Implementation of MCDM Methods in Road Safety Management

Gholamreza Khorasani, Ali Yadollahi, Milad Rahimi, and Ashkan Tatari

Abstract—With the ever increasing public awareness of complicated road safety phenomenon, much more detailed aspects of crash and injury causation rather than only crash data are extensively investigated in the current road safety research. Safety performance indicators (SPIs), which are causally related to the number of crashes or to the injury consequences of a crash, are rapidly developed and increasingly used. To measure the concept of road safety which cannot be captured by a single indicator, the exploration of a composite road safety performance index is vital for rational decision-making about road safety. In doing so, a proper decision support system is required. In this study, we investigate the usage of MCDM methods in road safety management and present two case study of using MCDM in word.

The proposed method provides with a promising intelligent decision support system to evaluate the road safety performance for a case study of a given set of European countries and prioritization of road safety indicators in roads. The importance of this article is to investigate the usage of these methods to enhance the quality of road safety and improved the management system of road safety and financing system for maintenance and improving road safety.

Keywords—Management, Multi-criteria decision making, Road safety performance indicators, Transportation

I. INTRODUCTION

DURING the past decades, there has been a steady increase in traffic volume, which resulted in continuously increasing traffic problems. Worldwide, an estimated 1.2 million persons are killed in road crashes every year and as many as 50 million are injured [13]. Besides analyzing the number of accidents and casualties, attention should be given to the underlying risk factors.

In the end, we want to have an idea of which measures to take to enhance the level of road safety in a country. Safety performance indicators (SPIs) are very useful in this respect. [4].

The economic and structural development of our present society is to a very large extent based on successive improvements in transport. By speeding up communications and the transport of goods and people, the transportation systems have become a crucial component of modernity, and have generated a revolution in contemporary economic and social relations. However, incorporating new technologies have not come about without cost: environmental pollution, urban stress and deteriorating air quality are all directly linked to modern transport systems. Above all, transportation is increasingly associated with the rise in the negative effects on safety, which is important not only because of the lost travel time or cost of property damage, but also because of the loss of human life and serious injuries sustained.

Of all the systems with which people have to deal every day, road traffic systems are the most complex and the most dangerous with the fact that the probability of being involved in road crashes is much greater than that in all other transportation modes (rail, air, maritime, etc.). During the past decades, rapid growth of road traffic volume results in continuously increasing safety problems, such as road crashes, premature deaths, as well as physical and psychological handicaps. These not only lead up to reduced worker productivity and trauma affecting a victim’s private life, but also cause great emotional and financial stress to the millions of families affected. Equally significant are the rising costs in health services and the added burden on public finances representing around 1 to 3% of the Gross Domestic Product (GDP) in most countries [12]. Consequently, road traffic injuries and fatalities have nowadays been recognized as one of the most important public health issues that requires concerted efforts for effective and sustainable prevention[10]. Better insight into the road safety situation of a particular country can be gained by studying the available data and comparing them to the data of other subjects. Nowadays, this country comparison in terms of road safety is mainly based on registered crash data. For example, the number of road fatalities per million inhabitants is often used for expressing the relative level of road safety in a country. However, these crash related figures are unable to indicate on which aspects of road safety an underperforming country should focus in order to improve its road safety level. Therefore, countries should be compared on a more detailed level as well[3].

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There are many strategic methods to prioritize road safety indicators to enhance road safety performance. In this study we investigate the usage of MCDM in road safety management to present the difference type of MCDM those can be applied in road safety to enhance the road safety performance and at last present two case study about using MCDM in road safety performance.

II. ROAD SAFETY MANAGEMENT

If you are using Word, use either the Microsoft Equation Editor or the MathType add-on (http://www.mathtype.com) for equations in your paper (Insert | Object | Create New | Microsoft Equation or MathType Equation). “Float over text” should not be selected.

Road Safety Management can be globally defined as a government area geared at reducing the number of road crashes and victims on the territory and in the population governed. Road Safety Management is thus justified by its outputs in terms of measures or action programs implemented to prevent or reduce road crashes and injuries and includes activities (policy-making tasks and transversal processes) as well as the organization necessary for these activities to take place (the Road Safety Management System).

Policy-making can be defined as a cyclical series of tasks (see Fig.1)[8]. It begins in the agenda setting stage with recognition and definition of a significant public problem and an organized call to government action. In response, the legislative and bureaucratic machinery of government and associated non-governmental stakeholders may formulate, adopt, and implement a strategy for addressing the problem. Analysis of policy effectiveness in turn often reveals shortcomings in formulation or implementation or new problems to add to the policy agenda[8].

III. WHY DO WE NEED ROAD SAFETY MANAGEMENT?

The high cost of motorized mobility to society and public health

Each year over 1 million people are killed and 50 million injured on roads around the world. Without new and effective action, deaths in low to middle-income countries are forecast to rise steeply. At the same time, progress has slowed in recent years in the better performing countries where investment in preventing and reducing serious health loss from road traffic injury is not commensurate with its high socio-economic cost. This cost has been estimated at around 2% of EU countries’ gross domestic product - around Euro 180 billion and twice the EU’s annual budget[11].

Road traffic injury is largely preventable

As highlighted in the World Report on Road Traffic Injury Prevention, fatal and long term crash injury is largely predictable, largely avoidable and a problem amenable to rational analysis and remedy. Research and experience in North America, Australasia and Europe has shown that very substantial reductions in road deaths and serious injuries have been achieved through the application of evidence-based measures against the background of increased motorization[11].

IV. MULTI-ATTRIBUTE DECISION MAKING (MCDM)

A GENERAL OVERVIEW:

Multi-Attribute Decision Making is the most well-known branch of decision making. It is a branch of a general class of Operations Research (or OR) models which deal with decision problems under the presence of a number of decision criteria. This super class of models is very often called multi-criteria decision making (or MCDM). According to many authors (see, for instance, [14]) MCDM is divided into Multi-Objective Decision Making (or MODM) and Multi-Attribute Decision Making (or MADM).

MODM studies decision problems in which the decision space is continuous. A typical example is mathematical programming problems with multiple objective functions. The first reference to this problem, also known as the "vector-maximum" problem, is attributed to [5]. On the other hand, MADM concentrates on problems with discrete decision spaces. In these problems the set of decision alternatives has been predetermined.

Although MADM methods may be widely diverse, many of them have certain aspects in common [1]. These are the notions of alternatives, and attributes (or criteria, goals) as described next.

V. ALTERNATIVES

Alternatives represent the different choices of action available to the decision maker. Usually, the set of alternatives is assumed to be finite, ranging from several to hundreds. They are supposed to be screened, prioritized and eventually ranked.
VI. MULTIPLE ATTRIBUTES

Each MADM problem is associated with multiple attributes. Attributes are also referred to as "goals" or "decision criteria". Attributes represent the different dimensions from which the alternatives can be viewed. In cases in which the number of attributes is large (e.g., more than a few dozens), attributes may be arranged in a hierarchical manner. That is, some attributes may be major attributes. Each major attribute may be associated with several sub-attributes. Similarly, each sub-attribute may be associated with several sub-sub-attributes and so on. Although some MADM methods may explicitly consider a hierarchical structure in the attributes of a problem, most of them assume a single level of attributes (e.g., no hierarchical structure).

Conflict among attributes:
Since different attributes represent different dimensions of the alternatives, they may conflict with each other. For instance cost may conflict with profit, etc.

Incommensurable units:
Different attributes may be associated with different units of measure. For instance, in the case of buying a used car, the attributes "cost" and "mileage" may be measured in terms of dollars and thousands of miles, respectively. It is this nature of having to consider different units which makes MADM to be intrinsically hard to solve.

Decision weights:
Most of the MADM methods require that the attributes be assigned weights of importance. Usually, these weights are normalized to add up to one.

Decision matrix:
An MADM problem can be easily expressed in matrix format. A decision matrix $A$ is an $(M \times N)$ matrix in which element $a_{ij}$ indicates the performance of alternative $A_i$ when it is evaluated in terms of decision criterion $C_j$, (for $i = 1,2,3,..., M$, and $j = 1,2,3,..., N$). It is also assumed that the decision maker has determined the weights of relative performance of the decision criteria (denoted as $w_j$, for $j = 1, 2, 3... N$). This information is best summarized in figure 2. Given the previous definitions, then the general MADM problem can be defined as follows [8]:

Definition:
Let $A = \{ A_i, \text{for} \ i = 1,2,3,..., M\}$ be a (finite) set of decision alternatives and $G = \{ g_i, \text{for} \ j = 1,2,3,..., N \}$ a (finite) set of goals according to which the desirability of an action is judged. Determine the optimal alternative $A^*$ with the highest degree of desirability with respect to all relevant goals $g_i$. Criteria Very often, however, in the literature the goals $g_i$ are also called decision criteria, or just criteria (since the 3 alternatives need to be judged (evaluated) in terms of these goals). Another equivalent term is attributes. Therefore, the terms MADM and MCDM have been used very often to mean the same class of models (i.e., MADM). For these reasons, in this paper we will use the terms MADM and MCDM to denote the same concept.

VII. CLASSIFICATIONS OF MCDM METHODS

As it was stated in the previous section, there are many MADM methods available in the literature. Each method has its own characteristics. There are many ways one can classify MADM methods. One way is to classify them according to the type of the data they use. That is, we have deterministic, stochastic, or fuzzy MADM methods (for an overview of fuzzy MADM methods see [1]). However, there may be situations which involve combinations of all the above (such as stochastic and fuzzy data) data types.

Another way of classifying MADM methods is according to the number of decision makers involved in the decision process. Hence, we have single decision maker MADM methods and group decision making MADM.

In [1] deterministic -- single decision maker -- MADM methods were also classified according to the type of information and the salient features of the information. The WSM, AHP, revised AHP, WPM, and TOPSIS methods are the ones which are used mostly in practice today and are described in later sections. Finally, it should be stated here that there are many other alternative ways for classifying MADM methods [1]. However, the previous ones are the most widely used approaches in the MADM literature.

VIII. SOME MCDM APPLICATION AREAS

Some of the industrial engineering applications of MCDM include the use of decision analysis in integrated manufacturing, in the evaluation of technology investment decisions, in flexible manufacturing systems, layout design, and also in other engineering problems. As an illustrative application considers the case in which one wishes to upgrade the computer system of a computer integrated manufacturing (CIM) facility. There is a number of different configurations available to choose from. The different systems are the alternatives. A decision should also consider issues such as: cost, performance characteristics (i.e., CPU speed, memory capacity, RAM size, etc.), availability of software, maintenance, expendability, etc. These may be some of the decision criteria for this problem[4].

In the above problem we are interested in determining the best alternative (i.e., computer system). In some other situations, however, one may be interested in determining the relative

Fig.2 Typical Decision Matrix
importance of all the alternatives under consideration. For instance, if one is interested in funding a set of competing projects (which now are the alternatives), then the relative importance of these projects is required (so the budget can be distributed proportionally to their relative importances).

Multi-criteria decision-making (MCDM) plays a critical role in many real life problems. It is not an exaggeration to argue that almost any local or federal government, industry, or business activity involves, in one way or the other, the evaluation of a set of alternatives in terms of a set of decision criteria. Very often these criteria are conflicting with each other. Even more often the pertinent data are very expensive to collect.

IX. MULTI-CRITERIA DECISION MAKING METHODS

There are three steps in utilizing any decision-making technique involving numerical analysis of alternatives:

a) Determining the relevant criteria and alternatives.
b) Attaching numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria.
c) Processing the numerical values to determine a ranking of each alternative.

This section is only concerned with the effectiveness of the four methods in performing step 3. The central decision problem examined in this paper is described as follows. Given is a set of M alternatives: A1, A2, A3, ..., AM and a set of N decision criteria C1, C2, C3, ..., CN and the data of a decision matrix as the one described in Figure 1. Then the problem is to rank the alternatives in terms of their total preferences when all the decision criteria are considered simultaneously[4].

1) The Weighted Sum Model
The weighted sum model (or WSM) is probably the most commonly used approach, especially in single dimensional problems[4].

2) The Weighted Product Model
The weighted product model (or WPM) is very similar to the WSM. The main difference is that instead of addition in the model there is multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion[4].

3) The Analytic Hierarchy Process
The analytic hierarchy process (or AHP) is based on decomposing a complex MCDM problem into a system of hierarchies (more on these hierarchies can be found in [4]).

4) The Revised Analytic Hierarchy Process
Belton and Gear [1983] proposed a revised version of the AHP model. They demonstrated that an inconsistency can occur when the AHP is used. They presented a numerical example which deals with three criteria and three alternatives. In that example the indication of the best alternative changes when an identical alternative to one of the no optimal alternatives is introduced now creating four alternatives[4].

5) The ELECTRE Method
The ELECTRE (for Elimination and Choice Translating Reality; English translation from the French original) method was first introduced in [4]. The basic concept of the ELECTRE method is to deal with "outranking relations" by using pairwise comparisons among alternatives under each one of the criteria separately.

6) The TOPSIS Method
TOPSIS (the Technique for Order Preference by Similarity to Ideal Solution) was developed by Hwang and Yoon [1981] as an alternative to the ELECTRE method. The basic concept of this method is that the selected alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution in a geometrical sense. TOPSIS assumes that each attribute has a tendency of monotonically increasing or decreasing utility. Therefore, it is easy to locate the ideal and negative-ideal solutions. The Euclidean distance approach is used to evaluate the relative closeness of alternatives to the ideal solution. Thus, the preference order of alternatives is yielded through comparing these relative distances[4].

7) 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. 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, [6] 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. In general, they embody the fuzzy nature of the comparison or evaluation process and strengthen the comprehensiveness and rationality of the decision-making process[13].

8) Hierarchical fuzzy TOPSIS
Due to the ever increasing complexity of today’s performance evaluation and decision making activities, such as in the road safety context, not only the knowledge from the decision makers or experts, but also the information on the criteria or indicators themselves, i.e., their hierarchical structure, should be taken into account. Therefore, extension of the fuzzy TOPSIS method to a hierarchical one is valuable, and can be treated as a natural generalization of the one-layer fuzzy TOPSIS. However, in that model, after computing the final weight score for each sub-criterion, which was the product of the main criterion weight score and the sub-criterion weight score with respect to the corresponding main criterion, all the sub-criteria were actually treated as in the same layer and the meaning of their hierarchy was actually disappeared. Therefore, in this study, we design a new
hierarchical fuzzy TOPSIS model, which can completely reflect the layered hierarchy of all criteria[13].

X. CASE STUDY

Two case study have done in word during these years the first one is Improved hierarchical fuzzy TOPSIS for road safety performance evaluation and another one is Prioritization of road safety factors in roads with Topsis method.

1) Improved hierarchical fuzzy TOPSIS for road safety performance evaluation[9]

To measure the concept of road safety which cannot be captured by a single indicator, the exploration of a composite road safety performance index is vital for rational decision-making about road safety. In doing so, a proper decision support system is required. This case study proposes an improved hierarchical fuzzy TOPSIS model to combine the multilayer SPIs into one overall index by incorporating experts’ knowledge. Using the number of road fatalities per million inhabitants as a relevant reference, the proposed model provides with a promising intelligent decision support system to evaluate the road safety performance for a case study of a given set of European countries. It effectively handles experts’ linguistic expressions and takes the layered hierarchy of the indicators into account.

The comparison results with those from the original hierarchical fuzzy TOPSIS model further verify the robustness of the proposed model, and imply the feasibility of applying this model to a great number of performance evaluation and decision making activities in other wide ranging fields as well. The figure 3 [9] shows the road safety parameters those had been prioritized in this case study.

2) Prioritization of road safety factors in roads with Topsis method[7]

In this case study engineers attempt to understand and investigation of road safety indicators and prioritization of them based on their effectiveness on severity and amount of accident in roads. In this study first the road safety indicators and index in different country investigated and after that these questioner were full fill with some of experts of road safety. These questioners were based on effectiveness of those indicators on amount and severity of road accident. After that data collection was done with data mining from this questioner and after that those indicators were ranked by Topsis method. Table 1[7] shows the 17 indicator those ranked by this article.

![Fig.3 Road safety parameters](image)

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<thead>
<tr>
<th>No</th>
<th>Indicators</th>
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<tbody>
<tr>
<td>1</td>
<td>Percent of driver using seatbelt</td>
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<tr>
<td>2</td>
<td>Percent of drivers extend the standard speed</td>
</tr>
<tr>
<td>3</td>
<td>Percent of road coverage by police</td>
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<tr>
<td>4</td>
<td>Average arrival of police to accident</td>
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<tr>
<td>5</td>
<td>Percent usage of Airbag and ABS breaks</td>
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<tr>
<td>6</td>
<td>Number of removed hazardous points in roads</td>
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<td>7</td>
<td>Finance allocation of roads</td>
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<td>8</td>
<td>Cost of maintenance and safety projects</td>
</tr>
<tr>
<td>9</td>
<td>Percent coverage of highway and expressway by CCTV</td>
</tr>
<tr>
<td>10</td>
<td>Annual percent of education for drivers and pedestrian</td>
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<tr>
<td>11</td>
<td>Percent coverage of road by standard medical emergency</td>
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<tr>
<td>12</td>
<td>Number of emergency medical and rescue station based per hundred kilometers</td>
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<tr>
<td>13</td>
<td>Average time of emergency medical and rescue team to accident point</td>
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<tr>
<td>14</td>
<td>Percentage of total fatality of accidents during transfer to medical centers</td>
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<tr>
<td>15</td>
<td>Number of rescue vehicles per one hundred kilometer in road</td>
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<tr>
<td>16</td>
<td>Average times of training teachers and students in field of road safety</td>
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<tr>
<td>17</td>
<td>Average times of training teachers and students in field of road safety</td>
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XI. CONCLUSION

Composite indexes for performance evaluation are increasingly recognized as a useful tool in policy analysis and public communication. In this study, we mainly focused on the use of multi-criteria decision making methods for composite index research in the context of road safety. In this article there are two case study mentioned that the first one was to incorporate the knowledge from the experts which was given in linguistic terms and to reflect the information on the layered hierarchy of the indicators, a new hierarchical fuzzy TOPSIS method was realized as a promising intelligent decision support system and was proved valuable for road safety performance evaluation.

The realization of the new hierarchical TOPSIS method (improved from the original one) which enabled taking the hierarchical structure of indicators into account more completely made it particularly suitable in combining layered road safety performance indicators into one overall index. In the application, the derived composite index scores for a set of
The second case study was about the prioritization of road safety performance with Topsis method. In that case study the 17 indicators of road safety ranked by this method and at last it was shown that with indicator should be first to improved or witch one is not important to financed.

This article shows the usage of MCDM methods in road safety and transportation to prioritized and ranked indicators and safety index in road so with this method engineers can rank and prioritize the indicators and index to enhance the quality of safety and enhance the safety of roads.

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