Oral Presentations

Elaborating an Index Methodology for Creating an Overall Road Safety Performance Score for a Set of Countries

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Abstract

Compared to traditional road safety research using crash data, risk factors causing crashes and casualties are studied in this research. More specifically, several risk factors (e.g., alcohol and drugs) are quantified by performance indicators (e.g., the share of road users with a blood alcohol content above the legal limit) and these indicator values are compared across countries. Given the high number of relevant road safety performance indicators, the creation of an index - i.e., a combination of indicators - is beneficial. One of the main advantages of an index over a set of individual indicators is that an overall road safety picture is presented capturing a multitude of risk information. However, to create a valuable road safety performance index in terms of communication, benchmarking, monitoring and policy supporting, a scientifically sound and appropriate index methodology is required. By critically studying the index development process in other domains (such as the environmental sustainability index) and taking the specific road safety case into account, this study describes the different steps that are essential in the construction of a road safety performance index. The selection of indicators and the data preparation are described, the issue of weighting and aggregating indicators is discussed and the robustness of the index in terms of the ranking of the countries assessed. These steps are illustrated using performance indicator data for 21 countries.

1. Introduction

Road safety is a topic that is correctly receiving a lot of attention lately. Given the high number of casualties and the corresponding suffering and costs, measures are needed in order to reduce the number of road casualties. Worldwide, over 1.2 million people are killed in road crashes each year and 20 to 50 million are injured (World Health Organization, 2009). This means that every day around the world, more than 3,000 people die from road traffic injury.

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.

In this study, we focus on risk factors underlying the occurrence of crashes and casualties. More specifically, each risk factor (e.g., speed) is quantified by appropriate safety performance indicators (SPIs) (e.g., the share of persons driving at a speed above the legal limit). The purpose of SPIs is threefold: to reflect the current safety conditions of a road traffic system; to measure the influence of safety interventions; and to compare different road traffic systems such as countries (SafetyNet, 2005). By comparing the indicator values across countries the main problem areas in a particular country can be revealed. Appropriate measures can then be selected able to tackle the main risk aspects before they result in crashes and casualties.

A set of important risk factors will be used. In general, a risk factor is considered as an important one in case it has a strong relationship with road safety, contributes largely to crashes and can be influenced by measures (European Transport Safety Council, 2001). Here, we start from the seven risk domains identified at the European level, i.e., alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management (SafetyNet, 2005). However, apart from studying each risk domain (or even each indicator) separately, the overall road safety performance of countries is aimed at.

Road safety being a complex matter that is affected by numerous factors, a high number of relevant road safety performance indicators can be considered. As a result, the creation of a composite road safety performance index - which is a combination of road safety performance indicators - is valuable. Of course, the set of individual indicators provides an enormous amount of information. Nevertheless, as different risk factors jointly affect the frequency and severity of crashes, it is valuable to study the set of performance indicators simultaneously and combine all indicator information in one index.

This paper deals with the combination of road safety performance indicators into one index. In order to create a valuable index, a scientifically sound and appropriate methodology is required. The objective of this paper is to offer insight into the various steps of the methodology for the creation of a composite road safety performance index. The different methodological aspects involved in the index construction process are listed, briefly described in terms of theory and illustrated using a real road safety indicator data set. Based on the index score - taking the performance on several road safety risk factors into account rather than solely the number of road fatalities - valuable insight is gained into the overall relative road safety performance of a set of European countries. Although the focus is on safety performance indicators representing important road safety risk factors, the methodological process described in this paper is of value to combine other types of road safety indicators as well.

The next section deals with the index methodology. In particular, an overview of the methodological steps involved in index constructing is given followed by a more detailed discussion of each step. Section 3 presents the main conclusions and topics for further research.

2. Index methodology

The creation of indexes in various domains has largely progressed in recent years. Examples of composite indicators are the internal market index 2004 (Tarantola et al., 2004); the European e-business readiness index (Pennoni et al., 2005); the technology achievement index (United Nations, 2001); the environmental sustainability index (Yale Center for Environmental Law and Policy & Center for International Earth Science Information Network, 2005); and the index of economic and social well-being (Salzman, 2003). Nevertheless, very limited research has been performed regarding the combination of road safety indicators. Therefore, indexes developed in other domains and thereby using a particular methodology have been studied as they are helpful in developing a sound road safety index.

The process of combining a set of safety performance indicators in one composite road safety performance index is discussed in this paper. In general, we aim to create a road safety performance index that can be used for ranking countries based on their index score and therefore being an effective communication tool; for benchmarking as the relative road safety performance of each country can be assessed and the best-in-class country can be revealed; for monitoring the evolution over time and making predictions; and for policy supporting purposes since targets can be set and measures justified.

In general, advantages as well as disadvantages are linked to an index in contrast to a set of individual indicators (Saisana & Tarantola, 2002; Tarantola et al., 2004). Complex and multidimensional phenomena can be summarized in an index; an index is easier to interpret than a set of indicators; and one overall index score offers advantages in terms of benchmarking and communication. At the same time, a number of disadvantages can be listed. A combination of information into one score may lead to misleading messages or too simplistic conclusions. Moreover, the results might be manipulated by the way in which the index was constructed. Given the possible disadvantages it is essential to develop a scientifically sound and appropriate methodology. The various methodological steps - depicted in Figure 1 - need thorough study and different possibilities need to be weighed against each other. In the next paragraphs, each step is discussed in more detail.

Figure 1: Methodological steps in the index process

1. Selecting appropriate indicators to combine in an index : for each risk domain, possible indicators should be listed from literature and subsequently evaluated taking several selection criteria such as relevance and measurability into account.
2. Collecting indicator data : various data sources need to be consulted in order to collect data for the indicators selected in the previous step. An extensive data set containing road safety performance indicator values for a large set of countries referring to a particular period is aimed at.
3. Performing data analyses : analyses are performed on the collected indicator data set in order to gain more insight into each indicator separately (by means of univariate analysis) as well as into the structure and interrelationships of the whole indicator set (by means of multivariate analysis).
4. Assigning a weight to each indicator : common weighting methods - such as factor analysis, analytic hierarchy process, budget allocation, data envelopment analysis and equal weighting - need to be studied and their advantages, disadvantages and requirements learned. Several methods can be applied and the resulting index scores and countries' rankings compared.
5. Aggregating indicators : the mathematical formula for combining the indicators into an index needs to be selected. The aggregation research field can be taken as starting point. In general, the class of averaging operators - in which the index score is bounded by the lowest and highest indicator value - and in particular, the ordered weighted averaging (OWA) operators - assigning weights to magnitudes of performances - are useful aggregation operators for the road safety index case.
6. Testing the robustness of the index : given the multistage index process, the index developer is left with a number of methodological choices (with respect to indicator selection, weighting method, aggregation operator, etc) that might influence the final countries' ranking. Performing uncertainty and sensitivity analyses is an essential part of the index process as it shows how robust the index is and which extra information would imply more robustness.
7. Computing, evaluating and visualizing final index scores : taking all previously acquired information into account a final index methodology needs to be decided upon. More specifically, the most promising methods of the previous steps are to be applied to the indicator data set in order to obtain a final index score for each country. Countries can then be ranked in decreasing order of road safety performance. Furthermore, the relationship between the constructed index and other related indicators and indexes could be assessed. The index process is closed with a visualization of the final results.

2.1. Selecting appropriate indicators

The first step in the index methodology relates to indicator selection. In particular, we want to determine which indicators to combine into the index. Here, a road safety performance index will be created consisting of seven risk domains. We will compose an index score which summarizes the performance of a country with respect to alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management. Therefore, indicators representing these risk domains need to be selected. First, possible indicators for each risk domain are listed based on literature (Al Haji, 2005; European Transport Safety Council, 2001; Morsink et al., 2007). Next, each indicator is evaluated using a set of selection criteria. The degree to which the indicator is relevant (and valid), measurable, understandable, has data available, is reliable, comparable (and coherent), specific and sensitive is assessed. Based on these eight criteria, so-called best available indicators are deduced from the set of possible indicators. In the selection of best indicators a distinction is made between best available indicators on the one hand and best needed indicators on the other (European Commission, 2005). In the determination of the best needed indicators only five - not data related - criteria are considered. They are the most ideal indicators among the evaluated ones whereas for best available indicators data of an acceptable quality are available. Best available indicators are currently used to illustrate the index methodology.

2.2. Gathering data

Next, indicator data need to be collected. The data can be gathered by consulting various international data sources such as the World Health Organization or the European Union Road Federation. We aim for indicator values that represent each of the risk domains, are available for a large set of European countries and refer to the same time period or year.

The degree of maturity of performance indicators as well as the level of data availability and quality varies between the risk domains. In the end, the data collection efforts resulted in values for six indicators. It was decided not to include the daytime running lights domain at present mainly because the best available indicator already scored below-average on the selection criteria. For the remaining six risk domains, values were obtained for 21 European countries, referring to 2003. The indicator data relate to the following six indicators:

- the percentage of car drivers reporting to respect the legal alcohol limit represents the alcohol and drugs domain;
- the speed domain is captured by the percentage of car drivers reporting to respect the legal speed limit in built-up areas;
- the percentage of persons wearing a seat belt in the front seats of a car or van gives an idea about the performance regarding protective systems;
- the percentage of relatively new cars (which are cars less than six years old) represents the vehicle domain;
- the density of motorways (or the length of motorways divided by the area of a country) is the roads indicator used;
- and trauma management is expressed by the expenditure on health as share of the gross domestic product.

Note that all indicators are formulated in such as way that high indicator values are to be aimed at as they imply a high road safety performance (or a low number of fatalities per million inhabitants). Data issues limited the final indicator selection to some extent. The best available roads and trauma management indicator are proxy indicators for measuring the performance regarding these two risk domains. Furthermore, self-reported data with respect to alcohol and drugs as well as speed is to be used. Nevertheless, the index methodology is illustrated on a data set consisting of valuable road safety performance information.

2.3. Gaining insight into the data set

Thirdly, some analyses are performed on the data set in order to gain insight into each indicator separately (by means of univariate analyses) and into the structure and interrelationships in the entire data set (by means of multivariate analyses) (Nardo et al., 2005). The univariate part consists of three aspects. First, a description in terms of summary statistics (such as the mean and the variance) and a visualization (to easily identify best performing countries with respect to a particular indicator) are given; second, normalization is applied. Because the indicators are expressed in different measurement units and on different scales the data are transformed in order to render them comparable. Standardization, rescaling and the use of rank numbers are often used normalization techniques. Third, the issue of missing values can be tackled.

Moreover, several multivariate analyses are performed. The degree of association between the indicators can be assessed; the internal consistency can be quantified in order to determine whether the indicators are measuring the same underlying construct; insight can be gained into the grouping of indicators as well as the grouping of similarly performing countries; and the explanatory power of the six performance indicators concerning the number of road fatalities per million inhabitants can be studied. These data analyses provide useful information about the indicator data set to combine.

Figure 2: Normalized road safety performance values per group of countries

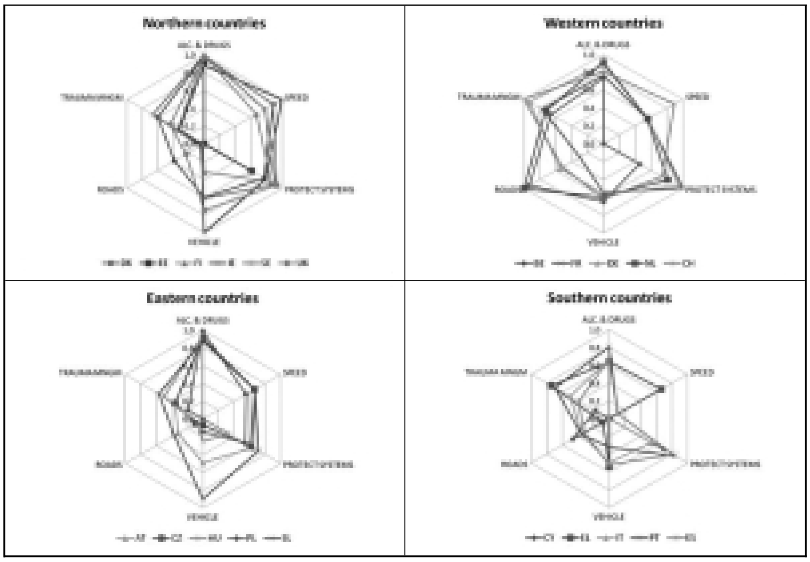

Figure 2 shows normalized indicator values (rescaled between 0 and 1) for the 21 European countries. It can be seen that Northern countries on average perform best in terms of alcohol and drugs, speed and protective systems whereas Western countries have a high score on the roads and trauma management indicator. The group of Eastern and Southern countries are characterized by smaller scores and thus a lower performance. Based on these graphs good and bad aspects can be deduced for each country.

Additionally, several multivariate analysis techniques are carried out. The correlation analysis resulted in four significant pairs of safety performance indicators (i.e., alcohol and drugs & roads; speed & vehicle; vehicle & trauma management; and roads and trauma management). The internal consistency of the six indicators has been checked by means of Cronbach's alpha. It appeared that the indicators are more or less measuring the same underlying construct. The principal components analysis grouped the six indicators in three components - alcohol and drugs & speed; vehicle & roads & trauma management; protective systems - explaining 79% of the variance. By means of cluster analysis, the set of 21 European countries has been divided into four similarly performing classes. Cyprus appeared to have an extremely different performance on the six indicators and was not grouped with another country. Finally, by building some regression models it could be concluded that the six selected indicators already explain some part of the variance in the number of road fatalities per million inhabitants.

As the results from the multivariate analyses are satisfactory, i.e., the indicators have some level of correlation, internal consistency, clustering and explanatory power, the next step in the construction of a road safety performance index, i.e., the weighting of the indicators, can be discussed.

2.4. Assigning a weight to each indicator

After having an idea about which indicators to combine, which data to use and after having insight into the data set, the issue of weighting is handled next. Given the large number of possibilities in literature and its large impact on the end result (Hermans et al., 2009), it is a methodological step that requires careful attention. Indicator weights can be assigned in a number of ways. By studying other indexes, five common weighting methods were selected for further investigation. Weights obtained by means of factor analysis are based on correlations; analytic hierarchy process and budget allocation weights result from expert's opinions questioned in a different way (in the former case, the relative contribution per pair of indicators is required; in the latter case, experts are asked to distribute a budget over the different indicators);

data envelopment analysis (DEA) weights are deduced from a constrained optimization model; and equal weighting assigns the same weight to each indicator. More information on the theory behind these methods as well as their advantages, disadvantages and requirements can be found in Hermans et al. (2008). Each method was applied resulting in a specific set of indicator weights (e.g., in the case of budget allocation most experts assigned the highest weight to the speed indicator), index scores and ranking of the countries.

Based on a qualitative and quantitative assessment, the DEA method appeared to be the most promising weighting method of the five in the road safety index context. Firstly, the ranking of countries resulting from the DEA computed index scores showed the best fit with the reference ranking based on the number of road fatalities per million inhabitants. More importantly, DEA can be preferred based on a qualitative assessment as well. This method results in best possible yet acceptable weights as the most optimal index scores are obtained under the imposed restrictions regarding the share of each indicator in the overall index score (e.g., the overall index score consists for a maximum of 30% of the weighted protective systems value). Moreover, this method can clearly distinguish between best performing countries and underperforming countries.

2.5. Deciding on the way of aggregating the indicators

The next step in the index process tries to find an answer on which aggregation operator to use in the construction of the index. Starting from the extensive aggregation research field, the class of averaging aggregation operators was selected because in this case the index score is limited by the highest and lowest indicator value (Beliakov et al., 2007). Within this class, several types of operators exist. Apart from the often applied weighted mean operators (for example used in case of linear aggregation) the class of ordered weighted averaging or OWA operators was discussed. The arithmetic mean operator is in fact a special type of OWA operator in which case the index score equals the sum of the product of the (normalized) indicator value and its weight. Although this is a very straightforward way of aggregation, it should be noted that it is only plausible if no synergies or conflicts exist between the indicators.

One interesting feature of OWA operators is that irrespective of the meaning of the indicator they allow good and bad performances to contribute differently to the index score. Moreover, an aggregation idea such as 'in case a country scores badly on more than a few indicators, its final road safety score should be small' can be translated into OWA weights (Yager & Kacprzyk, 1997). Taking the aggregation idea of a panel of experts into account, an OWA vector was obtained in which the worst performances are emphasized. This guarantees that bad scores (e.g., regarding speed) cannot be fully compensated by a good score (e.g., on alcohol and drugs). In other words, a high road safety performance index score requires good or average performances on (almost) all risk domains.

2.6. Testing the robustness of the index

Based on the previous steps, various possible road safety performance indexes can be formulated. Since the rank of a country can be largely influenced by the decisions taken at the different stages of the index process, the influence of a change in methodology on the end result is assessed by means of uncertainty and sensitivity analysis. For seven different options of indicator sets, three possible normalization techniques, four possible weighting methods, nine expert's opinions and three ways of aggregation the final countries' ranking is compared to a particular reference ranking and the global average shift in rank is quantified (for more information we refer to Hermans, 2009). The uncertainty analysis resulted in a shift of 3.87 positions with respect to the ranking based on the number of fatalities per million inhabitants. The sensitivity analysis results indicated the factors accounting for most uncertainty in the output. It could be concluded that the choice of the weighting method and the set of indicators to combine require careful evaluation and justification.

2.7. Computing, evaluating and visualizing final index scores

All the information acquired in the previous steps of the methodological process is considered when determining the final index scores. To compute these scores, the final index methodology needs to be decided upon. In this study, the six best available indicators listed above are combined in a road safety performance index. Moreover, a decision regarding the weighting method is taken. We start from the data envelopment analysis method and further elaborate it in terms of aggregation.

The most optimal index score is then computed for each country, thereby respecting the restrictions concerning the share of each indicator in the overall index score (for example the speed performance contributing more than the vehicle performance). Furthermore, the idea of emphasizing bad performances is incorporated by adding an extra constraint to the DEA model. Based on the final index scores three groups of countries can be distinguished (see Figure 3). South-East Europe is characterized by a low index score. Belgium belongs to the group with an average index score, in contrast to its neighboring countries which are performing better.

Figure 3: Coloured map on road safety performance in Europe

In addition to the computation and visualization of the final index scores, an evaluation takes place. More specifically, the road safety performance index ranking is compared to the results of other, related indicator and index studies. There appears to be a high degree of agreement with the results from the SUNflowerNext study (Wegman et al., 2008), the countries' ranking based on the number of road fatalities per million inhabitants and the results from the corruption perceptions index (Lambsdorff, 2004).

3. Conclusion and further research

The complex and multidimensional concept of road safety can be quantified by means of indicators. Safety performance indicators offer new insights as they represent important road safety risk factors and help in detecting the key problem areas in a particular country. Moreover, their combination into an index offering an enriched picture of road safety performance enables ranking countries based on their overall performance and monitoring the evolution in road safety risk over time.

The multistage index process with its various options requires careful investigation. In the end, a scientifically sound and appropriate index is a prerequisite for its acceptance and use. This paper aimed at identifying and discussing the different methodological steps. The methodological index process has been illustrated using a best available yet imperfect data set. The future gain in importance of concepts like road safety performance indicators is expected to produce reliable, comparable and ideal indicator values. Apart from the data used, the methodological insights described in this paper are of value in future index development.

In the future, the index methodology could be applied to a more extensive data set. The number of risk domains as well as the number of indicators representing a risk domain could be increased to better reflect reality. In addition, more countries could be involved in the analysis. At the same time, a larger data set implies tackling the issue of missing values.

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