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Hotspots identification and ranking for road safety improvement: An alternative approach

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ABSTRACT

During the last decade, the concept of composite performance index, brought from economic and business statistics, has become a popular practice in the field of road safety, namely for the identification and classification of worst performing areas or time slots also known as hotspots. The overall quality of a composite index depends upon the complexity of phenomena of interest as well as the relevance of the methodological approach used to aggregate the various indicators into a single composite index. However, current aggregation methods used to estimate the composite road safety performance index suffer from various deficiencies at both the theoretical and operational level; these include the correlation and compensability between indicators, the weighting of the indicators as well as their high "degree of freedom" which enables one to readily manipulate them to produce desired outcomes (Munda and Nardo, 2003, 2005, 2009). The objective of this study is to contribute to the ongoing research effort on the estimation of road safety composite index for hotspots' identification and ranking. The aggregation method for constructing the composite road safety performance index introduced in this paper, strives to minimize the aforementioned deficiencies of the current approaches. Furthermore, this new method can be viewed as an intelligent decision support system for road safety performance evaluation, in order to prioritize interventions for road safety improvement.

1. Introduction

The strain that road traffic collisions place on the society is undeniable, with the impacts extending far beyond the obvious financial burden. Some of the more serious consequences deriving from the occurrence of road traffic collisions include the loss of life and sustained physical injuries. Worldwide, it is estimated 1.2 million people die in road traffic collisions annually and between 20 and 50 million are injured (Peden et al., 2004). With the rapid growth in motorization, these figures are set to rise in the future unless timely and appropriate actions are taken to improve road safety.

Safety indicators are increasingly used to identify and combat the rising problems of road safety. In general terms, a road safety indicator is defined as a quantitative or qualitative measure derived by a series of observed facts relative to a particular collision Wegman et al. (2008). Examples of road safety indicators include: number and severity of casualties, number of vehicles involved in collisions, type of collision ... Safety Indicators are advantageous in that they can display large amounts of information in a more simplified format. However, given the multitude of factors influencing road traffic collisions, it is somewhat difficult to assess indicators on an individual basis. Therefore, to facilitate decision making, it is often preferable to have the various indicators aggregated into a single composite index, also referred to as the Composite Safety Performance Index (CSPI) (Wegman et al., 2008). CSPIs are often used to analyse the current safety conditions of road traffic systems and assess their performance on an ongoing basis. Furthermore, they can be applied to compare and subsequently benchmark the road safety performance of different regions or countries as well as monitoring the impact of various road safety interventions, as illustrated in the literature, see e.g. Al Haji (2005), Gitelman et al. (2010), Hakkert et al. (2007), Hermans et al. (2008), Highway Safety Manual (2010), PIARC (2003), Wegman et al. (2008, 2005), Weijermars et al. (2008), and the references therein.

The construction of the CSPI consists of the following key steps: the selection of the road safety indicators to be aggregated and the choice of the method to be used to aggregate them. The methods commonly used to aggregate road safety indictors are weighting techniques, which consist of assigning weights to each of the selected indicators to emphasize their importance, so that they can contribute to the CSPI accordingly. In recent years, a number of studies, see e.g. Al Haji (2005), Biao et al. (2012), Gitelman et al. (2010), He et al. (2009), Hermans et al. (2008), Nardo et al.

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(2008), Shen et al. (2010), Wegman et al. (2008, 2005) and the references therein, have used various aggregation methods to estimate road traffic CSPI. These methods include: equal weighting, budget allocation, analytic hierarchy process, data envelopment analysis, principal component analysis, factor analysis, neural networks, grey delphi method, and the fuzzy method. However, despite the significant research effort in the area, the theory of aggregating road safety indicators into a CSPI is far from being complete. Current aggregation methods, used in the development of CSPI exhibit various deficiencies at both the theoretical and operational level (Nardo et al., 2008). These shortcomings include the correlation and compensability between indicators, strong reliance on expert opinions, sensitivity to sample size and range of data as well as their high "degree of freedom" which enables one to readily manipulate them to produce desired outcomes (Munda and Nardo, 2003, 2005, 2009).

This study aims to contribute to the ongoing research effort on the estimation of the road CSPI by introducing an alternative approach which is free from some of the major deficiencies inherent to the traditional weighting methods, in order to provide an improved safety performance assessment tool. The introduced approach consists of the following key steps: the selection of the appropriate road safety indicators to be aggregated, the pairwise comparisons of indicators, and the development of the composite safety performance index. Since road safety is a complex phenomenon which includes various known and unknown factors, controllable and uncontrollable parameters, the selection of key indicators to be aggregated can be delicate or even controversial (Wegman et al., 2008). In this study, we will focus on quantitative uniformly measurable indicators, such as: the number of collisions, the number of vehicles involved in the collisions, the number of fatalities, the number of serious injuries, and quantitative measurements which can be objectively inferred from these. As recommended in Munda and Nardo (2009), the method to construct the CSPI, proposed in this study, depends not only on the selected indicators but also takes into consideration the underlying relationship between these indicators including the measurement unit, the degree of non compensability between individual indicators as well as their hierarchical structure.

In order to prioritize road safety interventions, policy makers rely on hotspot analysis to decide whether to address a group of hotspots together or to address each hotspot individually, on a cost-benefit analysis basis (OECD, 2013). Thus, the obvious benefit stemming from a high quality composite index is to assist them to make better informed decisions so as to put in place effective safety interventions, when and where they are most needed. Since the method introduced in this study can be viewed as an intelligent decision support system for road safety performance evaluation in order to prioritize interventions for road safety improvement, for illustration purpose, the new method will be used to identify and rank temporal hotspots in Northern Ireland as well as spatial hotspots across the different policing areas of the region.

This paper is organized as follows. Section 2 provides a brief overview of the aggregation methods commonly used to estimate the CSPI, and discusses their relevance and limitations. Section 3 presents the main conceptual framework and the rationale behind the new approach, the corresponding algorithmic steps as well as their illustration using some selected road safety indicators. Section 4 is dedicated to the application of the new method to a case study, in which the spatial and temporal hotspots for Northern Ireland are identified and ranked. Furthermore, for validation purpose, a comparative study between the new method and two other traditional aggregation methods for estimating CSPI has been carried out. Finally, Section 5 provides some conclusions and directions for further research.

2. Brief overview of the aggregation methods

In recent years, there has been a growth of interest in the use of the composite index, by policy makers, as a tool for road safety assessment, see e.g. Al Haji (2005), Gitelman et al. (2010), Hermans et al. (2008), Wegman et al. (2008, 2005) and Weijermars et al. (2008). Although a wide variety of methods for estimating the CSPI exist in the literature, these methods are essentially based on the aggregation of some selected indicators into a single composite index termed CSPI. As no widely agreed method exists on the aggregation, the choice of the aggregation method is merely based on the type of individual indicators and the researchers preference (Nardo et al., 2008). Roughly speaking, the aggregation techniques used in the construction of the CSPI can be classified into two categories: participatory methods and statistical methods.

2.1. Participatory methods

Many aggregation techniques, used in the construction of the CSPI, are generally based on participatory methods. These techniques are essentially based on the estimation of the weight to be assigned to each indicator, and then these weights are used to average normalized indicators' values to obtain the CSPI. This section will briefly describe some of the most common ones including the equal weighting method, the analytic hierarchy process method, the budget allocation method, and the data envelopment analysis.

2.1.1. Equal weighting method

Equal weighting is the most basic aggregation technique which involves placing equal weights on individual indicators, and these are used to average normalized indicators' values to obtain the CSPI. For instance, if m is the number of indicators then w_i the weight of the indicator i, is given by $w_i = 1/m$, for all $i = 1, \ldots, m$. Although this method is quite straightforward and easy to implement, its major shortcoming is its assumption of equal importance of the indicators, while in reality these contribute to road safety in different degrees. Therefore, different weights must be attached to indicators to account for this disparity. This method can only be used as a last resort when there is insufficient knowledge on the individual indicators and/or where there are no statistical or empirical grounds for choosing a different approach (Nardo et al., 2008).

2.1.2. Budget allocation method

In the budget allocation method, experts are given a budget of N points to be distributed over a number of indicators, allocating more points to those indicators for which they want to stress their importance (Nardo et al., 2008); and these points are used to derive the weights of the indicators which are eventually used to average normalized indicators' values to get the CSPI. In general, the budget allocation method consists of four phases. Firstly, a panel of experts is selected. It is vitally important to bring together experts that have a wide spectrum of knowledge and experience, so as to ensure that a proper weighting system is found for a given application (Hermans et al., 2008). Secondly, each expert allocates the predetermined budget of N points to the indicators. In the third phase the weights are calculated and the final phase, which is optional, consists of iterating phases one to three until convergence is reached. One of the main limitations to this method is that it is primarily based on experts' opinions. However, experts' opinions are somewhat subjective and may differ across a field, potentially resulting in a biased weighting.

2.1.3. Analytic hierarchy process method

Analytic hierarchy process is a weighting estimation method which also incorporates expert opinions. It is based on the decomposition of a complex problem into a hierarchy and ensures that