An AHP/DEA method for measurement of the vehicle roadworthiness performance index - VRWPI

Kristina Jakimovska PhD.
Assistant Professor
"Ss. Cyril and Methodius" University Skopje
Faculty of Mechanical Engineering

Čedomir Duboka PhD.
Professor emeritus
University of Belgrade
Faculty of Mechanical Engineering

Dimitar Karastoyanov PhD.
Professor
Bulgarian Academy of Sciences - Sofia
Institute of Information and Communication Technologies

There is a high level of variation in the results of influence of technical defects on accidents. For sure, vehicle roadworthiness plays a significant role in vehicle safety. This study proposes fuzzy AHP (Analytic Hierarchy Process) method to gain real values for the vehicle roadworthiness indicators. Within the proposed methodology, a decision group and vehicle roadworthiness framework containing 6 indicators are firstly established.
Optimal MCDM (Multi-Criteria Decision Making) method i.e. DEA (Data Envelopment Analysis) method was chosen for the evaluation of vehicle roadworthiness performance of motor vehicles depending on their condition and that assessment is presented through Vehicle Roadworthiness Performance Index - VRWPI of a motor vehicle in operation. This study also proposes DEA method to combine the vehicle condition indicators into one overall index. In the research 6 indicators are taken into consideration and in the next part of the paper will be made aggregation of indicators into one Composed Indicator i.e. VRWPI. The results demonstrate the engineering practicability and effectiveness of AHP and DEA method in vehicle roadworthiness evaluation also importance of the weights on the various indicators are being illustrated.

Keywords: *Vehicle Roadworthiness, AHP, DEA, Composite indicator, Vehicle Roadworthiness Performance Index - VRWPI.*

1. INTRODUCTION

There is a significant variation in study findings regarding the role of vehicle defects in crash causation and the effectivness of Periodic Motor Vehicle Inspections programs in reducing defects and crashes [1,2]. There are significant methodological and statistical difficulties and shortcomings in many of the studies , including the difficulty of identifying and detecting defects in crashed vehicles and their contribution to a crash.

2. VEHICLE ROADWORTHINESS AS PART OF VEHICLE SAFETY

From a safety viewpoint, it would appear axiomatic that vehicles need to be roadworthy and that this should be a prerequisite for their registration. What is really at issue is how this roadworthy condition can best be achieved and maintained.

Roadworthiness itself can be achieved in a combination of two ways, by 'Keep Vehicles Roadworthy' and by 'Produce Roadworthy Vehicles' [3]. One can not keep a vehicle roadworthy, if it is not produced to be and to remain roadworthy. The other way around is that one doesn't need to produce a roadworthy vehicle, if no one keeps it roadworthy [19].

2.1 Defining vehicle roadworthiness indicators

Council Directives [16], [17], [18] were gudielines for definition of the vehicle roadworthiness indicators presented in Table 1.

Table 1. Vehicle roadworthiness performance indicators

nr.	Vehicle roadworthiness performance indicators
1	Vehicle age (years)
2	Vehicle mileage (km)
3	Maintenance history
4	Accident involvement history
5	Vehicle modifications
6	Proper vehicle systems and devices

Grade of the vehicle roadworthiness is more or less depending on abovementioed indicators and measuring and monitoring of their degradation is of great importance for vehicle safety.

3. FUZZY AHP

The AHP established by Saaty is a method to solve multiple criteria decision problems by setting their priorities. Triangular fuzzy numbers are adopted to handle inherent uncertainty and imprecision of the data involved in the decision process [4,5].

Within the proposed methodology, a decision group and vehicle roadworthiness framework containing 6 indicators are firstly established an the fuzzy weights of the vehicle roadworthiness indicators are calculated based on the pair-wise comparisons [20].The calculation of the weight factor with fuzzy AHP method can be described in the following steps[6,8,9,10,11]:
Step 1: Comparison of factors

Experts are required to compare each factor in pairs in a matrix form with size *n* x *n*, where *n* is the number of factors. Expert comparisons are in scale of 9 values (Table 2) and are denoted by r_{ij}. The results of the comparison of the experts are grouped into a pairwise comparison matrix using the average mean.

$$R= \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \cdots & A_n \end{array} \\ \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \end{array} \qquad (1)$$

Comparing values in pairs expressed by fuzzy lingustic values (Table 2)

Table 2. Points of fuzzy evaluation for fuzzyfication of the comparison values in pairs

Linguistic value	Real value	Fuzzy value ñ
Absolutely strong (AS)	9	(8, 9, 9)
Very strong (VS)	7	(6, 7, 8)
Fairly strong (FS)	5	(4, 5, 6)
Slightly strong (SS)	3	(2, 3, 4)
Equal (E)	1	(1, 1, 1)
Slightly weak (SW)	1/3	(1/4, 1/3, 1/2)
Fairly weak (FW)	1/5	(1/6, 1/5, 1/4)
Very weak (VW)	1/7	(1/8, 1/7, 1/6)
Absolutely weak (AW)	1/9	(1/9, 1/9, 1/8)

Step 2: Perform the consistency test
In order to control the consistency of subjective opinions and accuracy of the weight factors, it is neccessary to calculate the factor of consistency - *CF* who is defined as:

$$CF = (\lambda_{max} - n)/(n-1) \qquad (2)$$

where λ_{max} is the maximum eigenvalue of the matrix R and *n* is the number of factors. If the consistency factor or less than 0.1 it is regarded that the pairwise comparisons are acceptable [7, 12].
Step 3: Converting parameters in fuzzy numbers
The values of the pairwise comparison matrix are converted into triangluar fuzzy numbers in accordance with the rules for conversion (in Table 2).

$$\tilde{R} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \cdots & A_n \end{array} \\ \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{12} & \cdots & \tilde{r}_{1n} \\ \tilde{r}_{21} & \tilde{r}_{22} & \cdots & \tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{r}_{n1} & \tilde{r}_{n2} & \cdots & \tilde{r}_{nn} \end{bmatrix} \end{array} \qquad (3)$$

Step 4: Calculation of fuzzy weight factor dimensions
Fuzzy weight factor dimensions can be calculated with the formula:

$$\tilde{u}_i = (\tilde{r}_{i1} \odot \tilde{r}_{i2} \odot \ldots \odot \tilde{r}_{in})^{1/n} \qquad (4)$$

Step 5: Calculate of final fuzzy weight factors
Final fuzzy weight factors for every criterion can be obtained with:

$$\widetilde{w}_i = \tilde{u}_i \odot (\tilde{u}_{i1} \oplus \tilde{u}_{i2} \oplus \ldots \oplus \tilde{u}_{in})^{-1} \qquad (5)$$

Step 6: Calculation of the true values of the weight factors
Final fuzzy weight factors of every criterion can be obtained by the formula:

$$w_i = \left[\left(w_i^u - w_i^l\right) + \left(w_i^m - w_i^l\right)\right]/3 + w_i^l \qquad (6)$$

by using the values from $\widetilde{w_i} = (w_i^l, w_i^m, w_i^u)$

4. COMPOSITE INDICATOR - CI AND DEA METHOD

A composite indicator - *CI* is an mathematical aggregation of a set of individual indicators that measure multidimensional concept but usually no common units of measurement. The graphical representation of *CI* construction is illustrated on Fig. 1. There are m decsion making units - *DMU* which means comparised alternatives, each *DMU* consist *n* sub-indicators I_{ij}. For each *DMU* is evaluated *CI*. Sub-indicators usually have no common measurable units.

$$\begin{array}{c} DMU_1 \\ DMU_2 \\ \vdots \\ DMU_m \end{array} \begin{bmatrix} I_{11} & I_{12} & \cdots & I_{1n} \\ I_{21} & I_{12} & \cdots & I_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ I_{m1} & I_{m2} & \cdots & I_{mn} \end{bmatrix} \rightarrow \begin{bmatrix} CI_1 \\ CI_2 \\ \vdots \\ CI_m \end{bmatrix}$$

Figure 1. Construction of CI

Generally the structure of *CI* can be expressed by equation:

$$CI = \sum_{i-1}^{n} w_i I_i \qquad (7)$$

where w_i means weight assigned to indicator *i*.

DEA is a performance measurement technique that can be used for evaluating the reative efficiency of *DMUs*. For each *DMU* the efficiency is defined as a ratio of the weighted sum of outputs to the weighted sum of inputs [13,15].

An application of DEA was proposed in [14] to construct CI, where two sets of weights are calculated by using two slightly different DEA models.The final *CI* values are results of combination of these two DEA models and it represents Vehicle Roadworthiness Performance Index - VRWPI .

In the first DEA model for particular DMU_j in the data set ($j=1,2,...,m$) a gI_i value is determined using a set of the best indicator weights w_{ij} ($i=1,2...n$) which gI_i value of the DMU_i and satisfies the restrictions.

$$gI_i = \max \sum_{j=1}^{n} w_{i,j}^{g} I_{i,j} \qquad (8)$$

$$s.t. \sum_{j=1}^{n} w_{i,j}^{g} I_{i,j} \leq 1, \quad k = 1,2,\ldots,m \qquad (9)$$

$$w_{i,j}^{g} \geq 0, \quad j = 1,2,\ldots,n \qquad (10)$$

In the second DEA model for a each DMU_j a bI_j value is determined using a set of the worst indicator weights w_{ii} $(i=1,2...,n)$ with the simirarly restirctions:

$$bI_i = \min \sum_{j=1}^{n} w_{i,j}^{b} I_{i,j} \qquad (11)$$

$$s.t. \sum_{j=1}^{n} w_{i,j}^{g} I_{i,j} \geq 1, \quad k = 1,2,...,m \qquad (12)$$

$$w_{i,j}^{b} \geq 0, \quad j = 1,2,...,n \qquad (13)$$

In different words, DEA is a linerar programming model, where each entity selects a set of weights which are most favorable for itself to give a standardized efficiency score (between zero and one). The first DEA model can help each entity to select the "best" sets of weights for use, the second DEA model measures how close the evaluated entity is from the worst case under the worst possible weights.

Models (8-10) and (11-13) are giving as a results indexes based on weights w_{ij} that are most favorable and less favorable for each entity and these two indexes are combined to CI form in the following way:

$$CI_i = k \frac{gI_i - gI^-}{gI^* - gI^-} + (1-k) \frac{bI_i - bI^-}{bI^* - bI^-} \qquad (14)$$

where

$gI^* = \{max\ gI_i,\ i=1,2,..,m\}$
$gI^- = \{min\ gI_i,\ i=1,2,...,m\}$
$bI^* = \{max\ gI_i,\ i=1,2,..,m\}$
$bI^- = \{min\ gI_i,\ i=1,2,...,m\}$
$0 \leq k \leq 1$

Coefficient k is an adjusting parameter which is determined by decision maker and usually has a value 0,5.

5. CONSTRUCTING VEHICLE ROADWORTHINESS PERFORMANCE INDICATOR - VRWPI

The construction of Composite Indicator - *CI* involves stages where subjective judgement has to be made: the selection of indicators, the choice of aggregation model, the weights of the indicator etc. and it can be said that obtained *CI* i.e. *VRWPI* is based only on expert group opinion.

Considering vehicle roadworthiness indicators described in Table 1 and AHP evaluation matrix in Table 3 based of expert opinion a calculation with fuzzy AHP method is performed. Obtained results are presented in Table 4.

Correspondence to: Dr Kristina Jakimovska, assistant professor
Faculty of Mechanical Engineering - Skopje
Karposh II bb P.O.Box 464, 1000 Skopje, MK
E-mail: kristina.jakimovska@mf.edu.mk

Table 3. AHP evaluation matrix with linguistic values of 6 indicators

Indicators	1	2	3	4	5	6
1	E	SS	VS	VS	SS	AS
2	SW	E	SW	FS	SW	SS
3	FS	FW	E	FS	E	AS
4	FW	VW	FW	E	SW	FS
5	AW	FW	E	FS	E	VS
6	AW	AS	SW	AS	VW	E

Table 4. Weighted factors obtained by fuzzy AHP 6 indicators

Indicators	Fuzzy value	Real value
1	(0,07 ; 0,09; 0,12)	**0,092**
2	(0,14; 0,20; 0,26)	**0,198**
3	(0,051; 0,065; 0,076)	**0,062**
4	(0,15; 0,20; 0,29)	**0,176**
5	(0,04; 0,06; 0,08)	**0,06**
6	(0,34; 0,41; 0,55)	**0,412**

Obtained weighted factors by fuzzy AHP method are further used in the abovementioned DEA models.The objective is is to merge these vehicle roadworthiness indicators into a single valued composite indicator defined as Vehicle Roadworthiness Performance Indicator - VRWPI [20].

In Table 5 are presented results for the VRWPI as obtained by the above methodology.

Table 5. Six vehicle roadworthiness indicators and CI values for 10 vehicles

Vehicles	gI	bI	CI ≡VRWPI
V1	0,873	1,053	0,366
V2	1	1,358	0,761
V3	0,965	1,347	0,592
V4	1	1,003	0,521
V5	0,972	1,567	0,634
V6	0,882	1,210	0,479
V7	0,950	1,607	0,604
V8	0,877	1,279	0,654
V9	0,953	1,542	0,728
V10	1	1,355	0,720

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6. CONCLUSION

The paper describes a decision making methodology for vehicle roadworthiness based on the fuzzy AHP and DEA method. Although this research considers only 6 representative vehicle roadworthiness indicators, it is exportable to even more of them.

A remarkable feature in DEA-methodology is that it looks for endogenous (possibly constrained) weights, yielding an overall score that depicts the analyzed decision making unit in its best possible light relative to the other observations.

With the proposed evaluation matrix we can see that vehicle mileage and accident involvement are valued as with great impact on vehicle roadworthiness performance; vehicle systems and devices condition is also valued with high priority. The contribution of this paper is to propose an efficient and effective decision framework for evaluation of vehicle roadworthiness performance using fuzzy AHP and DEA method.

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