# BRINGING STRUCTURE INTO ROAD SAFETY EVALUATION: A HIERARCHY OF INDICATORS

Elke Hermans, Tom Brijs and Geert Wets
Transportation Research Institute (IMOB) – Hasselt University
Wetenschapspark 5 bus 6, 3590 Diepenbeek, Belgium
Phone: +32 11 26 91 41 Fax: +32 11 26 91 99
E-mail: elke.hermans@uhasselt.be

## ABSTRACT

In recent years, there has been an explosion of interest in indicators in several domains. This reflects growing recognition of the important role indicators can play as a tool for enhancing the quality of decision making. Indicators express an aspect of a phenomenon in an understandable and relevant way and are useful in terms of monitoring, evaluation and communication. Like other policies, road safety policy could benefit from the use of indicators able to measure changes and progress towards postulated targets. Currently, the number of road fatalities or injury accidents per million inhabitants are often used indicators. Nevertheless, many more relevant road safety indicators exist. In order to increase the level of road safety, as many factors as possible influencing the frequency and severity of accidents should be considered. For example, key road safety risk factors (such as alcohol and drugs, speed, protective systems, vehicles, etc) should be represented by appropriate indicators as well.

To keep an overview on the structure and interrelationships between all indicators a framework should be elaborated on. This paper aims at presenting a hierarchical road safety indicator framework that provides a clear structure in the set of road safety indicators and is an interesting starting point for indicator (and index) analysis. In the first layer, general categories of road safety indicators are distinguished such as outcome indicators, risk indicators, etc. Next, each category (e.g. risk) is divided into different aspects (e.g., speeding). At the subsequent level of the hierarchy, various specific (e.g. speed) indicators are formulated (e.g., the average speed per road type; the share of drivers violating the legal speed limit; etc). By making use of a layered hierarchy the structure within the extensive set of road safety indicators can be overseen.

Furthermore, the combination of various indicators into an aggregated index has advantages in terms of communication and benchmarking. The hierarchy of indicators enables a stepwise combination in which first the most specific (e.g. speed) indicators are combined in a (speed) index. Together with other (e.g. alcohol and drugs) indexes an overall risk index can be composed, which can be grouped with other indexes (e.g. the outcome index) in the end. That way, it is possible to evaluate the road safety performance of countries on the overall road safety index level, the risk index level, the speed index level or the level of an individual indicator (depending on the context).

## 1 INTRODUCTION

Road safety is an important topic as the price paid for mobility is too high. Every day around the world, more than 3,000 people die from road traffic injury (World Health Organization, 2004). In the European Union, every year more than 40,000 persons are killed and more than 1.7 million

injured (European Commission, 2006). Although the number of road fatalities in Europe dropped significantly at the beginning of the 1990s, the trend has been less marked in recent years. In the battle for road safety, the European Union has set itself the ambitious goal to reduce the number of people killed in traffic between 2000 and 2010 by half (European Commission, 2001). In addition, challenging road safety targets have been set on national levels (see e.g., European Road Safety Observatory, 2006; Organisation for Economic Co-operation and Development and European Conference of Ministers of Transport, 2006). However, in order to meet these challenging targets insight in the road safety issue is required. In other words, information on the incidence and types of accidents as well as a detailed understanding of the circumstances that lead to accidents is necessary to guide safety policy (World Health Organization, 2004). The use of indicators – for quantifying the complex phenomenon of road safety – is valuable in this respect. Therefore, the concept and purpose of indicators is explained first, followed by the introduction of a hierarchical framework for bringing structure into the set of indicators (Section 2). In Section 3, another topic with regard to an extensive set of indicators is handled, i.e., the combination of indicators into an index. In particular, the idea behind this summary of information is explained as well as the theoretical aspects that need to be considered. This paper concludes with some conclusions (Section 4).

In recent years, there has been an explosion of interest in indicators in several domains such as environment (e.g., Hens et al., 2005), economy (e.g., Kaminsky et al., 1998) and innovation (e.g., Kleinknecht et al., 2002). Indicators can be described as measures that summarize an aspect of a phenomenon in an understandable and relevant way. They express scientific knowledge in a form that supports decision makers to take better informed and more appropriate choices. From literature (Al Haji, 2005; Hens et al., 2005; Litman, 2005; Nardo et al., 2005; Organisation for Economic Co-operation and Development, 2001; Salzman, 2003; Van Reeth and Vanongeval, 2005) it appears that indicators can be used in a number of ways, such as:

- measuring relative performance/benchmarking: indicators are measures derived from a series of observed facts that can reveal relative positions in a given area. Best-in-class and superior performance can be established.
- drawing attention to particular issues: indicators are suited for communication purposes, such as informing policymakers or activating and stimulating the public alertness.
- identifying trends: in case an indicator is measured at regular intervals, the directions of change over time and across different subjects can be pointed out.
- predicting problems: indicators can serve as warning signal for policymakers and are important guidelines for governments and authorities.
- assessing the impact of policy measures: indicators can be used for evaluating intended output and policy effects, enabling to judge several options.
- setting targets and priorities: based on former indicator values and values from other subjects, targets can be set. A comparison between different indicators may reveal which aspects need (more) urgent action.
- evaluating progress towards targets: in case of indicator measurements at regular moments in time the progress towards stated targets can be monitored closely and the achievement estimated. At certain time points, re-evaluation of goals or remedial action might be appropriate.

- presenting in a comprehensible way: indicators can present a large amount of information in a clear way. They are means for visualising the current situation. That way, problems become more concrete and subject to discussion.

The idea of using indicators for the continuous monitoring and analysis of processes exists for decades. Modern use of performance measures rose out of the Deming total quality management movements of the 1950s in Japan. The principles rely on developing goals that can be related to measurable results, monitoring those results and assessing strategies to improve performance (National Cooperative Highway Research Program, 2003).

## 2 HIERARCHICAL FRAMEWORK

In this section, indicator frameworks or conceptual models for structuring road safety indicators (and their interrelationships) are described. In literature (see e.g., Environment Canada et al., 1999; Maclaren et al., 1995; Segnestam, 2002) several types of indicator frameworks can be found. Each framework organizes the information in a unique way. For example, in a goal-based framework indicators are organized according to how they correspond to various goals; a causal-based framework structures indicators into categories of pressure, state and response (or an extension hereof).

Road safety being a complex matter that is affected by many factors in various ways, this research will present road safety indicators in a conceptual framework. More specifically, a hierarchical framework is developed consisting of several layers. The first layer is composed of general categories of road safety indicators. Based on literature (see e.g. Wegman et al., 2008), four general categories are identified. Outcome indicators refer to the situation after an accident happened and injuries occurred. Nowadays, the road safety situation in a country is often described and compared to that in other countries using the number of fatalities (for example per million inhabitants). Apart from these outcome indicators, risk indicators provide useful information. They quantify the main aspects leading to the occurrence of accidents and casualties. The European Transport Safety Council (2001) advised to develop indicators with respect to behavior (such as speeding), vehicles, infrastructure and trauma management. Thirdly, the initiatives taken by policymakers aimed to improve the level of road safety can be expressed by means of policy indicators. By studying these indicators, the efforts (e.g., the number of hours of police patrol regarding drunk driving) can be quantified and subsequently linked to the effects (i.e., the share of persons driving while being under the influence of alcohol). Finally, a set of background indicators (e.g., the age distribution of the population) is considered. Although they have a less direct link with the road safety outcome level, they should be taken into account when drawing conclusions concerning road safety.

Next, each of the four categories can be further elaborated in the second layer. In order to obtain a well-structured road safety indicator set in the end, each category is divided into subcategories. The outcome category may consist of injury accidents, fatalities, casualties, etc. The risk category is captured by some human, vehicle and environmental factors (see e.g., Sabey and Taylor, 1980). With respect to policy, a division into engineering, enforcement and education (referred to as the 3 E's) is often made. And finally, the background category is concretized by demographic, economic, geographic and transport factors.

In the third layer, each subcategory is further specified. Here, this is illustrated for the human-vehicle-environment risk factors. The hierarchical framework visually presented in Figure 1 shows this third layer for these subcategories only. However, the idea is the same for the other subcategories. The third layer breaks the human category down into road safety risk factors

related to the human behavior, such as alcohol, speed, protective systems, etc. The vehicle factor can refer to several aspects, for example cargo, visibility and technical aspects. The environmental factor captures the infrastructure on the one hand and trauma management on the other.

Since the third layer still consists of generally broad subcategories for which road safety indicators need to be developed, a fourth layer can be presented. The factor speed for example can be divided into average speed, variability in speed and speed offences. With respect to protective systems, seatbelts (in the front and back seats) can be separated from helmets and child's seats. A last example concerns the trauma management factor for which the process of medical assistance can be expressed at the accident scene, during the transportation and during the stay in the hospital.

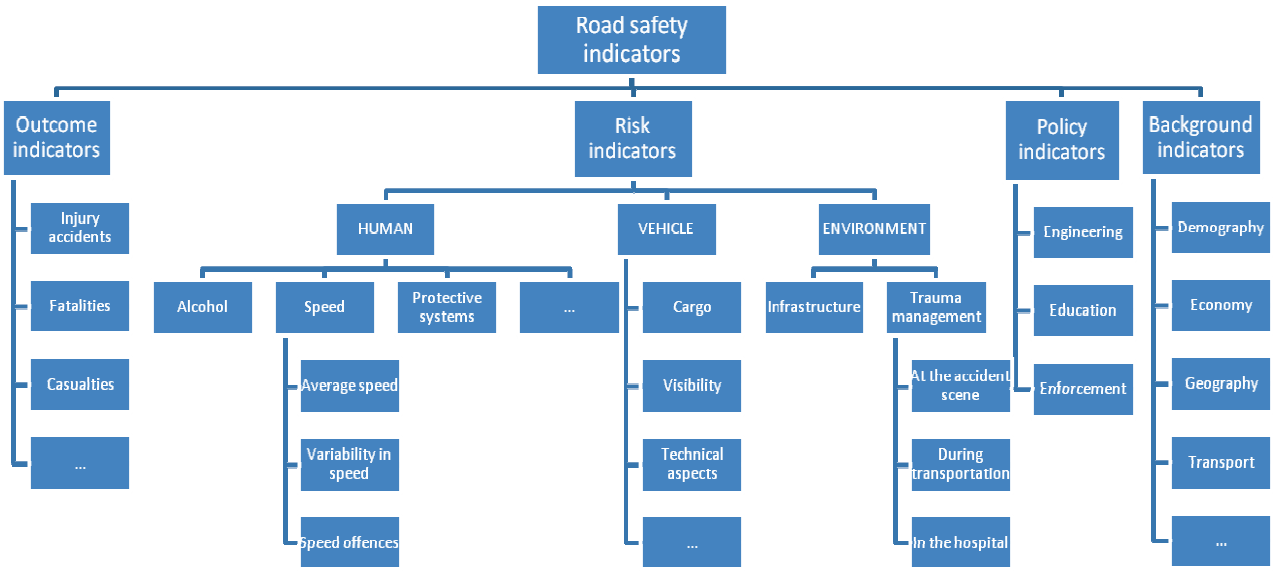


Figure 1: Hierarchical framework for road safety indicators

Different layers in the hierarchy have been presented. By concretizing each aspect in a subsequent layer based on existing theory and literature, a more extensive and well-balanced framework is obtained. Each of the factors in the final layer need to be expressed by appropriate indicators. The selection of indicators is outside the scope of this paper which focuses on the concept of a hierarchical framework for structuring indicators. Nevertheless, the evaluation of possible road safety indicators based on a set of selection criteria – such as relevance, measurability, data reliability, etc – has been discussed in earlier research (see Hermans, 2009). In addition, several sources listing road safety indicators can be found nowadays. In order to obtain an enriched indicator set for drawing road safety enhancing conclusions, indicators referring to each aspect in the above framework should be considered.

## 3 COMBINATION OF INDICATORS

Each indicator (whether it concerns the number of casualties, the average speed, the cargo, the quality of the trauma care in the hospital or the transport situation in a country) can be studied separately. Indicator data can be collected, either for one particular country over time or for a

number of countries at one (or more) moment(s) in time. However, the simultaneous considering of several indicators can offer new insight. Given the high number of relevant road safety risk aspects (of which some are listed in Figure 1), the combination of indicators in a so-called index is valuable. One of the main advantages of an index is that a more overall picture is presented as a multitude of information is captured in this index. Moreover, the combination of indicators results in one index score, enabling easy comparison across countries. Wegman et al. (2008) state that an index is characterized by the words 'simplification', 'quantification' and 'communication'.

The final aim is to create a road safety index which captures all relevant (outcome, risk, policy and background) road safety aspects. Based on an extensive set of indicator values and an appropriate combination methodology, a road safety index score can be computed for each country. This score can then be used for ranking countries based on their index score and is therefore an effective communication tool. Moreover, it can be used for benchmarking as the relative road safety performance of each country can be assessed and the best-in-class country can be revealed. Finally, this index enables monitoring the evolution over time and making predictions.

Limited research has been performed regarding the combination of road safety indicators. However, the creation of indexes in other domains offers valuable insights. During the last decade, indexes have been developed in various domains. Some well-known examples are the human development index (by the United Nations), the environmental sustainability index (by the World Economic Forum) and the growth competitiveness index (by Harvard University) (Saisana and Tarantole, 2002).

In general, two basic approaches are available for aggregating indicators (Sharpe, 2004). The first one is the monetary approach in which variables are expressed in monetary terms first and then simply added (the gross domestic product is an example hereof). The second approach is the composite indicator approach in which domains represented by a set of indicators are combined using weights. This second approach is described in the handbook on constructing composite indicators (Nardo et al., 2005). Different methods for assigning weights to indicators have been used in practice (see e.g. the internal market index 2004 (Tarantola et al., 2004), the environmental sustainability index (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2005) and the meta-index of sustainable development (Cherchye and Kuosmanen, 2004)).

However, applications of the index methodology on a hierarchy of indicators are rare. It is nevertheless essential to take the hierarchical structure of indicators into account. In the next paragraphs, the main steps to take in creating an index are discussed. Next, the methodological process behind the combination of a hierarchy of indicators is discussed.

Eight steps need to be taken in the creation of an index (Hermans, 2009):

1. Selecting indicators: this first step decides on which indicators to combine in an index.
2. Collecting indicator data: data need to be found for the indicators deduced in the previous step. Ideally, time series data for a large set of countries are easily accessible in reliable databases.
3. Univariate analysis: based on the collected indicator values, each indicator is studied separately. By means of visualisation and basic summary statistics, an idea about the distribution of the indicator values can be obtained. Extreme values might need a closer look as they could become unintended benchmarks. Next, all data should be made comparable. This process is called normalisation. As the indicators might differ in magnitude, be expressed in different units or expose great variation with respect to the

mean, they may cause bias in the index. Often used methods for normalisation are standardisation, rescaling and rank numbers. Thirdly, the imputation of missing values in the data set is dealt with at this stage. Several possible methods can be considered in this respect, like mean substitution, regression imputation, expectation-maximisation imputation or multiple imputation (Nardo et al., 2005).

4. Multivariate analysis: this step provides insight into the structure and interrelationships of the data set by studying the indicators simultaneously. The appropriateness of the indicator set for combination in an index is assessed by means of correlation analysis, internal consistency analysis, principal components analysis, cluster analysis and regression analysis.
5. Weighting: a weight should be assigned to each indicator. The set of weights has a large impact on the index scores. In literature, several weighting methods can be found, none of them being a priori the best technique. Weights based on statistical methods (such as factor analysis), participatory methods (e.g., budget allocation), optimization methods (like data envelopment analysis) and equal weighting are the most common techniques. Relevant methods for the problem under study should be evaluated.
6. Aggregation: the mathematical formula for combining the indicators needs to be selected. In this respect, it is important to decide how the index consists of its indicators and to which extent compensation between good and bad indicator scores is allowed.
7. Robustness testing: it is important to rigorously test the robustness of the index to the assumptions and methodological choices made. The uncertainty in the final result with respect to the indicators included, the imputed missing values, the normalisation technique chosen, the selected weighting method and the applied aggregation operator can be quantified. Moreover, it can be indicated which of these factors imply the largest uncertainty and should therefore be decided upon.
8. Computing, evaluating and visualising the index scores: using the (imputed) normalised indicator data, the weights and the aggregation operator, a final index score can be calculated for each country. The relationship between the composite road safety index and other related indicators or indexes (such as the corruption perceptions index; Lambsdorff, 2004) will be assessed. Finally, the results should be visualised in a clear way. In addition to a ranking, various types of graphs can be produced.

In case of a hierarchy of indicators, the eight steps in the methodological process for combining indicators need to be applied more than once. This is shown in Figure 2. First, the methodology is used to combine the indicators of the final (fourth) layer. In other words, the average speed indicator, the variation in speed indicator and the speed offences indicator are combined in a so-called speed index. The same applies to the other factors in the fourth layer (such as alcohol, protective systems, etc). Next, these constructed indexes are combined in a so-called human index. Each country will obtain a score on this human index which represents its relative performance with respect to alcohol, speed, protective systems, … behavior. Subsequently, a risk index score can be obtained by applying the methodology to the human index, the vehicle index and the environment index. In the end, one overall road safety score can be computed in which the outcome index, the risk index, the policy index and the background index are represented.

Depending on the context, the road safety situation in a country can be evaluated at an overall or a more detailed level. The overall road safety index score can be computed – which captures a multitude of divers indicators – and subdivided into an outcome performance, a risk performance, a policy performance and a background performance. At the same time, a human index, a vehicle index and an environment index score are provided. This enables a country to have an idea on its strong and weak road safety aspects. From a methodological point of view, this layered hierarchy allows a researcher to incorporate weight boundaries that should apply to particular layers only.

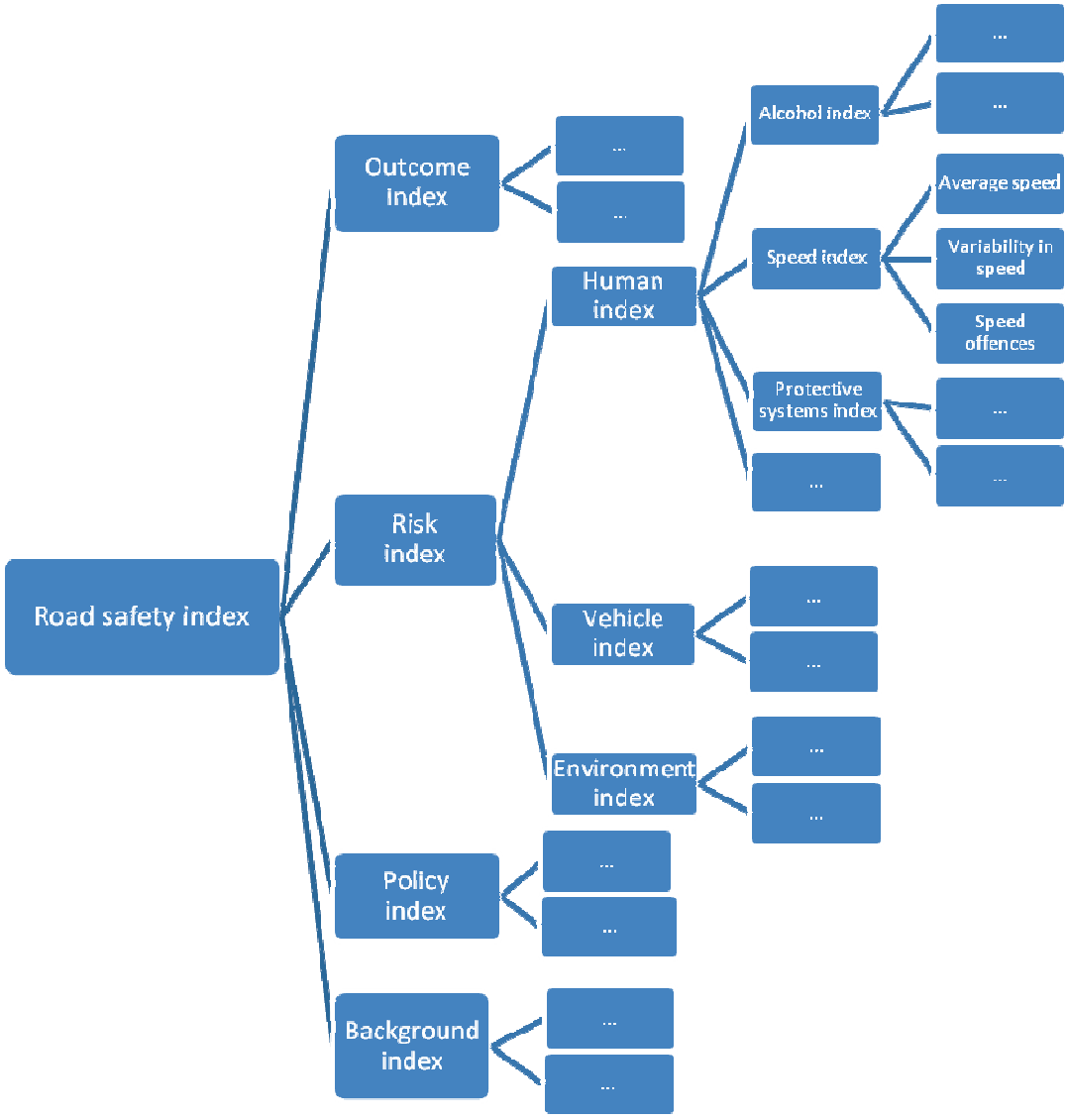


Figure 2: Index creation based on a hierarchy of indicators

## 4 CONCLUSION

In this paper, the value of using indicators for the road safety field has been illustrated. Indicators are useful in terms of communication, benchmarking, monitoring, etc. However, given the multidisciplinary and complex character of the road safety phenomenon, numerous indicators can

be listed. In order to keep an overview and guarantee a well-balanced indicator set in which the main aspects are represented, a theoretical framework is to be used.

In this paper, a hierarchical road safety indicator framework has been presented. On the one hand, this framework provides a clear structure in the extensive set of relevant road safety indicators; on the other hand, it offers an interesting starting point for indicator (and index) analysis. First, four main categories were listed. In particular, a good road safety indicator set should consist of outcome as well as risk, policy and background indicators. Subsequently, each category was further divided into more specific aspects.

Next, the benefits of combining indicators in an index were discussed. After showing the eight necessary steps in creating an index, the idea of the hierarchy of indicators needed to be incorporated with the index methodology. Therefore, the index methodology has to be applied repeatedly.

In the future, the conceptual ideas discussed in this paper will be further explored. In particular, the hierarchical road safety indicator framework will be filled out. Next, data for the selected indicators will be gathered and analysed. With respect to the combination of a hierarchy of indicators several indexes and an overall road safety index could be created and interpreted. Moreover, the impact of creating indexes out of other indexes will be assessed by means of uncertainty and sensitivity analysis.

## REFERENCES


Al Haji, G. (2005). *Towards a road safety development index*. PhD Thesis. Linköpings universitet.

Cherchye, L. and Kuosmanen, T. (2004). *Benchmarking sustainable development: A synthetic meta-index approach*. United Nations University - World Institute for Development Economics Research.

Environment Canada, CMHC and Westland Resource Group (1999). *Sustainable community indicators software: Applications and proposed indicators*.

European Commission (2006). *European road safety action programme - Mid-term review*. Commission of the European Communities.

European Commission (2001). *White Paper: European transport policy for 2010: time to decide*. Commission of the European Communities.

European Road Safety Observatory (2006). *Quantitative road safety targets*.

European Transport Safety Council (2001). *Transport safety indicators*. ETSC.

Hens, L., Lafère, J. and De Wit, J. (2005). *Inventarisatie van milieu-gezondheids-indicatoren op internationaal en nationaal vlak*. Brussels: Steunpunt Milieu en Gezondheid.

Hermans, E. (2009). *A methodology for developing a composite road safety performance index for cross-country comparison*. PhD Thesis. Hasselt university.

Kaminsky, G., Lizondo, S. and Reinhart, C.M. (1998). *Leading Indicators of Currency Crises*. International Monetary Fund.

Kleinknecht, A., Van Montfort, K. and Brouwer, E. (2002). *The non-trivial choice between innovation indicators*. Economics of Innovation and New Technology, Vol. 11 (2), pp.109-121.

Lambsdorff, J.G. (2004). *Background paper to the 2004 Corruption Perceptions Index*. Transparency International and University of Passau.

Litman, T. (2005). *Well measured: Developing indicators for comprehensive and sustainable transport planning*. Victoria Transport Policy Institute.

Maclaren, V.W., Labatt, S., McKay, J. and Vande Vegte, M. (1995). *Developing indicators of urban sustainability: A focus on the Canadian experience*. Presented at the Measuring Urban Sustainability: Canadian Indicators Workshop, Toronto.

Nardo, M., Saisana, M., Saltelli, A., Tarantola, S., Hoffman, A., Giovannini, E. (2005). *Handbook on constructing composite indicators: methodology and user guide*. OECD.

National Cooperative Highway Research Program (2003). *Performance measures of operational effectiveness for highway segments and systems*. Transportation Research Board.

Organisation for Economic Co-operation and Development (2001). *Performance indicators for the road sector: Summary of the field tests*. OECD.

Organisation for Economic Co-operation and Development and European Conference of Ministers of Transport (2006). *Country reports on road safety performance*.

Sabey, B.E. and Taylor, H. (1980). *The known risks we run: The highway*. Transport and Road Research Laboratory.

Saisana, M. and Tarantola, S. (2002). *State-of-the-art report on current methodologies and practices for composite indicator development*. Joint Research Centre.

Salzman, J. (2003). *Methodological choices encountered in the construction of composite indices of economic and social well-being*. Centre for the Study of Living Standards.

Segnestam, L. (2002). *Indicators of environment and sustainable development: theories and practical experience*. The international bank for reconstruction and development.

Sharpe, A. (2004). *Literature review of frameworks for macro-indicators*. Centre for the Study of Living Standards.

Tarantola, S., Liska, R., Saltelli, A., Leapman, N. and Grant, C. (2004). *The internal market index 2004*. European Commission DG Joint Research Centre.

Van Reeth, W. and Vanongeval, L. (2005). *Natuurrapport 2005: Indicatoren*.

Wegman, F., Commandeur, J., Doveh, E., Eksler, V., Gitelman, V., Hakkert, S., Lynam, D., Oppe, S. (2008). *SUNflowerNext: Towards a composite road safety performance index,* Deliverable D6.16 of the EU FP6 project SafetyNet.

World Health Organization (2004). World Report on Road Traffic Injury Prevention, http://www.who.int/violence_injury_prevention/publications/road_traffic/world_report/en/.

Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network (2005). *2005 environmental sustainability index*. Yale University and Columbia University.