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Evaluation of Road Safety Performance Based on Analytic Hierarchy Process

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Abstract— This article present the evaluation of SPIs (safety parameter indicator) affecting on road safety with using the MCDM method. Multi criteria decision making is one the method that used in decision management with more than one criteria to prioritize the factors. MCDM has types of technique to prioritize the factors but one of this technique is AHP (Analytic Hierarchy Process) used in this article. Statistical data in this article are taken from 21 European countries. All data classified in 11 safety performance indicators and used in AHP method. All 21 countries will be ranked with AHP based on these data and after ranking we can analysis that wich country has better policy and appropriate safety plane to enhance the quality of safety and transportation.

Index Terms—Analytic Hierarchy Process, AHP, MCDM, Road Safety Indicators, Safety Management.

I. INTRODUCTION

Due to the human as well as financial suffering caused by road crashes, road safety is a relevant theme to study. The World Health Organization estimates that worldwide each year 1.3 million people are killed and between 20 and 50 million are injured in road crashes [1]. In 25 countries of the European Union a total of almost 40,000 fatalities were registered in 2006, which is a decrease of 30% compared to the number in 1997. However, if the trend continues at the same rate, the European Commission's goal of halving the number of fatalities by 2010 will not be achieved. Researchers like [11,14] state that the easy problems in traffic safety have already been addressed (by taking measures based on common sense) and as a result more complex problems need to be handled to achieve further reductions in road crashes and casualties. To improve the road safety level in a country, it is therefore interesting to study the various factors that influence it, leading to valuable policy recommendations [1].

The role of safety performance indicators in safety management Road safety can be assessed in terms of social costs of accidents and injuries. However, simply counting crashes or injuries is often an imperfect indicator of the level of road safety. Frequently, accidents and injuries are only the tip of the iceberg, because they occur as the "worst case" of unsafe operational conditions of the road traffic system. At the same time, road safety policymakers and analysts aiming at a higher level of safety need to take into account as many factors influencing safety as possible or, at least, those factors they are able to affect or control. Additional safety performance indicators (rather than accident/ injury numbers) might provide a means for monitoring the effectiveness of safety actions applied. ETSC (2001) details the reasons for the need in safety performance indicators, as follows [6]:

• The number of road crashes and injuries is subject to random fluctuations, where a short term change in the recorded numbers does not necessarily reflect a change in the underlying, long-term expected numbers [6];

• Reporting of crashes and injuries in official road accident statistics is incomplete. Thus, an observed change in the number of crashes could merely be a change in the propensity to report crashes by the police.

• A count of crashes sometimes says nothing about the processes that produce crashes. It is, to some extent, a matter of chance whether a hazardous situation or a near miss results in a crash or not. It is possible that in spite of risky conditions, luckily, no accident occurred [6].

• In order to develop effective measures to reduce the number of accidents/ injuries it is necessary to understand the processes that lead to accidents. Safety performance indicators can serve this purpose. Safety performance indicators (SPIs) are seen as any measurement that is causally related to crashes or injuries and is used in addition to the figures of accidents or injuries, in order to indicate safety performance or understand the process that leads to accidents [6].

They also provide the link between the casualties from road accidents and the measures to reduce them. As believed, safety performance indicators can give a more complete picture of the level of road safety and can point to the emergence of developing problems at an early stage, before these problems show up in the form of accidents. Safety performance indicators help illustrate how well road safety programs are doing in meeting their objectives or achieving the desired outcomes. They are a means of monitoring, assessing and evaluating the processes and operations of road safety systems concerning their potential to solve the problems they are up against. They use qualitative and quantitative information to help to determine a program's success in achieving its objectives [6].

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They could be used to track progress and could provide a basis to evaluate and improve performance. In order to properly perform their function, SPIs need to be relevant to the program's desired outcomes and objectives, and to be quantifiable, verifiable and unbiased. Before the elaboration of SPIs for specific problem areas, it is important to define a uniform vision and common methodology for their development. The common approach should ensure the reliability and validity of SPIs, increase the acceptance and application of SPIs and at last get transparency for the potential users of SPIs.

The European Transport Safety Council (ETSC) recently initiated a project of a close follow up of the progress achieved in road safety by the EU-countries. The project is presented as a new policy instrument assisting to compare Member States' performance in promoting safe road user behavior, infrastructure and vehicles, as well as sound and evidence-based policy-making. The main idea of the instrument is to compare the countries by means of the Road Safety Performance Index (so-called "Road Safety PIN") which is based on generally accepted road safety indicators including accident data and data related to road safety performance. For example, compared the countries in terms of percentage of change in the national numbers of fatalities, over the years 2001-2005; background considerations of the causes to a remarkable progress made by some countries (e.g. France, Belgium, Luxembourg, Portugal, and the Netherlands) accompanied the figures presented. According to the 2003 European action program, the use of performance indicators makes it possible to target actions in key areas systematically and to monitor implementation. These may concern particular groups of road users such as children, new drivers or professional drivers, or compliance with important safety rules such as seat belt wearing, or cover specific areas such as the urban road network, country roads or the trans-European network. Performance indicators for speed, drinking and driving, the use of restraint systems and safety devices, number of roadside checks are already used in some member States and therefore could be adopted by other countries. The following stage is seen in the development of indicators in areas relating to the management of road network standards, the characteristics of vehicles on the roads and the emergency services provided [6].

Road traffic accidents comprised the second largest cause of death. Some data was obtained from Statistics Norway indicated that there are more injuries in urban Hordaland, but more deaths in rural Hordaland and Finnmark. The discrepancy between fatality and injury rates may be due to differences in accident severity, disadvantages in rural trauma care, or both. Although urban areas may have higher injury rates due to higher traffic density, they may also have lower accident severity as a result of lower speeds. Conversely, rural accidents may be more severe owing to higher speeds, but possibly also to more head-on collision, older, less crash-secure cars; and different attitudes towards seatbelt use [10,2,9]. Disadvantages in rural trauma care may come from longer discovery and transport times due to long distances or weather conditions [5], or health care workers in rural areas may be less experienced in handling trauma because they see fewer cases than their urban colleagues [4]. Reference to a non-trauma centre has been shown to adversely affect outcome in trauma [6]. In an area as rural as Finnmark, direct transfer is often not an option, which in turn may have an impact on mortality rate. Local hospitals in Finnmark have improved in-house trauma care by the regular multiprofessional trauma team training that seems to even out differences between urban and rural care [15].

II. MULTI-CRITERIA DECISION MAKING TECHNIQUES

"Decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker (DM). Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that has the highest 11 probability of success or effectiveness and best fits with our goals, desires, lifestyle, values, and so on. "In one word, the process of decision making is the selection of an act or courses of action from among alternative acts or courses of actions such that it will produce "optimal" results under some criteria of "optimization" [14].

Multi-criteria decision making (MCDM) is one of the most well-known branches of decision making, which offers the methodology for decision making analysis when dealing with problems that involve multiple objectives under the presence of a number of conflicting decision criteria [14 MCDM can help users understand the results of integrated assessments, including tradeoffs among policy objectives, and can use those results in a systematic, defensible way to develop policy recommendations. A typical MCDM problem is modeled as Eq. (1)[14]:

$$(MCDM) = \begin{cases} Select : A_1, A_2, \ldots, A_m \\ S.t : C_1, C_2, \ldots C_n \end{cases} \quad (1)$$

Where $A = (A_1, A_2, \ldots, A_m)$ denotes m alternatives, $C = (C_1, C_2, \ldots C_n)$ represents n criteria.

III. BASIC CONCEPTS

According to many authors (e.g., [14]), MCDM is divided into multi objective decision making (MODM) and multi-attribute decision making (MADM). MODM problems involve designing the best alternative given a set of conflicting objectives. A typical example is mathematical programming problems with multiple objective functions [14]:. In contrast to MODM problems, MADM refers to making preference decisions (e.g., evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes. Very often the terms MADM and MCDM are used to mean the same class of models (i.e., MCDM). Although MCDM methods may be widely diverse, many of them share the following common characteristics [14]:

Alternatives: Usually alternatives represent the different choices of action available to the decision maker. A finite number of alternatives, ranging from several to thousands, 12 are supposed to be screened, prioritized, selected, and/or ranked. The term 'alternative' is synonymous with 'option', 'policy', 'action', or 'candidate', among others [13].

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Multiple Attributes: Each MCDM problem is associated with multiple attributes, and they are also referred to as 'decision criteria'. Attributes represent the different dimensions from which the alternatives can be viewed. The number of attributes depends on the nature of the problem. In case the number of criteria is large, attributes may be arranged in a hierarchical manner. That is, there are some major criteria, and each may be associated with several sub-criteria [14].
Decision Weights: Almost all MCDM methods require information regarding the relative importance of each criterion to the decision, and it is assumed to be positive. The weights of the criteria are usually determined on subjective basis. They represent the opinion of a single decision maker or synthesize the opinions of a group of experts using a group decision technique, as well [14].
Decision Matrix: A MCDM problem can be concisely expressed in a matrix format, where rows indicate criteria considered in a given problem and rows list Competing alternatives. Thus a typical element xij of the decision matrix (Dm× n) indicates the performance of alternative Ai when it is evaluated in terms of decision criterion Cj (for i=1, 2, ⋯, m, and j=1, 2, ⋯, n). For the sake of simplicity we assume that a higher score value means a better performance since any goal of minimization can be easily transformed into a goal of maximization. It is also assumed that the decision maker has determined the weights of relative performance of the decision criteria which are denoted as wj (j=1, 2, ⋯, n). The information is summarized in a matrix format in Eq. (2):

$$D = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ A_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ A_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{matrix} \qquad (2)$$

$$w = [w_1 \quad w_2 \quad \cdots \quad w_n]$$

Where the values of xij and wj, $\forall_i$, j can be crisp or linguistic variables that are described by any form of fuzzy numbers. For example, in triangular fuzzy numbers, xij=(aij, bij, cij) and $w_j = (w_{j1}, w_{j2}, w_{j3})$ [Elke, 2000].

IV. THE AHP

The AHP is a multi-attribute decision tool that allows financial and non-financial, quantitative and qualitative measures to be considered and trade-offs among them to be addressed. The AHP is aimed at integrating different measures into a single overall score for ranking decision alternatives. Its main characteristic is that it is based on pair-wise comparison judgments. The description is developed in three steps [13].
Step 1: this step relates the comparison of the alternatives and the criteria. Once the problem has been decomposed and the hierarchy is constructed, prioritization procedure starts in order to determine the relative importance of the criteria within each level. The pairwise judgment starts from the second level and finishes in the lowest level, alternatives. In each level, the criteria are compared pairwise according to their levels of influence and based on the specified criteria in the higher level [12].
Following matrix (A) shows the pairwise comparison method.

$$A = [a_{im}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & 1 & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} i, m = 1, 2, ..., m. \qquad (3)$$

Let C1, C2, . . .,Cn denote the set of elements, while aim represents a quantified judgment on a pair of elements, Ci and Cm. Saaty constitutes a measurement scale for pair-wise comparison. Hence, verbal judgments can be expressed by degree of preference: Equally preferred with 1, Moderately preferred with 3, Strongly preferred with 5, Very strongly preferred with 7 and Extremely preferred with 9; 2, 4, 6 and 8 are used for compromise between the above values.
Step 2: Normalize the decision matrix. Each set of column values is summed. Then, each value is divided by its respective column total value. Finally, the average of rows is calculated and the weights of the decision-maker ' s objectives are obtained. A set of n numerical weights w1, w2, . . .,wi are obtained.
Step 3: Do consistency analysis [12].

$$A * w_i = \lambda_{\max} * w_i, \quad i = 1, 2, ..., n. \qquad (4)$$

Then consistency index (CI) is calculated as:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \qquad (5)$$

The consistency index of a randomly generated reciprocal matrix shall be called to the random index (RI), with reciprocals forced. An average RI for the matrices of order 1 – 15 was generated by using a sample size of 100. The table of random indexes of the matrices of order 1 – 15 can be seen in [13]. The last ratio that has to be calculated is CR (consistency ratio). Generally, if CR is less than 0.1, the judgments are consistent, so the derived weights can be used. The formulation of CR is [12]:

$$CR = \frac{CI}{RI} \qquad [6]$$

V. SELECTION OF SPIS

The selections of SPIs have been done [3]. The policy of selecting SPIs was having determined the essential road safety risk domains and indicated the relation between each of them and road traffic accidents/casualties, the focus was on finding appropriate SPIs for each domain. In that respect, eight selection criteria, i.e., a safety performance indicator should was relevant, measurable, understandable, data available, reliable, comparable, specific and sensitive, were summarized by [8] in order to identify the best needed and best available SPIs. As the unavailability of reliable and comparable data limit the use of best needed indicators to some extent, only one–best available–indicator was used to represent each of the six risk domains in her study. They are:

- ✓ 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);

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- ✓ 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).

Since the collection and searching for additional data on the best needed indicators is an

Ongoing process, some other best available indicators were found and served as the complements of the above six indicators, which are:

- ✓ 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).

In other words, two or more SPIs can be formulated to represent some of the six risk domains. Moreover, the indicators belonging to a particular domain may also be linked to one another constituting a hierarchical structure, which is illustrated in Figure 1.

VI. DATA COLLECTION

From a wide range of international databases and recent publications of international working groups, and also based on the research work of [14], values related to 2003 were obtained for the developed 11 SPIs for 21 European countries being Austria (AT), Belgium (BE), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Hungary (HU), Ireland (IE), Italy (IT), the Netherlands (NL), Poland (PL), Portugal (PT), Slovenia (SL), Spain (ES), Sweden (SE), Switzerland (CH), and United Kingdom (UK). More specifically,

1) As the indicator for the alcohol and drugs domain, i.e., the percentage of car drivers often driving while having a blood alcohol concentration above the legal limit, the data are obtained from the Social Attitudes to Road Traffic Risk in Europe (SARTRE) research [14];

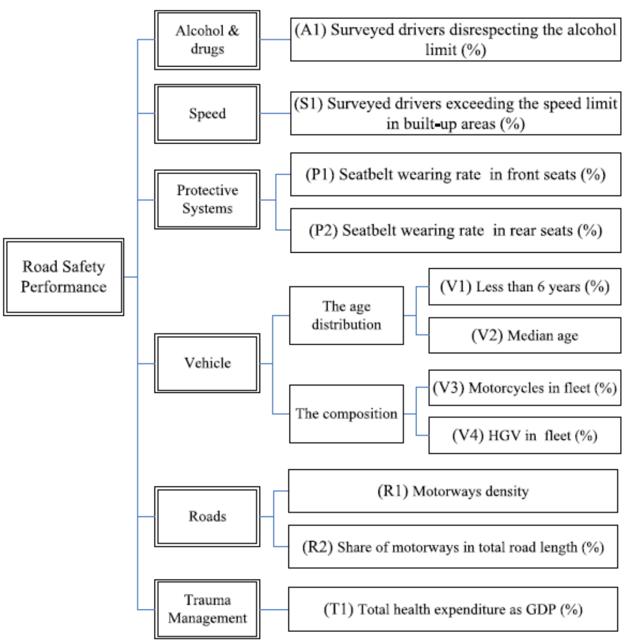

Fig.1. The hierarchical structure of the SPIs.

2) For the speed domain, the percentage of drivers exceeding the maximum speed limit in built-up areas is the chosen indicator. These data were also derived from SARTRE;
3) As third domain indicators, we select the percentage of persons wearing a seatbelt in the front seats as well as the percentage in the rear seats, with data from the ETSC [2] and Safety Net, respectively [Elke, 2000];
4) For the vehicle domain, the first two indicators related to the age distribution of the vehicle fleet, which are the share of relatively new passenger cars (i.e. less than 6 years old) and the median age of the passenger car fleet, and the data are available in the United Nations Economic Commission for Europe (UNECE) [14]. While for the other two indicators about the composition of the vehicle fleet, i.e., the shares of motorcycles and HGV in the vehicle fleet, respectively, the data are collected from the European Commission [14];
5) The infrastructural indicators, the motorway density (defined as the ratio of the total length of the motorway and the area of the country), and the share of motorway in total road network are constructed using data from Eurostat [Eurostat, 2009] and UNECE [14];
6) Finally, the trauma management domain and specifically the share of the gross domestic product spent on health uses data derived from the World health Organization .In Table 1 [14], the data set with 11 indicators is presented. The last row indicates the 2003 number of road fatalities per million inhabitants (F1) in the 21 countries, with the data from the European Commission.

Now according to step 1 we should provide pairwise comparison matrix. In this project all the data and statistics for 12 SPIs had been collected from 21 European countries as shown in table 1. To calculate the pairwise comparison with this data to ranked the total countries each safety factor in one country should be divide on another safety factor in another country so that number shows the pairwise comparison of that two countries on same road safety factor. For example in road safety indicator of A1 if we want to calculate the pairwise comparison between two countries of AT and BE the process is like this:

$$\text{pairwise } comparison = \frac{\text{A1 of AT}}{\text{A1 of BE}} = \frac{2.6}{5.8} = 0.448 \approx 0.45 \qquad (6)$$

All pairwise comparison matrix A for each SPI had been done with excel and ready to use in other formula.

$$A = [a_{im}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & 1 & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} i, m = 1, 2, \ldots, m. \qquad (7)$$

Pairwise comparison for all safety indicators have been done as mentioned.

In step 2 the pairwise matrix will be normalized. To normalizing the pairwise comparison matrix first all values of each column will be summed and after that each value divided by sum of its columns. For example in first column and first value the normalizing will done as follow:

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$$\text{sum of column} = 31.49$$

$$Normalazing \text{ value} = \frac{\text{value}}{\text{Sume of column}} = 0.031756113$$

Now to determine the weights of the decision-maker the value of each row in normalized matrix will be summed and after that the average of that row will be calculated. For example the weights of the decision-maker of first row calculated as below:

$$weights \text{ of decision maker} = \frac{sum \text{ of row values}}{\text{numbers of columns}} = \frac{0.6657}{21} = 0.032 \quad (9)$$

All weights of decision makers have been calculated and it's shown in table (4).

The last step for ranking of each SPI id consistency index (CI) that calculated as:

$$A * w_i = \lambda_{\max} * w_i \,, \quad i = 1, 2, \ldots, n.$$

$$\lambda_{\max} = 40.519$$

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{40.519 - 17}{17 - 1} = 1.47$$

This calculation was done for prioritization of 21 European countries aspect of safety parameter indicator A1. The last ranking is the averaging of 11 priority table for all countries. The sum of all prioritization aspect of each SPIs were calculated and then divided by number of SPIs so the last ranking was ready.

Table 1 is based on 21 countries ranking in Europe, those ranked by AHP method with comparing the PSIs. The rankings show each country's policy of employing modern security systems to control the roads, raising the standards of quality vehicles and other plans that they use in their country to enhance the level of road safety.

Table 1. Last Ranking of countries

Countries	Average
ES	1
DE	2
NE	3
BE	4
CY	5
CH	6
IT	7
PT	8
DK	9
FR	10
AT	11
SL	12
EL	13
UK	14
SE	15
CZ	16
FI	17
HU	18
EE	19
IE	20
PL	21

VII. CONCLUSION:

In this article 21 countries were ranked based on 11 SPIs, each country has a policy and developing program to enhance the level of quality in safety that all of these policy and plans have been investigated and at last an overview of safety performance of all 21 country based on 11 SPIs have been done by averaging of all unique ranking. In result Spain, Denmark and Belgium have best safety level of quality and Poland has lowest level of safety policy and developing performance between those 21 European countries.

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