Impact of methodological choices on road safety ranking

E. Hermans, F. Van den Bossche, G. Wets

PROMOTOR ▶ Prof. dr. Geert Wets
ONDERZOEKSLIJN ▶ Risicobepaling
ONDERZOEKSGROEP ▶ UHasselt
RAPPORTNUMMER ▶ RA-MOW-2007-001

WETENSCHAPSPARK 5
B 3590 DIEPENBEEK
T ▶ 011 26 91 12
F ▶ 011 26 91 99
E ▶ info@steunpuntmowverkeersveiligheid.be
I ▶ www.steunpuntmowverkeersveiligheid.be

Impact of Methodological Choices on Road Safety Ranking

RA-MOW-2007-001

Elke Hermans, Filip Van den Bossche, Geert Wets

Onderzoekslijn Risicobepaling

DIEPENBEEK, 2007.
STEUNPUNT MOBILITEIT & OPENBARE WERKEN
SPOOR VERKEERSVEILIGHEID

Documentbeschrijving

Rapportnummer:	RA-MOW-2007-001
Titel:	Impact of Methodological Choices on Road Safety Ranking
Ondertitel:	
Auteur(s):	Elke Hermans, Filip Van den Bossche, Geert Wets
Promotor:	Prof. dr. Geert Wets
Onderzoekslijn:	Risicobepaling
Partner:	Universiteit Hasselt
Aantal pagina's:	22
Projectnummer Steunpunt:	6.2
Projectinhoud:	Opstellen van verkeersveiligheidsindicatoren

Uitgave: Steunpunt Mobiliteit & Openbare Werken – Spoor Verkeersveiligheid, november 2007.

Paper accepted for presentation at the 87th annual meeting of the Transportation Research Board, January 2008, Washington D.C. and forthcoming in the proceedings of this conference.

Steunpunt Mobiliteit & Openbare Werken
Spoor Verkeersveiligheid
Wetenschapspark 5
B 3590 Diepenbeek

T 011 26 91 12
F 011 26 91 99
E info@steunpuntmowverkeersveiligheid.be
I www.steunpuntmowverkeersveiligheid.be

Samenvatting

Samengestelde indicatoren aggregeren een veelheid aan informatie in één index op basis waarvan landen vaak gerangschikt worden. De positie van een land kan echter sterk beïnvloed worden door de methodologische keuzes die gemaakt worden tijdens het proces waarbij een samengestelde indicator wordt gecreëerd. Dit proces bestaat uit verschillende fasen zoals het selecteren van geschikte indicatoren, het normaliseren van de indicatorwaarden, het toekennen van een gewicht aan elke indicator en het selecteren van een aggregatieoperator.

Om een robuuste index te garanderen waarbij in elke fase verscheidene mogelijke en alternatieve technieken worden beschouwd, is een onderzekerheid- en sensitiviteitanalyse essentieel. Onderzoekers, beleidmakers alsook de weggebruikers zullen voordeel halen uit zulke analyse. We identificeren immers de belangrijkste methodologische aspecten waarvoor bijkomende informatie het meest waardevol is om de onzekerheid in het eindresultaat te verminderen. Onzekerheid- en sensitiviteitanalyse als een noodzakelijk onderdeel van het indexproces beschouwen, zal zorgen voor een hogere aanvaardbaarheid van samengestelde indicatoren.

In dit onderzoek wordt de verkeersveiligheidsrangschikking van landen op basis van verschillende indicator- en wegingsopties bestudeerd. De resultaten tonen dat de rangschikking van landen significant verschilt naargelang de gekozen wegingsmethode, expert en set van indicatoren. Van deze drie factoren blijkt de indicatorset de meest beïnvloedende factor te zijn. Bijkomend onderzoek met betrekking tot de selectie van geschikte verkeersveiligheidsindicatoren (naast andere aspecten) zal de onderzekerheid in de rangschikking verminderen en bijdragen tot het verkrijgen van een robuuste verkeersveiligheidsindex.

English summary

Title Impact of Methodological Choices on Road Safety Ranking

Subtitle

Abstract

Composite indicators aggregate a lot of information in one index based on which countries are often ranked. However, the position of a country can largely be influenced by the methodological choices made during the composite indicator process. This process consists of several phases such as selecting appropriate indicators, normalising the indicator values, assigning a weight to each indicator and selecting an aggregator.

In order to guarantee a robust index considering several possibilities and alternative techniques during each phase, an uncertainty and sensitivity analysis is essential. Researchers, policymakers as well as the community of road users will benefit from such analysis. The most influencing methodological aspects will be indicated for which extra information is most valuable in order to reduce the uncertainty in the end result. Incorporating the necessary uncertainty and sensitivity analysis in the process is an aspect that will enlarge the acceptability of composite indicators.

In this research, the road safety ranking of countries based on different weighting and indicator options is studied. The results show that the ranking of countries differs significantly according to the selected weighting method, expert and set of indicators. Of these three factors, the indicator set resulted to be the most influencing factor. Additional research on the selection of appropriate indicators (beside other aspects) will reduce the uncertainty in ranking and help in obtaining a robust road safety index.

Inhoudsopgave

1. INTRODUCTION

In recent years, the interest in and the use of indicators and indexes are rapidly increasing. In general terms, an indicator is a quantitative or a qualitative measure derived from a series of observed facts that can reveal relative positions (e.g. of a country) in a given area (1). Their usefulness for policymakers and communication purposes is a key advantage. Trends can be identified, problems predicted, policy targets and priorities set, the impact of measures assessed, attention achieved, … (1,2). In domains like economics (the human development index), technology (the technology achievement index) and sustainability (the environmental sustainability index) the aggregation of indicators in one index is common (3). The most important advantage of one index over an accumulation of individual indicators is that all relevant information is aggregated in one final score which can be used for ranking countries, tracking changes over time, etc. However, the process of obtaining such an index intended to present a valid and correct vision on the topic under study is a methodologically challenging one.

In this research we focus on the road safety domain which is currently showing much interest in the use of indicators (e.g. SafetyNet project (4)). Although countries are often compared on their level of road safety by means of the number of traffic deaths per million inhabitants, the development of a road safety performance index will provide new and valuable insights. There are a number of disadvantages linked to accident data, like for example the lack of uniformity in definitions and the problem of under-registration (5). However, the most important drawback is that knowledge of the number of accidents and casualties in a country is insufficient to understand the processes that lead to these accidents. To enhance the road safety level in a country, the first step is to identify the measures that have the potential of reducing the number of accidents and casualties. Road safety indicators can help in this respect.

International research in the past focused on the influential factors of road safety to develop appropriate measures. The relationship between numerous explanatory variables on the one hand – behavioural, economic, climatologic, infrastructural, legislative, etc – and the number of accidents and casualties on the other hand has been studied amongst others by Hakim et al. (6), Scuffham (7), Eisenberg (8), Van den Bossche et al. (9) and Hermans et al. (10). The most contributing road safety dimensions are road user behaviour (speed, alcohol, seatbelt use), vehicle safety (composition and age of the vehicle fleet) and environmental factors (infrastructural investments, urban population, hospital care) (11,12).

For the most influencing road safety risk factors, so called safety performance indicators are presently being developed and data collected at the European level (4,13). A safety performance indicator is defined as any measurement that is causally related to accidents and casualties and used in addition to a count of accidents and casualties in order to indicate the safety performance or understand the process that leads to accidents (13). Based on a set of carefully selected indicators, the safety conditions of a country can be reflected, the impact of safety interventions can be measured and the safety performance of different countries can be compared (4). On the one hand, indicators will provide an insight into the road safety aspects that require more attention. On the other hand, the aggregation of useful indicators into one road safety index offers a valuable tool for the road safety domain. A sound methodology for constructing a road safety performance index is however prerequisite for its use. To this end, a composite indicator methodology for road safety has to be elaborated. In Nardo et al. (1) ten steps to create an aggregated index are discussed. The theoretical framework, the selection of indicators, the imputation of missing data, the normalisation, weighting and aggregation of the indicators are all necessary components in the development of a (road safety) index.

In the past, limited attention has been paid to the construction of a road safety index (for example (14)), and we believe that a methodologically valid composite indicator approach is a new, challenging and necessary matter in road safety. The subjective choices involved in the process of developing an acceptable road safety index need to be justified and their impact on the end result quantified. As there is no agreement or a priori knowledge on the best or ideal method to be used in the steps above, in each of the steps several possible choices need to be tested. The end result – such as the ranking of countries based on their road safety index score – can be heavily influenced by the choices made in the index construction process. In this respect, it is essential to know which decisions have the largest impact on the final ranking. Uncertainty analysis (UA) and sensitivity analysis (SA) are a requirement for composite indicators because they offer insights in the size and sources of uncertainty in the aggregation process of road safety indicators. As stated in Nardo et al. (15) the iterative use of uncertainty and sensitivity analysis contributes to the structure of the composite indicator, provides information concerning the robustness of the countries' ranking and identifies ways to reduce the uncertainty in the ranking for a better monitoring and policy. The main objective of this paper is to test the robustness of a road safety index and the corresponding position of the countries in the ranking. More specifically, we will assess how a decision related to the weighting method, expert selection and the set of indicators influences the final ranking of 18 European countries.

The remaining of this paper is structured as follows. In the next section the design of this study is described. The third section focuses on the methodology. The theoretical considerations of uncertainty and sensitivity analysis are discussed. Subsequently, the results of this research are shown. This paper closes with the main conclusions and some topics for further research.

2. Study Design

The aim of our research is to assess the robustness of a road safety index and the ranking of countries by means of an uncertainty and sensitivity analysis. For that purpose, we will use several methods in each step of the construction process. In (1) and (3) a number of often used and relevant methods for imputation, normalisation, weighting and aggregation are given. In our study, we will investigate the impact of the selected methodology on the road safety ranking of countries.

First, the theoretical framework needs to be developed (see figure 1). The selection of road safety indicators follows from a number of steps. First, road safety is translated in the number of accidents and casualties. Next, the domains which contribute to either accidents, casualties or both are listed. As stated before, in literature there is agreement on a group of relevant risk factors. The European SafetyNet project (4) on safety performance indicators has selected the following 7 domains as crucial road safety risk factors: alcohol and drugs, speed, protective systems, visibility, vehicle, infrastructure and trauma management. In theory, each risk domain is characterized by several indicators. Choosing appropriate indicators is not an easy task. A selection for each risk domain can be made based on their strengths and weaknesses. Several sources discuss criteria that can be used to select suitable indicators (1,2). Litman (2) states that the following six aspects should be taken into account:

- Diversity: choose a set of indicators that reflect all relevant domains
- Usefulness: select indicators that can be applied to planning decisions
- Ease of understanding: prefer indicators understandable to experts and the general public
- Data availability and collection costs: choose indicators that rely on data that are available or can be collected with available resources
- Comparability: if possible, opt for indicators and data that are suitable for comparison with other jurisdictions, times and organizations
- Performance targets: select indicators that are suitable for establishing useful performance targets.

To illustrate the methodology in this paper, we selected one indicator for each of the seven risk domains, taking the aforementioned criteria into account. With these seven indicators, we cover all domains that were identified as being relevant in a road safety context. All indicators are understandable and can be used as remedial measures to improve road safety. Moreover, they are available for and comparable over all countries in the study. Of course, the presented framework can be easily extended to take into account more indicators per risk domain. The indicators are presented in figure 1 and all have the same interpretation: a higher value implies less accidents and casualties. The 7 indicator values related to 2003 are known for the 18 European countries in our data set leaving the imputation of missing values unhandled in this study.

The construction of a composite index involves several major steps. All (collected and imputed) indicator values need to be normalised and consequently weighted and aggregated. As subjective choices are often made during the construction process, the uncertainty and sensitivity analysis is an essential step. Finally, for each country a (range of possible) index score(s) is obtained based on which a ranking can be provided. The last column in figure 1 presents a possible, often used ranking which makes use of the number of road fatalities per million inhabitants in 18 European countries (in 2003). Notice that this ranking is based on just one indicator and not on an index. Sweden, the United Kingdom and the Netherlands are the countries with the lowest number of fatalities in this road fatality ranking (RFR).

To illustrate the importance and implication of an uncertainty and sensitivity analysis, three methodological aspects will be discussed in this paper. We will consider two weighting methods (a), incorporate the opinion of several experts (b) and assess the impact of the indicator/domain selection (c) on the ranking of the 18 countries in our data set. The impact of imputation of missing values, normalisation of the different scales and aggregation using a certain degree of compensation (1) are not handled here but can be assessed in the same way.

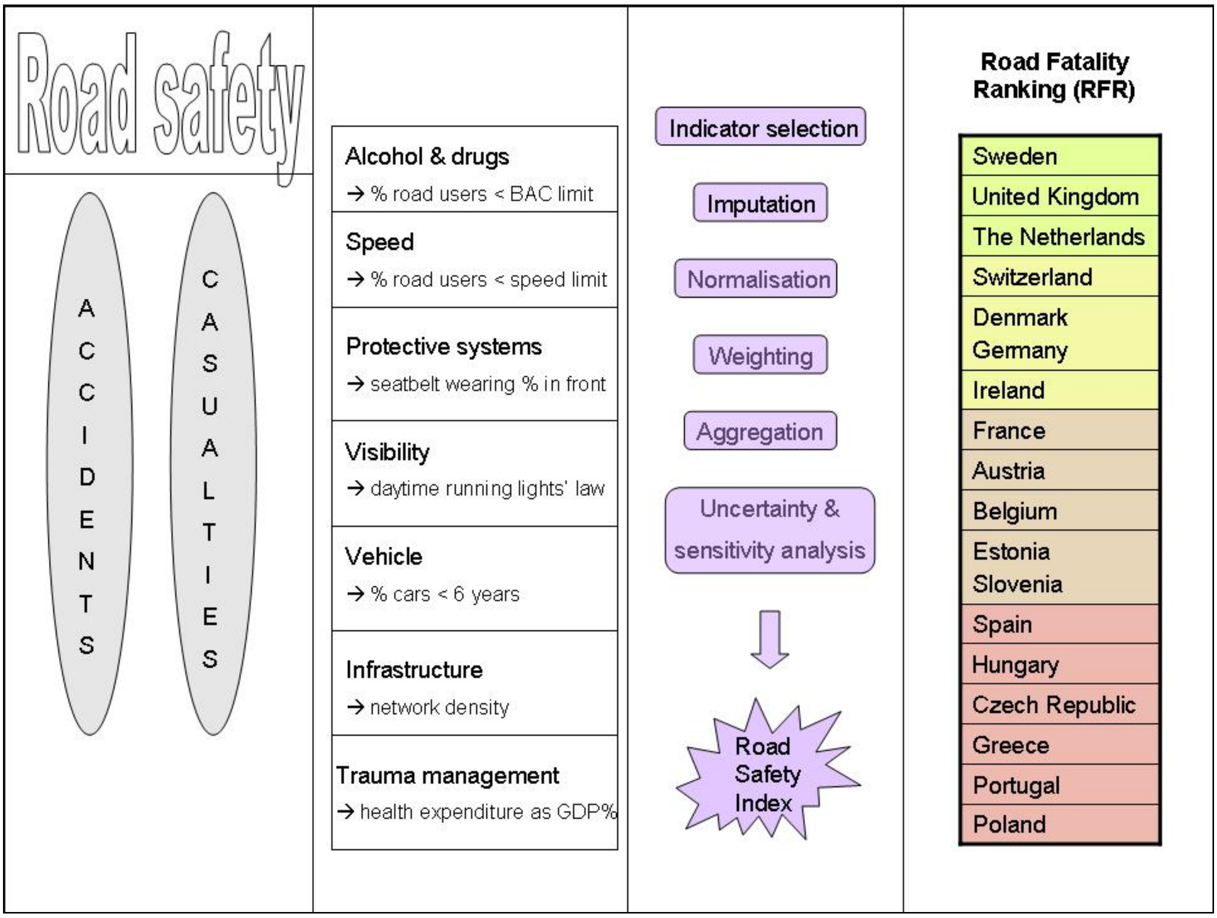

Figure 1: Framework of the road safety performance index.

The first factor that is allowed to change in the sensitivity analysis is the weighting method. From the weighting methods described in (3) we will test two methods based on expert opinions, namely the Analytic Hierarchy Process (AHP) and Budget Allocation (BA). Instead of assigning weights based on correlation, indicator values or simply compute the average, more realistic weights will be obtained when experts are involved. AHP developed by Saaty (16) is a comprehensible and valuable technique for assessing indicator weights. For each pair of indicators, an expert is asked to indicate which of the two is more contributing to road safety and how large the intensity of the difference is. This expert information is presented in a matrix from which the indicator weights and the degree of consistency are calculated using the eigenvector technique. BA is another well-known method for obtaining indicator weights. A number of experts are asked to distribute a given budget over the indicators in such a way that spending more on an indicator implies that (s)he wants to stress its importance (1). The share of the budget assigned to each indicator determines its weight. The results of comparisons in pairs of the road safety indicators as well as the allocation of a budget over the indicator set were recently obtained from nine road safety experts from different European countries. Usually, the average indicator weights over the experts are used (16). However, we will consider all available, valuable information and assess the impact of selecting the weights from one particular expert under each of the two methods. Therefore, the selection of the expert is the second factor in the sensitivity analysis. The third factor in the analysis is the set of included indicators. The countries' ranking will also be studied in case one of the seven indicators is no longer included in the road safety index.

In general, the results of the uncertainty and sensitivity analysis will indicate how robust the ranking is, which of these three methodological choices has the largest impact on average rank shift and which input factor needs special effort in order to reduce the uncertainty. Like in other composite indicators studies (e.g. 15) the average change in the countries' ranking for several possible (methodological) scenarios is studied. Each ranking resulting from a specific scenario is compared against a "reference ranking". This is often a ranking on the subject that has been published earlier. One possible reference would be a ranking based on equal weighting, where every indicator gets the same weight. In the context of a road safety index, however, it might be more useful to have a reference ranking which is based on available road safety information, like for example the number of traffic fatalities per million inhabitants. In the end, we want to construct a road safety index that approaches the number of traffic fatalities and can be divided into several risk components. In addition to studying the average shift in rank of the road safety index relative to the ranking based on fatalities, an analysis on the country level will be performed to show which countries have the largest change in rank under the different methodological options.

3. METHOD

3.1 Introduction

Uncertainty analysis and sensitivity analysis are terms that often appear in the context of models. Although it seems that everyone agrees on the importance of these analyses, in practice this step is often lacking. Similar to for example the confidence interval around the regression coefficient of a particular explanatory variable, a confidence interval should be added to the rank position of a country. Even though the position of a country in the ranking is very appealing for communication purposes, there is the danger that attention is paid to this number only without considering the methodological assumptions that were made. The uncertainty in the ranking related to the methodological choices needs to be quantified. This makes the context of composite indicators one in which UA and SA are essential.

The composite indicators process consists of several steps: indicators need to be selected, missing values imputed, all values need to be normalised, the scores weighted and aggregated and in the end, an index score for each country is obtained, based on which a countries' ranking can be produced. As the number of different methods in the index construction process is substantial, the end result can be manipulated relatively easy. Suppose, we select – at random – the following options: 7 indicators, no imputation, standardisation, equal weighting and linear aggregation. Under this scenario, Belgium for example ranks 4th. Using the same set of indicators, the same normalisation and aggregation but weight by means of budget allocation the 10th position is assigned to Belgium. Policymakers as well as the general public focus on the final ranking, without considering the methodological choices made. Although the possibility of efficiently presenting a large amount of information is a major advantage of the composite indicators methodology, it should be clear that very different conclusions will be drawn in case the 4th or the 10th position out of 18 is obtained.

This simple example in which only the weighting technique changed already shows the major implications. In fact, a researcher should elaborate the most justifiable methodological options related to the context (several sets of indicators, normalisation and imputation techniques, weighting methods and aggregation procedures) and present the results in such a way that the uncertainty of the end result is known for the users of the ranking as well. The sensitivity analysis indicates which aspects need more research in order to reduce the uncertainty to an acceptable level. This information can be used to construct a more robust index which will be better accepted.

3.2 Description of the Uncertainty and Sensitivity Analysis

In general, uncertainty analysis estimates the uncertainty in the output taking into account the uncertainty affecting the input factors. Rather than being a unique value the estimated output represents a distribution of values and elementary statistics such as the mean, standard deviation and percentiles are used to describe its features (17). At the same time, sensitivity analysis is defined as the study of how uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input. Saltelli et al. (17) present a step-by-step plan for performing a sensitivity analysis on a model. First, the goal of the analysis and consequently the form of the output function need to be defined. Second, a decision has to be made on which input factors to include in the analysis. Third, for each input factor, a distribution function is chosen. Fourth, a sensitivity analysis method is selected. Next, the input sample is generated. Then the model needs to be elaborated on the generated sample and the output produced. Finally, the model output is analysed and conclusions are drawn.

3.3 Global Variance based Sobol Method

A wide range of methods for sensitivity analysis can be found in literature. First, a distinction can be made between local methods on the one hand and global methods on the other hand. As local methods explore only one point of the factor's space and factors are changed one at a time, a global analysis is more appropriate for composite indicators. Global methods explore the entire interval of each factor and the effect for a factor is the average over the possible values of the other factors. In recent years global quantitative sensitivity analysis techniques have received considerable attention in literature (17).

One important and promising class of sensitivity methods is referred to as variance based techniques. Their characteristic of being model-free (i.e. applicable to non-linear and non-additive models) makes them very useful for composite indicators, in which several layers of uncertainty are simultaneously present (1). Variance based techniques have a number of advantages (17): they can explore the whole range of variation of each input factor instead of sampling the factors over a restricted number of values, they are able to capture interaction effects apart from the fractional contribution of input factor X_i to the variance of the model output *Y*, are easy to interpret and explain, are quantitative, etc.

In this study we use the method of Sobol for generating the input sample and obtaining uncertainty and sensitivity results. This variance based method is a well-known, often used method with useful characteristics as it requires no seed (and hence this has no impact) and handles discontinuities well.

3.4 Technical Considerations of Sensitivity Analysis Indices

The following algebraic elaboration of sensitivity indices has been deduced from Saltelli et al. (17). The uncertainty of the model output is quantified by its unconditional variance $V(Y)$. We use SA to identify the most important factor(s). This is defined as the one that, if determined (i.e. fixed to its true albeit unknown value) would lead to the greatest reduction in the variance of the output *Y*. Our objective is to put in order the factors according to $V(Y|X_i = x_i^*)$, i.e. the amount of output variance that is removed when we learn the true value of a given input factor X_i.

The problem is that we do not know what x_i^* is for each X_i. Therefore, it sounds sensible to look at the average of the above measure over all possible values x_i^* of X_i i.e. $E(V(Y|X_i))$ and take the factor with the smallest $E(V(Y|X_i))$. Given that $V(Y)$ is a constant and $V(Y) = V(E(Y|X_i)) + E(V(Y|X_i))$ betting on the lowest $E(V(Y|X_i))$ is equivalent to betting on the highest $V(E(Y|X_i))$. If we normalise it by the output (unconditional) variance we obtain $\frac{V(E(Y|X_i)}{V(Y)}$. This ratio S_i is the first-order effect of X_i on Y. Synonyms are importance measure, correlation ratio or sensitivity index.

In case all variance is explained by the *i* first-order indices ($\sum_i S_i = 1$), there are no interaction effects between the input factors and the model is called additive. Two factors are said to interact when their effect on Y cannot be expressed as a sum of their single effects on Y. $V(Y) - V(E(Y|X_j) - V(E(Y|X_i)$ is the interaction term between the variables X_j and X_i. In practice, it is often needed to compute higher-order sensitivity indices able to capture the interaction effects between the input factors. Nevertheless, a model with k factors implies that the total number of indices that has to be calculated equals 2^k-1. The total effect sensitivity index offers the solution as it is more compact and concentrates all interactions of factor X_i in one term. The total effect terms S_{Ti}'s give information on the non-additive part of the model and are defined as $\frac{[V(Y) - V(E(Y|X_{-i})]}{V(Y)} = \frac{E(V(Y|X_{-i})}{V(Y)}$ (with X_{-i} representing all input factors but X_i). The total effect sensitivity index is the sum of all terms of any order that include a certain factor. For $k = 3$, as is the case in this study, the total effect sensitivity index of the first input factor S_{T1} equals $S_1 + S_{12} + S_{13} + S_{123}$.

Saltelli et al. (17) state that computing all S_i terms plus all S_{Ti} terms, a fairly complete and parsimonious description of the model can be obtained in terms of its global sensitivity analysis properties. The main aspects of the first-order and total effect sensitivity index are summarized in table 1.

Table 1: Summary information on first-order and total effect sensitivity indices

$S_i = \frac{V(E(Y\|X_i)}{V(Y)}$	S_i indicates how much on average the output variance can be reduced if X_i is fixed
S_i = high	X_i is an influencing input factor which drives the model output variance and deserves future effort to reduce the uncertainty
$S_{Ti} = \frac{E(V(Y\|X_{-i})}{V(Y)}$	S_{Ti} captures the total effect of X_i on Y ($S_{Ti} \geqslant S_i$ in case of orthogonal input)
$S_{Ti} - S_i$	This measure indicates how much X_i is involved in interactions with other input factors
$S_{Ti} = 0$	X_i is non-influential
$\sum_i S_{Ti} > 1$ or $\sum_i S_i < 1$	Interactions exist between the factors

3.5 Software

Simulation Laboratory for Uncertainty and Sensitivity Analysis (SIMLAB) software has been developed by the institute for Systems, Informatics and Safety within the European Union Joint Research Centre for Monte Carlo analysis (http://simlab.jrc.cec.eu.int/). It is based on the performance of multiple model evaluations with probabilistic selected model input. In this study, SIMLAB version 3.0.8 is used.

4. ANALYSIS AND RESULTS

Following the step-by-step plan discussed in the previous section an uncertainty and sensitivity analysis is performed on our road safety data set with 7 indicator values for 18 countries. In the present study, we will compare the obtained index rank of each country to the road fatality rank of the country and the average over these 18 values is the output of interest. A higher shift indicates a larger uncertainty. First, we decide on the input factors (*F*). The first input factor selects between the AHP and BA weighting method. The second input factor is used to select one of the 9 experts. Thirdly, it needs to be determined if all 7 indicators are considered or 6 indicators (there are 8 alternatives for this input factor). To each input factor we assign a uniform distribution between the integer values 1 and 1+the number of options resulting in [1,3] for the first input, [1,10] for the second and [1,9] for the third one. From these distributions, values are drawn using the Sobol technique. The number of runs for this model is a factor 2^k of 256 (k=0,1,2,...). As we want to draw conclusions based on several thousands of runs, an input sample matrix *M* consisting of *N* (=8,192) rows and *F* (=3) columns is generated. Subsequently, each of the 8,192 rows of our generated sample is evaluated to obtain a score for the output of interest. As we make use of triggers to select one of the options for each factor, the sampled values need to be translated in a set of weights W (based on the weighting method and the chosen expert) and (standardized) indicator values Z to calculate the composite road safety index scores for the 18 countries. This working method is illustrated in figure 2 for the second row of sample M. Next, a road safety rank (RSR) is assigned to the countries based on their road safety index score (a higher index score implies a higher rank). Using the road fatality ranking of the 18 countries (resulting from the number of road fatalities per million inhabitants) the difference between the two rank numbers is calculated for each country. Subsequently, the average of these 18 absolute values is taken resulting in the output value for this row. This process is repeated until N output values are obtained.

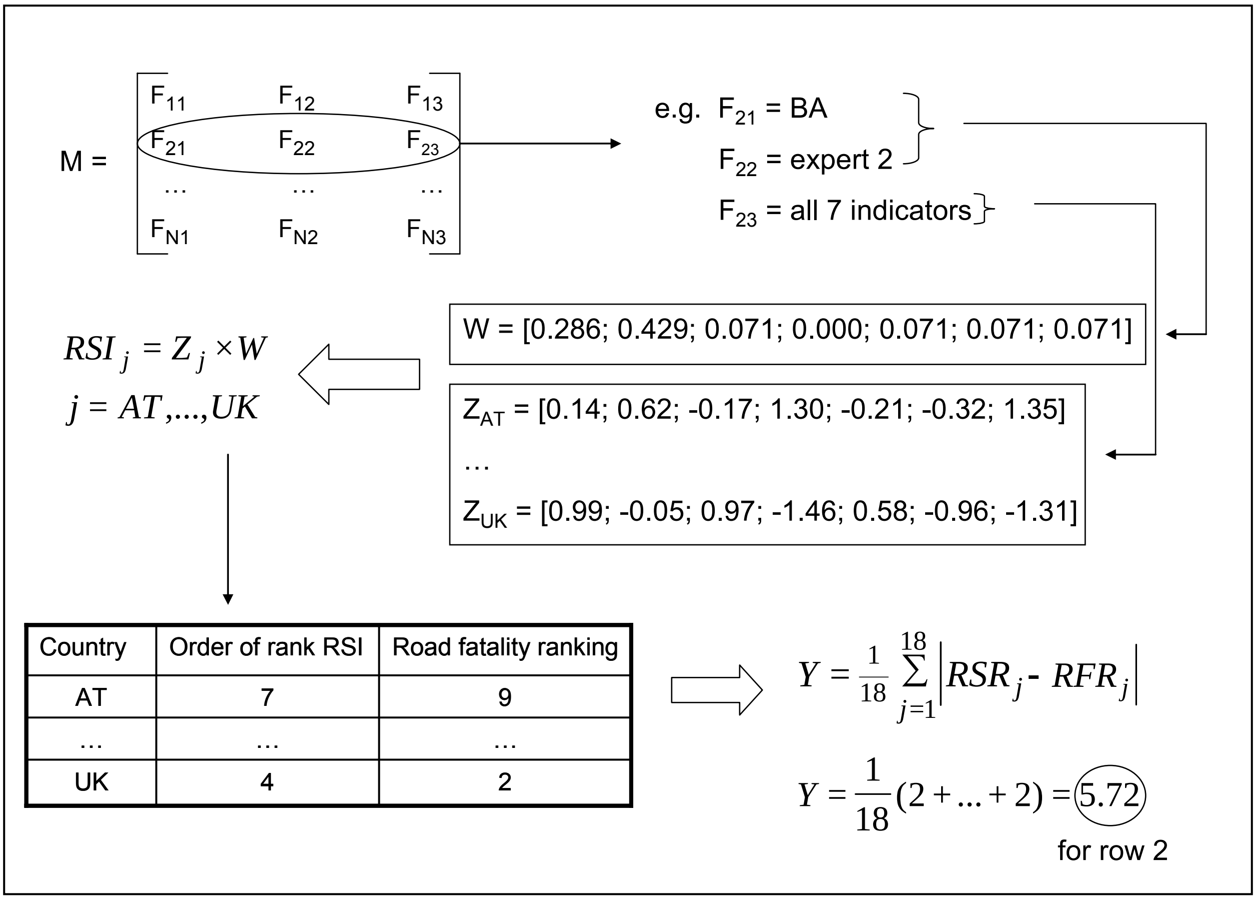

Figure 2: Scheme describing the assessment of the output of interest.

The *N* output values are used to obtain the uncertainty and sensitivity outcomes. The uncertainty analysis results in the output distribution over the sample. As shown by the histogram in figure 3 (a), the average shift in ranking over all 18 countries compared to the road fatality ranking has an average of 5.64 positions with a variance of 0.78 positions. A detailed analysis of the results learns us that the largest average shift in country ranking occurs in case the composite indicator consists of the weights assigned by expert 6 using the budget allocation method and 6 road safety indicators (i.e. the infrastructure indicator is no longer part of the data set). Due to the specific nature of our data, we already expected quite large differences between the two rankings. Although we aim to describe the road safety performance of countries by means of relevant indicators, there still may be some discrepancy with the ranking based on road traffic fatalities. Some indicators may not have a causal relationship with the number of traffic fatalities, we probably need to incorporate more road safety indicators, some indicators may only be relevant for a certain group of countries or the quality of the data may be rather poor. However, the road fatality ranking offers valuable information and is an appropriate benchmark for our composite indicator ranking. Secondly, we use a rather small data set of European countries for which a change of a few ranks is more likely to happen than in case of a larger set of countries on a world scale having a more distinct motorization and road safety level.

The (b) graph in figure 3 shows the disaggregation of the global average shift in rank. For each country the average over 8,192 values of the absolute difference between their rank based on their road safety index score and their road fatality rank is shown in increasing order. The road safety index score for Poland results in a better road safety rank than its 18th place in the road fatality ranking. A detailed look at the data shows that Poland was evaluated as having low driver’s alcohol use and high compliance with speed limits and to these indicators above-average weights are mostly assigned by the experts.

This large discrepancy for Poland influences the global average shift. The methodological choices in this study only slightly affect the rank number of countries like Greece and Germany.

Finally, the sensitivity analysis calculates for each of the three input factors the first-order index S_i which captures the fractional contribution to the model output variance due to the uncertainty in X_i and the total effect index S_{Ti} which concentrates all the interactions involving factor X_i in one single term. As shown by the left (c) graph in figure 3 the set of road safety indicators has a very high first-order index (0.508). Additionally, the index of expert selection (0.300) is also relatively high. Consequently, the sum of the three first-order sensitivity indices –0.852– approaches one, meaning that the model is not totally additive and interactions emerge between the input factors. Therefore, the calculation of total effect sensitivity indices is justified. These three values are presented in the right (c) graph in figure 3. The relative differences between the total effect and first-order sensitivity indexes indicate that the factor expert selection accounts for most of the interaction effects (0.167). The selection of the set of indicators is the most influencing input factor. The uncertainty in the average shift in countries' ranking could be reduced most if more effort was directed in this topic. Nevertheless, the influence of the choice of the expert to assign the weights is also significant. The weighting method (analytic hierarchy process or budget allocation) is the least important factor with limited interaction effects with the other input factors.

Based on the results of this study a number of road safety enhancing recommendations can be formulated. First, it has been shown by the uncertainty analysis that the global average shift in ranking based on the road safety index compared to the road fatality ranking of the 18 countries in our data set equals 5.6 positions. Rankings receive a lot of attention from policymakers as well as the public. Since an average country shift in rank between 2 and 13 implies that a particular country can be ranked very high under certain assumptions while a change in methodology may result in a bad rank, it is required to always assess the impact of methodological choices on the ranking of countries. We therefore recommend the frequent use of uncertainty analysis as essential part of the methodology of the road safety index development process.

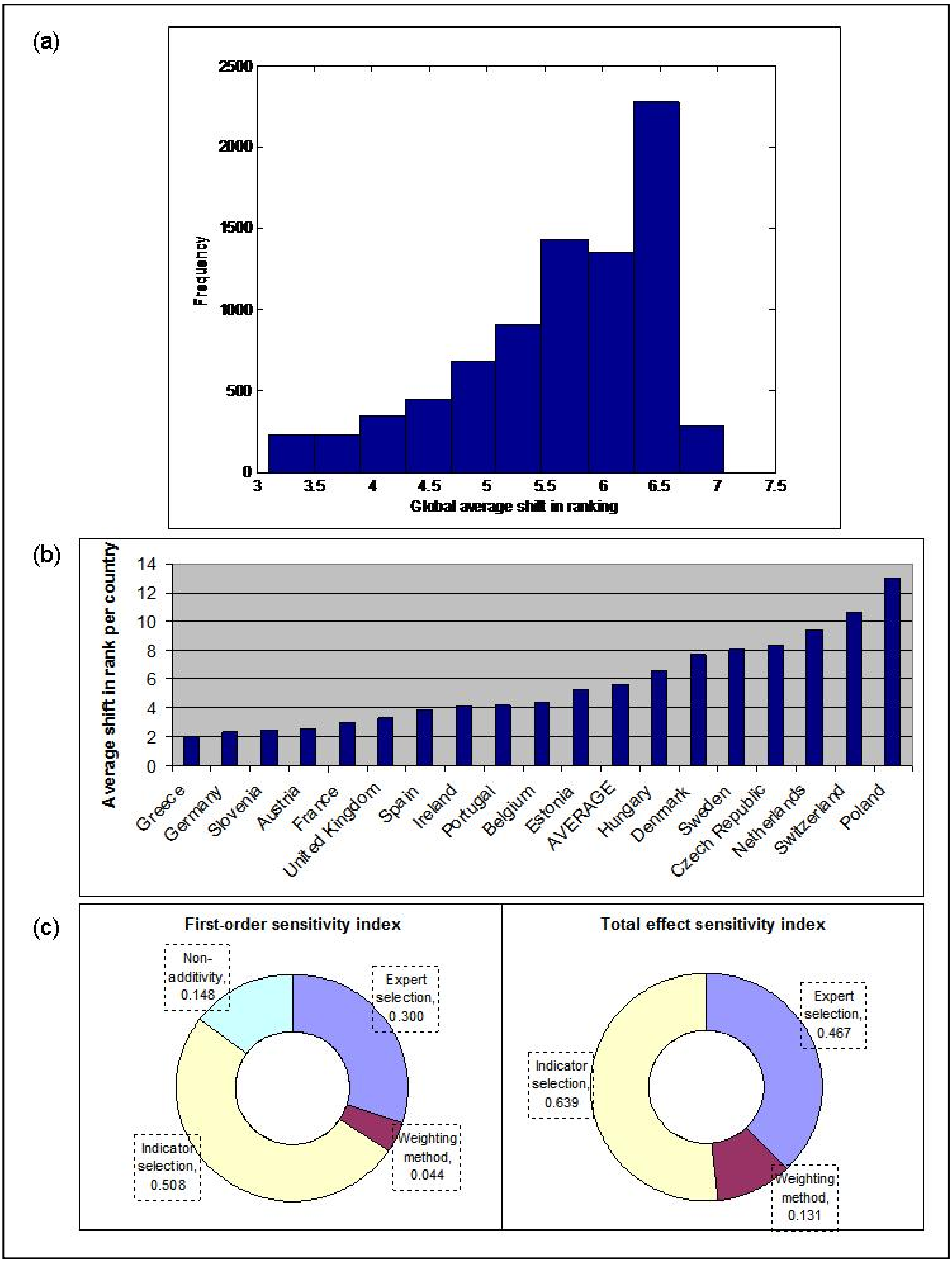

Figure 3: Uncertainty and sensitivity results.

The sensitivity analysis answered the question which of the uncertain input factors is the most influencing one. The set of indicators that is used to construct the road safety index seems to have the largest impact on a shift in ranking. Therefore, the theoretical framework of a road safety performance index needs some careful thought. More specifically, the risk domains of road safety need to be identified and attention should be paid mainly to the indicators describing these domains. Of the seven indicators in the present study, a data set without the protective systems indicator, without the infrastructure indicator or without the alcohol indicator caused the highest global shift in countries' ranking. In the future, more indicators could be considered. The sensitivity results can then be used to assess the quality of the selected indicators per risk domain. For example, if a higher shift in ranking occurs without alcohol indicator A than without alcohol indicator B, it may be an option to prefer indicator A over B. This way, a better conformity between the road safety index and the number of fatalities can be obtained.

Besides the indicators, the road safety index consists of a set of indicator weights. The analysis showed that the expert selection (more than the weighting method) had an impact on the shift in countries' ranking (fractionally as well as through interaction with the other input factors). Therefore, the selection of experts is crucial and needs consideration. A group of experts with an excellent knowledge and experience in road safety but at the same time a specific view and background has to be found. The weighting method is the factor with the least impact. However, this result is probably caused by the similarity between the two alternatives. AHP and BA belong to the same family of participatory methods which possibly makes the choice between them of lesser impact.

In other composite indicator studies the uncertainty and sensitivity analysis resulted in more or less the same results. Nardo et al. (15) for example tested normalisation, indicator selection, aggregation, weighting, expert selection and imputation for the technology achievement index and concluded that the indicator selection, the weighting method and the choice of the expert were the most important factors. The sensitivity results of our study indicate that these aspects need further attention in the development of a road safety index as well.

5. CONCLUSIONS AND FURTHER RESEARCH

The research presented in this paper illustrates the impact of methodological choices on a road safety ranking. The importance of carefully selecting suitable road safety indicators and the practical advantages of a road safety composite indicator are fairly well known by the road safety community. Offering policymakers a useful tool to capture changes in risk in time, to benchmark and to assess the impact of measures, this road safety index can help enhancing road safety in several countries. Nevertheless, the process of constructing such an index is complex and consists of several phases: the theoretical framework needs to be defined, indicators selected, data collected and imputed if necessary and the indicators have to be weighted and aggregated. In literature, there is no agreement on which method or technique to use in each phase. As a result, one method is often chosen (at random or based on simplicity) and the index score or country ranking is presented and used without considering the assumptions made during the process. However, one should be aware that every choice that is made in the creation of a composite index might have an impact on the ranking that will finally be produced. This finding is a trigger for the development of a framework in which a road safety index can be developed from beginning to end, that is from the selection of indicators up to (and including) the sensitivity analysis of the results. Knowledge of influential factors in the ranking is the first step to controlling its variance. Given the important decisions that usually depend on the results of rankings, and the scarce resources that can be reserved for road safety programs, we believe that this analysis should become part of the standard toolkit of road safety policymakers.

In this study, an uncertainty and sensitivity analysis has been elaborated. We examined the impact of three aspects (the selection of the weighting scheme, the expert and the indicator set) on the average shift in countries' ranking based on the road safety index compared to the road fatality ranking. The following conclusions could be drawn. The average shift in rank equals 5.6 positions. This implies that in case the weights from one expert were used resulting from one of the participatory methods together with a data set of at least 6 road safety indicators to construct the road safety index, the final ranking of the countries would differ to some extent from the ranking based on another road safety index using different weights and indicators. The sensitivity analysis helped finding the most influencing factor. From literature, it already appeared that the factors studied here are all very important. The set of indicators that is used to construct the road safety index seemed to have the largest impact on a shift in ranking. Using the sensitivity results to assess the quality of possible indicators, the theoretical framework of the road safety performance index can be improved. Concerning the weight, the selection of the expert had the largest impact. This implies careful thought in expert selection. Although the influence of the weighting method (AHP or BA) on the output appeared to be limited in this study, in the future this aspect should be considered in a broader sense. Alternative often used weighting techniques such as data envelopment analysis should be incorporated in the model.

As the road safety performance index is still under development and this paper shows the advantages of an uncertainty and sensitivity analysis by means of a case study, several topics for further research can be stated. The other aspects in the development process should be included in the analysis as well, like aggregation, normalisation and imputation of missing values. The complexity of the model can be reduced in case the least influential inputs are identified and subsequently fixed to an acceptable technique. Furthermore, a more detailed analysis on country level could identify the assumptions under which each country performs best. Finally, in case of several inputs, factors could be grouped which may provide new insights. The uncertainty and sensitivity results, e.g. an ordering of all input factors in terms of importance, can be used to make sound decisions on certain methodological aspects. That way, the added value of the road safety index together with its acceptance and use will increase.

6. REFERENCES

(1) Nardo, M., M. Saisana, A. Saltelli, S. Tarantola, A. Hoffman, & Giovannini, E. (2005). *Handbook on Constructing Composite Indicators: Methodology and User Guide: STD/DOC(2005)3*. OECD.

(2) Litman, T. (2007). Developing Indicators for Comprehensive and Sustainable Transport Planning. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

(3) Saisana, M., & Tarantola, S. (2002). *State-of-the-Art Report on Current Methodologies and Practices for Composite Indicator Development: EUR20408EN*. JRC.

(4) SafetyNet. (2005). *State of the Art Report on Road Safety Performance Indicators: D3.1*. SWOV.

(5) Evans, L. (2004). *Traffic Safety*. Michigan: Bloomfield Hills.

(6) Hakim, S., D. Shefer, A. S. Hakkert, & Hocherman, I. (1991). A Critical Review of Macro Models for Road Accidents. *Accident Analysis and Prevention, 23*, pp. 379-400.

(7) Scuffham, P.A. (2001). An Econometric Analysis of Motor Vehicle Traffic Crashes and Macroeconomic Factors. PhD thesis: Otago University, New Zealand.

(8) Eisenberg, D. (2004). The Mixed Effects of Precipitation on Traffic Crashes. *Accident Analysis and Prevention, 36*, pp. 637-647.

(9) Van den Bossche, F., G. Wets, & Brijs, T. (2007). Analysis of Road Risk per Age and Gender Category: Time Series Approach. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

(10) Hermans, E., F. Van den Bossche, & Wets, G. (2006). The Frequency and Severity of Road Traffic Accidents Studied by State Space Methods. *Journal of Transportation and Statistics, 9*, pp. 63-76.

(11) Al Haji, G. (2005). Towards a Road Safety Development Index. PhD thesis: Linköpings university, Sweden.

(12) World Health Organization. (2004). World Report on Road Traffic Injury Prevention. www.who.int/world-health-day/2004/infomaterials/world_report/en.

(13) European Transport Safety Council. (2001). *Transport Safety Performance Indicators*. ETSC.

(14) Al-Haji, G. (2003). Road Safety Development Index. Presented at 16th ICTCT Workshop, Soesterberg.

(15) Nardo, M., M. Saisana, A. Saltelli, & Tarantola, S. (2005). *State-of-the-Art Report on Simulation and Indicators: D7.1*. JRC.

(16) Saaty, T. L. (1980). *The Analytic Hierarchy Process*. USA: McGraw-Hill, Inc.

(17) Saltelli, A., S. Tarantola, F. Campolongo, & Ratto, M. (2004). *Sensitivity Analysis in Practice: A Guide to Assessing Scientific Models*. West Sussex: John Wiley and Sons, Ltd.