**APPLICATION OF FUZZY TOPSIS AND AHP METHOD IN EVALUATING VEHICLE ROADWORTHINESS PERFORMANCE**

1Kristina, Jakimovska\*, 2Čedomir, Duboka, 3Dimitar, Karastoyanov

1Ss. Cyril and Methodius University - Faculty of Mechanical Engineering - Skopje, address: Karposh II bb, P.O.Box 464, 1000 Skopje, MK; e-mail: kristina.jakimovska@mf.edu.mk; 2 University of Belgrade - Faculty of Mechanical Engineering, address: Kraljice Marije 16, Beograd 35, Pf.34, Serbia; e-mail: cduboka@eunet.rs; 3 Bulgarian Academy of Sciences - Institute of Information and Communication Technologies, address: Acad. G. Bonchev str. bl.2, 1113 Sofia, Bulgaria; e-mail:dkarast@iinf.bas.bg

**Keywords -** composite indicator, fuzzy TOPSIS, fuzzy AHP, vehicle roadworthiness performance index - VRWPI

Roadworthiness itself can be achieved in a combination of two ways, by ‘Keep Vehicles Roadworthy’ and by ‘Produce Roadworthy Vehicles’. 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. First, 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 14 indicators are firstly established. Optimal MCDM method i.e. fuzzy TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) 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 fuzzy TOPSIS method to combine the vehicle roadworthiness indicators into one overall index. The results demonstrate the engineering practicability and effectiveness of AHP and TOPSIS method in vehicle roadworthiness evaluation also importance of the weights on the various indicators are being illustrated.

# I. INTRODUCTION

Many studies about the effect of technical defects on road traffic accidents have been conducted. There is a high level of variation in the results. It starts out at almost no influence of technical defects on accidents and ends at 28 percent [14, 15]. The problem of the condition of vehicles with regard to their safety is especially evident in the case of accidents when formally and essentially there is a need to determine their cause. Although international experiences show that a large percentage of such events (from 85% to 95%) are caused by driver error, or because of the human factor, the condition of the vehicle that was involved in the accident is a very important element.

# II. VEHICLE ROADWORTHINESS

Many vehicle owners do not adequately maintain their vehicles so significant numbers of defective vehicles are in use, a matter of concern as poor vehicle condition has an adverse affect on safety and the environment [3]. The level of defects in vehicles in use in Europe remains high and shows no signs of improving with the introduction of new technologies and manufacturing systems.The information collected in [4] was analysed and collated into a common format in order to establish a picture of the current state of knowledge of roadworthiness enforcement generally, how it is performed and organised in all member states of the European Union and with what results. Roadworthiness itself can be achieved in a combination of two ways, by ‘Keep Vehicles Roadworthy’ and by ‘Produce Roadworthy Vehicles’. 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. ‘Keep Vehicles Roadworthy’ (may also be called ‘roadworthiness Assurance’) splits up into two parts, which are the forced way ‘Roadworthiness Enforcement’ and the voluntary way ‘Voluntary Inspection’. Roadworthiness can be achieved in different ways [4].

## Vehicle roadworthiness indicators

The choice of the vehicle roadworthiness performance indicators was based on the guidelines given in vehicle roadworthiness Directives [9,10,11] and the studies presented in [12,13]. The final selection of vehicle roadworthiness performance indicators is shown in Table 1. Each of the vehicle roadworthiness performance indicators is further explained. Two sets of indicators to evaluate the vehicle roadworthiness are proposed in this study and for each of the indicators are assigned unique items I to XV (indicators from V to XIII are pooled in one indicator XV).

Each of these vehicle roadworthiness indicators take part in smaller or bigger percentage in vehicle safety assessment according to their condition i.e. grade/valuation in vehicle roadworthiness.

### The age of the vehicle, expressed in years is always influential parameter of vehicle safety, and thus the vehicle roadworthiness. This indicator is inversely proportional with increasing age of the vehicle reduces vehicle roadworthiness performance.

### Mileage (expressed in number of traveled kilometers) indicator that is considered here is included only by amount, and not regarding the conditions of exploitation. It should be noted that this indicator certainly have important influence on vehicle roadworthiness.

### The history of maintenance is an influential factor, since this indicator monitors the condition of the vehicle throughout its lifespan. Whether performed preventive maintenance, corrective or a combination of both, of great importance is that the maintenance is performed in an authorized service of the manufacturer, where there is certainty that the maintenance is done according to the manufacturer's instructions and using original parts and materials. Recently, the authorities in our country and worldwide increasingly introduce frequent checks for fraud in keeing with used vehicles.

### History of involvement in accidents is an indicator that shows how often a vehicle for his lifetime will be involved in a car accident.

### When a technical malfunction or an accident happens, repairs that are performed on the vehicle are recognized in the indicator History of repair .The condition of the vehicle after the repair depends largely on whether it is done professionally or not, and its consequences are described in detail by Berg et al. (2008) [7].

### Braking condition in many papers is associated with the safety of the entire vehicle. By reducing its accuracy, proportionally the vehicle roadworthiness is also reduced.

### Steering condition, tyre condition, lighting condition, belt and components for fastening child seats condition and emission control are also parameters that reflect the safety condition of the vehicle and are also evaluated during the periodic control of the vehicle.

### The overall safety status indicator evaluate the safety of the vehicle in terms of the number of available advanced safety systems (ABS/ASR, SRS, ESS, ACC, etc.) that are included in the vehicle.

### Number of defects per failed vehicle expresses the number of simultaneous failures of vehicle malfunction.

### Modifications to the vehicle are common and have a significant stake in vehicle roadworthiness performance [8].

### Table 1. Vehicle roadworthiness indicators

|  |  |
| --- | --- |
| **Vehicle roadworthiness indicators** | |
| ***Variant A*** | ***Variant B*** |
| I Vehicle age (years) | I Vehicle age (years) |
| II Vehicle mileage (km) | II Vehicle mileage (km) |
| III Maintenance history | III Maintenance history |
| IV Accident involvement history | IV Accident involvement history |
| V Repair history | XV Proper vehicle systems and devices |
| VI Proper braking condition |
| VII Proper steering condition |
| VIII Proper tyre condition |
| IX Proper lighting condition |
| X Proper belt and components for fastening child seats condition |
| XI Proper emission control |
| XII Overall safety status |
| XIII Number of defects per failed vehicle |
| XIV Vehicle modifications | XIV Vehicle modifications |

# III. ASSIGNING INDICATOR WEIGHTS BY FUZZY AHP

The essence of the AHP - method is in comparison of pairs of stacking attributes values. It is performed by making comparisons between pairs of values ​​of certain indicators, while asking which of the two compared indicators is more important and how. The scale of the relative importance to measure comparison is expressed using a scale from 9 to 1/9. Value 1 indicates equality between two individual indicators, while the value 9 or 1/9 indicates that the relevant indicator is 9 times more important than the other or 9 times less important than the other [19].

The inability of AHP - method to deal with uncertainty and subjectivity in the process of pairwise comparison can be overcome by using fuzzy AHP - method, where instead of well-defined values, the fuzzy AHP - method used a range of values ​​that would be able to cover the uncertainty of the decision. For that reason, fuzzy AHP - method is chosen for the calculation in the current research. The calculation of the weight factor with fuzzy AHP method can be described in the following steps:

* Step 1: Comparison of factors

Based on expert opinion the pairwise comparison of factors is being prepared. The 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. Comparisons of the experts are in a scale of 9 values ​​(Table 2) and are denoted by . The results of the comparison of the experts are grouped into a pairwise comparison matrix using the average mean.

R (1)

Comparing values ​​in pairs expressed by fuzzy linguistic values ​​(see Table 2).

### Table 2.

|  |  |  |
| --- | --- | --- |
| ***Linguistic value*** | ***Real value*** | ***Fuzzy value*** |
| Absolutely strong | 9 | (8,9,9) |
| Very strong | 7 | (6,7,8) |
| Fairly strong | 5 | (4,5,6) |
| Slightly strong | 3 | (2,3,4) |
| Equal | 1 | (1,1,1) |
| Slightly weak | 1/3 | (1/4, 1/3, 1/2) |
| Fairly weak | 1/5 | (1/6, 1/5, 1/4) |
| Very weak | 1/7 | (1/8, 1/7, 1/6) |
| Absolutely weak | 1/9 | (1/9, 1/9, 1/8) |

* Step 2: Perform the test of consistency

In order to control the consistency of subjective opinions and accuracy of the weight factors, it is necessary to calculate the factor of consistency - CF who is defined:

(2)

where *λ* max is the maximum eigenvalue of the matrix *R,* and *n* is the number of factors. If the consistency factor is less than 0.1 it is regarded that the pairwise comparisons ​​are acceptable.

* Step 3: Converting parameters in fuzzy numbers

The values of the pairwise comparison matrix are converted into triangular fuzzy numbers in accordance with the rules for conversion (in Table 2)

(3)

* Step 4: Calculation of fuzzy weight factor dimensions

Fuzzy weight factor dimensions can be calculated with the formula:

(4)

* Step 5: Calculate of final fuzzy weight factors

Final fuzzy weight factors for every criterion can be obtained with:

(5)

* Step 6: Calculation of the true values of the weight factors

Final fuzzy weight factors of every criterion can be obtained with:

(6)

by using the values from

**IV. COMPOSITE INDICATOR AND FUZZY TOPSIS METHOD**

TOPSIS is a [multi-criteria decision analysis](http://en.wikipedia.org/wiki/Multi-criteria_decision_analysis" \o "Multi-criteria decision analysis) method, which was originally developed by Hwang and Yoon in 1981 with further developments by Yoon in 1987 and Hwang, Lai and Liu in 1993. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion, normalizing scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion. An assumption of TOPSIS is that the criteria are [monotonically](http://en.wikipedia.org/wiki/Monotonic_function" \o "Monotonic function) increasing or decreasing. [Normalization](http://en.wikipedia.org/wiki/Normalization_%28statistics%29" \o "Normalization (statistics)) is usually required as the parameters or criteria are often of incongruous dimensions in multi-criteria problems [19]. Compensatory methods such as TOPSIS allow trade-offs between criteria, where a poor result in one criterion can be negated by a good result in another criterion.

A composite indicator (CI) is an mathematical aggregation of a set of individual indicators that measure multi-dimensional concept. There are *m* comprised alternatives, each alternative consist *n* sub-indicators *xij*. For each alternative is evaluated CI. CI is used for performance measurement, benchmarking, via providing an aggregated performance index in various fields such as Human Development Index, Road Safety Development Index – RSDI [5].The graphical representation of CI construction is illustrated on Fig. 1, *C*1 – *Cn* means criteria.

Figure 1. Construction of composite indicator

The TOPSIS method is used to analyze a multi-criteria decision making problem with *m* alternatives with *n* criteria. In TOPSIS method, the best alternative should have the shortest Euclidean distance from the positive ideal solution (PIS) and the longest distance from the negative ideal solution (NIS). The PIS is a hypothetical solution which maximum values from database of all alternatives, the NIS is a hypothetical solution which minimum values from database of all alternatives. TOPSIS defines an index called relative closeness to the PIS and remoteness from the NIS. This index can be used as a CI of alternatives. The main procedure of the TOPSIS method is described in the following steps:

* Step 1: Define a decision matrix

The decision matrix ***D*** of *m* x *n* dimension consists values of *n* sub-indicators for *m* alternatives:

* Step 2: Normalize the decision matrix

The values of sub-indicators are normalized to scale 0-1. In case of "benefit type" indicators, what means a higher value is better, is used formula:

 (7)

“Cost type” sub-indicators, what means the lower value is better, are normalized in the following way:

 (8)

As a result is obtained the normalized decision matrix ***D’***.

* Step 3: Compute the weighted normalized decision matrix

Elements of the normalized decision matrix ***D’*** are multiplied by weight vector ***W***, which consist *n* weight factors *w.* These factors express the relatively importance of criteria. The elements of weighted normalized decision matrix ***V*** are expressed as:

 (9)

* Step 4: Identify the PIS and NIS

The positive ideal solution ***A+*** and the negative ideal solution ***A-*** can be expressed as:

 (10)

 (11)

* Step 5: Calculate the distance to PIS and NIS

For each alternative *i* the Euclidean distance *di+* to the positive ideal solution and distance *di-* to the negative ideal solution is defined [20].

* Step 6: Compute the relative closeness data to CI

Values *dj+* and *dj+* are combined to relative closeness index *Ci*:  (12)

The *Ci* is a composed indicator - CI of alternative *i* .

To express the subjectiveness and imprecision of the evaluation process, the sub-indicators and weights are represented by a triangular fuzzy number [6]. A triangular fuzzy number *ñ* can be define by a triplet (*a*, *b*, *c*) shown in Fig.2. The membership function *μñ* is defined:  (13)

where *a*<*b*<*c*. The *b* is the most possible value of fuzzy number. Similarly as in the case of real numbers, operations of positive fuzzy numbers can be defined [6].

The distance between fuzzy numbers can be defined:

 (14)

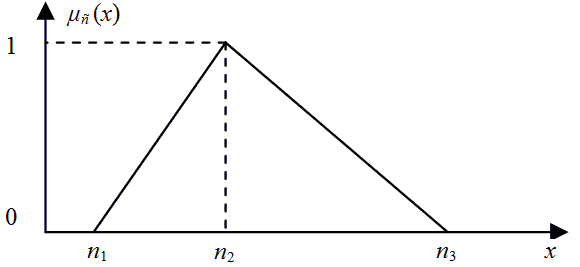


Figure 2. A triangular fuzzy number *ñ*

In step 1 decision matrix is generated, in step 2 this matrix is normalized. After normalization, the real values in the decision matrix and weight values are converted into fuzzy numbers. The 7-level scale of fuzzy numbers expressed in linguistic terms is used (Table 3).

### Table 3.

|  |  |  |
| --- | --- | --- |
| ***Real value x*** | ***Linguistic value*** | ***Fuzzy value*** *ñ* |
| 0 ≤ *x*< 1/7 | Very low | (0,0,1/6) |
| 1/7 ≤ *x*< 2/7 | Low | (0,1/6,2/6) |
| 2/7 ≤ *x*< 3/7 | Medium low | (1/6,2/6,3/6) |
| 3/7 ≤ *x*< 4/7 | Medium | (2/6,3/6,4/6) |
| 4/7 ≤ *x*< 5/7 | Medium high | (3/6,4/6,5/6) |
| 5/7 ≤ *x*< 6/7 | High | (4/6, 5/6, 1) |
| 6/7 ≤ *x* ≤ 7/7 | Very high | (5/6, 1, 1) |

The calculations in step 3 are proceeded with the fuzzy values. In step 4, the fuzzy values of PIS and NIS is identified and in step 5 is calculated the distance to PIS and NIS by formula (14), in step 6 the relative closeness is estimating by (12).

**V. RESULTS OF THE CALCULATIONS**

Calculations of the weight factors with fuzzy AHP are shown in Table 4. Assigned weights of the criteria were applied to fuzzy TOPSIS model and Table 5 presents the results of the calculations.

### Table 4.

|  |  |  |
| --- | --- | --- |
| ***Indicator*** | ***Fuzzy value*** | ***Real value*** |
| I | (0,07 ; 0,09; 0,12) | **0,092** |
| II | (0,14; 0,20; 0,26) | **0,198** |
| III | (0,051; 0,065; 0,076) | **0,062** |
| IV | (0,15; 0,20; 0,29) | **0,176** |
| XIV | (0,04; 0,06; 0,08) | **0,06** |
| XV | (0,34; 0,41; 0,55) | **0,412** |

### Table 5.

|  |  |  |
| --- | --- | --- |
| ***Experts*** | ***VRWPI with TOPSIS*** | ***VRWPI with fuzzy TOPSIS*** |
| 1 | **0** | **0** |
| 2 | **0.515** | **0.503** |
| 3 | **0.645** | **0.408** |
| 4 | **0.770** | **0.860** |
| 5 | **0.642** | **0.720** |
| 6 | **0.440** | **0.496** |
| 7 | **0.442** | **0.400** |
| 8 | **0.575** | **0.592** |
| 9 | **0.597** | **0.700** |
| 10 | **0.453** | **0.640** |
| 11 | **0.522** | **0.667** |
| 12 | **0.564** | **0.440** |
| 13 | **0.700** | **0.815** |
| 14 | **0.528** | **0.775** |
| 15 | **1.000** | **1.000** |

**V. CONCLUSIONS**

A composed indicator has been accepted as a useful tool in many non-technical areas, such as economy, society and environment. In this paper is presented application of CI in the field of technical sciences. Among numerous methods of multi-criteria decision making, the fuzzy AHP is very suitable for evaluating alternatives when qualitative and quantitative advertence are expressed only with linguistic vagueness. The contribution of this paper is to propose an efficient and effective decision framework for evaluation of vehicle roadworthiness using fuzzy AHP method.A fuzzy TOPSIS method was also realized to deal with the subjective kind of uncertainty of data (i.e. linguistic variables given by experts) and proved valuable in creating Vehicle Roadworthiness Performance Index - VRWPI. The construction process of this method is transparent and can be used to support the desired policy.

**ACKNOWLEDGMENT**

The author gratefully acknowledge the support by the project AComIn: Advanced Computing for Innovation funded by the FP7 Capacity Programme Research Potential of Convergence Regions, grant number 316087.

**REFERENCES**

[1] Jakimovska K (2014) Development of methodology for condition based vehicle assessment.

PhD thesis, University Ss. Cyril and Methodius - Faculty of Mechanical Engineering - Skopje

[2] AUTOFORE project WP 200: Current situation and trends in roadworthiness enforcement

[3] AUTOFORE project WP 300: Vehicle technology / Diagnostic technology

[4] AUTOFORE project WP200: Current situation of roadworthiness enforcement on E.U.

[5] Al Haji G, (2005) Development of an International Index to Measure Road Safety

Performance. Dissertation thesis, Department of Science and Technology, Campus Norrköping,

Linköping University Norrköping, Sweden

[6] Bo Y, Klir G (1995) Fuzzy Sets and Fuzzy Logic - Theory and Applications. Prentice Hall PTR

[7] Berg F.A, Rucker P, Leimbach F, Schmortte U, Chirwa E.C, Chinnaswamy G.K (2008)

The effects of unprofessional repairs on quality and safety of road vehicles subjected to crash

loading. Proceedings of ICRASH Kyoto, Japan

[8] Berg F.A, Rücker P, Leimbach F, Kiebach H (2009) The project „fair repair“ – A

contribution to highlight possible impacts of non-professional repair on the quality and safety of

vehicles. XXII Science and Motor Vehicles Conference Belgrade, Serbia

[9] Council Directive 96/96/EC of 20 December 1996 - Official Journal of the European Communities

[10] Council Directive 2010/48/EC of 5 July 2010 - Official Journal of the European Communities

[11] Council Directive 2009/40/EC of 6 May 2009 - Official Journal of the European Communities

[12] Duboka Č (2010) Vehicle Condition-Based Roadworthiness Performance Indicator. World

Automotive Congress FISITA Budapest, Hungary

[13] Duboka Č (2011) Vehicle Safety Performance Indicators & Indexes. XXIII Science and

Motor Vehicles Conference Belgrade, Serbia

[14] DEKRA Automobil GmbH - Road Safety Report 2008 – Strategies for preventing accidents on Europa’s roads

[15] DEKRA Automobil GmbH – Verkehrssicherheitsreport Landstrassen 2013 – Strategien zur Unfallvermeidung auf den Strassen Europas

[16] Hermans E, (2009) A methodology for developing a composite road safety performance

index for cross-country comparison. PhD thesis - University of Hasselt, Belgium

[17] Hui S, Zhiqing F, Ye S, (2010) Research on Comprehensive Evaluation of Urban Public

Transportation Competitiveness in Hebei Province based on TOPSIS. IEEE

[18] Javadian N, Kazemi M, (2009) A General Fuzzy TOPSIS Based on New Fuzzy Positive

and Negative Ideal Solution. IEEE IEEM

[19] Kahraman C (2008) Fuzzy Multi-Criteria Decision Making-Theory and Applications with Recent Developments Volume 16

[20] Nardo M, Saisana M, Saltelli A, Tarantola S, Hoffman A, Giovannini E, (2005)

Handbook on constructing composite indicators: methodology and user guide. OECD Statistics

Working PaperVol. 3

[21] Sezhian M.V, Muralidharan C, Nambirajan T, Deshmukh S.G (2011) Performance

measurement in a public transport sector passenger bus transport company using fuzzy TOPSIS,

fuzzy AHP and ANOVA - a case study. International Journal of Engineering Science and

Technology