International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-3 Issue-5, October 2013

Application of Multi Criteria Decision Making Tools in Road Safety Performance Indicators and Determine Appropriate Method with Average Concept

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Abstract*—This article presents the implementation of Multi Criteria Decision Making to evaluation of road safety performance in 21 European countries. These countries will be prioritizing based on 11 safety indicator. Simple Additive Weight method will used to evaluate 21 countries to determine which country has a best safety performance to reduce the fatality and accidents and which factors has more effect on performance measures. At last three methods of MCDM such as SAW, AHP and FUZZY TOPSIS will be compared to determine with method is sufficient for ranking of these countries based on safety factors and the result is closer to reality.

Index Terms*—Multi Criteria Decision Making, SAW, AHP, FUZZY TOPSIS, Road Safety Indicators.

I. INTRODUCTION

Road traffic collisions are a major cause of premature death and disability worldwide: every year, 20 to 50 million people involved in collisions are injured and around 1.3 million die.[17] In particular, road traffic injuries are the main cause of death among adolescents and young adults.[16] The World Health Organization (WHO) estimates that death from road traffic injuries will become the fifth leading cause of death worldwide in 2030;3 in 2004, it was the ninth.[6] Although 90% of these deaths are concentrated in low- and middle-income countries, road traffic collisions in WHO's European Region cause at least 120 000 deaths and injure 2.4 million people each year.[6]

Road traffic injuries have not always been considered a preventable health problem,5 but it has long been known that they are related to modifiable determinants. Tackling them is not substantially different from tackling other health problems.[9] Actions to prevent road traffic injuries and reduce associated mortality and disability include modifying the various factors involved in collisions.

Manuscript published on 30 October 2013.
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These factors may play a role before, during or after a collision and may be related to the characteristics of the individuals involved, the vector that made the transfer of mechanical energy possible (e.g. the vehicle) or physical and socioeconomic circumstances.6 Several interventions have proved effective in preventing road traffic injuries. Among them are legal measures aimed at restricting driving under the influence of alcohol and at ensuring gradual access to driving licences, as well as improvements in the design of vehicles and the road network.[11]

In the early years of the twenty-first century, the government of Catalonia, an autonomous region in north-eastern Spain, endorsed the European Commission's goal of cutting by half the number of deaths from road traffic collisions between 2000 and 2010 and included this goal in road safety and health policy.[7,21,5] The development of new road safety policies was made possible by a social and political consensus on the importance of road safety. Actions were taken to decrease traffic speed, reduce driving under the influence of alcohol, increase the use of safety equipment and improve the road infrastructure. Several interventions were implemented: educational campaigns were run through the mass media, police monitoring was increased and fines were used more extensively. In 2006, legal measures were introduced to fine reoffenders using a penalty point system and to make serious traffic infractions a criminal offence. Studies have shown that the incidence of road traffic injuries can be greatly reduced by speed cameras,[12] by including road safety in the political agenda,[13] by using a penalty point system13 and by criminalizing traffic offences.[15,22]

One factor that has an impact on the success of the highway safety programs investigated is the existence of strong highway safety support activities. Each country does a significant amount of data collection and analysis to show the impacts of existing or planned safety improvements, monitor and evaluate the effectiveness of measures, and investigate the performance of operating agencies. Significant funding is provided to highway safety research agencies for their active technical support, expertise, and policy analysis capabilities. Substantial intellectual capacity is directed to the highway safety field. In several cases, the national government provides a significant portion of the funding for research organizations with highway safety analysis capabilities and nongovernmental organizations. Nongovernmental organizations, for the most part, are direct participants in the highway safety programming and plan development decision-making process. They challenge governmental approaches and operate as a watchdog or representative of the general public [3].

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II. MULTI CRITERIA DECISION MAKING

The Multi criterion Decision-Making (MCDM) are gaining importance as potential tools for analyzing complex real problems due to their inherent ability to judge different alternatives (Choice, strategy, policy, scenario can also be used synonymously) on various criteria for possible selection of the best/suitable alternative [19]. These alternatives may be further explored in-depth for their final implementation. Multi criterion Decision-Making (MCDM) analysis has some unique characteristics such as the presence of multiple non-commensurable and conflicting criteria, different units of measurement among the criteria, and the presence of quite different alternatives. It is an attempt to review the various MCDM methods and need was felt of further advanced methods for empirical validation and testing of the various available approaches for the extension of MCDM into group decision-making situations for the treatment of uncertainty. The weighted sum model (WSM) is the earliest and probably the most widely used method. The weighted product model (WPM) can be considered as a modification of the WSM, and has been proposed in order to overcome some of its weakness. The analytic hierarchy process (AHP), as proposed by Saaty is a later development and it has recently become popular. Recently modification to the AHP is considered to be more consistent than the original approach. Some other widely used methods are the ELECTRE, SAW and the TOPSIS methods [19].

III. ENTROPY SHANON METHOD

Entropy is a method for assessment of weights of decisionmatrix attributes which seems to be a major concept in physical and social sciences and also in the information theory where it measures the expected information content of a certain message [1]. In other words, in information theory, Entropy is a criterion for determination of the degree of unreliability of a discrete probability distribution P_i in such a way that this unreliability in biased distributions is more than sharper distributions [10]. This unreliability is demonstrated as follows [23,8]:

$$E_i = S(P_1, P_2, \ldots, P_n) = -K \sum P_i Ln\,\mathrm{P_i} \qquad (1)$$

$$(\mathrm{i} = 1, 2, 3, \ldots, \mathrm{m})$$

Such that k is a positive constant to fulfill $0 \le E_i \le 1$.

E is computed from the probability distribution P_i based on a statistical mechanism and its amount will be maximum if P_i are equal with each other $P_i = \frac{1}{n}$.

A decision matrix contains information which can be evaluated via Entropy technique. Now consider a decision matrix below:

$$D = \begin{matrix} & X_1 & X_2 & \cdots & X_n \\ A_1 & r_{11} & r_{12} & \cdots & r_{1n} \\ A_2 & r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & r_{m1} & r_{m2} & \cdots & r_{mn} \end{matrix} \qquad (2)$$

Elements $(P_{ij})j$ of this matrix are initially calculated as follows:

$$P_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad ;\ \mathrm{j} = 1, \ldots, \mathrm{n}\ \forall_{\mathrm{ij}} \qquad (3)$$

For E_j from the set P_{ij} for any attribute we have:

$$E_j = -K \sum_{i=1}^{m} P_{ij}.Ln(P_{ij}) \quad \mathrm{j} = 1, \ldots, \mathrm{n}\ \forall_j \qquad (4)$$

K represents a constant $K = \frac{1}{Ln(m)}$ which guarantees that $0 \le E_j \le 1$

Now the degree of unreliability or the same degree of deviation from constructed information d_j for the attribute J is as follows:

$$d_j = 1 - E_j\ , \forall_{\mathrm{j}} \qquad (5)$$

Eventually, in order to calculate the weight of each attribute J we have:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j}, \forall_{\mathrm{j}} \qquad (6)$$

In a case that decision maker has a subjective judgment λ_j as a relative importance for the attribute J, and then th calculated w_j can be adjusted via Entropy as below [8]:

$$W_j = \frac{\lambda_j w_j}{\sum_{j=1}^{n} \lambda_j w_j}, \forall_{\mathrm{j}} \qquad (7).$$

IV. SAW METHOD

In this method, the coefficient of determination or decision criteria based on Shannon entropy weighting and vector methods such as special least squares, with Using the weighted average , importance coefficient of each alternatives are obtained and the most number of them will be considered as an optimized factor[1,8].

As a given W and a sufficient factor A^*, thus A^* will be obtained as bellow [8].:

$$A^* = \left\{ A_i \middle| \max_i \frac{\sum_{j=1}^{n} W_j r_{ij}}{W_j} \right\} \qquad (8)$$

If $\sum W_j = 1$ then A^* equal to:

$$A^* = \left\{ A_i \middle| \max_i \sum_{i=1}^{n} W_j r_{ij} \right\} \qquad (9)$$

V. ROAD SAFETY INDICATORS

In this section according to collected data by saaty we have 11 road safety indicators with statistics data those had been collected between 21 European countries. These indicators are classified in six different

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-3 Issue-5, October 2013

groups that some of groups have subsets. The indicators are shown as bellow [20]:

- The percentage of surveyed car drivers disrespecting the alcohol limit (A1);
- The percentage of surveyed car drivers exceeding the speed limit in built-up areas (S1);
- The seat belt wearing rate in front seats (P1);
- The share of relatively new passenger cars (i.e. less than 6 years old) (V1);
- The motorway density (R1);
- The expenditure on health care as share of the gross domestic product (T1).
- The seat belt wearing rate in rear seats (P2);
- The median age of the passenger car fleet (V2);
- The share of motorcycles in the vehicle fleet (V3);
- The share of heavy goods vehicles (HGV) in the vehicle fleet (V4);
- The share of motorway in total road network (R2).

VI. MCDM APPLICATIONS ON ROAD SAFETY INDICATORS

MCDM method in road safety management is used to optimize the financial and performance management of road safety science. In 2012 statistics of 11 safety indicator from 21 Europeans countries were collected to rank the road safety performance of these countries. All data analyzed with two type of MCDM method collected and these countries were ranked under these methods with different procedure. The methods were AHP method and FUZZY TOPSIS method. In the following presented briefly the procedure and concepts of these methods and at last the ranking of 21 country will be shown in table1 and table 2 [20].

VII. FUZZY TOPSIS METHOD

In most real world contexts, MCDM problems at tactical and strategic levels often involve fuzziness in their criteria and decision makers judgments. For example, due to the uncertainty of human cognition and vague judgment, linguistic assessments rather than crisp numerical values are usually given by decision makers or experts [20]. As a result, the application of the classical TOPSIS method may face serious practical problems. To deal with these qualitative, imprecise, or even ill-structured decision problems, suggested employing the fuzzy set theory as a modeling tool for complex systems that can be controlled by humans but are hard to be defined exactly. During the last two decades, an extension of the classical TOPSIS to the fuzzy environment was widely investigated and a large number of fuzzy TOPSIS methods were developed in the literature. In general, they embody the fuzzy nature of the comparison or evaluation process and strengthen the comprehensiveness and rationality of the decision-making process. The ranking of 21 countries under the FUZZY TOPSIS method is shown in table 1[20].

Table1. Ranking with FUZZY TOPSIS method

Alternatives	FUZZY TOPSIS	PRIORITY
Germany	0.681	1
United Kingdom	0.651	2
Sweden	0.632	3
Netherlands	0.621	4
Slovenia	0.62	5
Switzerland	0.617	6
Denmark	0.607	7
Ireland	0.568	8
France	0.558	9
Austria	0.539	10
Belgium	0.524	11
Spain	0.505	12
Finland	0.497	13
Portugal	0.453	14
Hungary	0.429	15
Czech Republic	0.422	16
Italy	0.421	17
Estonia	0.377	18
Poland	0.361	19
Greece	0.35	20
Cyprus	0.348	21

VIII. AHP METHOD

The indicators those mentioned before may not equally affect the safety of a road. A system of weights therefore needs to be introduced to reflect the contribution to safety of each element and factor. The relative weights of the above elements and subsequent factors are determined using Analytical Hierarchy Process (AHP). As a mathematical procedure, AHP can find the contribution of each item (e.g., element) in a problem. Moreover, if there is a hierarchy of items, as is the case in this study, where there are elements and then factors, AHP can also attribute a weight to the sub items (e.g., factors).

Mathematically, AHP uses pair-wise comparisons to systematically scale the items. It calculates the eigenvalues of the Relative Weight Matrix, and determines the relative weights by determining the eigenvector [20,23].Table 2 shows the ranking of 21 countries under AHP method.

Table2. Ranking with AHP method

Alternatives	AHP	PRIORITY
Spain	0.135545	1
Germany	0.124455	2
Netherlands	0.119455	3
Belgium	0.114091	4
Cyprus	0.113636	5
Switzerland	0.093636	6
Italy	0.084636	7
Portugal	0.080182	8
Denmark	0.076091	9
France	0.076	10
Austria	0.073909	11
Slovenia	0.073364	12
Greece	0.059909	13
United Kingdom	0.057636	14
Sweden	0.053545	15
Czech Republic	0.052	16
Finland	0.048455	17
Hungary	0.044727	18
Estonia	0.042182	19
Ireland	0.039091	20
Poland	0.037091	21

In this section according to collected data from 21 Europeans countries all these

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countries will be ranked under the SAW method.

IX. RANKING WITH SAW METHOD

At this step to start SAW method we need the normalized decision matrix and then P_{ij} will be calculated from decision matrix.

In next step E_j will be calculated with using P_{ij}.

K Value will calculated from following formula:

$$K = \frac{1}{Ln(21)} = 0.32845873\ 9$$

Following table 4 shows the value of geometric mean.
Following Table 3 shows the value of geometric mean.

Table3. Geometric Mean

Geometric Mean (Wj)
0.087
0.093
0.087
0.092
0.092
0.091
0.092
0.093
0.092
0.091
0.09

With using geometric means and formula 8 the prioritization value will be calculated.
After the SAW procedure the last prioritization table of 21 countries is shown in table 4.

Table4. Ranking with SAW method

Country	Ranking	Priority
Germany	1	0.6813
Sweden	2	0.6045
United Kingdom	3	0.6044
Ireland	4	0.5898
Netherlands	5	0.5896
Switzerland	6	0.5830
Slovenia	7	0.5781
Denmark	8	0.5438
Spain	9	0.5176
France	10	0.5131
Belgium	11	0.5076
Austria	12	0.4821
Finland	13	0.4631
Portugal	14	0.4111
Italy	15	0.4099
Estonia	16	0.3906
Hungary	17	0.3775
Poland	18	0.3743
Czech Republic	19	0.3732
Cyprus	20	0.3732
Greece	21	0.3561

All the 21 European countries were ranked based on three MCDM methods. But according to difference of ranking between these three methods we should verify that which method is better for ranking. In this step to select the best method to obtain sufficient and appropriate ranked data for managing in road safety, the averaging method will be used to specify best method in prioritization.

Table 6 shows the data to determine best method between SAW, AHP and FUZZY TOPSIS. First the average of three methods was calculated and mentioned in average column. The next column Δ_1 is the difference between average and SAW method. The Δ_2 shows the difference between average and FUZZY TOPSIS data, Δ_3 show the difference between average and AHP method.

After calculating the difference between methods and average of them now to determine best MCDM method to ranking all difference data for each column will be summed and then will divided to 21 countries and then will specify which one is closer to zero, this that method is best method in country ranking.

According to tables 5 and 6 the average of delta were obtained and the average of SAW method is closest number to zero thus this method in best and sufficient method between three MCDM method.

Table5. Average of three methods

COUNTRIES	SAW	FUZZY TOPSIS	AHP	AVERAGE
Austria	0.4821	0.5390	0.0739	0.3650
Belgium	0.5076	0.5240	0.1141	0.3819
Cyprus	0.3732	0.3480	0.1136	0.2783
Czech Republic	0.3732	0.4220	0.0520	0.2824
Denmark	0.5438	0.6070	0.0761	0.4090
Estonia	0.3906	0.3770	0.0422	0.2699
Finland	0.4631	0.4970	0.0485	0.3362
France	0.5131	0.5580	0.0760	0.3824
Germany	0.6813	0.6810	0.1245	0.4956
Greece	0.3561	0.3500	0.0599	0.2553
Hungary	0.3775	0.4290	0.0447	0.2838
Ireland	0.5898	0.5680	0.0391	0.3990
Italy	0.4099	0.4210	0.0846	0.3052
Netherlands	0.5896	0.6210	0.1195	0.4434
Poland	0.3743	0.3610	0.0371	0.2575
Portugal	0.4111	0.4530	0.0802	0.3148
Slovenia	0.5781	0.6200	0.0734	0.4238
Spain	0.5176	0.5050	0.1355	0.3860
Sweden	0.6045	0.6320	0.0535	0.4300
Switzerland	0.5830	0.6170	0.0936	0.4312
United Kingdom	0.6044	0.6510	0.0576	0.4377

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SUM	-	-	-	-
AVERAGE	-	-	-	-

Table6. Difference between three averages

COUNTRIES	Δ_1	Δ_2	Δ_3
Austria	-0.2248	-0.2030	0.3259
Belgium	0.0044	-0.0471	0.3372
Cyprus	-0.2393	-0.2267	0.1427
Czech Republic	-0.2956	-0.3376	0.2091
Denmark	-0.0541	-0.0880	0.3605
Estonia	-0.3345	-0.3621	0.2164
Finland	-0.0737	-0.0848	0.2515
France	0.0263	0.0324	0.3224
Germany	0.0135	-0.0434	0.4217
Greece	-0.3491	-0.3957	0.1977
Hungary	-0.1273	-0.1692	0.2036
Ireland	-0.1141	-0.1590	0.3230
Italy	-0.0691	-0.0558	0.2681
Netherlands	-0.0643	-0.0806	0.3293
Poland	-0.3255	-0.3595	0.1638
Portugal	-0.2749	-0.3062	0.1953
Slovenia	0.0332	0.0468	0.3816
Spain	-0.2953	-0.2950	0.2616
Sweden	-0.1138	-0.1770	0.3539
Switzerland	0.0580	0.0092	0.3792
United Kingdom	0.0645	0.0897	0.3240
SUM	-2.7557	-3.2128	5.9685
AVERAGE	-0.1312	-0.1530	0.2842

X. CONCLUSION

In this article according to needs of road safety management, MCDM methods were used to determine in which country the policy and safety measure are appropriate to reduce the numbers of accident and fatality in European countries. Two methods of AHP and FUZZY TOPSIS were implemented to prioritize these countries but in this article another MCDM method was used to show new prioritization system to evaluation road safety performance. According to the last part of article to determine which method is best method to use in this science the averaging concept was used and at last Simple Additive Weight was specified the best method to prioritize these countries.

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