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Combining road safety information in a performance index

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ABSTRACT

In this paper we focus on an essential step in the construction process of a composite road safety performance indicator: the assignment of weights to the individual indicators. In the composite indicator literature, this subject has been discussed for a long time, and no agreement has been reached so far. The aim of this research is to provide insights in the most important weighting methods: factor analysis, analytic hierarchy process, budget allocation, data envelopment analysis and equal weighting. We will give the essential theoretical considerations, apply the methods on road safety data from various countries and discuss their advantages and disadvantages. This will facilitate the selection of a justifiable method. It is shown that the position of a country in the ranking is influenced by the method used. The weighting methods agree more for countries with a relatively bad road safety performance. Of the five techniques, the weights based on data envelopment analysis resulted in the highest correlation with the road safety ranking of 21 European countries based on the number of traffic fatalities per million inhabitants. This method is valuable for the development of a road safety index.

1. Introduction

The concept of indicators has gained popularity in recent years. In general, an indicator can be defined as a quantitative or qualitative measure that is deduced from a series of observed facts to reveal the relative positions of objects in a certain area (Nardo et al., 2005). One of the useful characteristics is that an indicator can represent large amounts of information in a simple manner. Indicators can be used for several objectives, like monitoring performance, identifying trends, predicting problems, assessing policy impact, prioritizing measures, benchmarking, etc. (Litman, 2007; Sharpe, 2004).

Moreover, there is a rapid development of composite indicators – or indexes which are a combination of individual indicators – in several domains. Examples are the Human Development Index, the Technology Achievement Index and the Environmental Sustainability Index (Saisana and Tarantola, 2002). In order to combine information from several underlying dimensions into one index, an essential step is to assign a correct weight to each indicator. That way, policymakers have a useful tool for prioritising their actions. In the literature, some attention has already been paid to the issue of weighting (Nardo et al., 2005; Sharpe, 2004). In general, opinions are different regarding this aspect, resulting in two groups. The one in favour of aggregating information believe that a summary statistic can capture reality, is meaningful and attracts attention, while opponents claim that no aggregation should be performed because of what they call the arbitrary nature of the weighting process (Sharpe, 2004).

Road safety is one of the policy areas where the use of indicators is rapidly gaining ground (e.g. SafetyNet, 2005). The multidisciplinary character of road safety implies that policymakers should take various influential factors into account. Also, being an international issue, the level of road safety is often compared over countries. To reduce the dimensions of the problem, the creation of a composite indicator can be helpful. One of the main issues in creating a road safety performance index is the weighting of the indicators. This exercise implies that a value judgement is needed for each of the possible measures taken to influence road safety. A higher weight for a certain indicator stresses its relatively higher importance in the global measurement of road safety. Given the limited resources that can be used to improve road safety, a well-considered construction of indicator weights is crucial to steer future investments.

In our opinion, the advantages of combining road safety information can be decisive, given that a sound weighting framework is created. Therefore, we focus in this paper on the development of a composite road safety indicator for European countries. That is, our aim is to assign to a country an index score that captures all relevant information concerning the road safety situation in order to benchmark the performance of that country. Despite the recent

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interest of the road safety domain in indicators, the development of one road safety index is a new and challenging matter.

A number of steps are involved in the creation of a composite indicator (Nardo et al., 2005). The theoretical framework has to be developed, appropriate indicators selected and data found. Next, these values are weighted, aggregated and clearly presented. We start by translating the multidimensional road safety problem into a number of relevant factors related to accidents and casualties. Research regarding the identification of risk factors has already been carried out (Al Haji, 2005; WHO, 2004). Although the possibilities of risk factors are numerous, a safety performance indicator or SPI – as defined in ETSC (2001) and used on the European level in the SafetyNet project (SWOV, 2007), as well as the road safety performance index programme (ETSC, 2007) – is a measurement that is causally related to unsafety and used in addition to counting accidents or casualties, in order to indicate the safety performance or to understand the process that leads to accidents. Contrary to accident statistics and the related disadvantages – random fluctuation, under-registration, lack of uniformity in definitions, etc. – safety performance indicators are situated on the level of the underlying processes that cause accidents and casualties. SPIs give a more complete image, are able to detect problems before they result in accidents, are available earlier, etc. (ETSC, 2001). A large number of potential SPIs exist. The importance of the different indicator candidates depends on the strength of the relationship with unsafety, the amount of contribution to the accidents and the degree to which the factor can be influenced by policy measures (ETSC, 2001). The latter characteristic eliminates important road safety risk factors such as the weather (Eisenberg, 2004). In general, road safety performance indicators are related to the road user (e.g. speeding), the vehicle (e.g. defects) and the road (e.g. bad maintenance) (WHO, 2004).

This paper is organised as follows. In Section 2, the selected indicators that will be used to illustrate the different weighting methods are briefly discussed. The next section gives an overview of the characteristics of the five most often used weighting techniques. For factor analysis, analytic hierarchy process, budget allocation, data envelopment analysis and equal weighting, a theoretical description of the technique is given and its strengths and weaknesses discussed. Subsequently, the five methods are applied to the road safety data set. The evaluation is the focus of Section 4 which compares the methods and deals with the robustness of the final results. The paper ends with conclusions and topics for further research.

2. Data

In the European SafetyNet project (2005) on safety performance indicators, the following seven domains are agreed on to be the most important road safety risk areas: alcohol and drugs; speed; protective systems; visibility; vehicle; infrastructure; and trauma care. For each risk domain, at least one appropriate indicator needs to be defined. Indicators for every risk domain are selected based on policy relevance, data availability, clarity and reliability (Litman, 2007; Nardo et al., 2005). To obtain an overall road safety index, two separate aggregation steps are to be performed. First, the individual indicators per risk domain are aggregated into one indicator per domain. Several possible indicators for each of the seven risk domains are presented in Fig. 1. Next, the domain indicators are aggregated in one road safety index. In this paper, it is assumed that each road safety risk domain can be fully represented by one carefully selected indicator. That is, the analysis is limited to the second aggregation step, in order to avoid unnecessary data complexities and to focus on the problem of weighting various risk domains in one safety performance index. However, the presented framework can easily be extended to allow more indicators per risk domain.

For 21 European countries values for the 7 selected indicators are available from several international sources, amongst others the IRTAD international road traffic accident database, Eurostat, the World Health Organization and the SARTRE project on social attitudes to road traffic risk in Europe. As the indicators are expressed in different measurement units, we will use the standardised indicator values, as presented in Table 1. All indicator values can be interpreted in the same way: a higher value implies a higher level of road safety.

3. Weighting methods

In this section, the theory behind five common weighting techniques is discussed. We describe the working method and focus on the advantages and disadvantages of, respectively, factor analysis (Section 3.1), analytic hierarchy process (Section 3.2), budget allocation (Section 3.3), data envelopment analysis (Section 3.4) and equal weighting (Section 3.5). The application to the road safety data is the subject of Section 4.1.

3.1. Factor analysis

The first weighting procedure is based on factor analysis (FA). A factor analysis is often used to reduce the dimensions of a problem. In our road safety example there are 7 (l) dimensions explaining 100% of the variance of the problem. However, it would be interesting to reduce the problem to a smaller number of dimensions ($p < l$), called factors, which explain a large part of the total variance. Each factor consisting of a number of indicators can be given an interpretation. Several guidelines are available for assessing the optimal number of factors to which the problem can be reduced (Sharma, 1996). If the optimal number of factors is three or less, a graphical presentation can provide some useful insights. Having decided to consider p factors, rotation is a next step in order to enhance the interpretability. This results in each indicator (i) having a large factor score (a_{ij}) on one of the factors (j) only. The indicator weights can be deduced from these rotated factor loadings by means of relatively limited computation.

The procedure of deducing indicator weights from the rotated factor scores a_{ij} ($i = 1, \ldots l$; $j = 1, \ldots, p$) is a simplified but equivalent approach (compared to the calculations suggested in Nardo et al., 2005) and consists of the following steps. Define $u_{ij} = a_{ij}^2 / \sum_{m=1}^{l} \sum_{n=1}^{p} a_{mn}^2$. The preliminary weight of indicator i, $u_i = \max_j (u_{ij})$. However, $U = \sum_i u_i < 1$ due to the reduction of the problem, leaving a small part of the variance unexplained. The final weight for each indicator i is equal to $w_i = u_i / U$ and, by construction, $W = \sum_i w_i = 1$.

The use of factor analysis in the composite indicators field (e.g. the e-Business Readiness Index (Pennoni et al., 2005)) is not rare. However, this technique is often used to examine the interrelationships between the indicators instead of determining weights. The most important drawback is that weights are based on correlations which do not necessarily correspond to the real-world links between the phenomena being measured (Saisana and Tarantola, 2002). In addition, deducing weights from factor analysis requires a certain level of correlation (to reduce the problem in a number of factors), a justified selection of the optimal number of factors (as the weights depend on the chosen number of factors) and clear rotation results (because only the highest rotated factor loadings are used in the computation of weights). This method is most valuable in case several indicators are considered to measure each risk domain.