

## **AN AHP/TOPSIS METHOD FOR MEASUREMENT OF THE VEHICLE ROADWORTHINESS PERFORMANCE INDEX - VRWPI**

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**ABSTRACT** –

There is a high level of variation in the results of influence of technical defects on accidents. A properly maintained and fully functioning vehicle meeting all safety requirements is less likely to be involved in a road accident. 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 14 indicators are firstly established. Optimal MCDM (Multi-Criteria Decision Making) method i.e. 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 TOPSIS method to combine the vehicle condition indicators into one overall index. In the research 14 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.

## 1. INTRODUCTION

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 [32,33]. This fact is not taken into account well enough during the analysis of traffic accidents, especially on the Balkans, where on-site examination cares little for collecting relevant data on the vehicle which was involved in the accident. So today, not only here, but worldwide, there is a problem of identification, qualification and quantification of the impact of the condition of the vehicle on safety, and depending on the age of the vehicle, the traveled path in exploitation, vehicle maintenance and other influential factors. The reduction of functional features and performance of the vehicle shall result in the reduction of the safety, and reduce the cost or increase the cost of use and maintenance.

## 2. VEHICLE ROADWORTHINESS INDICATORS

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. As an average for the causal factors, five to ten percent can be assumed. The average for the contribution to accidents is a little higher, at about ten to twenty percent. The main reason for the different numbers is the different background of each study. They were conducted in different countries on different continents and at different times as well as over different time periods. Different groups of people gathered the data under different circumstances. Despite these differences, it can be stated that vehicle defects have a significant effect on road traffic accidents. 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 [34]. The different ways and their relations /dependencies are shown in the following picture. These are just the major ways. There are probably hundreds of subgroups and mixtures of these roadworthiness assurance methods.

The choice of the vehicle roadworthiness performance indicators was based on the guidelines given in vehicle roadworthiness Directives [10], [11] and [12] are the studies presented in [13], [14] and [15]. 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).

Table 1. Variants A and B of different number of indicators

<i>Variant A</i>	<i>Variant B</i>
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

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 keeping 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 in [16].

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 [17, 18, 16, 19].

### 3. 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 [20, 21]. The calculation by *AHP* - method can be based on real values or fuzzy values [22, 23, 24, 25]. 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 [20]. 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  $n \times n$ , where  $n$  is the number of factors. Comparisons of the experts are in a scale of 9 values (Table 2) and re denoted by  $r_{ij}$ . The results of the comparison of the experts are grouped into a pairwise comparison matrix using the average mean.

$$\begin{matrix}
 A_1 & A_2 & \dots & A_n \\
 \\
 R = & \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \dots & r_{nn} \end{bmatrix}
 \end{matrix} \tag{1}$$

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

Step 2: Perform the test of consistency (consistency test)

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

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

where  $\lambda_{\max}$  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

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

Linguistic value	Real value	Fuzzy value $\tilde{n}$
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 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)

$A_1 \quad A_2 \quad \dots \quad A_n$

$$\tilde{R} = \begin{matrix} A_1 & A_2 & \dots & A_n \end{matrix} \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{12} & \dots & \tilde{r}_{1n} \\ \tilde{r}_{21} & \tilde{r}_{22} & \dots & \tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{r}_{n1} & \tilde{r}_{n2} & \dots & \tilde{r}_{nn} \end{bmatrix} \quad (3)$$

Step 4: Calculation of fuzzy weight factor dimensions

Fuzzy weight factors dimensions can be calculated with the formula:

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

Step 5: Calculate of final fuzzy weight factors

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

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

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



### Step 1: Define a decision matrix

The decision matrix  $D$  of  $m \times n$  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:

$$x'_{ij} = \frac{x_{ij} - \min_i \{x_{ij}\}}{\max_i \{x_{ij}\} - \min_i \{x_{ij}\}} \quad (7)$$

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

$$x'_{ij} = \frac{\max_i \{x_{ij}\} - x_{ij}}{\max_i \{x_{ij}\} - \min_i \{x_{ij}\}} \quad (8)$$

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:

$$v_{ij} = w_j \cdot x'_{ij} \quad (9)$$

### Step 4: Identify the PIS and NIS

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

$$A^+ = \left( \max_i \{v_{i,1}\}, \dots, \max_i \{v_{i,n}\} \right) = (v_1^+, \dots, v_n^+) \quad (10)$$

$$A^- = \left( \min_i \{v_{i,1}\}, \dots, \min_i \{v_{i,n}\} \right) = (v_1^-, \dots, v_n^-) \quad (11)$$

### Step 5: Calculate the distance to PIS and NIS

For each alternative  $i$  the Euclidean distance  $d_i^+$  to the positive ideal solution and distance  $d_i^-$  to the negative ideal solution is define [43].

### Step 6: Compute the relative closeness data to CI

Values  $d_j^+$  and  $d_j^-$  are combined to relative closeness index  $C_i$ :

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (12)$$

The  $C_i$  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 [44]. A triangular fuzzy number  $\tilde{n}$  can be define by a triplet  $(a, b, c)$  shown in Fig. 1. The membership function  $\mu_{\tilde{n}}$  is defined as:

$$\mu_{\tilde{n}}(x) = \begin{cases} \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & \text{otherwise} \end{cases} \quad (13)$$

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 [44].

The distance between fuzzy numbers can be defined:

$$D(\tilde{n}_1, \tilde{n}_2) = \sqrt{\frac{1}{3} [(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2]} \quad (14)$$

Used fuzzy-TOPSIS model is similar to classic TOPSIS method. 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).

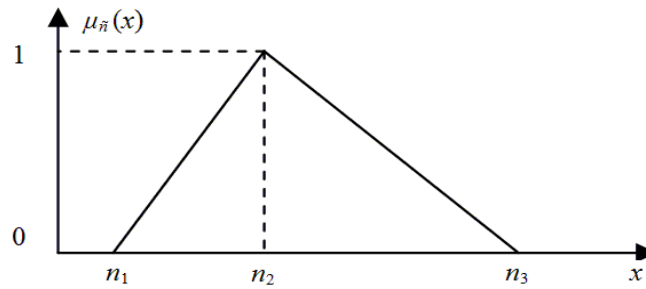


Figure 2. A triangular fuzzy number  $\tilde{n}$

Table 3. Table of conversion real values into fuzzy values

Real value x	Linguistic value	Fuzzy value $\tilde{n}$
$0 \leq x < 1/7$	Very low	$(0, 0, 1/6)$
$1/7 \leq x < 2/7$	Low	$(0, 1/6, 2/6)$
$2/7 \leq x < 3/7$	Medium low	$(1/6, 2/6, 3/6)$
$3/7 \leq x < 4/7$	Medium	$(2/6, 3/6, 4/6)$
$4/7 \leq x < 5/7$	Medium high	$(3/6, 4/6, 5/6)$
$5/7 \leq x < 6/7$	High	$(4/6, 5/6, 1)$
$6/7 \leq x \leq 7/7$	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).

## 5. RESULTS

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.

<b>Indicator</b>	<b>Fuzzy value</b>	<b>Real value</b>
<b>I</b>	(0,07 ; 0,09; 0,12)	<b>0.092</b>
<b>II</b>	(0,14; 0,20; 0,26)	<b>0.198</b>
<b>III</b>	(0,051; 0,065; 0,076)	<b>0.062</b>
<b>IV</b>	(0,15; 0,20; 0,29)	<b>0.176</b>
<b>V</b>	(0.02; 0.03; 0.036)	<b>0.030</b>
<b>VI</b>	(0.095; 0.115; 0.122)	<b>0.113</b>
<b>VII</b>	(0.06; 0.08; 0.09)	<b>0.079</b>
<b>VIII</b>	(0.02; 0.03; 0.036)	<b>0.030</b>
<b>IX</b>	(0.02; 0.03; 0.036)	<b>0.030</b>
<b>X</b>	(0.015; 0.022; 0.029)	<b>0.020</b>
<b>XI</b>	(0.015; 0.022; 0.029)	<b>0.020</b>
<b>XII</b>	(0.043; 0.051; 0.058)	<b>0.050</b>
<b>XIII</b>	(0.037; 0.045; 0.052)	<b>0.043</b>
<b>XIV</b>	(0,04; 0,06; 0,08)	<b>0.060</b>

Table 5.

<i>Experts</i>	<i>VRWPI with TOPSIS</i>	<i>VRWPI with fuzzy TOPSIS</i>
1	<b>0</b>	<b>0</b>
2	<b>0.515</b>	<b>0.503</b>
3	<b>0.645</b>	<b>0.408</b>
4	<b>0.770</b>	<b>0.860</b>
5	<b>0.642</b>	<b>0.720</b>
6	<b>0.440</b>	<b>0.496</b>
7	<b>0.442</b>	<b>0.400</b>
8	<b>0.575</b>	<b>0.592</b>
9	<b>0.597</b>	<b>0.700</b>
10	<b>0.453</b>	<b>0.640</b>
11	<b>0.522</b>	<b>0.667</b>

12	<b>0.564</b>	<b>0.440</b>
13	<b>0.700</b>	<b>0.815</b>
14	<b>0.528</b>	<b>0.775</b>
15	<b>0.643</b>	<b>0.766</b>
16	<b>0.800</b>	<b>0.867</b>
17	<b>0.793</b>	<b>0.811</b>
18	<b>0.433</b>	<b>0.621</b>
19	<b>0.798</b>	<b>0.835</b>
20	<b>1.000</b>	<b>1.000</b>

## 6. CONCLUSIONS

Multi-criteria decision making is a powerful tool used widely to solve problems containing multiple conflicting criteria. 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.

## 7. REFERENCES

- (1) COMMISSION RECOMMENDATION of 5 July 2010 on the assessment of defects during roadworthiness testing in accordance with Directive 2009/40/EC of the European Parliament and of the Council on roadworthiness tests for motor vehicles and their trailers, Brussels 2010
- (2) Van Steen J., Safety performance measurement, European Process Safety Centre, 2005
- (3) Guidance on Safety Performance Indicators, OECD 2003
- (4) Abdullah, L., Zamri, N., On the Causes of Road Accidents: Fuzzy TOPSIS, Second Int. Conference on Computer Research and Development, 2010
- (5) <http://www.cita-vehicleinspection.org> (International Motor Vehicle Inspection Committee)
- (6) <http://www.erscharter.eu/> (European Road Safety Charter)
- (7) ETSC PIN Annual Report 2009
- (8) AUTOFORE WP 300: Vehicle technology / Diagnostic technology
- (10) Council Directive 96/96/EC of 20 December 1996 - Official Journal of the European Communities
- (11) Council Directive 2010/48/EC of 5 July 2010 - Official Journal of the European Communities
- (12) Council Directive 2009/40/EC of 6 May 2009 - Official Journal of the European Communities
- (13) Duboka, Č., Automobilsko forenzičko inženjerstvo, XXII Science and Motor Vehicles Conference Belgrade 2009
- (14) Duboka, Č., Vehicle Condition-Based Roadworthiness Performance Indicator, World Automotive Congress FISITA Budapest 2010
- (15) Duboka, Č., Vehicle Safety Performance Indicators & Indexes, XXIII Science and Motor Vehicles Conference Belgrade 2011
- (16) Berg F.A., Rucker, P., Leimbach, F., Schmorte, U., Chirwa, E.C., Chinnaswamy, G.K., The effects of

- unprofessional repairs on quality and safety of road vehicles subjected to crash loading, Proceedings of ICRASH 2008, Edited by E C Chirwa & H Hiroyuki, Kyoto, Japan, July 2008
- (17) Gordić, M., Procena vrednosti vozila – analiza primene metodasa različitih aspekta posmatranja, (EN:Vehicle value estimation – An analyses of applied methods from different stand-points, AMSS-Centar za motorna vozila, Beograd, XXIII Science and Motor Vehicles Conference 2011
  - (18) Berg F.A., Rücker P., Leimbach F., Kiebach H., 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 2009
  - (19) <sup>1</sup>Jiménez, F., <sup>1</sup>Furones, A., <sup>2</sup>Aguilar, M., <sup>2</sup>del Pozo, V., <sup>1</sup>Aparicio, F., ESTIMATE OF THE INFLUENCE ON SAFETY OF VANS RENEWAL IN SPAIN, <sup>1</sup>University Institute for Automobile Research. Universidad Politécnica de Madrid, INSIA-UPM, Madrid, <sup>2</sup>Instituto de Estudios de Automoción (IEA), Spain, paper EAEC 2011
  - (20) Kahraman, C., Fuzzy Multi-Criteria Decision Making-Theory and Applications with Recent Developments, Volume 16 – 2008
  - (21) Gwo-Hsung, T., Jih-JengH., Multiple Attribute Decision Making – Methods and Applications, CRC Press, Taylor & Francis Group - 2011
  - (22) Erol, O., Kilkis, B., An energy source policy assessment using analytical hierarchy process, Energy Conversion and Management 2012
  - (23) Shin Chul-Oh Yoo, Seung-Hoon, Kwak Seung-Jun, Applying the analytical hierarchy process to evaluation of the national nuclear R&D projects: the case of Korea, Prog Nucl Energy 2007
  - (24) Hamalainen Raimo P., Seppalainen Timo O.,The analytic network process in energy policy planning.,SocioEcon Plan Sci 1986
  - (25) Ramanathan, R., A note on the use of the analytic hierarchy process for environmental impact assessment, J Environ Manage 2001
  - (26) Kahraman, C., Fuzzy Multi-Criteria Decision Making-Theory and Applications with Recent Developments, Volume 16 – 2008
  - (27) <http://www.etsc.be> (European Transport Safety Council)
  - (28) SafetyNet Final Activity Report2009 – Building the European Road Safety Observatory, [www.erso.eu](http://www.erso.eu)
  - (29) Jakimovska, K. "Development of methodology for condition based vehicle assessment "PhD thesis - University Ss. Cyril and Methodius - Faculty of Mechanical Engineering - Skopje, 2014
  - (30) Nardo M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., Giovannini, E., “Handbook on constructing composite indicators: methodology and user guide”–OECD Statistics Working Paper – 2005 - vol. 3
  - (31) Hwang, C.L.; Yoon, K.,“Multiple Attribute Decision Making: Methods and Applications”, New York: Springer-Verlag, 1981
  - (32) DEKRA Automobil GmbH - Road Safety Report 2008 – Strategies for preventing accidents on Europa’s roads
  - (33) DEKRA Automobil GmbH – Verkehrssicherheitsreport Landstrassen 2013 – Strategien zur Unfallvermeidung auf den Strassen Europas
  - (34) Awasthi, A., Chauhan, S., Omrani, H., Application of fuzzy TOPSIS in evaluating sustainable transportation systems, Expert Systems with Applications 2011
  - (35) Hwang, C.L.; Yoon, K.,“Multiple Attribute Decision Making: Methods and Applications”, New York: Springer-Verlag, 1981
  - (36) Yoon, K., “A reconciliation among discrete compromise situations”, 38. pp. 277–286, 1987
  - (37) Hwang, C.L., Lai, Y.J.; Liu, T.Y., "A new approach for multiple objective decision making". Computers and Operational Research20: 889–899, 1993
  - (38) Yoon, K.P., Hwang, C., “Multiple Attribute Decision Making: An Introduction” California: SAGE publications, 1995
  - (39) Zavadskas, E.K., Zakarevicius, A., Antucheviciene, J., "Evaluation of Ranking Accuracy in Multi-Criteria Decisions". Informatica17 (4): 601–618, 2006
  - (40) Greene, R.; Devillers, R.; Luther, J.E.; Eddy, B.G., "GIS-based multi-criteria analysis", Geography Compass5/6: 412–432, 2011
  - (41) Nardo M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., Giovannini, E., “Handbook on constructing composite indicators: methodology and user guide”–OECD Statistics Working Paper – 2005 - vol. 3

- (42) Al Haji, G., "Development of an International Index to Measure Road Safety Performance", Dissertation thesis, Department of Science and Technology, Campus Norrköping, Linköping University Norrköping, Sweden 2005
- (43) Huang, J., Chen, R., Wang, X., Zhou, Y. "Study on the Application of Fuzzy TOPSIS to the Multi-objective Decision Making", International Conference on Intelligent Computation Technology and Automation, proceedings paper, 2010
- (44) Hwang, C.L.; Yoon, K., "Multiple Attribute Decision Making: Methods and Applications", New York: Springer-Verlag, 1981