certain legally prescribed thresholds, vehicles are submitted to periodical technical inspections by third parties, specialised for such an activity. If the technical inspection results in a negative finding regarding vehicle condition, it is withdrawn from the transport process and remains "unready for operation" until maintenance accomplishes all necessary interventions. This is the interdependence of the "environment", transport and maintenance processes. Accordingly, in the paper by (Samaras & Kitsopanidis, 2001), the authors recommend a methodology to evaluate the efficiency of alternative short tests applied to inspection and maintenance (I/M) to monitor vehicle exhaust gas emissions.

According to (Johnson, 2002), controlled maintenance management system consists of organising, planning, supervision, coordination and control of the functions necessary to ensure that equipment perform its designed function within economic possibilities. The system ensures that the company will obtain the most efficient utilisation of labour, equipment and materials in achieving defined objective.

One of the objectives of fleet maintenance management is in providing vehicles from the most adequate CO groups in state "ready for operation" in required periods, according to OP within defined economic possibilities. This objective facilitates rational transport service, while accomplishing all planed transport tasks according to OP requirements, while at the same time enhances vehicle fleet energy efficiency (Vujanović, Momčilović, Papić, & Bojović, 2011). Besides the maintenance management objective of increasing company's profitability is the objective of limiting the consumption of non-renewable resources, such as fuel, lubricants, tyres, and materials.

The result of integrated fleet maintenance management is rational realisation of transport services with energy efficient vehicles, and by doing so accomplishing clients' requests and making profit. In order to improve fleet maintenance management it is indispensable to measure continually certain measure implementation effects through appropriate indicators. For that reason, based on an extensive set of references and authors' experience, in the subsequent text a set of suitable indicators of efficient fleet maintenance management was selected.

2.2. Fleet maintenance management indicators

The authors of the paper (Papić et al., 1999) have used simulation and the AHP method for determining the most favourable fleet maintenance strategy. As suitable indicator, among others, the authors have chosen the *Operation Plan (OP) realisation percentage* (hereafter referred as *T1*). The indicator *T1* represents the percentage of realised transport tasks in relation to the total number of planned transport tasks (in tonne-kilometres), according to the requested OP in the observed period. The value of this indicator influences company's income. Paper by (Milosavljević et al., 1996) addresses a model based on fuzzy sets theory of vehicle allocation to transport tasks, according to OP which is explained in detail. In the paper are presented two different versions of vehicle allocation to transport tasks, and as an indicator for these variants evaluation an indicator (*T1*) was used. Accordingly (Li, Mirchandani, & Borenstein, 2009) researched the problem of vehicle reallocation to the tasks in case of vehicle failure, one of the criteria being to maximise the realisation of transport tasks, i.e. maximisation of indicator *T1*. The paper by (Haghani & Shafahi, 2002) demonstrates several forms to solve the vehicle maintenance scheduling problem, where the adopted criterion was to minimise disruption in OP realisation, i.e. maximisation of the indicator *T1*.

As this paper addresses efficient maintenance management in order to increase fleet energy efficiency, in paper by (Vujanović, Mijailović, Momčilović, & Papić, 2010) has been indicated that significant increase in freight transport energy efficiency lies in better use of vehicle cargo capacity. In this sense, a suitable indicator affecting fleet energy efficiency within the transport process would be *Vehicle Payload Utilisation* (hereafter referred as *T2*), in other words cargo capacity utilisation. Indicator *T2* is the ratio of the carried consignment mass (or volume) and vehicle payload capacity (or available cargo compartment volume) in observed period. The authors (Vujanović et al., 2010) show how improving indicator *T2* leads to a reduction of specific fuel consumption per unit of realised transport volume – q_t (l/100 tonne-km), namely decrease the total amount of consumed fuel by the fleet for OP realisation, thus reducing transport costs and maintenance. Equally (Vujanović et al., 2011) stress the importance of improving indicator *T2* in order to increase energy efficiency by fleet maintenance management. In the paper (McKinnon, 1999) it is noted that measures improving the vehicle payload utilisation are amongst the most important for increasing fleet energy efficiency. Also (Kamakaté & Schipper, 2009) and (Ruzzenenti & Basosi, 2009) advocate high potential to increase energy efficiency to better vehicle cargo capacity utilisation.

As well paper (Papić et al., 1999) emphasises significant savings, compared to the current situation, in number of vehicles required for OP realisation by application of different strategies leading to considerable savings in energy and materials for approximately the same value of indicator *T1*. Savings shown in the paper represent a good basis for introducing another indicator – *Vehicle Fleet Utilisation Rate* (hereafter referred as *T3*). Indicator *T3* represents the ratio of number of vehicles necessary for OP realisation and total (inventory) number of vehicles in certain period. The difference will represent an additional number of "spare" vehicles, which could be used as replacement for those undergoing maintenance. According to (Haghani & Shafahi, 2002), efficient scheduling of vehicles to maintenance would require less replacement vehicles in order to succeed in OP realisation, thus improving indicator *T3*, altogether reducing transport and maintenance costs.

In the handbook (Mobley, Higgins, & Wikoff, 2008) it is noted that when analysing equipment reliability, an indicator of *Mean Time Between Failures* (MTBFs) can be used, hereafter referred as *M1*. *M1* is calculated from the ratio of vehicle working hours (or kilometres), and number of failures in the observed period. If you get to improve the indicator *M1*, you can expect higher vehicle reliability, which equally enhances vehicle safety. Also (Parida & Kumar, 2009) state that *M1* is one of the most important indicators for measuring maintenance productivity, while (Norat, 2008) considers the indicator *M1* as a key performance indicator (KPI) of the maintenance process.

Besides previously mentioned, the author (Norat, 2008) considers as another maintenance process' KPI – the *Mean Time to Repair* (MTTR). According to (Mobley et al., 2008), the indicator MTTR is a measure of system's maintainability. MTTR is calculated from the ratio of total labour working hours required to carry out repairs and interventions to the total number of failures in the reporting period (Parida & Kumar, 2009). However, for the fleet maintenance process, a special interest should be given to the indicator of *Mean Vehicle Downtime* (hereafter referred as *M2*), i.e. vehicle in the state "unready for operation". This indicator is obtained by the ratio of total hours when vehicle was unavailable for operation and number of failures in the observed period. Unlike indicator MTTR, when calculating indicator *M2* it is taken into account the required repair or maintenance intervention preparation time e.g. waiting for spare parts, free (available) workers, free dedicated workspace in the workshop and so on, as well as eventual time between (to or from) the maintenance workshop and transport company.

A useful tool in the maintenance management is a Maintenance Plan (MP) according to (Momčilović et al., 2007) and (Maróti & Kroon, 2005). MP is a document used by managers while making decisions on planned workspaces and timeframe to carry out necessary maintenance interventions on vehicles. To adequately prepare the MP, managers must: record maintenance requests, have knowledge of OP, be familiar with the capacity of their own workshops (vehicle workspaces, available workers, spare parts, equipment, materials, etc.), be acquainted with external specialised maintenance facilities on the market (location, specialisation, quality, etc.), monitor the adequate realisation of planned interventions in the MP. As appropriate indicator for measuring the MP realisation efficiency within the maintenance process appears *Realisation of MP* (hereafter referred as *M3*). According to (Arts, Knapp, & Mann, 1998) and (Dhillon, 2002), indicator *M3* is the ratio of number of work orders realised according to the MP and total number of planned work orders from the MP in analysed period. In his paper (Norat, 2008) considers indicator *M3* as another key performance indicators of the maintenance process.

Another suitable indicator of the maintenance process can be the *Planned Maintenance Percentage* (hereafter referred as *M4*). According to (Arts et al., 1998), indicator *M4* is the percentage of labour working hours on planned maintenance work orders from total labour working hours in a period. According to (Mobley et al., 2008), while the percentage of planned maintenance increases, it reduces the percentage of unplanned maintenance, which equally affects the maintenance costs reduction. Growing percentage of planned maintenance gives the greater opportunities for integration of transport and maintenance processes, in this manner increasing the fleet energy efficiency (Vujanović et al., 2011).

Regarding the environmental impact on the fleet maintenance management the indicator *Percentage of Fleet Roadworthiness* (hereafter referred as *E1*). Indicator *E1* represents the percentage of vehicles complying with minimum requirements regarding technical condition checked on technical inspection, i.e. vehicle roadworthiness test, in terms of vehicle safety and emissions, compared to the total number of vehicles controlled on technical inspection in certain period. In the paper (Bin, 2003) is shown the percentage of road vehicle manufacturers not meeting the legal requirements (thresholds) on emissions inspection. Those range about 4–10% of

Table 1
Fleet maintenance management indicators.

Interdependent groups	Indicators (factors)	Indicator definition
1. Transport process (T_P)	Operation Plan (OP) Realisation percentage *T1*	*T1* = (amount of realised tonne-kilometres/amount of planned tonne-kilometres, in OP) × 100
	Vehicle payload utilisation *T2*	*T2* = consignment mass (volume)/ cargo (compartment volume) capacity
	Vehicle fleet utilisation rate *T3*	*T3* = number of required vehicles for operation/total number of vehicles
2. Maintenance process (M_P)	Mean time between failures *M1*	*M1* = vehicle realised working hours (or kilometres)/number of failures
	Mean vehicle downtime *M2*	*M2* = vehicle total hours "unready for operation"/number of failures
	Maintenance Plan (MP) Realisation *M3*	*M3* = number of realised work orders from MP/total number of planned work orders in MP
	Planned maintenance percentage *M4*	*M4* = (labour working hours on planned maintenance work orders/total labour working hours) × 100
3. Environment (*E*)	Percentage of fleet roadworthiness *E1*	*E1* = (number of vehicles complying with minimum requirements/total number of vehicles controlled on technical inspections) × 100
	Percentage of vehicle roadworthiness in accidents *E2*	*E2* = (number of vehicles in accidents that complied with minimum safety requirements/ total number of vehicles in accidents) × 100

the number of tested vehicles. Meanwhile (Christensen & Elvik, 2007) have noted that number of vehicle technical malfunctions decrease when increasing the number of performed technical inspections in a given period. In addition, another indicator is also appropriate *Percentage of Vehicle Roadworthiness in Accidents* (hereafter referred as *E2*). Indicator *E2* is the percentage of vehicles that participated in traffic accident and complied with minimum requirements regarding critical vehicle safety systems (e.g. braking, steering, suspension, lighting system and so on) relative to the total number of vehicles that participated in accidents in the observed period. The paper (Randhawa, Miller, Bell, & Montagne, 1998) states that a technical malfunction or failure caused about 5% of the observed accidents of commercial vehicles. Besides, authors (Rechnitzer, Haworth, & Kowadlo, 2000) provide an overview of the results of studies showing that in 3% of analysed accidents vehicle condition had certain impact on traffic accidents, i.e. technical malfunction or failure were the principal cause of accident.

In the subsequent Table 1 are shown the fleet maintenance management indicators within transport, maintenance and environmental fields, further addressed in this paper.

3. Applied methodology

DEMATEL method was used in this paper as to determine the level of interdependences existing between selected indicators of maintenance management as well as to construct a network relationship map (NRM). Based on constructed NRM and on the calculated level of interdependences of indicators, the structure of the model has been developed. By an integrated implementation of DEMATEL and ANP methods significances are calculated, i.e. relative weight of observed indicators in the model related to the defined objective, which is to increase fleet energy efficiency by maintenance management.

In this regard, firstly DEMATEL method for calculating the level of interdependences of selected indicators will be explained. Total influence matrix that will be used in the ANP method is shown afterwards. Next ANP method will be explained and integration with DEMATEL for calculating the relative weight of chosen indicators. The survey to collect all the necessary data will be explained then in detail. Based on the methodology presented the relative weight of each of the observed indicators will be calculated.

3.1. DEMATEL method

DEMATEL (Decision-Making Trial and Evaluation Laboratory) is a comprehensive method for designing and analysing structural models of causal relationships between complex factors (Wu & Lee, 2007). Unlike the Analytical Hierarchy Process (AHP) method which considers factors that are independent of each other, DEMATEL method takes into account interdependent factors and determines the level of interdependence between them. The observed method is based on graph theory, allowing visual planning and problem solving so that the relevant factors can be divided into causal and consequential for a better understanding of mutual relations (Li & Tzeng, 2009). This scientific research method could improve understanding of the complex structure of the specific *problematique* and contribute to identification of relationships between factors, workable solutions by a hierarchical structure (Tzeng et al., 2007). The end product of the DEMATEL process is a visual representation – an individual map of the mind – by which the respondent (manager) organises his or her own action in the world (Lin, Chen, & Tzeng, 2009).

The procedure of calculating the level of interdependence of the considered factors with DEMATEL method can be represented by the following steps:

Step 1: Create experts perception matrixes $X^1, X^2, \ldots, X^H$. Assuming that there are H experts in the observed survey and n factors that are considered, each expert should determine the level of influence of factor i to the factor j. The comparative analysis of couple of factors i and j by the expert k is denoted by the x_{ij}^k, while: $i = 1, \ldots, n$; $j = 1, \ldots, n$; $k = 1, \ldots, H$. The value of each couple x_{ij}^k adopts an integer value with a following meaning: 0 – no influence; 1 – low influence; 2 – medium influence; 3 – high influence; 4 – very high influence. The answer of the expert k is represented by a matrix of rank $n \times n$, while each element k of the matrix in the expression $X^k = [x_{ij}^k]_{n\times n}$ denotes a non-negative number x_{ij}^k, where $k = 1, \ldots, H$. Accordingly, matrixes $X^1, X^2, \ldots, X^H$ represent answer matrixes of each of H experts. The diagonal elements of each expert answer matrix are all set to zero because the factor cannot affect itself.

Step 2: Calculate average perception matrix A. Based on determined answer matrixes $X^k = [x_{ij}^k]_{n\times n}$ from all of the H experts, it could be calculated the average answer matrix, $A = [a_{ij}]_{n\times n}$, which represents a medium value of opinions of all H respondents (experts) for each element of matrix A in a following way:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots, & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \vdots & a_{nn} \end{bmatrix} \tag{1}$$

where:

$$a_{ij} = \frac{1}{H}\sum_{k=1}^{H} x_{ij}^k \tag{2}$$

Matrix A shows the initial effects caused by a particular factor, but also the initial effects he receives from other factors.

Step 3: Calculate of the average normalised perception matrix D. The matrix D is calculated from the matrix A, as follows:

Let

$$S = \max\left(\max_{1\leqslant i\leqslant n}\sum_{j=1}^{n} a_{ij}; \max_{1\leqslant i\leqslant n}\sum_{i=1}^{n} a_{ij}\right) \tag{3}$$

Then

$$D = A/s \tag{4}$$

As the sum of each row i of the matrix A represents total direct effects that the factor i given to other factors, the expression $\max_{1\leqslant i\leqslant n}\sum_{j=1}^{n} a_{ij}$, represents the most important total direct effects from the specified factor given to other factors. Similarly, as the sum of each column j of the matrix A represents total direct effects that the factor j received from other factors, the expression $\max_{1\leqslant j\leqslant n}\sum_{i=1}^{n} a_{ij}$, represents the most important total direct effects that certain factor has received from other factors. The value s (3) takes into account the major value of above mentioned two expressions. Matrix D is obtained when each element a_{ij} of matrix A is divided by expression s. Each element d_{ij} of the matrix D takes values between 0 and less than 1.

Step 4: Calculate the total relation matrix T. Matrix T is an $n \times n$ matrix and it is calculated as follows:

$$T = D(I - D)^{-1} \tag{5}$$

where I is an $n \times n$ identity matrix.

Let the sums of rows and columns of the matrix T are separately represented by a vector R and vector $C_{n\times 1}$, explicitly:

$$T = [t_{ij}]_{n\times n}, i,j = 1, 2, \ldots, n \tag{6}$$

$$R = [r_{ij}]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \tag{7}$$

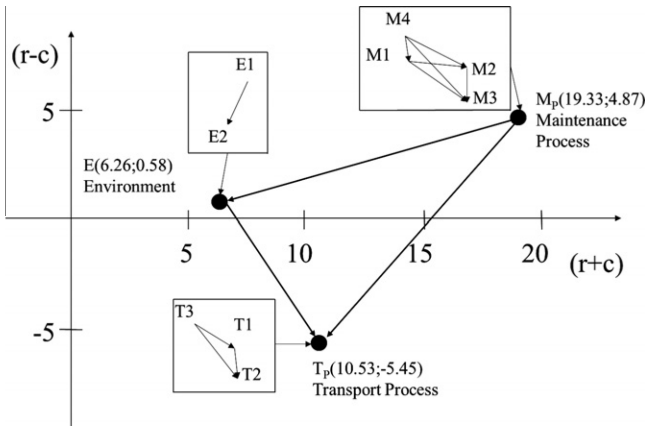

Fig. 2. Influence relationship map.

$$C = [c_j]'_{n\times 1} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} \tag{8}$$

where symbol ′ stands for a transposed matrix. Let r_i be the sum of the ith row in matrix T. Then r_i represents total direct and indirect effects that the factor i has given to other factors. Let c_j represents the sum of jth column in matrix T. Then c_j shows the total effects, both direct and indirect received by a factor j given by other factors. In the case when $i = j$, then the term $(r_i + c_i)$ represents a degree of importance of the factor, and the term $(r_i - c_i)$ represents the net effect that the factor contributes to the system in relation to other factors. If the term $(r_i - c_i)$ is positive, the factor i is net causer, and if the previous expression is negative factor i is a net receiver (Tzeng et al., 2007).

Step 5: Set a threshold value p and obtain Network Relationship Map (NRM). On the basis of expert opinion is determined the threshold value p, which filters out negligible or small effects in the matrix T. The value of elements of matrix T, which are smaller or equal than the adopted value p, is set to zero, while other elements of the matrix T, which are larger than the adopted value p, retain their present value. Should the adopted value p be too low, the structure of the system will remain complex and difficult to understand, while if threshold value p is too high, the structure would be oversimplified and important influences ignored. Therefore, based on the adopted threshold value p, we can filter minor effects in matrix T, based on which it will be obtained NRM, as shown on Fig. 3, which facilitates understanding of the relationships in the considered system.

3.2. Integration of DEMATEL and ANP methods

ANP method was developed to avoid the hierarchical constraints that exist in the AHP method (Saaty, 1996). In this paper ANP, combined with DEMATEL will be used to calculate the relative weight of factors (indicators) that are used in the fleet maintenance management.

When using only conventional ANP to calculate the relative weight of factors, the levels of interdependences of factors are treated as reciprocal values. However, according to DEMATEL method, the levels of interdependences of factors do not have reciprocal value, which is closer to the real system (Yang & Tzeng, 2011). Therefore, to calculate relative weight of factors it will be used the total relation matrix (matrix T) within a DEMATEL, in order to avoid the shortcomings mentioned in the ANP.

According to (Lee et al., 2011), DEMATEL method is not going to be used only to calculate the level of impacts among different groups of factors, but the normalised total-influence matrix will be incorporated into un-weighted supermatrix W in the ANP to calculate the level of interdependences of different factors.

In this regard, the proposed methodology of integration of DEMATEL and ANP method consists of four steps. The first step is based on the NRM (Fig. 3) and the total-influence matrix T to construct the network hierarchical structure of the observed system to the defined objectives. The second step is to calculate un-weighted supermatrix W. The sums of influences of each factor in relation to the factors of each group in the factor matrix of the total-influence in DEMATEL, is shown in (9).

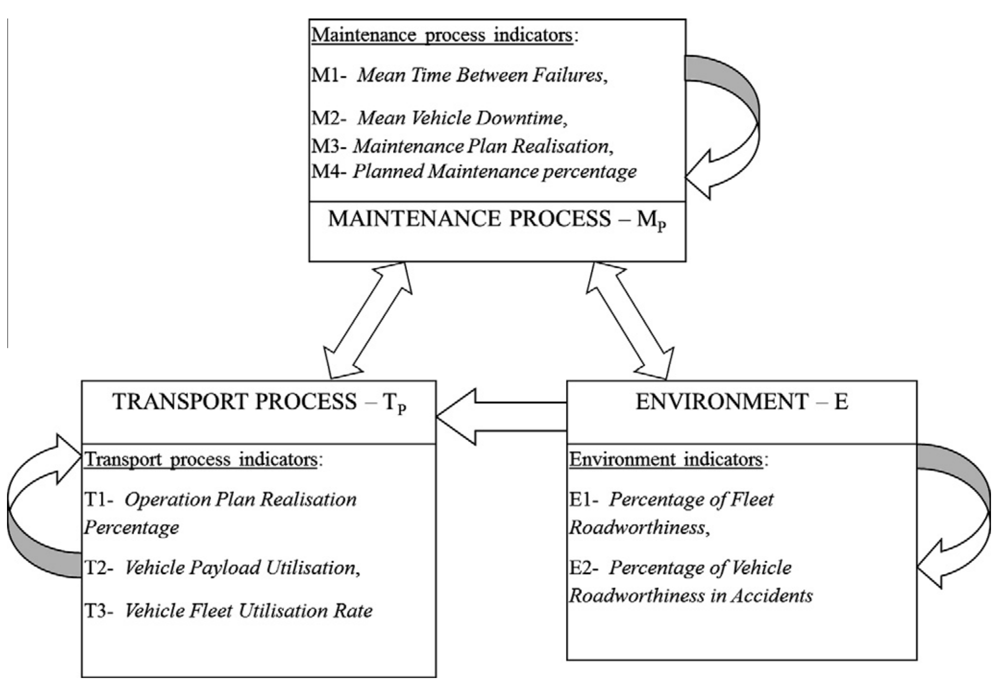

Fig. 3. Network relation map (NRM).

$$T_c = \begin{array}{cc} & \begin{array}{cccc} D_1 & D_2 & \cdots & D_n \\ c_{11}\cdots c_{1m_1} & c_{21}\cdots c_{2m_2} & \cdots & c_{n1}\cdots c_{nm_n}\end{array} \\ \begin{array}{cc} D_1 & \begin{array}{c} c_{11}\\ c_{12}\\ \vdots \\ c_{1m_1}\end{array} \\ D_2 & \begin{array}{c}c_{21}\\c_{22}\\ \vdots\\ c_{2m_2}\end{array}\\ \vdots & \vdots \\ D_n & \begin{array}{c}c_{n1}\\c_{n2}\\ \vdots\\ c_{nm_n}\end{array}\end{array} & \begin{bmatrix} T_c^{11} & T_c^{12} & \cdots & T_c^{1n} \\ T_c^{21} & T_c^{22} & \cdots & T_c^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ T_c^{n1} & T_c^{n2} & \cdots & T_c^{nn}\end{bmatrix}\end{array} \tag{9}$$

While matrix T_c^{11} is matrix of factors from the group D1 and influences in respect of the factors from the group D_1, shown in (10), and T_c^{12} matrix of factors from group D_1 and influences in respect of the factors from the group D_2 and so on.

$$T_c^{11} = \begin{bmatrix} t^{11}_{c11} & \cdots & t^{11}_{c1j} & \cdots & t^{11}_{c1m_1} \\ \vdots & & \vdots & & \vdots \\ t^{11}_{ci1} & \cdots & t^{11}_{cij} & \cdots & t^{11}_{c1m_1} \\ \vdots & & \vdots & & \vdots \\ t^{11}_{cm11} & \cdots & t^{11}_{cm1j} & \cdots & t^{11}_{cm1m1} \end{bmatrix} \tag{10}$$

Factor total-influence matrix T_c after normalisation becomes matrix T_c^{α}, as shown in (11).

$$T_c^{\alpha} = \begin{array}{cc} & \begin{array}{cccc} D_1 & D_2 & \cdots & D_n \\ c_{11}\cdots c_{1m_1} & c_{21}\cdots c_{2m_2} & \cdots & c_{n1}\cdots c_{nm_n}\end{array} \\ \begin{array}{cc} D_1 & \begin{array}{c} c_{11}\\ c_{12}\\ \vdots \\ c_{1m_1}\end{array} \\ D_2 & \begin{array}{c}c_{21}\\c_{22}\\ \vdots\\ c_{2m_2}\end{array}\\ \vdots & \vdots \\ D_n & \begin{array}{c}c_{n1}\\c_{n2}\\ \vdots\\ c_{nm_n}\end{array}\end{array} & \begin{bmatrix} T_c^{\alpha 11} & T_c^{\alpha 12} & \cdots & T_c^{\alpha 1n} \\ T_c^{\alpha 21} & T_c^{\alpha 22} & \cdots & T_c^{\alpha 2n} \\ \vdots & \vdots & \ddots & \vdots \\ T_c^{\alpha n1} & T_c^{\alpha n2} & \cdots & T_c^{\alpha nn}\end{bmatrix}\end{array} \tag{11}$$

where $T_c^{\alpha_{11}}$ is a normalised matrix of sums of factor influences $c_{11},\ldots,c_{1m1}$ related to factors from group D1 and calculated upon (12).

$$T_c^{\alpha_{11}} = \begin{bmatrix} t^{11}_{c11}/d^{11}_a & \ldots & t^{11}_{c1j}/d^{11}_1 & \ldots & t^{11}_{c1m_1}/d^{11}_a \\ \vdots & & \vdots & & \vdots \\ t^{11}_{ci1}/d^{11}_i & \ldots & t^{11}_{cij}/d^{11}_i & \ldots & t^{11}_{cim_i}/d^{11}_i \\ \vdots & & \vdots & & \vdots \\ t^{11}_{cm_1 1}/d^{11}_{m1} & \ldots & t^{11}_{cm_1 j}/d^{11}_i & \ldots & t^{11}_{cm_1 m_1}/d^{11}_{m_1} \end{bmatrix} = \begin{bmatrix} t^{\alpha 11}_{c11} & \ldots & t^{\alpha 11}_{c1j} & \ldots & t^{\alpha 11}_{c1m_1} \\ \vdots & & \vdots & & \vdots \\ t^{\alpha 11}_{ci1} & \ldots & t^{\alpha 11}_{cij} & \ldots & t^{\alpha 11}_{cim_i} \\ \vdots & & \vdots & & \vdots \\ t^{\alpha 11}_{cm_1 1} & \ldots & t^{\alpha 11}_{cm_1 j} & \ldots & t^{\alpha 11}_{cm_1 m_1} \end{bmatrix} \tag{12}$$

While sums of influences of factors $c_{11},\ldots,c_{1m1}$ are related to the group D_1 as follows:

$$d_i^{11} = \sum_{j=1}^{m_1} t^{11}_{cij};\ \text{for } i = 1, 2, \cdots m_1 \tag{13}$$

Elements t^{11}_{cij} represent values of factor influences $c_{11},\ldots,c_{1m1}$ in relation to factors from the group D_1, and elements $t^{\alpha_{11}}_{c11}$ their normalised values.

Calculation procedure for $T_c^{\alpha_{nn}}$, as well as all other normalised matrixes within matrix T_c^{α} is identical. Normalised values of factor influences in relation to the factors from each group are incorporated into the calculation of un-weighted matrix W, being used within the ANP method, according to (14).

$$W = \begin{array}{cc} & \begin{array}{cccc} D_1 & D_2 & \cdots & D_n \\ c_{11}\cdots c_{1m_1} & c_{21}\cdots c_{2m_2} & \cdots & c_{n1}\cdots c_{nm_n}\end{array} \\ \begin{array}{cc} D_1 & \begin{array}{c} c_{11}\\ c_{12}\\ \vdots \\ c_{1m_1}\end{array} \\ D_2 & \begin{array}{c}c_{21}\\c_{22}\\ \vdots\\ c_{2m_2}\end{array}\\ \vdots & \vdots \\ D_n & \begin{array}{c}c_{n1}\\c_{n2}\\ \vdots\\ c_{nm_n}\end{array}\end{array} & \begin{bmatrix} W^{11} & W^{12} & \cdots & W^{1n} \\ W^{21} & W^{22} & \cdots & W^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ W^{n1} & W^{n1} & \cdots & W^{nn}\end{bmatrix}\end{array} \tag{14}$$

where the matrix W^{11} represents the values of factor influences from the group D_1 in relation to factors from the D_1 group, according to (15). Vector of factor influences with the value zero indicates the independent effect of this factor with respect to that group. In the identical way the matrix W^{nn} is obtained and other matrices within the supermatrix W.

$$W^{11} = \begin{array}{cc} & \begin{array}{ccccc} c_{11} & \cdots & c_{1j} & \cdots & c_{1m_1}\end{array} \\ \begin{array}{c} c_{11} \\ \vdots \\ c_{1i} \\ \vdots \\ c_{1m_1}\end{array} & \begin{bmatrix} t^{\alpha 11}_{c11} & \cdots & t^{\alpha 11}_{cj1} & \cdots & t^{\alpha 11}_{cm_1 1} \\ \vdots & & \vdots & & \vdots \\ t^{\alpha 11}_{c1i} & \cdots & t^{\alpha 11}_{cji} & \cdots & t^{\alpha 11}_{cm_1 i} \\ \vdots & & \vdots & & \vdots \\ t^{\alpha 11}_{c1m_1} & \cdots & t^{\alpha 11}_{cjm_1} & \cdots & t^{\alpha 11}_{cm_1 m_1} \end{bmatrix}\end{array} \tag{15}$$

In the third step, it is calculated the weighted supermatrix W_w as to normalise sums of influences of each group of factors in relation to all groups from the matrix of total group influences (16).

$$T_D = \begin{bmatrix} t_D^{11} & \ldots & t_D^{1j} & \ldots & t_D^{1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{i1} & \ldots & t_D^{ij} & \ldots & t_D^{in} \\ \vdots & & \vdots & & \vdots \\ t_D^{n1} & \ldots & t_D^{nj} & \ldots & t_D^{nn} \end{bmatrix} \tag{16}$$

While t_D^{11} determines the sum of all influences from the matrix T_c^{11}, and t_D^{nn} determines the sum of all influences from the matrix T_c^{nn}. The normalisation procedure is calculated upon (17).

$$T_D^{\alpha} = \begin{bmatrix} t_D^{11}/d_1 & \dots & t_D^{1j}/d_1 & \dots & t_D^{1n}/d_1 \\ \vdots & & \vdots & & \vdots \\ t_D^{i1}/d_i & \dots & t_D^{ij}/d_i & \dots & t_D^{in}/d_i \\ \vdots & & \vdots & & \vdots \\ t_D^{n1}/d_n & \dots & t_D^{nj}/d_n & \dots & t_D^{nn}/d_n \end{bmatrix} = \begin{bmatrix} t_D^{\alpha 11} & \dots & t_D^{\alpha 1j} & \dots & t_D^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha i1} & \dots & t_D^{\alpha ij} & \dots & t_D^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ t_d^{\alpha n1} & \dots & t_D^{\alpha nj} & \dots & t_D^{\alpha nn} \end{bmatrix} \quad (17)$$

where:

$$d_i = \sum_{j=1}^{n} t_d^{ij}; \text{ for } i = 1, \dots, n \quad (18)$$

Calculation of weighted supermatrix W_w is obtained by integrating the un-weighted matrix W into the normalised matrix of group factors influences T_c^{α}, in accordance with (19).

$$W_w = \begin{bmatrix} t_D^{\alpha_{11}} xW^{11} & t_D^{\alpha_{21}} xW^{12} & \dots & \dots & t_D^{\alpha_{n1}} xW^{1n} \\ t_D^{\alpha_{12}} xW^{21} & t_D^{\alpha_{22}} xW^{22} & & \vdots & \vdots \\ \vdots & \dots & t_D^{\alpha_{ij}} xW^{ij} & \dots & t_D^{ni} xW^{in} \\ t_D^{\alpha_{1n}} xW^{n1} & t_D^{\alpha_{2n}} xW^{n2} & \dots & \dots & t_D^{\alpha_{nn}} xW^{nn} \end{bmatrix} \quad (19)$$

In the fourth step a limited supermatrix is calculated by several multiplying of weighted supermatrix W_W until the vector values in a limited supermatrix become stable, in other words:

$$\lim_{z \to \infty} = W_w^z \quad (20)$$

while the number z tends to infinity. Vectors of the limited supermatrix represent relative weights of each factor in relation to the defined objective.

3.3. Realised data collection

On the basis of selected indicators of fleet maintenance management, a survey was carried out as to collect experts' perceptions on interdependent influences of the observed indicators of transport, maintenance processes and environment. For this purpose a group of professors from the Faculty of Transport and Traffic engineering in Belgrade were selected, along with other experts from the field of vehicle fleets operation and maintenance with long-term working experience. The survey was conducted during the period from January to May 2011. Experts' perceptions were obtained by a survey. Based on experts' survey and combined implementation of DEMATEL and ANP methods, a model was obtained with relative weights of maintenance management indicators with the objective to increase the vehicle fleet energy efficiency.

3.4. Results

Based on the conducted surveys of experts and use of DEMATEL method, according to (5) the total-influences matrix T was calculated (Table 2). Besides threshold values were established by expert assessment ($p = 0.2$). Only the levels of interdependences of indicators larger than the threshold value, established by experts, were taken into account in continuation, while other interdependences were neglected i.e. considered independent, and their value set to zero. Based on Table 2, it is obvious that there is an independent influence of the transport process in relation to indicators of the environment and to the indicators $M1$ and $M4$ of the maintenance process.

Pursuant the calculated total given and received indicators effects, according to (7) and (8), in Table 3 can be seen that the most important indicator is *Realisation of MP* ($M3$) with the highest value of $(r + c)$, followed by the indicator *Average Vehicle Downtime* ($M2$) and the *Average Time Between Failures* ($M1$), while the least important indicator is *Percentage of Vehicle Roadworthiness in Accidents* ($E2$). The indicator influencing the most the change in other indicators' values is *Planned Maintenance Percentage* ($M4$), with the highest value of $(r - c)$, followed by the indicator of *Mean Time Between Failures* ($M1$). Indicator, which is under the major influence of all other indicators is the *Vehicle Payload Utilisation* ($T2$), with the lowest value of $(r - c)$, followed by *OP Realisation Percentage* ($T1$).

When from the total-influence matrix T we sum up all the indicators' effects related to the group, or field, we obtain the matrix of total group influences T_D (Table 4). The Table 4 shows that the most important influence have the maintenance process indicators in relation to the transport process indicators. Due to the selected threshold value ($p = 0.2$) set by experts, transport process indicators are considered insignificant compared to environmental indicators influences, and therefore neglected. Table 5 shows that overall most important influences come from the maintenance process indicators. The latter for the most part "give" their influence to other indicators, since they have the highest value $(r - c)$. Meanwhile transport process indicators, with the lowest value $(r - c)$ are therefore largely subject to impacts from other indicators, i.e. largely "receiving" the effects and influences from other indicators.

According to the results in Tables 2–5, the following Fig. 2 displays the map of interdependence between the observed groups (fields), as well as the influences among the indicators within the group. Map of interdependences allows better understanding the

Table 2
Matrix of total influence of indicators T.

Indicators	$T1$	$T2$	$T3$	$M1$	$M2$	$M3$	$M4$	$E1$	$E2$
$T1$	0.00	0.28	0.24	0.00	0.00	0.28	0.00	0.00	0.00
$T2$	0.27	0.00	0.00	0.00	0.23	0.26	0.00	0.00	0.00
$T3$	0.25	0.28	0.00	0.00	0.21	0.24	0.00	0.00	0.00
$M1$	0.43	0.44	0.36	0.21	0.34	0.41	0.25	0.30	0.26
$M2$	0.43	0.46	0.40	0.27	0.24	0.45	0.23	0.25	0.22
$M3$	0.47	0.48	0.40	0.24	0.34	0.30	0.24	0.29	0.25
$M4$	0.46	0.46	0.36	0.35	0.36	0.44	0.00	0.39	0.35
$E1$	0.34	0.36	0.28	0.28	0.29	0.29	0.00	0.00	0.30
$E2$	0.27	0.30	0.00	0.00	0.23	0.26	0.00	0.24	0.00

Table 3
Total sum of effects given and received by indicators.

Indicators	$r + c$	$r - c$
$T1$	3.70	−2.11
$T2$	3.82	−2.31
$T3$	3.01	0.99
$M1$	4.35	1.64
$M2$	5.18	0.73
$M3$	5.91	0.08
$M4$	3.88	2.43
$E1$	3.59	0.65
$E2$	2.66	−0.07

Table 4
Matrix of total group influences $-T_D$.

Groups of indicators	Transport process (T_P)	Maintenance process (M_P)	Environment (E)
Transport process (T_P)	1.32	1.22	0.00
Maintenance process (M_P)	5.13	4.67	2.30
Environment (E)	1.54	1.34	0.54

Table 5
Total group delivered and received effects.

Groups of indicators	$r + c$	$r - c$
Transport process (T_P)	10.53	−5.45
Maintenance process (M_P)	19.33	4.87
Environment (E)	6.26	0.58

relationship between indicators and groups within the overall structure of the model.

Pursuant calculation of the total-influence matrix – T within DEMATEL and the adopted threshold value ($p = 0.2$) by experts, on Fig. 3 below shows the network relations map (NRM), in order to facilitate understanding of the model structure used in the ANP method for calculation of relative weights.

By incorporating total-influence matrix T in un-weighted supermatrix W and by using the total group influence matrix T_D for calculation of weighted supermatrix W_W, it has been obtained a limited supermatrix W_w^z from the ANP, whose vectors represent the relative weights of indicators in the model (Table 6). The Table 6 below shows that the most important indicators for improving energy efficiency in the fleet maintenance management are: *Maintenance Plan Realisation* (*M3*), *Operational Plan Realisation Percentage* (*T1*), *Vehicle Payload Utilisation* (*T2*). Indicator *Maintenance Plan Realisation* (*M3*) with the highest value of relative weight of 0.233 belongs to the maintenance process group. However, subsequent two indicators by significance are the *Operational Plan Realisation Percentage* (*T1*) and *Vehicle Payload Utilisation* (*T2*) both belonging to the transport process group. The indicators with the lowest level indicators were *Planned Maintenance Percentage* (*M4*), with the relative weight of 0.032 and the *Mean Time Between Failures* (*M1*), with the relative weight of 0.044, belonging to the maintenance process group, as well as *Percentage of Vehicle Roadworthiness in Accidents* (*E2*), with relative weight of 0.046, which belongs to the environment group.

When you observe the relative weights of the groups, the most important for the fleet maintenance management is the transport process, and the least important group is the environment.

Below are shown the results of the model implementation with the relative weights of indicators within several companies with vehicle fleets with the objective of managers' evaluation in terms of maintenance management in these companies.

4. Implementation of the model within transport companies

The Model shown with relative weights of selected indicators has been implemented in several companies with vehicle fleets in the Republic of Serbia. To this end, managers of the following companies were involved in the survey: Public Utility Company (PUC) "Sanitation" Belgrade, Urban Public transport GSP "Beograd" PUC "Belgrade water supply and sewage" and a private company for sales and distribution of automotive spare parts "Delmax" Ltd.

Table 6
Model with relative indicator weights.

Indicators	Relative weights	Rank of importance	Relative weights of fields
Operation Plan (OP) Realisation percentage *T1*	0.195	2	$T_P = 0.472$
Vehicle payload utilisation *T2*	0.169	3	
Vehicle fleet utilisation rate *T3*	0.108	5	
Mean time between failures *M1*	0.044	8	$M_P = 0.431$
Mean vehicle downtime *M2*	0.122	4	
Maintenance Plan (MP) Realisation *M3*	0.233	1	
Planned maintenance percentage *M4*	0.032	9	
Percentage of fleet roadworthiness *E1*	0.051	6	$E = 0.097$
Percentage of vehicle roadworthiness in accidents *E2*	0.046	7	

In the period from June to August 2011 the surveys in form of interviews were conducted with 19 managers in the selected companies in terms of perception of nine indicators. Managers were tasked to evaluate the indicators from 1 to 5 in relation to two aspects.

At the first evaluation, management determined to what extent was each observed indicator appropriate for measurement of effects of the maintenance management, bearing in mind that the lowest score 1 indicates minor advantage (or a higher disadvantage), meanwhile score 5 designated major advantages.

At the second evaluation, managers and experts from the Faculty of Transport and Traffic engineering have evaluated selected indicators according to their actual values in the observed enterprises (again the score 1 was for the least efficient parameter, and 5 for the most efficient indicators – highly valued in companies/vehicle fleets).

In both above mentioned evaluations an average score was calculated for each indicator and by the implementation of the proposed model with relative weights were obtained realised indicators values, which when summed give an overall score S' and S'' in the observed companies.

The total score in the evaluation of indicators benefits show some degree of awareness among managers in the companies about the importance of maintenance management for increasing the fleet energy efficiency (S'). The total score in the evaluation of indicators in relation to the realised value within the company shows the effectiveness and efficiency of managers in managing their fleet maintenance management (S''). The results of this survey are shown in detail below.

4.1. Results of the accomplished evaluation

Pursuant the results shown in Table 7, "Delmax" Ltd. company executives have achieved the best overall score of $S' = 4.129$. Executives in this company have a highly developed perception of the importance of fleet maintenance management on profit. In this sense, managers in this company have easily recognised the potentials to achieve savings and increase profits solely in this field. Compared to managers from other companies, those from this company have given the best score to the indicator of *Maintenance Plan Realisation* (*M3*), which has the highest relative weight in the model. With better realisation of the maintenance plan the availability of the most appropriate vehicles in a state "ready for operation" in the required time periods as required by OP. It will affect the successful realisation of the OP, as well as better *Vehicle Payload Utilisation*, thereby increasing fleet energy efficiency, and thus the profit of the companies. Executives occupying the second place with an overall score 4.092 were from the Urban Public transport – GSP "Beograd". Managers from the company PUC "Belgrade water supply and sewage" have achieved the lowest overall score with 3.120.

In terms of overall score by S'' dealing with effectiveness and efficiency of maintenance management, the company "Delmax" managers once again have achieved the best S'' score with 3.968 (Table 8). This company has achieved higher actual values of those indicators, which are significant in the model, compared to other companies. Thus, for example "Delmax" achieved the highest value of the indicator *Maintenance Plan Realisation* (*M3*), *Operational Plan Realisation Percentage* (*T1*) and *Vehicle Payload Utilisation* (*T2*). Efficient maintenance management has provided more vehicles in the state "ready for operation" in the required time periods, which affects better realisation of the Operational Plan, as well as achieving

Table 7
Results of indicators' evaluation regarding their adaptability for measuring the maintenance management effects in observed companies.

Relative weights of indicators	PUC "Sanitation"		GSP "Beograd"		PUC "Belgrade water supply and sewage"		"Delmax" Ltd.	
	Average score	Realised value	Average score	Realised value	Average score	Realised value	Average score	Realised value
T1 – 0.195	3.000	0.585	4.800	0.936	2.714	0.529	4.000	0.780
T2 – 0.169	4.000	0.676	2.200	0.372	2.429	0.410	3.667	0.620
T3 – 0.108	5.000	0.540	4.400	0.475	3.714	0.401	3.000	0.324
M1 – 0.044	3.000	0.132	4.000	0.176	3.286	0.145	3.333	0.147
M2 – 0.122	4.000	0.488	4.000	0.488	3.429	0.418	4.667	0.569
M3 – 0.233	3.750	0.874	4.600	1.072	3.143	0.732	5.000	1.165
M4 – 0.032	3.250	0.104	4.200	0.134	3.571	0.114	3.667	0.117
E1 – 0.051	4.500	0.230	5.000	0.255	4.286	0.219	4.667	0.238
E2 – 0.046	3.250	0.150	4.000	0.184	3.286	0.151	3.667	0.169
Total score *S'*		3.778		4.092		3.120		4.129

Table 8
Results of indicators' evaluation in view of realised values in observed companies.

Relative weights of indicators	PUC "Sanitation"		GSP "Beograd"		PUC "Belgrade water supply and sewage"		"Delmax" Ltd.	
	Average score	Realised value	Average score	Realised value	Average score	Realised value	Average score	Realised value
T1 – 0.195	1.200	0.234	4.000	0.780	2.625	0.512	5.000	0.975
T2 – 0.169	2.400	0.406	1.167	0.197	2.625	0.444	3.667	0.620
T3 – 0.108	3.400	0.367	3.833	0.414	3.375	0.365	4.667	0.504
M1 – 0.044	1.600	0.070	3.667	0.161	3.125	0.138	3.667	0.161
M2 – 0.122	1.400	0.171	3.500	0.427	3.125	0.381	3.000	0.366
M3 – 0.233	3.000	0.699	3.167	0.738	3.250	0.757	3.333	0.777
M4 – 0.032	2.400	0.077	4.000	0.128	2.750	0.088	3.000	0.096
E1 – 0.051	4.000	0.204	4.500	0.230	3.375	0.172	5.000	0.255
E2 – 0.046	1.600	0.074	3.500	0.161	3.500	0.161	4.667	0.215
Total score *S″*		2.301		3.236		3.017		3.968

greater profit. In addition, the efficient maintenance management has facilitated greatly the allocation to transport tasks of the most appropriate vehicle, which increased vehicle payload utilisation, thereby increasing their energy efficiency and indirectly improved profitability. Managers from GSP "Beograd" in this case were ranked second with 3.236. Once again, managers of the Public Utility Company "Sanitation" had the lowest overall score *S″* regarding the effectiveness and efficiency of the maintenance management with as low as 2.301.

In all four companies a considerably better overall evaluation of managers was regarding their perception of the importance of maintenance management (*S'*) compared to the overall score for the efficiency of their maintenance management (*S″*). This is especially true in the company PUC "Sanitation", where the total score of *S'* was 3.778, while the overall score of *S″* was just 2.301. Therefore, managers clearly recognise the importance of the fleet maintenance management but in matter of implementation they are lacking of will or realistic objectives in their own companies.

5. Conclusions

This paper analyses the impact of interdependent indicators used to measure the implementation effects of specific measures within the maintenance management in order to increase the vehicle fleet energy efficiency. Since an efficient fleet maintenance management needs to be observed altogether with the core (transport) process and its environment, it is essential to evaluate all these indicators in these specific fields. Upon literature review and our expert deliberation we have selected nine provisional indicators for evaluation. A combination of DEMATEL and ANP methods was used for determining the level of interdependence of indicators and to calculate their relative weights. A model was obtained with the relative weights of maintenance management indicators with the primary objective to increase fleet energy efficiency.

Some conclusions drawn from the developed model could be that the indicators are interdependent in three observed groups/fields, with varied levels of interdependence and no apparent trade-off. The indicator of *Maintenance Plan Realisation* (*M3*) has an utmost importance for the efficient fleet maintenance management. If all maintenance work orders were realised at the planned timeframe according to the maintenance plan (MP), it will almost always facilitate the most appropriate vehicle to the transport task during the required time periods as required by the Operation Plan (OP), which will reduce transport and maintenance costs. Improving the value of this indicator is largely affected by the improvement in value of other interdependent indicators. The second in rank of significance for the maintenance management is the *Operational Plan Realisation Percentage* (*T1*) while the third in ranking is for the *Vehicle Payload Utilisation* (*T2*) indicator. Other significant indicators are *Mean Vehicle Downtime* (*M2*), *Vehicle Fleet Utilisation Rate* (*T3*), *Percentage of Fleet Roadworthiness* (*E1*), *Percentage of Vehicle Roadworthiness in Accidents* (*E2*), *Mean Time Between Failures* (*M1*), and *Planned Maintenance Percentage* (*M4*).

The proposed model with the relative weights of indicators has been implemented for the evaluation of managers in several companies with road vehicle fleets in the Republic of Serbia. Executives at "Delmax" Ltd. have achieved the best overall score in terms of developed awareness of the importance of maintenance management to increase vehicle fleet energy efficiency (*S'*), as well as the best evaluation of the maintenance management efficiency (*S″*) compared to managers in other companies. Managers have achieved higher scores regarding the importance of maintenance management to attain an increase in fleet energy efficiency (*S'*) than the scores in terms of actual efficient maintenance management in their companies (*S″*). Based on overall evaluation of managers in terms of efficient maintenance management, it is concluded that in the Public Utility Companies, as PUC "Sanitation," GSP "Belgrade" PUC "Belgrade water supply and sewerage" there is a significant potential to improve a value of indicators with more important relative weights in the developed model, which will help them manage their maintenance to become more effective and efficient.

Acknowledgements

The research in this paper has been realised within the project "Development of the Model for Managing the Vehicle Technical Condition in Order to Increase its Energy Efficiency and Reduce Exhaust Emissions" supported by the Ministry of Science and Technological Development of the Republic of Serbia.

References

Arts, R., Knapp, G. M., & Mann, L. J. (1998). Some aspects of measuring maintenance performance in the process industry. *Journal of Quality in Maintenance Engineering, 4*(1), 6–11. http://dx.doi.org/10.1108/13552519810201520.

Ashayeri, J., Teelen, A., & Selen, W. (1996). A production and maintenance planning model for the process industry. *International Journal of Production Research, 34*(12), 3311–3326.

Bin, O. (2003). A logit analysis of vehicle emissions using inspection and maintenance testing data. *Transportation Research Part D: Transport and Environment, 8*(3), 215–227. http://dx.doi.org/10.1016/S1361-920903)00004-X.

Brandolese, M., Franci, M., & Pozzetti, A. (1996). Production and maintenance integrated planning. *International Journal of Production Research, 34*(7), 2059–2075.

Christensen, P., & Elvik, R. (2007). Effects on accidents of periodic motor vehicle inspection on Norway. *Accident Analysis & Prevention, 39*(1), 47–52. http://dx.doi.org/10.1016/j.aap.2006.06.003.

Chung, S.-H., Lee, A. H., & Pearn, W. L. (2005). Analytic Network Process (ANP) approach for product mix planning in semiconductor fabricator. *International Journal of Production Economics, 96*(1), 15–36. http://dx.doi.org/10.1016/j.ijpe.2004.02.006.

Coulter, K., & Sarkis, J. (2005). Development of a media selection model using the analytic network process. *International Journal of Advertising, 24*(2), 193–215.

Dhillon, B. S. (2002). *Engineering Maintenance: A modern approach*. Boca Raton, Florida, USA: CRC Press.

Fontela, E., & Gabus, A. (1974). DEMATEL, innovative methods. Report no. 2 structural analysis of the world problematique. Geneva, Switzerland: Battelle Geneva Research Institute.

Fontela, E., & Gabus, A. (1976). The DEMATEL observer. Geneva, Switzerland: Battelle Institute. Geneva Research Center.

Haghani, A., & Shafahi, Y. (2002). Bus maintenance systems and maintenance scheduling: Model formulations and solutions. *Transportation Research Part A: Policy and Practice, 36*(5), 453–482. http://dx.doi.org/10.1016/S0965-856401)00014-3.

Johnson, P. D. (2002). *Principles of controlled maintenance management*. Lilburn, Georgia, USA: The Fairmont Press Inc.

Kamakaté, F., & Schipper, L. (2009). Trends in truck freight energy use and carbon emissions in selected OECD countries from 1973 to 2005. *Energy Policy, 37*(10), 3743–3751. http://dx.doi.org/10.1016/j.enpol.2009.07.029.

Lee, W.-S., Huang, A. Y., Chang, Y.-Y., & Cheng, C.-M. (2011). Analysis of decision making factors for equity investment by DEMATEL and Analytic Network Process. *Expert Systems with Applications, 38*(7), 8375–8383. http://dx.doi.org/10.1016/j.eswa.2011.01.027.

Leung, L. C., Lam, K. C., & Cao, D. (2006). Implementing the balanced scorecard using the analytic hierarchy process & the analytic network process. *Journal of the Operational Research Society, 57*(6), 682–691. <http://www.jstor.org/stable/4102352> Retrieved.

Li, J.-Q., Mirchandani, P. B., & Borenstein, D. (2009). Real-time vehicle rerouting problems with time windows. *European Journal of Operational Research, 194*(3), 711–727. http://dx.doi.org/10.1016/j.ejor.2007.12.037.

Li, C.-W., & Tzeng, G.-H. (2009). Identification of a threshold value for the DEMATEL method using the maximum mean de-entropy algorithm to find critical services provided by a semiconductor intellectual property mall. *Expert Systems with Applications, 36*(6), 9891–9898. http://dx.doi.org/10.1016/j.eswa.2009.01.073.

Lin, C.-W., Chen, S.-H., & Tzeng, G.-H. (2009). Constructing a cognition map of alternative fuel vehicles using the DEMATEL method. *Journal of Multi-Criteria Decision Analysis, 16*(1–2), 5–19. http://dx.doi.org/10.1002/mcda.438.

Lin, Y.-H., Chiu, C.-C., & Tsai, C.-H. (2008). The study of applying ANP model to assess dispatching rules for wafer fabrication. *Expert Systems with Applications, 34*(3), 2148–2163. http://dx.doi.org/10.1016/j.eswa.2007.02.033.

Lin, C.-L., Hsieh, M.-S., & Tzeng, G.-H. (2010). Evaluating vehicle telematics system by using a novel MCDM techniques with dependence and feedback. *Expert Systems with Applications, 37*(10), 6723–6736. http://dx.doi.org/10.1016/j.eswa.2010.01.014.

Lin, Y.-T., Yang, Y.-H., Kang, J.-S., & Yu, H.-C. (2011). Using DEMATEL method to explore the core competences and causal effect of the IC design service company: An empirical case study. *Expert Systems with Applications, 38*(5), 6262–6268. http://dx.doi.org/10.1016/j.eswa.2010.11.092.

Maróti, G., & Kroon, L. (2005). Maintenance routing for train units: The transition model. *Transportation Science, 39*(4), 518–525. http://dx.doi.org/10.1287/trsc.1050.0116.

McKinnon, A. (1999). A logistical perspective on the fuel efficiency of road freight transport, Report on the Workshop "Improving Fuel Efficiency in Road Freight: The Role of Information Technologies". Paris: International Energy Agency, European Conference of Ministers of Transport.

Milosavljević, N., Teodorović, D., Papić, V., & Pavković, G. (1996). A fuzzy sets theory approach to the vehicle assignment problem. *Journal of Transportation Planning and Technology, 20*(1), 33–47. http://dx.doi.org/10.1080/03081069608717578.

Mobley, R.K., Higgins, L.R., & Wikoff, D. J. (2008). Maintenance engineering handbook, 7 Ed., Inc., New York, New York, USA: The McGraw-Hill Companies. doi: 10.1036/0071546464.

Momčilović, V., Papić, V., & Vujanović, D. (2007). Quality of the fleet maintenance management: A factor influencing sustainable development. In Proceedings of the international congress "transport science & technology congress". Prague, Czech Republic, (pp. 457–464).

Niemira, M. P., & Saaty, T. L. (2004). An analytic network process model for financial-crisis forecasting. *International Journal of Forecasting, 20*(4), 573–587. http://dx.doi.org/10.1016/j.ijforecast.2003.09.013.

Nikolopoulos, K., Metaxiotis, K., Lekatis, N., & Assimakopoulos, V. (2003). Integrating industrial maintenance strategy into ERP. *Industrial Management and Data Systems, 103*(3), 184–191. http://dx.doi.org/10.1108/02635570310465661.

Norat, G.S. (2008). Maintenance KPI's, How to start? PdMtech Inc. White Paper. Vega Baja, PR: PdMtech Inc.

Papić, V., Medar, O., & Pejčić Tarle, S. (1999). Management of vehicle fleet maintenance in conditions of sustainable development. *Mobility & Vehicle Mechanics, 25*(2–3), 37–46. <http://www.mvm.fink.rs/journal/sajt/image/mobility1999/vol25,num2and3,1999/papic,vladimir,3.pdf> Retrieved.

Parida, A., & Kumar, U. (2009). Maintenance productivity and performance measurement. In M. Ben-Daya, S. O. Duffuaa, A. Raouf, J. Knezevic, & D. Ait-Kadi (Eds.), *Handbook of maintenance management and engineering* (pp. 17–41). London, UK: Springer.

Partovi, F. Y. (2006). An analytic model for locating facilities strategically. *Omega, 34*(1), 41–55. http://dx.doi.org/10.1016/j.omega.2004.07.018.

Randhawa, S. U., Miller, S. G., Bell, C. A., & Montagne, P. E. (1998). A study of commercial vehicle safety alliance's out-of-service criteria. *Accident Analysis and Prevention, 30*(1), 61–67. http://dx.doi.org/10.1016/S0001-457597)00062-6.

Rechnitzer, G., Haworth, N., & Kowadlo, N. (2000). The effect of vehicle roadworthiness on crash incidence and severity, Report No. 164. Monash University, Accident Research Centre, Clayton, Australia. <http://www.monash.edu.au/miri/research/reports/muarc164.pdf> Retrieved

Ruzzenenti, F., & Basosi, R. (2009). Evaluation of the energy efficiency evolution in the European road freight transport sector. *Energy Policy, 37*(10), 4079–4085. http://dx.doi.org/10.1016/j.enpol.2009.04.050.

Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting, resource allocation*. New York, London: McGraw-Hill.

Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process* (1st ed.). Pittsburgh, PA, USA: RWS Publications.

Saaty, T. L., & Vargas, L. G. (1998). Diagnosis with dependent symptoms: Bayes theorem and the analytic hierarchy process. *Operations Research, 46*(4), 491–502. <http://www.jstor.org/stable/223127> Retrieved.

Samaras, Z., & Kitsopanidis, I. (2001). Methodology and results of the evaluation of alternative short tests applied in inspection and maintenance programmes. *Transportation Research Part D: Transport and Environment, 6*(2), 111–122. http://dx.doi.org/10.1016/S1361-9209(00)00016-X.

Tesfamariam, D., & Lindberg, B. (2005). Aggregate analysis of manufacturing systems using system dynamics and ANP. *Computers and Industrial Engineering, 49*(1), 98–117. http://dx.doi.org/10.1016/j.cie.2005.05.001.

Tzeng, G.-H., Chiang, C.-H., & Li, C.-W. (2007). Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. *Expert systems with Applications, 32*(4), 1028–1044. http://dx.doi.org/10.1016/j.eswa.2006.02.004.

Vujanović, D., Momčilović, V., Papić, V., & Bojović, N. (2011). The vehicle fleet maintenance management's impact on energy efficiency. In Proceedings of the third regional conference on industrial energy and environmental protection in south-eastern europe countries – IEEP 2011. Kopaonik, Serbia: Yugoslav Society of Heat Transfer Engineers.

Vujanović, D., Mijailović, R., Momčilović, V., & Papić, V. (2010). Energy efficiency as a criterion in the vehicle fleet management process. *Thermal Science, 14*(4), 865–878. http://dx.doi.org/10.2298/TSCI090719010.

Waeyenbergh, G., & Pintelon, L. (2002). A framework for maintenance concept development. *International Journal of Production Economics, 77*(3), 299–313. http://dx.doi.org/10.1016/S0925-5273(01)00156-6.

Wu, W.-W. (2008). Choosing knowledge management strategies by using a combined ANP and DEMATEL approach. *Expert Systems with Applications, 35*(3), 828–835. http://dx.doi.org/10.1016/j.eswa.2007.07.025.

Wu, W.-W., & Lee, Y.-T. (2007). Developing global managers' competencies using the fuzzy DEMATEL method. *Expert Systems with Applications, 32*(2), 499–507. http://dx.doi.org/10.1016/j.eswa.2005.12.005.

Yamamoto, T., Madre, J.-L., & Kitamura, R. (2004). An analysis of the effects of French vehicle inspection program and grant for scrappage on household vehicle transaction. *Transportation Research Part B: Methodological, 38*(10), 905–926. http://dx.doi.org/10.1016/j.trb.2004.02.001.

Yang, J. L., & Tzeng, G.-H. (2011). An integrated MCDM technique combined with DEMATEL for a novel cluster-weighted with ANP method. *Expert Systems with Applications, 38*(3), 1417–1424. http://dx.doi.org/10.1016/j.eswa.2010.07.048.

Ou Yang, Y.-P., Shieh, H.-M., Leu, J.-D., & Tzeng, G.-H. (2008). A novel hybrid MCDM model combined with DEMATEL and ANP with applications. *International Journal of Operations Research, 5*(3), 160–168. <http://www.knu.edu.tw/lecture/%E8%AA%B2%E7%A8%8B%E8%B3%87%E6%96%99/ELECTRE/Exa.5.13.09/A%20Novel%20Hybrid%20MCDM%20Model%20Combined%20with%20DEMATEL%20and%20ANP%20with%20Applications. paper-3-IJOR-vol5_3_-Yu-Ping_Ou_Yang.pdf> Retrieved.

Zhu, G., & Pintelon, L. (2001). Integrated production maintenance management (IPMM) as an enterprise approach to maintenance management. In Proceedings of IIE annual conference, CD-ROM.

Zhu, G., Gelders, L., & Pintelon, L. (2002). Object/objective-oriented maintenance management. *Journal of Quality in Maintenance Engineering, 8*(4), 306–318. http://dx.doi.org/10.1108/13552510210448513.