# Developing a Theoretical Framework for Road Safety Performance Indicators and a Methodology for Creating a Performance Index

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*E. Hermans, T. Brijs, G. Wets*

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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

**TITEL: Ontwikkelen van een theoretisch kader voor verkeersveiligheid prestatie-indicatoren en een methodologie voor het creëren van een prestatie-index**

Dit rapport handelt over prestatie-indicatoren voor verkeersveiligheid. Er worden drie hoofddoelstellingen vooropgesteld. Ten eerste, het concept 'verkeersveiligheid prestatie-indicator' introduceren. Meer bepaald essentiële informatie over indicatoren in het algemeen en verkeersveiligheid prestatie-indicatoren in het bijzonder samenvatten. Ten tweede, een set van (ideale en bruikbare) verkeersveiligheid prestatie-indicatoren ontwikkelen. De selectie van deze indicatoren resulteert uit de uitwerking van het theoretisch kader. Ten derde, de methodologie beschrijven achter de ontwikkeling van één prestatie-index voor verkeersveiligheid waarin alle indicatorinformatie wordt gecombineerd.

Indicatoren zijn instrumenten om de status van een bepaald fenomeen te monitoren. Ze drukken wetenschappelijke kennis uit op een begrijpbare en relevante wijze. Indicatoren kunnen op tal van manieren gebruikt worden, zoals meten van relatieve prestatie, aandacht vestigen op een probleem, herkennen van trends, impact van een maatregel bepalen alsook stellen van doelen en prioriteiten. Hieruit blijkt reeds de waarde van indicatoren voor het verkeersveiligheidsdomein. De essentiële elementen van het veiligheid managementsysteem worden in de doelhiërarchie voor verkeersveiligheid voorgesteld: sociale kost; aantal doden en gewonden (finale uitkomsten); veiligheid prestatie-indicatoren (tussenliggende uitkomsten); veiligheidsmaatregelen en -programma's (beleidsoutput); en structuur en cultuur (beleidsinput). Een verkeersveiligheid prestatie-indicator kan omschreven worden als een meting die causaal gerelateerd is aan verkeersongevallen of –slachtoffers en daarbij de prestatie op vlak van veiligheid aangeeft en een beter inzicht biedt in het ongevallenproces. Verkeersveiligheid prestatie-indicatoren bieden nieuwe inzichten aan de verkeersveiligheidgemeenschap. Ze staan benchmarking toe op een gedetailleerder (en relevanter) niveau en kunnen prioriteiten toekennen aan belangrijke knelpunten (bijvoorbeeld snelheid). Bovendien laten ze toe om de nodige acties te ondernemen alvorens het probleem zichtbaar wordt aan de hand van een toegenomen aantal ongevallen en slachtoffers.

De prestatie op vlak van verkeersveiligheid kan vergeleken worden tussen verschillende items (zoals landen) aan de hand van een geschikte set van prestatie-indicatoren. De selectie van deze indicatorset wordt bepaald door het theoretisch kader uit te werken dat de volgende taken omvat. Ten eerste dient het fenomeen dat bestudeerd wordt duidelijk gedefinieerd te worden. Aangezien verkeersveiligheid een multidimensioneel probleem is, kan inzicht verkregen worden door dit probleem te ontleden in enkele componenten. Uit de literatuur kunnen een aantal relevante classificaties afgeleid worden, bijvoorbeeld de mens-voertuig-infrastructuur opdeling of de blootstelling-ongevallenrisico-verwondings-risico decompositie. Vervolgens worden de belangrijkste componenten of zogenaamde risicodomeinen van verkeersonveiligheid, overeengekomen op Europees niveau, geïdentificeerd zijnde alcohol en drugs, snelheid, beschermende uitrusting, motorvoertuigverlichting overdag, voertuig, weg en nazorg. Het DPSEAIEA kader (i.e. driving forces – pressure – state – exposure - accident risk - injury risk – effects - actions oftewel sturende krachten – druk – toestand – blootstelling – ongevallenrisico – verwondingsrisico – effecten - acties) voor het modeleren van de causale keten van verkeersveiligheideffecten wordt beschreven alsook de bestaande verbanden tussen de zeven risicodomeinen om zo het gehele concept beter te begrijpen. Vervolgens worden uit relevante literatuurbronnen mogelijke indicatorkandidaten voor het bepalen van de veiligheidprestatie in elk risicodomein opgelijst. Omwille van de kosten en andere praktische beperkingen bij de verzameling van data, moeten enkel geschikte indicatoren geselecteerd worden. Het is daarom nodig te bepalen welke de criteria zijn waaraan een goede indicator moet voldoen. Elke indicatorkandidaat wordt geëvalueerd op vlak van relevantie, meetbaarheid, interpretatie, data beschikbaarheid, betrouwbaarheid, vergelijkbaarheid, specificiteit en sensitiviteit.

Gegeven de beschikbaarheid en kwaliteit van gegevens voor verkeersveiligheidprestatie in Europa blijkt een opdeling tussen ideale ('best needed') indicatoren enerzijds en bruikbare ('best available') indicatoren anderzijds nuttig in dit geval. Een ideale indicator is de meest geschikte indicator waarvoor de concepten, definities of data nog niet bestaan; waarvoor data bestaan, maar niet gepubliceerd mogen worden of van onvoldoende of ongekende kwaliteit zijn; of waarvoor een vergelijking met andere landen beperkt mogelijk is. Bruikbare indicatoren zijn proxy's voor ideale indicatoren waarvoor data van voldoende kwaliteit beschikbaar zijn. Om de creatie en verzameling van de nodige data ter ondersteuning van het verkeersveiligheidsbeleid in een langer tijdsperspectief te garanderen, werd de onderstaande set geïdentificeerd als ideale verkeersveiligheid prestatie-indicatoren:

- het percentage bestuurders met een alcoholconcentratie boven de wettelijke limiet
- de gemiddelde snelheid per weg- en voertuigklasse, overdag en 's nachts
- de variatie in snelheid per weg- en voertuigklasse
- het gordeldracht percentage voor- en achterin personenwagens en bestelwagens, bussen en vrachtwagens
- het percentage (correct) gebruik van kinderzitjes
- het percentage helmdracht bij motorrijders en bromfietsers
- de verdeling van de voertuigenstroom naar leeftijdklassen
- het percentage weglengte met een middenberm of middenafscherming
- het percentage weglengte met een brede obstakelvrije zone of een bermconstructie
- de gemiddelde aankomsttijd van de medische hulpdiensten op de plaats van het ongeval
- het aandeel verkeersslachtoffers dat overlijdt gedurende de ziekenhuisopname

De evaluatie van indicatorkandidaten toonde aan dat het niet beschikbaar zijn van betrouwbare en vergelijkbare gegevens de set van bruikbare indicatoren in zekere mate beperkt. Hieronder wordt voor de zeven risicodomeinen de best bruikbare indicator op dit moment opgelijst:

- het percentage bevraagde autobestuurders dat de alcohollimiet overtreedt
- het percentage bevraagde autobestuurders dat de snelheidslimiet overtreedt, naar wegtype
- het gordeldracht percentage van personen voorin een personenwagen of bestelwagen
- het bestaan van een (volledige of gedeeltelijke) wet die het gebruik van motorvoertuigverlichting overdag verplicht
- het aandeel personenwagens per leeftijdsklasse
- de dichtheid van autosnelwegen
- de uitgave aan gezondheidszorg als aandeel van het bruto binnenlands product

Wanneer de waarden van elke indicator afzonderlijk worden vergeleken tussen items kan inzicht verkregen worden in de relatieve veiligheidprestatie alsook in best presterende items met betrekking tot een bepaald verkeersveiligheidsaspect. Nochtans is een soort samenvatting waardevol wanneer een groot aantal prestatie-indicatoren beschikbaar is. Met andere woorden, één totale verkeersveiligheid prestatie-indexscore waarin alle indicatorwaarden vervat zitten, kan bepaald worden voor elk item. Op die manier kan de informatie uit alle risicodomeinen tegelijkertijd bestudeerd worden. De ontwikkeling van indexen in onderzoeksdomeinen zoals economie en duurzaamheid is veelvoorkomend. Een prestatie-index zou ook het verkeersveiligheidsdomein ten goede komen aangezien het een waardevol instrument voor beleidmakers en andere eindgebruikers kan zijn. De voordelen van het samenvatten van een complex fenomeen voor beleid- en communicatiedoeleinden (bijvoorbeeld het opstellen van een rangschikking van landen op basis van een samenvattingscore van relevante prestatie-indicatoren in plaats van enkel het aantal verkeersdoden) weegt op tegen de nadelen (zoals misleidende of simplistische beleidsconclusies) wanneer een correcte, transparante en duidelijke methodologie wordt gebruikt voor de ontwikkeling van de index. De methodologie om een index te creëren – in het algemeen bestaande uit het selecteren van indicatoren, het voorbereiden van de data, wegen en aggregeren, het testen van de robuustheid en het berekenen, evalueren en visualiseren van de uiteindelijke scores – wordt beschreven. Hierbij komen vaak gebruikte methoden bij de ontwikkeling van andere indexen aan bod die mogelijk relevant zijn voor de verkeersveiligheidscontext.

Op basis van dit onderzoek kunnen we concluderen dat prestatie-indicatoren voor verkeersveiligheid enerzijds en een verkeersveiligheid prestatie-index anderzijds nieuwe en tegelijkertijd veelbelovende concepten zijn. Dit rapport biedt basisinformatie over deze onderwerpen. Meer bepaald worden essentiële concepten en relevante kaders met betrekking tot indicatoren uit de literatuur beschreven; het theoretische kader biedt nieuwe informatie over decompositie, onderlinge relaties, mogelijke indicatoren, selectiecriteria en resulteerde in een set van ideale en bruikbare prestatie-indicatoren voor verkeersveiligheid. Daarnaast worden de voordelen van een samengestelde index aangegeven, alsook de daarmee gepaard gaande methodologische uitdagingen op vlak van univariate en multivariate analyse, weging, aggregatie, robuustheid, evaluatie en visualisatie. Het dient opgemerkt te worden dat de uiteindelijke indexresultaten in aanzienlijke mate bepaald worden door de set van indicatorwaarden gebruikt voor het creëren van de prestatie-index. Om een waardevolle verkeersveiligheid prestatie-index te ontwikkelen, is verdere beschouwing van de methodologie alsook van de data nodig.

Er kan niet sterk genoeg de nadruk gelegd worden op de dringende nood aan verbetering van de beschikbaarheid en kwaliteit van verkeersveiligheid prestatie-indicatordata. Indien de belangrijkste risicodomeinen van verkeersonveiligheid omschreven worden aan de hand van een geschikte set van indicatoren die op correcte en regelmatige wijze gemeten wordt, dan kan bruikbare beleidsinformatie voor monitoring, evaluatie en communicatie beschikbaar worden. De relatieve veiligheidprestatie van items kan over de tijd en ten opzichte van andere regio's en landen bestudeerd worden. In de praktijk komen echter problemen voor met betrekking tot de set van items en de periode (of het jaar) waarvoor gegevens beschikbaar zijn, de definitie van de indicator en de meetmethode. Daarom zou aanzienlijke vooruitgang geboekt kunnen worden wanneer alle Europese lidstaten dezelfde (best practice) richtlijnen zouden volgen (zie de handleiding met betrekking tot veiligheid prestatie-indicatoren door Hakkert en Gitelman, 2007).

Verder onderzoek is nodig vooraleer we de verkeersveiligheidprestatie kunnen monitoren met deze index. In de nabije toekomst moeten gegevens voor de set van bruikbare verkeersveiligheid prestatie-indicatoren verzameld worden voor een groot aantal landen en het meest recente jaar. Univariate en multivariate analyses kunnen dan toegepast worden op de dataset gevolgd door weging en aggregatie. Vervolgens moet de robuustheid van de index met betrekking tot de verschillende veronderstellingen bepaald worden. Tot slot dienen de uiteindelijke indexscores geëvalueerd en gepresenteerd te worden. De relatieve positie van een land of regio ten opzichte van andere landen kan bepaald worden op basis van de indexscores. In tegenstelling tot traditioneel verkeersveiligheidsonderzoek zitten meerdere risicoaspecten vervat in deze score. Voorbeeldlanden kunnen bepaald worden evenals indicator- en indexdoelstellingen waarvan de evolutie opgevolgd kan worden indien indicatordata op systematische wijze worden verzameld.

## English summary

This report deals with road safety performance indicators. Three main objectives are postulated. First, to introduce the concept of road safety performance indicators. This involves summarising essential information on indicators in general and road safety performance indicators in particular. Second, to develop a set of (best needed and best available) safety performance indicators. The selection of these indicators results from the elaboration of the theoretical framework. Third, to describe the methodology behind the creation of an overall road safety index in which all indicator information is combined.

Indicators are tools for monitoring the status of a certain phenomenon. They express scientific knowledge in an understandable and relevant manner. Indicators can be used in a number of ways, such as measuring relative performance, drawing attention to problems, identifying trends, assessing the impact of policy measures as well as target and priority setting. From this, the value of indicators for the road safety domain already becomes clear. In the road safety target hierarchy the essential elements of the safety management system are presented: social cost; number of killed and injured (final outcomes); safety performance indicators (intermediate outcomes); safety measures and programmes (policy output); and structure and culture (policy input). A road safety performance indicator can be seen as a measurement causally related to traffic accidents or casualties indicating the safety performance and offering a better understanding in the process leading to accidents. Safety performance indicators offer new insights to the road safety community. They allow benchmarking on a more detailed (and relevant) level and can reflect and prioritize main problem areas (e.g. speed). Moreover, they enable taking necessary actions before the problem becomes visible in an increased number of accidents and casualties.

The road safety performance of a set of subjects (such as countries) can be compared by means of an appropriate set of performance indicators. The selection of this indicator set results from the elaboration of the theoretical framework which involves the following tasks. First, the phenomenon that is studied should be clearly defined. As road safety is a multidimensional problem, better insight is gained in case this problem is decomposed into several components. From literature, some relevant classifications can be obtained, such as the human-vehicle-infrastructure decomposition or the exposure-accident risk-injury risk decomposition. Next, the main components or so-called road safety risk domains agreed upon on the European level are identified, i.e. alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management. The DPSEAIEA framework (driving forces-pressure-state-exposure–accident risk-injury risk-effects-actions) for modeling the causal chain of road safety effects as well as the existing linkages between the seven risk domains are described in order to enhance the understanding of the overall concept. Next, possible indicator candidates for assessing the safety performance in each risk domain are identified from relevant literature sources. Due to collection costs and other practical limitations, only appropriate indicators should be selected. Therefore, it needs to be decided which criteria a good indicator should meet. Each indicator candidate is evaluated in terms of relevance, measurability, interpretability, data availability, reliability, comparability, specificity and sensitivity.

Following the discussion of road safety (performance) data availability and quality in Europe, a distinction between best needed indicators on the one hand and best available indicators on the other hand is useful in this case. A best needed indicator refers to an ideal indicator for which the concepts, definitions or data do not yet exist, for which data exist, but the quality is poor, unknown or does not allow publication or for which cross-country comparability is limited. A best available indicator is an indicator which can act as proxy for a best needed indicator and for which the available data are of sufficient quality. To assure the creation and collection of necessary data to support road safety policymaking in a longer time perspective, the following set has been identified as best needed road safety performance indicators:

- the percentage of drivers with an alcohol concentration above the legal limit
- the average (free flow) speed per road type and vehicle type during daytime and at night
- the variation in speed per road type and vehicle type
- the seat belt wearing rate in front and rear sets of cars and vans, busses and trucks
- the (correct) usage rate of child's seats
- the helmet wearing rate of motorcyclists and moped riders
- the usage rate of daytime running lights per road type and vehicle type
- the age distribution of the vehicle fleet
- the percentage of road length with a wide median or median barrier
- the percentage of road length with a wide obstacle-free zone or roadside barrier
- the average arrival time of emergency medical services at the accident scene
- the share of road casualties who died during hospitalisation

The evaluation of the indicator candidates revealed that the unavailability of reliable and comparable data restricts the best available indicator set to some extent. For the seven risk domains the currently best available indicator has been listed below.

- the percentage of surveyed car drivers disrespecting the alcohol limit
- the percentage of surveyed car drivers exceeding the speed limit on various road types
- the seat belt wearing rate of occupants in the front seats of a car or van
- the existence of a law – fully or partially – obligating the use of daytime running lights
- the share of the fleet of passenger cars per age class
- the motorway density
- the expenditure on health care as share of the gross domestic product

Comparing subjects on each indicator separately could provide insight into the relative safety performance and best-in-class subjects with respect to a certain road safety aspect. However, in case a large number of performance indicators is available, some summarization is valuable. In other words, one overall road safety performance index score in which all indicator values are combined can be developed for each subject. That way, information from all risk domains is studied at once. The development of indexes in research domains such as economy and sustainability is very popular. The road safety field could also benefit from a safety performance index as it can be a valuable tool for policymakers and other end users. The advantages of summarising a complex phenomenon in terms of policy and communication purposes (e.g. a ranking of countries based on a summary of relevant performance indicators instead of only the number of fatalities) counterbalance the disadvantages (such as misleading or simplistic policy conclusions) if a sound, transparent and clear methodology is used for developing the index. The methodology for creating an index – generally consisting of indicator selection, data preparation, weighting and aggregating, robustness testing, computing, evaluating and visualising the final scores – is indicated thereby briefly describing often used methods applied in other indexes which are probably relevant for the road safety case.

Based on this research, we conclude that road safety performance indicators on the one hand and a road safety performance index on the other hand are new but at the same time promising concepts. This report presented basic information on these topics. More specifically, essential concepts and indicator frameworks from literature have been described; the theoretical framework offered new information in terms of road safety decomposition, interrelationships, possible indicators, selection criteria and resulted in a set of best needed and a set of best available road safety performance indicators. In addition, the advantages of a combined index have been indicated, even as the resulting methodological challenges in terms of univariate analysis, multivariate techniques, weighting, aggregation, robustness testing, evaluation and visualisation. It should be noted that the final index results are influenced to a large extent by the set of indicator values used to create the performance index. In order to develop a valuable road safety performance index, the methodology as well as the data issue need future consideration.

The urgent need to improve the availability and quality of road safety performance indicator data cannot be overemphasized. In case the main road safety risk domains are captured by a set of best indicators which are correctly measured at regular intervals, useful policy information in terms of monitoring, evaluation and communication becomes available. The relative safety performance of subjects may be studied over time and with respect to other countries and regions. In practice, problems regarding the set of subjects and the period (or year) for which data are available, the indicator definition and the measurement method occur. Therefore, significant progress could be made in case all European member states would follow the same (best practice) guidelines (see the manual on safety performance indicators by Hakkert and Gitelman, 2007).

Further research is needed before we will be able to monitor road safety performance by this index. In the near future, data for the set of best available road safety performance indicators need to be collected for a large set of European countries and with respect to the most recent year. Univariate and multivariate analyses on the indicator data set are then to be applied followed by the issue of weighting and aggregating. The robustness of the index with respect to the different assumptions and choices can be assessed next. Finally, the final road safety performance index scores should be evaluated and presented. Based on the index scores, the relative rank of a country or region compared to other European countries in terms of road safety performance can be determined. Contrary to the traditional road safety research, this score takes several risk aspects into account. Furthermore, benchmark countries can be found serving as examples to follow. Indicator as well as index targets can be set and the progress can be monitored in case indicator data are collected in a systematic way.

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## List of Figures and Tables

# 1. INTRODUCTION

This study deals with road safety performance indicators and consists of three main chapters in addition to the introduction and conclusions chapter. In chapter 2 basic information on indicators in general and road safety indicators in particular is given. In chapter 3 the elaboration of the theoretical framework for road safety performance indicators is described and in chapter 4 the creation of a road safety performance index, which is a combination of individual road safety performance indicators, is discussed.

## 1.1 Problem statement

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. Better insight into the road safety situation of a particular subject (in this study we focus on the country level) 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 accident data. For example, the number of injury accidents and the number of casualties (divided into fatalities, serious casualties and slight casualties) per capita are computed and evaluated. The relative position of each country can then be assessed. However, these accident 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.

More specifically, the main underlying risk factors of road unsafety need to be determined. Each risk factor (e.g. alcohol and drugs) should be represented by appropriate safety performance indicators (e.g. the share of drivers with an alcohol concentration above the legal limit). The indicator values can then be compared across countries thereby resulting in the identification of the main problem areas in a particular country. Appropriate measures can then be selected able to tackle the main risk aspects before they result in accidents and casualties.

Countries could be compared on each indicator individually. However, as a high number of relevant road safety performance indicators can be considered, the creation of an overall road safety performance index – which is a combination of road safety performance indicators – is valuable. One of the main advantages of an index over a set of individual indicators is that the global road safety picture is presented as all risk information is captured in this index. Moreover, this gathering of indicators into one index score for each country enables easy comparison across countries. The methodological process underlying the road safety performance index will be described in Chapter 4. In the remainder of this introductory chapter the research objectives and the structure of the report are described.

## 1.2 Research objectives

In this research, the topic of road safety performance indicators on the one hand and a road safety performance index on the other hand is studied. More specifically, this report aims to reach the following research objectives:

- Introduce the concept of road safety performance indicator
- Develop a set of (best needed and best available) road safety performance indicators
- Describe the main methodological steps in creating an index

Given the broad indicators field (as will be shown in Chapter 2), this study is limited to some extent. First, the focus is on road safety instead of traffic safety. No indicators for air, sea or rail transport will be developed. However, the interested reader is referred to the report of the European Transport Safety Council (2001). Secondly, although some important indicator frameworks will be discussed (see sections 2.3; 2.5 and 3.4) the main focus is on developing safety performance indicators and limited attention is given to the other aspects in the framework. Thirdly, mainly indicators related to motorists will be developed in this study. Relevant indicators for pedestrians, e.g. the percentage of pedestrians respecting the red light at a crossing or the percentage of pedestrians (by age and sex) using a reflector in the urban area will be topics for further research. Finally, this report introduces the methodology for creating an index. The application of the methods using real data for comparing several European countries with respect to their road safety performance is outside the scope of this report.

## 1.3 Structure of the remaining chapters

Chapter 2 provides basic introductory indicator information and serves as a necessary basis for the subsequent chapters. Essential concepts referring to the indicator literature (e.g. indicator framework) and road safety terminology (e.g. mortality rate) used throughout this study are defined. The use of indicators (for measuring relative performance, target setting, trend identification, etc) and the broader planning process (in which the identification of performance indicators is one of the main steps) are discussed. Next, the road safety management system is given. This is a framework in which essential elements of road safety are presented in a pyramid. It consists of the following layers: social cost – number of killed and injured persons – safety performance indicators – safety measures and programmes – structure and culture. This chapter closes by noting the links between the road safety domain and other fields (e.g. mobility and environment).

Chapter 3 deals with the elaboration of the theoretical framework for obtaining a set of road safety performance indicators. In fact, the development of a sound theoretical framework consists of several tasks. First, the phenomenon that is studied – being road safety in this case – should be clearly defined. As road safety is a multidimensional problem, better insights are gained in case this problem is decomposed into several components. From literature, some relevant classifications can be obtained. Having determined the most important components or road safety risk factors, the existing linkages will be described and visualised. This will enhance the understanding of the overall concept. Each road safety risk factor needs to be measured by a set of indicators. Therefore, based on literature, existing road safety indicators will be listed. Next, the possible indicators are evaluated based on several selection criteria. In practice, a distinction between best needed and best available indicators is often made (European Commission, 2005; Ledoux et al., 2005). A best needed indicator refers to an ideal indicator for which the concepts, definitions or data do not yet exist, for which data exist, but the quality is poor, unknown or does not allow publication or for which cross-country comparability is limited. A best available indicator is an indicator which can act as proxy for a best needed indicator and for which the available data are of sufficient quality. Finally, this chapter closes with some conclusions on best available and recommendations for best needed road safety performance indicators.

Once a set of road safety performance indicators has been developed chapter 4 discusses the methodology for combining several performance indicators in one composite indicator or overall index. Apart from a comparison based on individual indicators an index allows to simultaneously study the information from all risk domains. Other advantages as well as disadvantages of combining indicators are discussed. Next, the main steps in the methodological index process are listed and subsequently described in more detail: data preparation, weighting and aggregating the individual indicators, testing the robustness of the road safety index, computing and evaluating the final index scores and presenting the results in a comprehensive way. This chapter deals with the following methodological aspects: are the different indicators appropriate for combination; which countries can be grouped based on their indicator values; how to deal with missing values; which techniques are available to equalize the different measurement units of the indicators;

how can the weight of each indicator be determined; is total compensation between good and bad indicator scores acceptable; how certain can we be about the constructed index and its scores; which extra information would imply a more robust index; and which methods for visualising the results are most appropriate.

Chapter 5 summarises the main conclusions of this report on road safety performance indicators and the road safety performance index and formulates recommendations for further research.

# 2. BASIC INFORMATION ON INDICATORS

In this chapter an introduction to indicators in general and road safety indicators in particular is given. First, the purposes of indicators, some basic concepts and the overall planning process are given. Subsequently, road safety performance indicators are introduced and some relevant frameworks already existing in literature are handled.

## 2.1 Why using indicators?

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 are instruments for monitoring the status of a certain phenomenon. They express scientific knowledge in a form that supports decision makers to take better informed and more appropriate choices. From literature (Organisation for Economic Co-operation and Development, 2001; Salzman, 2003; Al Haji, 2005; Hens et al., 2005; Litman, 2005; Van Reeth and Vanongeval, 2005; Nardo et al., 2005b) 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 of subjects in a given area. Based on the relative performance score, subjects such as countries can be ranked. Best-in-class and superior performance can be established.
- drawing attention to particular issues: indicators are suited for communication purposes, such as informing policymakers and the general public or activating and stimulating the public alertness.
- identifying trends: in case an indicator is measured at regular intervals, the directions of change (e.g. in risk) 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. Comparing the 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 comprehensive way: indicators can present a large amount of information in a clear way. However, being able to reduce the complexity of the system implies that the whole story is never told by means of a few indicators. They can be used as a first step or for the synthesis and reporting of more profound and explanatory research. They are also means for visualising the current situation. That way, problems become more concrete and subject to discussion. Several ways of presenting indicator information exist and will be discussed later.

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).

Contrary to other fields, the road safety community only lately recognized the contribution of indicators (European Transport Safety Council, 2001; Vis, 2005; Verkeersveiligheidsplan Vlaanderen, 2007). Therefore, one still needs to become familiar with the concept of indicators and its advantages. In this report, we focus on the development of road safety performance indicators and a road safety performance index. In section 2.2, some important terminology used throughout this report will be described.

## 2.2 Basic concepts

In this section some basic concepts are defined. The concepts refer to the indicator literature in general (European Commission, 2005; Hens et al., 2005; Litman, 2005; Nardo et al., 2005b), road safety in general (Al Haji, 2005; Morsink et al., 2007) and road safety indicators (European Transport Safety Council, 2001).

- Indicator: a measure that summarizes an aspect of a phenomenon in an understandable and relevant way
- Indicator data: values used for indicators
- Indicator framework: conceptual structure linking indicators to a theory, purpose or planning process
- Indicator set: a group of indicators selected to measure an overall phenomenon
- Best needed indicator: ideal indicator for which concepts, data and/or methodology do not exist yet; for which data exist, but the quality is poor, unknown or does not allow publication; or for which cross-country comparability is limited
- Best available indicator: indicator which can act as proxy for a best needed indicator and for which the available data are of sufficient quality
- Index or composite indicator: a combination of a group of indicators
- Theoretical framework: the first step in the index process resulting in the selection of indicators. More specifically, the multidimensional problem under study is described, essential underlying aspects (and their relationships) identified and possible indicator candidates evaluated on a number of selection criteria
- Normalisation: applying a data transformation to the indicator data in order to render all indicators comparable
- Aggregation: mathematical formula for combining indicators into an index
- Robustness testing: quantifying the impact of methodological choices and assumptions on the end result
- Target: a specific, measurable, achievable, relevant and timed objective
- Benchmark: a subject (e.g. country) with a higher success ratio compared to other subjects; this best-in-class can be seen as an example for ameliorating performance
- Casualties: the number of (fatally, seriously and slightly) injured persons from a road accident
- Mortality rate: the number of road traffic fatalities in a country divided by the number of inhabitants living in that country (per 100,000 inhabitants)
- Fatality rate: the number of road traffic fatalities in a country divided by the number of motorized vehicles (per 10,000 vehicles)
- Fatality risk: the number of road traffic fatalities in a country divided by the number of motorized vehicle kilometres (per 100 million vehicle kilometres)

- Aggregated data: data on a macro or national/regional level (e.g. the number of casualties in a country)
- Disaggregated data: detailed information for groups on a micro or local level (e.g. the number of casualties per age class and transport mode)
- Safety performance: the level of transport safety. A reduction in the number of accidents or the number of casualties corresponds to an amelioration of the safety performance
- Safety performance indicator (SPI): any measurement that is causally related to traffic accidents or casualties, used in addition to a count of accidents or casualties, in order to indicate safety performance or better understand the process that leads to accidents.

## 2.3 The planning process

Indicators can be used for monitoring, evaluation and communication. The identification of indicators can be seen as one step in a broader planning process. In general, a planning and decision making process is characterised by the following phases (Federal Highway Administration, 2004): understanding the problem; establishing institutional leadership, responsibility and accountability; defining desired outcomes; identifying performance indicators; comparing with other experiences; developing and implementing a systematic safety data collection and analysis process; developing a safety plan and integrating it into agency decision making; and monitoring the effectiveness of implemented strategies and actions. Each step is briefly described below in relation to Belgium/Flanders.

1. understand the problem: in order to come up with strategies and investments for enhancing road safety, the problem should be understood first. Insight should not only be gained in the number of casualties, but also in the most important factors leading to such outcomes. The main road safety problems in Belgium are: excessive and inappropriate speed, driving under influence, fatigue, driving education (young drivers), heavy good vehicles, vulnerable road users (pedestrians, cyclists, mopeds and motorcyclists), seat belt and protective systems, active and passive vehicle safety, infrastructure and help to road accident victims (Begeleidingscomité, 2001).
2. establish institutional leadership, responsibility and accountability: attention should be paid to a clear division of responsibility, coherent sets of competences and subsidiarity. Arrangements between the authorities responsible for taking measures are needed as several levels (i.e. European, federal, regional and local) are involved. Apart from the ministers of mobility, the federal government service of mobility and transport and the Flemish department of mobility and public works there exist several advisory bodies (e.g. Mobiliteitsraad van Vlaanderen), a number of institutes (e.g. Belgisch Instituut voor de Verkeersveiligheid, Instituut voor Mobiliteit), pressure groups (e.g. Federatie van de Auto en Tweewielerindustrie, Fietsersbond), etc.
3. define desired outcomes: in case a target is set, there is a higher involvement and tendency to achieve it. In general, targets should be credible, transparent, consistent and accountable (National Road Safety Committee, 2000). Desired outcomes can be aggregated, e.g. maximum 500 road fatalities on Belgian roads by 2015 (Federale Commissie voor de Verkeersveiligheid, 2007) as well as disaggregated, i.e. related to specific user groups or focussed on particular causes of accidents, e.g. maximum 55 fatalities and fatally injured persons per 1 million persons under 26 years (Ministerie van de Vlaamse Gemeenschap, 2001).
4. identify performance indicators: once desired outcomes have been established, the next step is to identify relevant performance indicators. Each road safety

problem should be represented by a set of appropriate indicators. In chapter 3, safety performance indicators will be extensively discussed. Since 2004 the Belgian ministry of transportation issues a barometer on road safety at regular intervals. On the basis of police reports, the monthly evolution in registered accidents and fatalities on the spot is shown, even as statistics on casualties by region and road type. Recently, a barometer for accidents involving heavy good vehicles and accidents during the weekend has been formulated. However, in this study we focus on performance indicators rather than outcome indicators for providing policy supporting information.

5. <u>compare with other experiences</u>: safety performance indicator data are often compared across regions or countries. The comparison process indicates the good and bad aspects of road safety in a country and reveals a benchmark that can be taken as an example.

6. <u>develop and implement a systematic safety data collection and analysis process</u>: a key to the success of national or regional road safety programs is the existence of a data collection and analysis system that provides frequent information on the safety performance of the transportation system. This information is used to monitor progress towards performance targets, identify topics or areas where further action is necessary, educate officials and the public on the importance of the topic and evaluate the effectiveness of implemented projects and strategies. Nowadays, large amounts of information are available, for example related to the location of accidents (Geographical Information System), weather characteristics, travel information, etc. Furthermore, collecting data on performance indicators will be valuable for identifying the road safety problems needing urgent action and for monitoring the evolution herein.

7. <u>develop a safety plan and integrate it into agency decision making</u>: the next step is to develop a road safety action plan outlining the road safety problem, challenges being faced, performance targets that have been established, actions being considered and institutional responsibilities for carrying out the plan. The key to a successful strategy is to find maximal safety at minimal cost; and to choose the best means of achieving it (Land Transport Safety Authority, 2000). Different measures can be fairly compared in terms of a cost-benefit analysis (see e.g. Hakkert and Wesemann, 2005). The safety plan usually consists of a range of strategies, actions and projects. For Flanders, seven main categories of measures have been stated (Verkeersveiligheidsplan Vlaanderen, 2007). Identifying the most appropriate combination of actions comes from both a technical process that identifies the likely effectiveness of different strategies and a political/public assessment of what might be feasible.

8. <u>monitor effectiveness of implemented strategies and actions</u>: determining the effectiveness of implemented strategies and actions is the eighth step. The effectiveness can be estimated from literature and research (see e.g. Elvik and Vaa, 2004; Nuyts, 2006). Monitoring outcomes is needed to see whether or not the forecast will be met (Land Transport Safety Authority, 2000).

This planning process needs to be revised from time to time. In the short run, performance monitoring may require a revision of the target or some extra measures. In the long run, a careful review of the strategy including the assumptions and reasoning is needed as unforeseen circumstances (e.g. faster population or mobility growth, new technical developments, etc) may push the strategy off course (National Road Safety Committee, 2000).

The identification of performance indicators is an essential yet largely uncovered issue at this moment. Therefore, the next chapter is devoted to this.

## 2.4 Road safety indicators

Like other policies, road safety policy is complex and could benefit from a collection of quantifiable parameters able to measure changes and progress towards postulated objectives (European Environment Agency, 1999; Hens et al., 2005). Indicators have to represent large amounts of information in a comprehensive manner and simplify the complexities in a straightforward and clear message. An analytical framework or model is used to structure data in order to identify and categorize appropriate indicators. It makes the information easier to interpret and describes eventual links. The Organisation for Economic Cooperation and Development mentions six different categories to which indicators can belong: social, health, economy, energy, housing and sustainability (Hens et al., 2005). Road safety belongs to the health category.

There is a large number of factors involved in road safety development and it is worthwhile to describe and convert them into direct and quick measurements. Therefore, a comprehensive set of indicators has to be set up, including as much as possible all the main interesting parameters in road safety instead of considering only a few isolated factors such as accident rates per population, vehicles or kilometres driven (Al Haji, 2005).

Traditionally, road safety research has been based on accident data. However, simply counting accidents and casualties gives an incomplete indication of the level of road safety (Al Haji, 2003). Accidents and casualties are subject to random fluctuations and a recorded number does not necessarily reflect the underlying 'expected' number, recording of accidents and casualties is incomplete and a count of accidents says nothing about the processes that result in accidents (European Transport Safety Council, 2001). Safety performance indicators (SPIs) are measurements that are causally related to accidents or casualties, used in addition to a count of accidents or casualties in order to indicate safety performance or understand the process that leads to accidents. 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 (Vis, 2005). SPIs can give a more complete picture of the level of safety, give direction to policy instruments and can point to the emergence of new problems at an early stage before these problems show up in the form of accidents (European Transport Safety Council, 2001; Luukkanen, 2003). Because of the high information density they allow quicker and more local analyses and monitoring than accidents do (European Transport Safety Council, 2001).

As is the case for all indicators (see section 2.1) road safety indicators can be used as a tool in policy analysis and communication. The current state and trend of road safety can be described and compared (in space and time). Moreover, safety indicators can indicate the success of countermeasure programs and support policy decisions regarding existing and new measures (National Research Council, 2002). Finally, they can be used to formulate road safety policy targets and priorities.

## 2.5 Road safety management system

To frame road safety performance indicators, it is valuable to start from the pyramid stating the essential elements of the safety management system (Luukkanen, 2003). The idea originates from the New Zealand’s road safety target hierarchy (National Road Safety Committee, 2000), has been adapted in the SUNflower project (Koornstra et al., 2002; Morsink et al., 2005) and is used in the SafetyNet project as well (Vis, 2005). A visual presentation of the role of safety performance indicators in road safety management is shown in Figure 1.

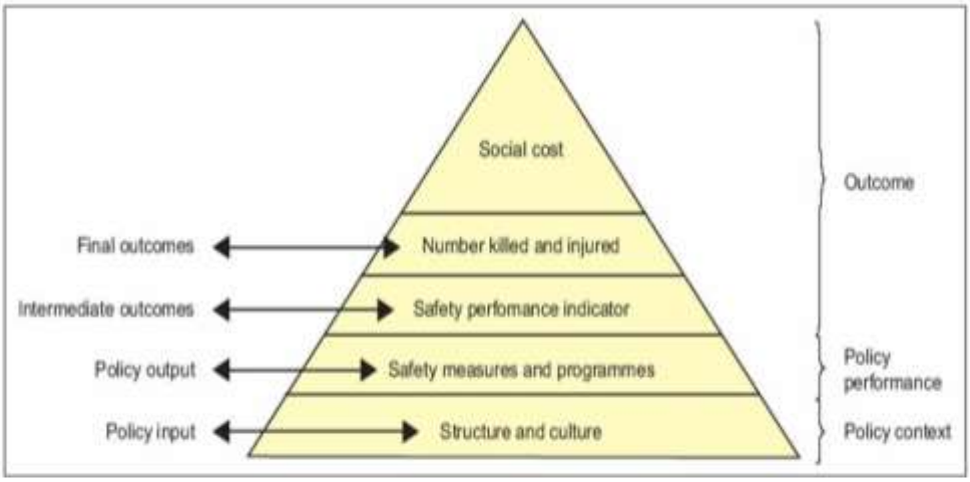


**Figure 1: A target hierarchy for road safety (Morsink et al., 2005)**

In fact, three dimensions should be considered (Morsink et al., 2005). The vertical dimension (shown in Figure 1) consists of five different levels of the pyramid. At the horizontal level, road safety problems can be specified in a disaggregated way, per road user group, transport mode, road type or region. The third dimension is time allowing to show the development of factors in both the horizontal and vertical dimension over time. Each component of the vertical dimension will be discussed below.

**Social cost**, at the top level of the pyramid, is the aggregated measure of all costs that accidents impose on the community (National Road Safety Committee, 2000). In order to determine the overall cost several cost components need to be taken into account. Economic costs do not reflect the pain, loss of function, disfiguration, emotional stress and other suffering to the casualties and immediate families (Evans, 2004). The Federal Highway Administration (Cambridge Systematics Inc. and Meyer, 2008) considers the following: property damage, lost earnings, lost household production, medical costs, emergency services, travel delay, professional rehabilitation, workplace costs, administrative costs, legal costs, and pain and lost quality of life. In 2005 dollars, this resulted in a per person cost of $3,246,192 for a fatality and $68,170 for an injury. The European Commission introduced the rule of thumb of €1 million per fatality. Later, €3.6 million has been quantified, taking into account immaterial costs as well. For Belgium, the marginal unit value of preventing a road casualty is estimated at €2,004,799 per fatality, €725,512 per seriously injured and €20,943 per slightly injured person (De Brabander and Vereeck, 2007). Empirical data on human and economic production losses as well as on direct accident costs such as medical costs, hospital visiting costs, accelerated funeral costs, property damage, administrative costs of insurance companies, lawsuit costs, police and fire department costs and congestion costs were used in this computation. The overall monetary outcome depends on the final outcomes at the level below.

**Final outcomes/number killed and injured** consist of the number of casualties and need to be as low as possible. They can be further described in terms of road user age, transport mode, location and type of accident (Luukkanen, 2003). Road safety targets may be defined either in terms of road safety risk or as an absolute level of road safety. Targets in absolute terms are more widely understood. However, by presenting final outcomes as fatality or mortality rate instead of absolute numbers, changes in mobility respectively population are taken into account. Rates per person (e.g. mortality rate), per vehicle (e.g. fatality rate) or per unit of travel (e.g. fatality risk) are often used.

**Intermediate outcomes/safety performance indicator** represent the risk conditions of road traffic responsible for the occurrence of accidents and casualties. The indicators at this level are called safety performance indicators. Thereby, these indicators provide the link between the final outcomes and the policy output. Intermediate outcomes are measured because they are generally reliable indicators of how well our road safety interventions are working (National Road Safety Committee, 2000). A certain road safety intervention will decrease a specific risk condition (e.g. speeding), which will eventually result in accident or injury reduction; and this should ultimately reduce the social cost. The process of establishing appropriate road safety performance indicators is discussed in the next chapter. For now, we can say that the road safety performance indicators most commonly used are those relating to behavioural characteristics such as impaired driving, speeding and the use of seat belts (Luukkanen, 2003). In addition, a number of vehicle, infrastructure and trauma related indicators are relevant (European Transport Safety Council, 2001).

**Policy output/safety measures and programmes** refer to the nature and context of national road safety plans, action programmes and safety related standards and legislation. Examples are the number of police patrols, the budget spent on road safety campaigns, the legal speed limit on different road types, the chance of getting caught for driving under influence of alcohol and the penalty level of seat belt violation (National Road Safety Committee, 2000; Morsink et al., 2005).

Finally, **policy input/structure and culture** refer to the policy context, such as public attitudes towards risk and safety, the organisation of a country and its historical and cultural background (Morsink et al., 2005).

In the target hierarchy, not one but many targets regarding road safety can be set (National Road Safety Committee, 2000). Social cost and final outcome targets are the headline targets designed to capture attention. These outcomes can be broken down (e.g. per road user group or per region). Nowadays, these targets are widely used in many countries in national, regional and local road safety strategies and programmes (European Road Safety Observatory, 2006). Intermediate outcome targets (e.g. a seat belt wearing rate or a speed violation share of x%) are of interest to road safety professionals as they reveal the effect of individual interventions. Policy output targets (such as the number of police checks in relation to speed) can point out how well the postulated work programme is respected whereas policy input targets can be formulated in terms of attitude (e.g. the proportion of drivers in favour of extra speed cameras).

The road safety target hierarchy presented here is an interesting and valuable framework. On all levels, indicators could be defined, targets set and values compared. In fact, even countries showing similar final outcomes may differ to a considerable extent (Koornstra et al., 2002; Morsink et al., 2005). Their specific transport problems, policy, background, norms, etc are captured in different indicator values. Although this study focuses on the intermediate outcome level, it is important to know that a multitude of factors affect road safety.

## 2.6 A broader view

In order to enhance the level of road safety in a country, interventions are needed. Safety performance indicators will help identifying the problem areas requiring urgent action. An appropriate set of measures aiming to improve the performance in a problem area and so reducing the number of casualties needs to be chosen. Obviously, it is possible that a certain measure has a positive effect in terms of road safety but at the same time affects other aspects in an unfavourable way. Therefore, other domains closely linked to the road safety field, need to be considered as well. The broader picture comprises energy and emission, congestion, mobility, etc (see e.g. Richardson, 2003). The European Commission recently released a handbook with estimates of external costs in the transport sector (Maibach et al., 2008). An overview of the main external costs – congestion and scarcity, accidents, air pollution, noise, climate change and other factors – is given.

Furthermore, road safety can be seen as a part of sustainable transportation which consists of three main dimensions: social sustainability (public health, safety and security, accessibility, social equity), economic sustainability (economic efficiency, economic development and financial affordability) and environmental sustainability (environmental integrity, natural resources and system resilience) (e.g. Jeon et al., 2008).

## 2.7 Conclusion

This chapter presented some basic information on (road safety) indicators. Indicators are tools for monitoring the status of a certain phenomenon. They express scientific knowledge in an understandable and relevant manner. In general, indicators can be used in a number of ways, such as measuring relative performance, identifying trends, assessing the impact of policy measures, target and priority setting as well as for communication purposes. From this, the value of indicators for the road safety domain becomes clear.

Several factors affect road safety. In the road safety management system essential elements are presented. In the remainder of this report we will study the middle layer in this pyramid, i.e. safety performance indicators. A safety performance indicator can be seen as a measurement causally related to accidents or casualties, used in addition to a count of accidents and casualties, that indicates safety performance and offers a better understanding of the process leading to accidents.

Safety performance indicators offer new insights to the road safety community. They allow benchmarking on a more detailed (and relevant) level and can reflect and prioritize main problem areas. They enable taking necessary actions before the problem becomes visible in an increased number of accidents and casualties. Moreover, they can be used to assess the impact of a specific measure. However, the identification of appropriate road safety performance indicators is essential and deserves particular attention. Therefore, the next chapter specifies the theoretical framework.

# 3. THEORETICAL FRAMEWORK

To formulate appropriate road safety performance indicators a theoretical framework has to be developed. More specifically, a clear understanding and description of the problem under study needs to be obtained, the essential underlying aspects need to be identified and possible indicator candidates need to be evaluated on a number of selection criteria.

## 3.1 Overview

Several questions related to the theoretical framework can be posed.

- First, how can the problem of road safety be described? (section 3.2)
- Second, which domains or subcomponents are of importance and need to be considered? (section 3.3)
- Third, how are the domains linked and how do they fit in a broader framework? (section 3.4)
- Fourth, which indicators can be used to measure each of the selected domains? (section 3.5)
- Fifth, based on which criteria will a final indicator selection be made? (section 3.6)

Each of these questions will be successively discussed in the following sections. This chapter closes with conclusions on the theoretical framework (section 3.7).

## 3.2 The road safety problem

Road safety is a topic that is correctly receiving a lot of attention lately. The price paid for mobility is too high. Worldwide, an estimated 1.2 million people are killed in road accidents each year and as many as 50 million are injured (World Health Organization, 2004). This means that every day around the world, more than 3,000 people die from road traffic injury. The economic cost of road accidents and casualties is estimated at 1 to 2% of the gross national product (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, 2006a). Road traffic injuries cause physical, psychological, material and economic costs. The estimated annual cost of road crash injury in European Union countries exceeds €180 billion (World Health Organization, 2004). Compared to other activities, the chance of dying in road traffic is per hour 40 times higher than at work and 12 times higher than during activities at home (Ministerie van de Vlaamse Gemeenschap, 2001). One person in three will be involved in a road accident with casualties at some point in his life (European Commission, 2001).

A closer look at the Belgian accident figures reveals that in 2007 the number of fatalities still exceeds 1,000 and the number of injured persons is almost 67,000 (http://www.statbel.fgov.be/downloads/accidents_dossier_2007_nl.xls). Compared to other European countries (the EU-27 average being 87 fatalities per million inhabitants in 2006) and particularly in relation to its neighbouring countries, Belgium scores relatively bad. In Figure 2, the number of fatalities per million inhabitants in 2006 is given for 27 European countries (European Union Road Federation, 2008) and Flanders (FL) (http://www.statbel.fgov.be).

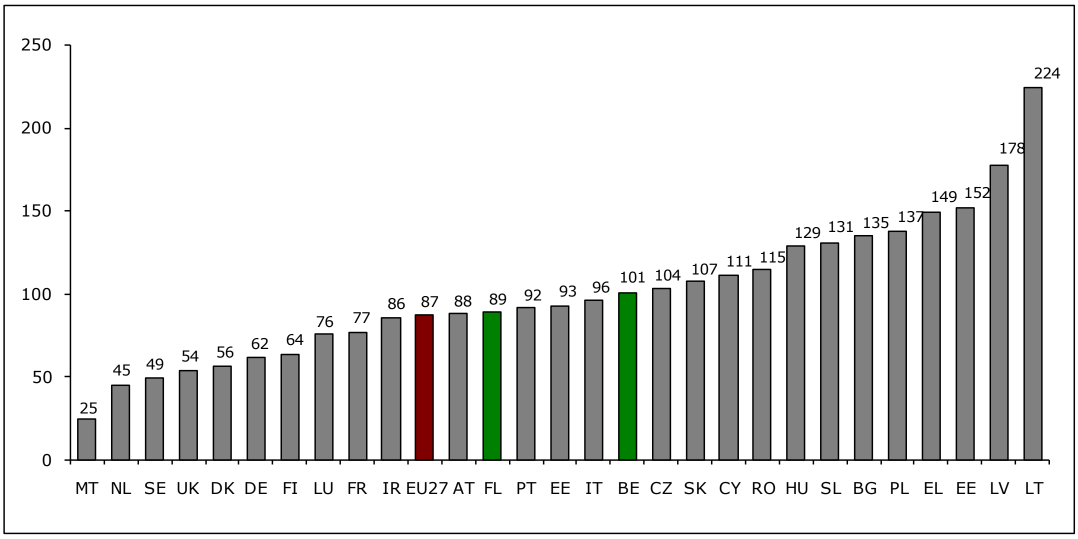


**Figure 2: Fatalities per million inhabitants in 27 European countries and Flanders (2006)**

Although the number of fatalities in road accidents dropped significantly at the beginning of the 1990s, the trend has been less marked in recent years (as illustrated in Figure 3). 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 Commission, 2006a; European Road Safety Observatory, 2006; Organisation for Economic Co-operation and Development and European Conference of Ministers of Transport, 2006; Federale Commissie voor de Verkeersveiligheid, 2007). However, if the trend continues at the same rate, according to the European Commission's Mid-Term Review (2006a) 32,500 people will die from road accidents in 2010. In order to achieve the EU-25 target of 25,000 fatalities at most by 2010, some additional effort will probably be needed.

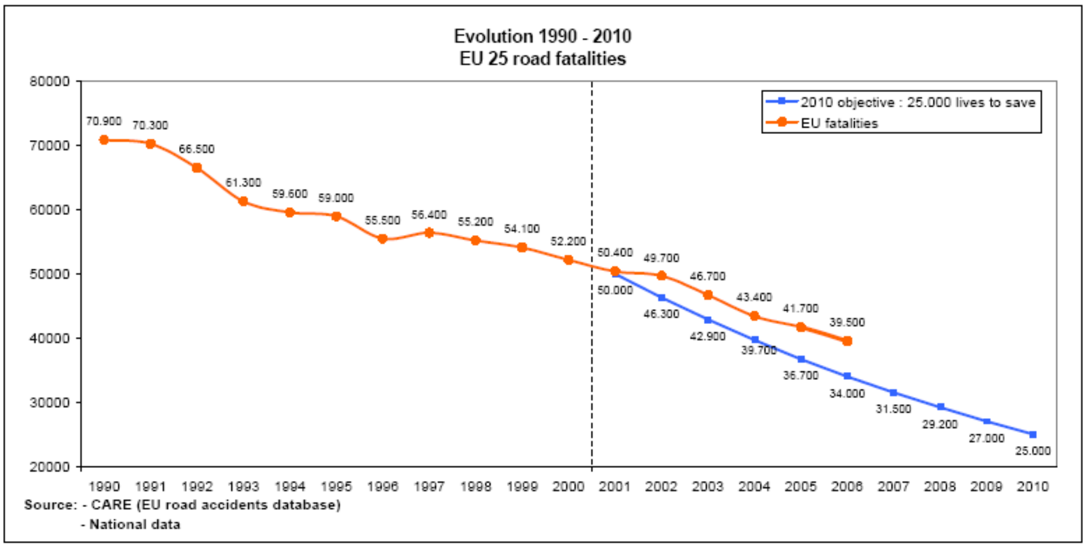


**Figure 3: Evolution of fatalities in the EU-25 (1990-2010) (European Commission, 2006a)**

By means of research the impact of several factors on road safety can be assessed including the effect of policy measures imposed to enhance road safety. This knowledge may be used to propose new road safety programmes and actions. We need to aim for frequent indications of change in the level of road safety risk and the degree of progress or decline with regard to the stated objectives. In this respect, safety performance indicators are very useful. To express road safety by means of measurable parameters, the most important risk domains causing accidents and casualties need to be defined first.

## 3.3 Decomposing the road safety problem

The former section indicated the size of the road safety problem on a worldwide, European and Belgian/Flemish scale. The occurrence of accidents and casualties results from a very complex mechanism. To enhance the level of road safety, it is essential to gain a clear insight into the underlying factors. In the past, many studies trying to explain why accidents occur have been conducted and various models have been developed aiming to describe the road safety situation in a country, to assess the impact of several influencing factors and measures and to forecast the evolution (Organisation for Economic Co-operation and Development, 1997; Christens, 2003; Van den Bossche and Wets, 2003; European Commission, 2004a; Raeside and White, 2004; Hermans et al., 2006b). Many studies, for example Elvik and Vaa (2004), found risk factors leading to an increase in accident frequency or severity. The goal in safety analysis is to examine factors associated with accidents in order to identify the factors that can be changed by countermeasures to enhance future safety (Evans, 2004). Significant determinants of road safety will be described below.

The remainder of this section is divided into four parts. First, the human-vehicle-infrastructure framework is explained, followed by the exposure-risk decomposition. Thirdly, the Haddon matrix and the C3-R3 systems approach are discussed and this section concludes with a description of the road safety risk domains that will be focused on for the selection of road safety performance indicators.

### *3.3.1 Human-vehicle-infrastructure*

Road safety problems have traditionally been viewed as the result of malfunctions in the road transport system. This road transport system consists of three components: the road user, the vehicle and the infrastructure (European Commission, 2004a). Each accident is in most cases a direct consequence of failure in one or several of these three factors who influence each other: the desired behaviour of the road user (e.g. no drunk driving), the intrinsic safety of the vehicle (e.g. no technical defects) and the intrinsic safety of the road (e.g. good road surface conditions). The human factor is considered to be the most contributory one (Sabey and Taylor, 1980).

The road transport system comprising these three components is integrated in a broader environment, where it interacts with other factors. In numerous national and international studies the impact of various factors on road safety has been assessed across countries and/or over time (e.g. Hakim et al., 1991; Fridstrøm et al., 1995; Scuffham, 2003; Eisenberg, 2004; Van den Bossche et al., 2005; Hermans et al., 2006c; Melinder, 2007). From the literature, we deduce the following influencing factors of road safety closely linked to the human-vehicle-infrastructure system:

- Regulation: laws related to alcohol and speed, safety actions and policies, …
- Demography: age of the population, family composition, …
- Economy: unemployment, gross national product, income, …
- Culture: religion, …
- Climate: precipitation, snow, sun, … .

### *3.3.2 Exposure-risk*

Several factors have an influence on the number of accidents and/or casualties. Some studies (such as Fridstrøm et al., 1995) label the degree of exposure as the most important factor for road safety. Exposure measures the degree of participation in traffic.

Road safety can be seen as the product of two main components, i.e. exposure and risk (Hauer, 1982). In other words, the number of accidents is equal to the product of exposure and the number of accidents divided by exposure. The latter term is the accident risk or the risk of getting involved in an accident given a certain amount of exposure.

$$\#\ accidents = exposure \times \left( \frac{\#\ accidents}{exposure} \right) \qquad (1)$$

In case we express road safety by the number of casualties, a third component appears in the formula, namely the injury risk (also called consequence) which expresses the probability of getting injured once an accident occurred (Rumar, 1999). In Equation 2 it is shown that a road casualty results from the presence of a person on the road (exposure), the fact that the person got involved in an accident (accident risk) and got injured (injury risk).

$$\#\ casualties = exposure \times \left( \frac{\#\ accidents}{exposure} \right) \times \left( \frac{\#\ casualties}{\#\ accidents} \right) \qquad (2)$$

The number of accidents and casualties can be obtained from the official accident database. Exposure data require some more search. There are several (traffic as well as persons at risk) exposure estimates. The size of the population (number of inhabitants), the vehicle fleet (number of registered vehicles), the length of the road network (number of kilometers) and the driver population (number of driving licenses) are available and often used measures. However, they do not always act as good measures of exposure. This is due to differences in socio-economic conditions, population density, vehicles per citizen and transport mode split between countries (Al Haji, 2005). Other possible exposure indicators are the number of trips or the time in traffic. In general, the number of vehicle (or passenger) kilometres travelled in an area (country or region) during a certain period of time (a year, a month, a day) is considered the most relevant measure for exposure. Unfortunately, this information – in the required level of detail and on a systematic basis – is usually lacking (SafetyNet, 2005b). Exposure data are often collected by counting traffic, travel surveys, local exposure measurements and indirect exposure estimates (e.g. based on fuel sales) (Organisation for Economic Co-operation and Development, 1997). Decomposition research would largely benefit from detailed counts of exposure in terms of distance travelled and time spent in traffic disaggregated by road type and vehicle type.

In principle, there are three ways for reducing the number of casualties: the amount of travel or the traffic volume can be reduced (e.g. promoting public transport); for a given level of exposure, the probability of an accident to happen can be reduced (e.g. driver training); and the level of severity in case an accident happened can be reduced (e.g. airbag). Such a decomposition enhances our knowledge since more information about the underlying road safety aspects becomes available. Working with this layered structure can be justified by the fact that each component – exposure, accident risk and injury risk – is influenced by a possibly different set of factors (World Health Organization, 2004; Hermans et al., 2006a). Economic and demographic factors affect exposure, while excessive speed and recreational drugs are examples of factors that influence accident involvement. Helmet wearing and medical care have a positive impact on (post-)accident injury severity.

### *3.3.3 Haddon matrix – C3-R3 systems approach*

The previous sections decomposed road safety in human-vehicle-infrastructure on the one hand and exposure-risk on the other hand. In this section, a systems approach is presented. The systems approach focuses on the relationships and dependencies between the various individual elements of the transport system. It identifies the different stages at which policymakers can intervene to promote road safety (Zein and Navin, 2003). In fact, effective road safety measures can merely be identified if all elements of the transport system are considered and the links between the elements are clear.

The first attempt to define road safety from a systems perspective occurred using the methods of Dr. Haddon (Zein and Navin, 2003). The three transport system components (road user, vehicle and road system) and three temporal sequences (before, during and after the crash) were combined into a Haddon matrix containing nine cells. Each cell identified the areas in which interventions could be initiated. For example, possible interventions aimed at the human factor are education (before the crash), restraints (during the crash) and trauma management (after the crash). We refer to Haddon (1980) for more information on this subject.

A further elaboration of the Haddon matrix resulted in 2003 in the presentation of the CR-R3 systems approach of Zein and Navin. The fundamental building blocks of the C3-R3 approach are:

- three entities: the road user, the vehicle and the road system
- three pre-crash timeline phases: creation, cultivation, conduct (which affect accident frequency)
- three post-crash timeline phases: response, recovery and reflection (which affect accident severity)

Every combination of entity and timeline phase represents a cell in the C3-R3 system. This approach is visualised in Figure 4. More information can be found in Zein and Navin (2003).

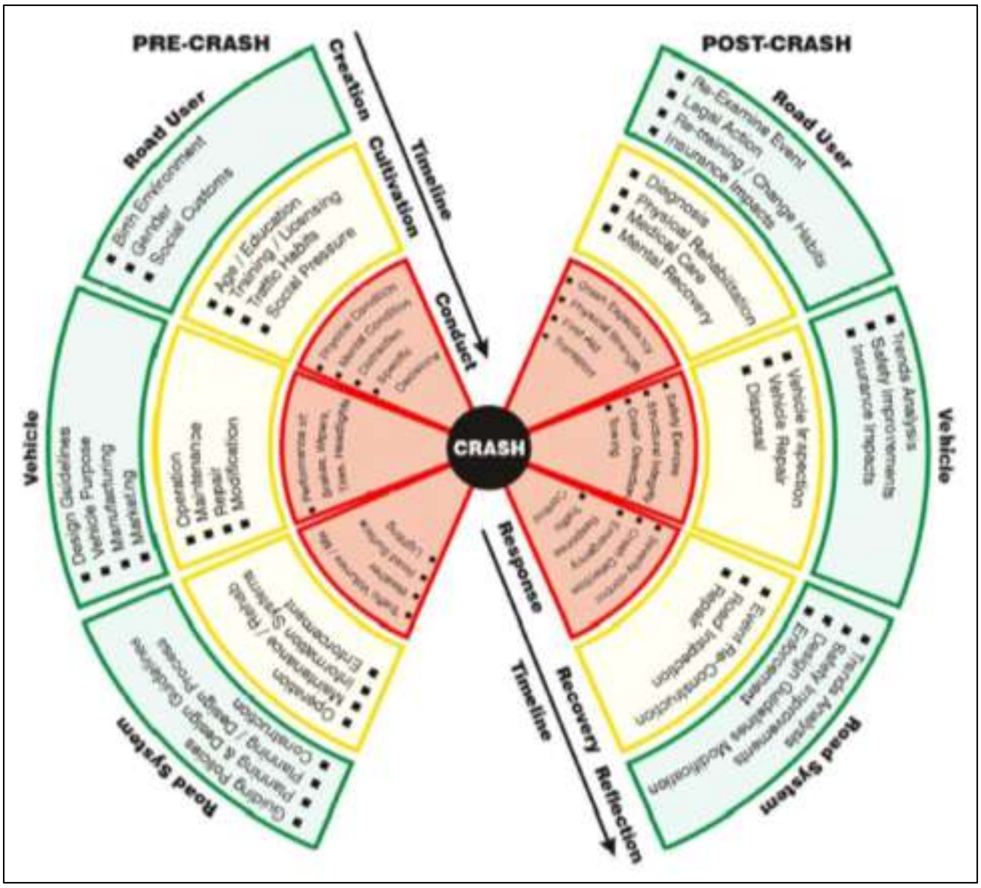


**Figure 4: The C3-R3 traffic safety systems approach (Zein and Navin, 2003)**

### *3.3.4 Road safety risk domains*

It can be inferred from the previous sections that road safety is a very complex matter. Many factors have an influence in various ways. As we intend to formulate a workable road safety performance indicator set, attention will be paid to the most important safety performance indicators. Importance can be described in terms of the next three aspects (European Transport Safety Council, 2001):

a) a stronger relationship with road safety

b) a larger contribution to accidents

c) to be influenced by measures

This last aspect, the policy impact, eliminates some important factors such as the weather and the demographic situation. However, this does not imply that we should not take these factors into account in the general framework (see also section 3.4). They do have a non-negligible impact. Based on the three aspects above as well as main road safety problems stated in national road safety plans (e.g. Begeleidingscomité, 2001) and relevant road safety indicators literature (European Transport Safety Council, 2001; World Health Organization, 2004; Vis, 2005) the following risk domains are proposed:

1. Alcohol and drugs
2. Speed
3. Protective systems
4. Daytime running lights (DRL)
5. Vehicle
6. Roads
7. Trauma management

The importance of each risk domain in the road safety context will be dealt with below. In general, justification for these seven risk domains can be found in literature. They can be considered to be the central themes of road safety, which can lead to a significant improvement in the level of road safety. Of course, other relevant risk domains could be considered as well. However, behavioural domains like alcohol, speed and seat belts are a natural starting point for comparisons across countries and over time. Domains related to the vehicle fleet, the road network and emergency services should be added to that (European Transport Safety Council, 2001). This research starts from the seven agreed upon road safety risk domains in the SafetyNet project (Vis, 2005) as it is the most recent source with respect to road safety performance indicators.

The association of the seven risk domains with the 'human/vehicle/infrastructure' decomposition on the one hand and 'exposure/accident risk/injury risk' on the other hand is briefly discussed. First, the seven domains can be assigned as follows to the human-vehicle-infrastructure framework. Alcohol and drugs, speed, protective systems and daytime running lights refer to the human behaviour. Other examples are distance-keeping, usage of crossing facilities and running a traffic light. The fifth domain is clearly linked to vehicle while the sixth domain represents infrastructure. In case the surroundings of an accident are looked at in a broader sense, the seventh domain – trauma management – is also linked to the third component in the framework.

Secondly, the relationship of the seven risk domains with accident risk and/or injury risk can be described (World Health Organization, 2004). Note that accident occurrence is linked to the pre-crash phases and accident severity to the post-crash phases of the C3-R3 approach. The domains alcohol and drugs, speed, vehicle and roads all both affect the probability of an accident to happen and the severity of the injury once the accident happened. Daytime running lights merely influences accident frequency whereas protective systems and trauma management have an impact on accident severity. All risk domains will be discussed successively.

### Alcohol and drugs

Driving while being intoxicated causes a higher accident risk. A larger blood alcohol concentration implies a higher chance of getting involved in an accident. More specifically, the relative risk of getting involved in an accident starts increasing significantly at a BAC level of 0.04 g/dl (World Health Organization, 2004). Moreover, in a number of studies (see Hakim et al., 1991) consumption of alcohol has been seen to increase the frequency of fatal accidents. Al Haji (2005) discusses a study (Thoresen et al., 1992) in which a positive correlation between the total number of fatalities in Victoria state (Australia) and alcohol sales was found and an inverse relationship with random BAC breath testing. Other findings are a negative relationship between both the number of accidents and the severity of injuries on the one hand and the minimum age for purchasing alcohol on the other hand (Hakim et al., 1991). A study from the United States (Zador, 1991 in World Health Organization, 2004) shows that for single-vehicle accidents, each 0.02% increase in BAC level nearly doubles the risk of getting involved in a fatal accident.

According to the alcohol and drugs questionnaire of the SafetyNet team (no public source), accidents in which at least one driver impaired by alcohol was involved caused 5.4% of the fatalities in Belgium in 2006. However, as an alcohol test is not always performed (from the questionnaire it appears that one third of the drivers involved in fatal accidents was tested), these figures are possibly an underestimation of the real size of the problem (Vanlaar, 2005). The Belgian Toxicology and Trauma Study (Belgian Toxicology and Trauma Study Research Group, 1997) estimated that 28% of all drivers who entered the emergency room after an injury accident had a blood alcohol concentration above the legal limit (Begeleidingscomité, 2001). During weekend nights, this percentage increased up to 50%.

In case of drugs, it is more difficult to quantify the impact as there is currently insufficient information about the concentration or combinations that may cause driving problems. In this respect, a distinction between medicinal and illicit drugs can be made. Moreover, the concentration of drugs is difficult to measure in a reliable way. However, it can be expected that drugs intoxication implies a higher risk.

### Speed

Inappropriate or excessive speed has been identified as a highly important factor influencing both the number of accidents and the severity of injuries (see e.g. Elvik, 2005; Kweon and Kockelman, 2005). In high-income countries, excessive and inappropriate speed is a main cause in one third of the fatal and serious accidents (World Health Organization, 2004). The probability of becoming involved in an injury accident increases with a higher (average) speed and/or larger speed differences (Al Haji, 2005; Vis, 2005). The level of road safety could improve if the curve representing the speed variation is narrowed (i.e. a smaller difference in speeds and few drivers exceeding the speed limit) (Begeleidingscomité, 2001).

The probability that an accident will result in injury is proportional to the square of the speed; for serious injury proportional to the cube of the speed; and for fatal injury proportional to the fourth power of the speed (World Health Organization, 2004). In addition, the probability of a pedestrian dying as a result of a car accident increases exponentially with the speed of the car. Reducing vehicle speeds appears to have a significant effect on road casualties and pedestrian accidents (e.g. Fridstrøm et al., 1995; Balkin and Ord, 2001).

Factors that affect the choice of a particular speed are related to the road (width, layout, markings, quality of the surface), the vehicle (type, maximum speed, comfort), the traffic (density, composition, prevailing speed), the environment (weather, light, enforcement) and the driver (age, sex, reaction time, risk acceptance, alcohol level, car occupancy) (World Health Organization, 2004).

**Protective systems**

Protective systems play a role in case an accident has occurred as they determine the severity of the injury. Mandatory seat belt use has been one of the greatest success stories of road injury prevention and has saved many lives. Several empirical studies in the United States, Great Britain, Sweden and The Netherlands have shown that seat belt legislation, when followed by law enforcement, significantly reduces the number of fatalities and the severity of injuries (Hakim et al., 1991).

Not wearing a seat belt or helmet implies an increased injury or fatal risk. Several studies have found that seat belts, helmets and child's seats are very effective. The level of effectiveness depends on the impact speed, the type of collision and the position of the occupant. The use of seat belts reduces the probability of being killed in an accident by 40-50% for drivers and front seat passengers and by 25% for passengers in the rear seats as shown in Elvik and Vaa (2004). The World report on traffic injury prevention (World Health Organization, 2004) shows the effectiveness of various protective systems. Wearing a seat belt reduces the risk of serious and fatal injury by 40-60%. In case motorised two-wheelers wear a helmet, fatal and serious head injuries are reduced by 20 to 45%. Furthermore, cyclist helmets diminish the risk on head and brain injuries (by 63 to 88%). Moreover, child's seats offer 70% reduction in the risk of dying for children under 1 year and 54% for children between 1 and 4 years (Begeleidingscomité, 2001).

**Daytime running lights**

Daytime running lights refers to motor vehicles having their headlights on during hours of daylight (SWOV, 2008). Daytime running lights help road users to better and earlier detect, recognise and identify vehicles (European Commission, 2006b). This increased visibility implies fewer accidents. The effect of daytime running lights on road accidents has been studied for several decades, starting in Northern European countries (see e.g. Elvik, 1993). In the handbook of road safety measures (Elvik and Vaa, 2004) a reduction in the number of multi-party accidents of 10 to 15% is linked to DRL use.

By 2006, in 14 member states there exists a regulation regarding daytime running lights i.e. Austria, Czech Republic, Denmark, Estonia, Finland, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Slovakia, Slovenia and Sweden. A report from Knight et al. (2006) concludes that the mandatory use of DRL in all member states would provide a net accident reduction.

**Vehicle**

Vehicles have become safer over time due to a progressively stricter regime of standards (European Environment Agency and Eurostat, 1999). Furthermore, there is a rapid evolution in vehicle technique and technology (Begeleidingscomité, 2001). Improvements in both active and passive safety resulted in a lower frequency and severity of accidents. Active safety features help the driver in avoiding an accident, such as anti-lock braking systems, traction control, driving aid systems and audible warning devices while passive safety features better protect occupants in the event of an accident, like frontal and side impact protection, airbags, load restraint and crush zones (National Road Safety Committee, 2000; Begeleidingscomité, 2001).

There is a link between vehicle age and risk. Not only have occupants of a car produced before 1984 approximately a three times higher injury risk compared to occupants of a newer car (World Health Organization, 2004), the vehicle fleet is continuously being renewed to higher safety standards. Moreover, the presence of safety features in the overall vehicle fleet can be estimated by means of the age of the fleet.

Over time, crashworthiness, i.e. the protection that a vehicle gives in case of an accident, has improved. Many countries pay attention to good safety standards in motor vehicles. The new car assessment program evaluates vehicle crash performance by rating the vehicle models on their safety level for occupant protection, child protection and pedestrian protection. The European new car assessment programme EuroNCAP (www.euroncap.com) supplies information to consumers about the performance of new cars in crash tests since 1996. A higher EuroNCAP rank implies fewer fatal and severe injuries (European Transport Safety Council, 2001).

It is known that poor vehicle maintenance and technical conditions can also contribute to accidents (Al Haji, 2005). In high-income countries, the contribution of vehicle defects to accidents is around 3% (World Health Organization, 2004). In terms of periodic vehicle inspections, different studies show different results. Elvik and Vaa (2004) concluded based on a review of macro studies that there is no clear evidence that periodic vehicle inspection has an effect on the number of accidents while Hakim et al. (1991) presented in another review of macro studies that periodic inspection of motor vehicles reduces the number of fatalities. In this latter review, the authors refer to a study (White, 1986) concluding that the probability of accident involvement increases with the length of time between inspections.

**Roads**

The safety performance of the road transport system is the result of the combination of the functionality, homogeneity and predictability of the network, the road environment, and the traffic involved (Vis, 2005). The road network influences accident risk as it determines how road users perceive the environment and offers instructions by means of signals (World Health Organization, 2004). Four influencing factors are safety awareness in the planning of new road networks, dealing with safety features in the design of new roads, safety ameliorations to existing roads and healing actions on locations with a high accident risk.

In addition, poor road surface conditions even as defects in road design and maintenance contribute to an increased accident risk (European Transport Safety Council, 2001; Al Haji, 2005). Objects along the road provide a risk in case the road user gets involved in a (run-of-the-road) accident. The performance tracking of roads is the focus of EuroRAP (Lynam et al., 2004). The EuroRAP road protection score aims at assessing the degree to which roads protect against severe injury in case of an accident.

The road network consists of several road types. Despite the high speed allowed motorways are considered to be the most safe type of roads. However, they represent only a few percentages (0 to 2.8%) of the total road network (European Union Road Federation, 2007). Rural roads account for a considerable share of all fatalities. The risk of being killed (per kilometre driven) is generally higher on rural roads than on urban roads and is four to six times higher than on motorways (Organisation for Economic Co-operation and Development, 2002). Rural road accidents are generally more severe than accidents on urban roads due to differences in operating speeds, road geometry, functionality, enforcement levels and other factors (Organisation for Economic Co-operation and Development, 2002).

**Trauma management**

Trauma management refers to the system responsible for the medical treatment of injured persons from a road accident. That way, it concerns the severity of an injury. The probability of surviving and the quality of life after the accident are influenced by the level of trauma management (European Transport Safety Council, 2001).

Noland (2003) concludes that advances in medical treatment and technology have resulted in reductions in traffic related fatalities in all developed countries over time (1970-1996). Fatality figures are correlated with the level of medical facilities available in a country expressed in terms of population per physician and population per hospital bed (see Al Haji, 2005).

A report from the European Transport Safety Council (1999) concluded based on a review of European studies on traffic mortality that almost 50% of road accident fatalities die within a few minutes at the accident scene or on their way to the hospital. Concerning hospitalised casualties 15% dies within one and four hours after the incident while 35% dies after 4 hours. The following chain applies: actions on the accident scene, access to the emergency medical system, help by paramedics, medical care provided before arriving to the hospital, medical care in the hospital and rehabilitative psychosocial care (Hussain and Redmond, 1994 in World Health Organization, 2004).

**Concluding remarks on the selected risk domains**

In the international literature, clear evidence for the link between each of the seven risk domains and road safety can be found. We believe that indicators for the domains alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management provide policymakers with a profound set of road safety performance information. Specific measures can be taken to tackle problem areas which in turn will result in fewer accidents and casualties and a reduced social cost (see Figure 1). Possible measures for each domain are listed below:

- alcohol and drugs: alcohol limit, enforcement and measures against recidivism, campaigns
- speed: speed limit, speed cameras, enforcement, sanctions, campaigns
- protective systems: enforcement, sanctions, campaigns
- daytime running lights: regulation, campaigns
- vehicle: design and maintenance standards, safety devices, informing potential buyers, motor vehicle taxation
- roads: safer road designs, hot spot analysis, road safety audits
- trauma management: investments in medical services and material, easy access to the accident scene

We conclude this section by remarking that the evolution in road safety cannot be entirely captured by these seven domains. We need to keep in mind that several other factors affect the frequency and severity of accidents. In case the level of road safety is studied over time or compared across regions, changes in demography, traffic volume and mobility behaviour should be taken into account to explain some part of the evolution in road safety. In the next section, the seven risk factors are put in a broader framework that summarizes the main road safety factors. Attention is paid to the interrelationships of these factors as well as of the seven risk domains.

## 3.4 Interrelationships

Based on the international literature, seven risk domains have been identified. In this section, we study their interrelationships. Moreover, it is essential to look at road safety in a broader framework, thereby paying attention to various contributing factors and their links as road safety is the end result of several influences acting together. As stated in section 3.3.2, road safety can be decomposed into two main components, i.e. exposure and risk. In this section, an overall framework will be presented in which not only the seven risk domains and exposure deserve a place, but also other influencing factors, such as demography. This broader framework is the result of our own research on the one hand and the framework used to describe and interpret the causal chain of road safety effects on the other hand (as stated in Farchi et al., 2006; Lammar, 2006). First, some history and concepts related to frameworks used for modeling causal relationships is provided.

### *3.4.1 Conceptual frameworks for modeling causal relationships*

From Van Reeth and Vanongeval (2005) the following brief overview has been deduced. In the 70s the Canadian statistician Friend developed the pressure-state-response (PSR) model for modeling causal relationships between environmental pressures, the state of the environment and the policy response. Due to the concept of sustainable development in the mid 80s, the driving forces-state-response (DSR) model arose. Based on previous models, the European Environment Agency developed during the 90s the DPSIR framework in which impact (I) was made explicit (European Environment Agency, 1999). The DPSIR framework assumes cause and effect relationships between its interacting components: driving forces of environmental change (D), pressures on the environment (P), state of the environment (S), impacts on population, economy and ecosystems (I) and response of the society (R).

Finally, the DPSEEA model is a framework to get insight into the causes and results of environmental disturbance (World Health Organization, 1999). DPSEEA is an acronym for driving forces/pressure/state/exposure/effect/action. Starting from driving forces (e.g. economic growth), a pressure on the ecosystem arises (e.g. emission of pollutants) resulting in a changed state of the environment (e.g. a change in habitat of animals). Subsequently, humans are exposed to these environmental risks causing health effects. Therefore, society should come into action.

These frameworks have been developed within the environmental field in which they are common knowledge. Road safety is closely linked to the aspect of health and it is valuable to use a structured framework for indicators as done in other domains. Therefore, the chain of environmental causes resulting in health effects can be applied to the road safety field. In Farchi et al. (2006) an elaboration of the DPSEEA model has been presented aimed at identifying and evaluating a core set of indicators to monitor the causal chain of road accident health effects. As the road safety context is characterized by specific features and differs from the environmental field, two extra aspects are added to the DPSEEA structure, namely accident risk and injury risk. In the next section, all different components of the framework will be described from a road safety point of view.

### *3.4.2 The DPSEAIEA framework*

To the DPSEEA framework two additional components essential in the study of road safety have been added, namely accident risk (A) and injury risk (I), resulting in the DPSEAIEA framework. The two risk factors provide the link between exposure and effect. In the subsequent sections (mainly based on Farchi et al., 2006; Lammar, 2006), each component is described and illustrated in relation to road safety.

**Driving forces**

The principal driving forces are factors that create the need to travel. The degree of mobility is affected by the economic status of a country (e.g. employment rate), the distribution of wealth (e.g. average income), the distribution of population (demographic factors such as the number of inhabitants, the age distribution, the family composition, etc) and the physical geography of the country.

**Pressure**

Pressure factors result from the need to travel. The most important ones are cultural and social norms which create the interest in having a car and mainly travelling by personal transport. Cultural believes may explain the difference in road safety between countries to some extent. Countries within a certain area (e.g. Europe) are considered to have more or less the same pressure as their level of mobility is quite similar.

**State**

The state consists of several topics related to the conditions that influence the quantity of exposure. The degree of urbanization, the relative location of homes, schools, shops and work places, the age and quality of the vehicle fleet, the size and quality of the road network, the organisation of public transport and the climate are considered to be the most important factors.

**Exposure**

Exposure has already been discussed in section 3.3.2. Two good ways to measure exposure is in terms of distance travelled and in terms of time spent in traffic. These quantities can be disaggregated by road user mode and road type. By means of activity based modeling (see e.g. Janssens and Wets, 2005), more detailed exposure information (e.g. travel route, travel mode choice and trip purpose) can become available, rendering the analysis more realistic. Exposure is affected by driving forces, pressure and state components (e.g. economic factors and urban population density) and influences the subsequent components.

**Accident risk**

The concept of risk has been discussed earlier (see sections 3.3.2 and 3.3.3). Risk factors that either increase or decrease the probability of an accident are sometimes referred to as primary risk factors. Secondary risk factors increase or reduce the injury in case an accident happened. Some factors affect both accident frequency and severity. Examples of accident risk factors are listed: drinking and driving, speeding, use of mobile phone, auditory or visual disturbance, active safety of vehicles, new driver, older road user, children without supervision, tiredness, medical disorder, infrastructural design and maintenance.

**Injury risk**

The following factors are considered to affect the level of injury: drinking and driving, speeding, usage of seat belts, helmets and other protective systems, passive safety of vehicles, young and older road users, infrastructural aspects such as crash-protective roadsides and barriers, quality level of the rescue and pre-hospital emergency care and the health care system, etc.

**Effects**

The former components result in health effects, namely accidents and casualties. From the registered accident information, the number of injury accidents, the number of fatalities and the number of injuries can be determined. Other interesting effect factors are the years of life lost, the degree of invalidity and the psychological effect.

**Actions**

Actions include a wide range of preventive interventions, policies, laws, structural changes, etc. These actions can be mainly related to engineering, education or enforcement. They are mostly aimed at reducing the health effects of accidents, reducing the prevalence of a risk factor or reducing the amount of exposure, but could also try to affect the driving forces, pressure and state. The effect of actions on the target can be monitored by means of indicators.

### *3.4.3 Interrelationships framework*

The DPSEAIEA framework is visually presented in Figure 5. For each of the eight components, some important factors are given. This figure presents on the one hand the causal chain between the components of road safety and on the other hand depicts the interrelationships between the seven risk domains.

Driving forces such as the economic, demographic and geographic situation exert pressure on our society leading to a certain state in terms of the size and quality of the vehicle park and road network. This influences the amount of exposure, expressed in kilometres travelled or hours spent in traffic. The probability of getting involved in an accident (given a certain level of exposure) is affected by primary risk factors such as alcohol and speed. Secondary risk factors for their part have an impact on the severity of injury once an accident happened. Several risk factors exist, of which the seven presented in the figure are generally agreed upon (see section 3.3.4). The risk ends in road safety outcomes or effects like the number of casualties. The last component in the causal chain for road safety consists of road safety enhancing policy measures. Actions can be targeted more or less directly (i.e. changing exposure or reducing accident and injury risk will result in fewer accidents and casualties) or indirectly (i.e. by trying to alter a particular driving force, pressure or state factor).

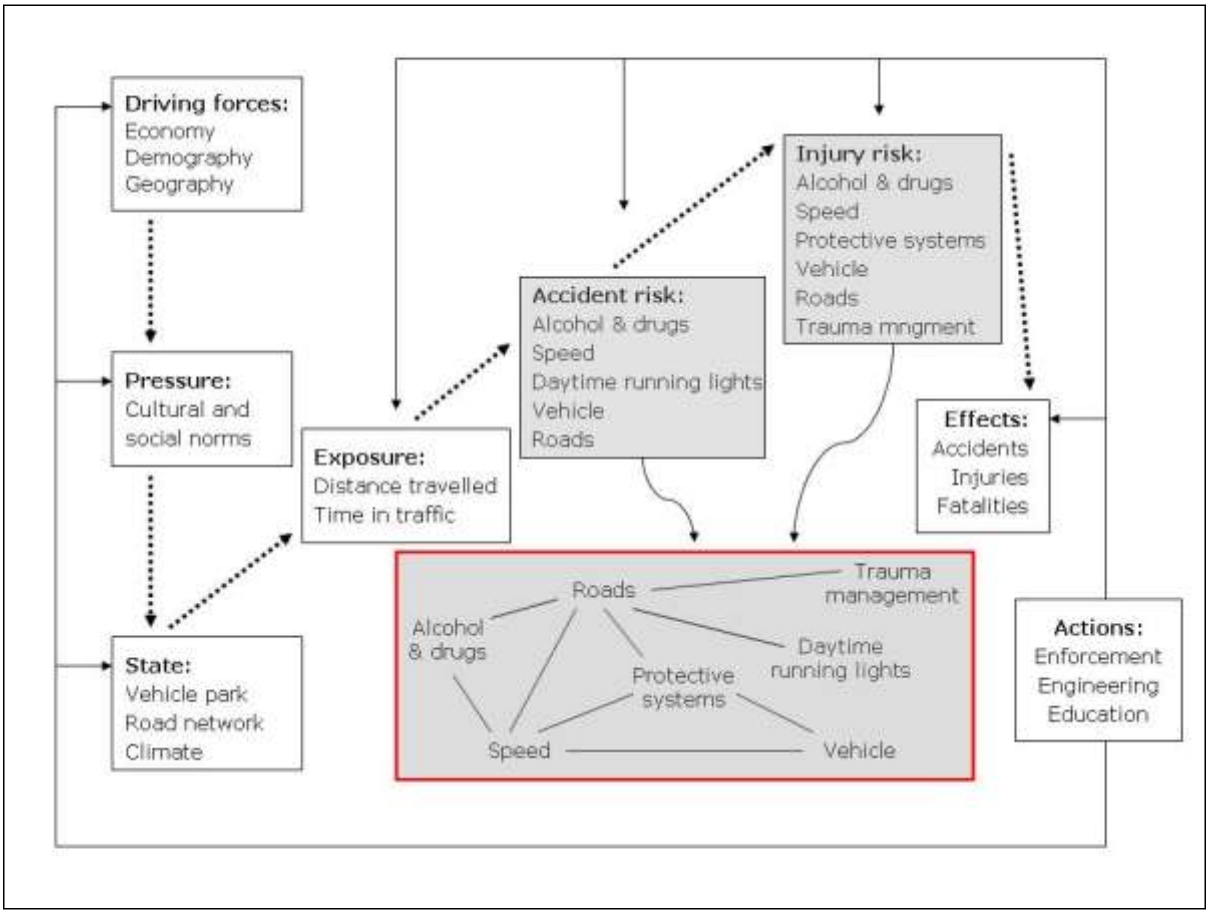


**Figure 5: Interrelationships between main road safety factors**

Instead of elaborating all components of the DPSEAIEA framework presented in Figure 5, we will focus on risk and the corresponding road safety performance indicators in the remainder of this study. The interested reader is referred to Lammar (2006) in which an overview of existing indicators for each component in the framework is given for Flanders. Focusing on the seven selected risk factors, the rectangle presented at the bottom of Figure 5, indicates nine assumed interrelationships. First, the risk domains alcohol and speed are connected. Persons disrespecting the speed limit have a tendency to break the alcohol law as well. Second, speed is linked to roads because the road environment has an influence on the perception of a safe speed. Third, the effectiveness of protective systems depends on the impact speed of the collision. Fourth, the domain of protective systems on the one hand and the speed domain on the other hand is related to the vehicle domain as auditory devices may affect the seat belt wearing rate and level of speed. Next, the use of protective systems respectively daytime running lights varies with the length of the trip and thus the road type (e.g. a higher rate on motorways). This also holds for alcohol and drugs as a different level can be found on different road types (e.g. motorways and main roads are avoided in case of drunk driving). Finally, a link between roads and trauma management can be assumed based on the efficient position of trauma management centres (i.e. close to main roads). These interrelationships should be kept in mind. In the next section, for each of the seven risk domains, several interesting indicators will be proposed able to indicate the level of occurrence of the risk factor.

## 3.5 Possible indicators

Having determined seven essential road safety risk domains (section 3.3) and having an idea about their interrelationships (section 3.4), we focus next on finding appropriate indicators for each domain. As required by the report of the European Transport Safety

Council (2001) each risk domain has a causal relationship with road safety based on well documented and known research results. All domains will be expressed quantitatively by means of performance indicators. Ideally, each risk domain is represented by several indicators able to indicate the performance on a certain domain in a realistic way. In the end, we want a comprehensive set of performance indicators that provides policymakers with a complete and accurate picture of road safety performance apart from the official accident registration.

In section 3.6 a selection from the extensive set of indicators listed below will be made taking several selection criteria into account. For now, we list possible indicators by posing the question: 'given the relationship between the risk factor and road safety, by means of which indicators can this risk domain be appropriately measured?'. The potential indicators for the seven domains listed below were identified by means of relevant literature (Begeleidingscomité, 2001; European Transport Safety Council, 2001; Al Haji, 2005; Morsink et al., 2007; Vis and Van Gent, 2007a). However, we would like to remark that in our opinion, some of the indicators suggested in literature, are state or effect indicators rather than performance indicators.

### *3.5.1 Alcohol and drugs indicators*

The occurrence of alcohol and drugs in traffic can be measured by the following indicators:

- the percentage of drivers with an alcohol concentration above the legal limit
- the percentage of drivers with a drugs concentration above the legal limit
- the percentage of surveyed (car) drivers disrespecting the alcohol limit
- the percentage of drivers impaired by alcohol or drugs
- the percentage of drivers impaired by alcohol and drugs
- the percentage of fatalities resulting from accidents involving at least one driver impaired by alcohol
- the percentage of fatalities resulting from accidents involving at least one driver impaired by drugs
- the percentage of fatal accidents in which someone was drinking and driving
- the percentage of road users involved in fatal accidents impaired by alcohol or drugs
- the subjective risk of getting caught while driving under influence
- the attitude towards driving under influence.

### *3.5.2 Speed indicators*

The following indicators can be used in relation to speed:

- the percentage of drivers exceeding the speed limit on various road types
- the percentage of surveyed (car) drivers exceeding the speed limit on various road types
- the average (free flow) speed per road type and vehicle type during daytime
- the average (free flow) speed per road type and vehicle type at night
- the variation in speed per road type and vehicle type
- the median (or another percentile) of the set of observed speeds divided by the speed limit of the road class

- the median of the set of absolute differences between each of the observed speeds in the road class and the median of all observed speeds divided by the median of the set of observed speeds
- the percentage of drivers with an inappropriate headway on various road types.

### *3.5.3 Protective systems indicators*

The protective systems indicators are expressed in terms of wearing rate. The wearing rate is the percentage of persons wearing the protective system divided by the total number of users of a certain vehicle type observed in a representative sample during an independent roadside survey (Vis, 2005). Possible indicators for testing the use of protective systems in traffic are:

- the percentage of persons wearing a seat belt in the front seats of a car or van
- the percentage of persons wearing a seat belt in the rear seats of a car or van
- the percentage of children under 12 years (correctly) sitting in a child's seat, in the front or rear seat of a car
- the percentage of persons wearing a seat belt in the front seats of a bus (above 3.5 tons) or a truck
- the percentage of persons wearing a seat belt in the passenger seats of a bus
- the percentage of cyclists wearing a helmet
- the percentage of moped riders wearing a helmet
- the percentage of motorcyclists wearing a helmet.

### *3.5.4 Daytime running lights indicators*

With respect to the daytime running lights domain the following indicators can be considered:

- the total usage rate of daytime running lights
- the usage rate of daytime running lights per road type and vehicle type
- the existence of a law – fully or partially (i.e. on certain road types, for certain vehicle types or during certain time periods) – obligating the use of daytime running lights.

### *3.5.5 Vehicle indicators*

Unsafe vehicle aspects relate to technical defects, crashworthiness, the level of safety equipment and compatibility. Therefore, the following indicators can be used for the vehicle domain:

- the percentage of cars failing the official vehicle inspection
- the EuroNCAP score: the percentage of new cars obtaining 0 respectively 1, 2, 3, 4 or 5 stars in the total number of new passenger cars
- the age distribution of the vehicle fleet: the percentage of vehicles of maximum 5 years; between 6-10 years, between 11-15 years and older than 15 years in the total number of registered vehicles (focus on passenger cars)
- the composition of the vehicle fleet: the percentage of cars, vans, buses, trucks and motorcycles in the total number of registered vehicles

Notice that each percentage can be considered as an individual indicator: the percentage of new cars with 5 stars or the percentage of vehicles older than 15 years or the percentage of trucks. Combining the indicators within a certain category is another option, e.g. the percentage of new cars obtaining 4 or 5 stars.

### *3.5.6 Roads indicators*

The roads domain can be characterized by the following indicators:

- the share of network length per road type (e.g. motorway)
- the share of intersections per type (e.g. roundabout, signalised T-junction)
- the intersection density (i.e. number of intersections divided by area)
- the network density (i.e. network length divided by area)
- the motorway density (i.e. motorway network length divided by area)
- EuroRAP road protection scores
- the percentage of road length with a wide median or median barrier
- the percentage of road length with a wide obstacle-free zone or roadside barrier
- the percentage of road length with facilities for separation of slow vulnerable traffic and other motorized traffic
- the percentage of the road network satisfying the safety design standard
- the expenditure on roads (in terms of engineering or maintenance) as share of the gross domestic product.

### *3.5.7 Trauma management indicators*

Possible indicators for the trauma management domain are:

- the percentage of calls to emergency medical services due to a road accident
- the average arrival time of emergency medical services at the accident scene
- the number of emergency medical services' staff per 10,000 citizens
- the number of hospital beds per 10,000 citizens
- the average length of stay in the hospital after a road accident
- the share of road casualties treated in intensive care units
- the share of road casualties who died during hospitalisation
- the expenditure on health care as share of the gross domestic product.

### *3.5.8 Concluding remarks on indicator candidates*

For each of the seven risk domains, a list with potential indicators has been formulated, one indicator being more appropriate than another. In the next section, attention will be paid to the evaluation of indicator candidates and the selection of appropriate safety performance indicators. There, relevant selection criteria as well as data issues are handled.

## 3.6 Selection of indicators

In this section, the choice of a set of appropriate road safety performance indicators is discussed. This indicator set will contribute to the establishment of a monitoring system in order to (Farchi et al., 2006):

- measure the road accident phenomenon, its determinants and the trends
- facilitate the planning, monitoring and evaluation of programs and actions
- provide organisations and policymakers with valuable information to make comparisons and support their policies

Choosing appropriate indicators is not an easy task. A selection for each risk domain can be made based on the strengths and weaknesses of each indicator. All relevant information can be summarized on an indicator card which can then be used to compare several indicator candidates based on the same aspects (see section 3.6.2). First, attention is paid to indicator selection criteria that are used in other studies (section 3.6.1). The availability and quality assessment of road safety information in European data sources is the topic of section 3.6.3. The final section (3.6.4) deals with some conclusions in terms of best available and best needed road safety performance indicators.

The chosen domains and corresponding indicators will not provide a complete picture of the road safety level in a country, but give important summary information on its performance. This knowledge can be used to assess progress over time and in relation to other countries. There are many indicators that may play an essential role and give a good indication of the risk factor but for practical purposes (e.g. collection costs) not all possible indicators can be selected. Moreover, the selection of appropriate performance indicators is a permanent process requiring regular revisions.

### *3.6.1 Selection criteria*

There exists tension between convenience and comprehensiveness when selecting an indicator set; a smaller set using easily available data is more convenient to collect and to analyze but may overlook important aspects while a larger set can be more comprehensive but have excessive data collection and analysis costs (Litman, 2005). In literature (National Cooperative Highway Research Program, 2003; Sharpe, 2004; Bird et al., 2005; Nardo et al., 2005b; Zietsman et al., 2008) several criteria for selecting good indicators can be found. The criteria suggested in a number of relevant sources are listed in Table 1.

**Table 1: Selection criteria used in literature**

| **Litman (2007)** | **Ledoux et al. (2005)** | **Hens et al. (2005)** | **Farchi et al. (2006)** | **Al Haji (2005)** |
|---|---|---|---|---|
| Understandable | Interpretable | Simple | Interpretable | Understandable |
| Useful | Comparable | Policy relevant | Clear definition | Clear definition |
| Comparable | Measurable | Available data | Relevant | Relevant |
| Available data | Continuous | Valid | Comparable | Comparable |
| Diverse | Cost effective | Reliable | Theoretically valid | Measurable |
| Target | Sensitive | Sensitive | Available data | Continuous |
| | Robust | Specific | Continuous | Reliable |
| | | | Timeliness | Accepted |
| | | | Reliable | Target |
| | | | Stable | |
| | | | Cost effective | |
| | | | Sensitive | |

Litman (2007) published a paper on indicators for comprehensive and sustainable transportation planning. Ledoux et al. (2005) and Hens et al. (2005) focused on sustainable, respectively environmental health indicators. The criteria recommended for selecting a good set of indicators in these fields are also valuable in the road safety indicators context. The criteria listed in the two final columns are deduced from road safety studies in which some conditions and requirements for indicators are described (Farchi et al., 2006; Al Haji, 2005).

Table 1 shows that some selection criteria are mentioned in almost all studies while others appear only once. In theory, an indicator should meet all these conditions. However, in practice, it is more interesting to evaluate the indicator set on a smaller number of essential selection criteria. Based on Table 1 and our own insights, good road safety performance indicators should satisfy each of the following eight criteria:

- Relevant/valid: can the indicator be associated with policy objectives? Is the indicator action-oriented and suitable for establishing a performance target? Does the indicator provide a good picture of the phenomenon that we want to measure?
- Measurable: is the indicator quantifiable and can it be measured in an objective way?
- Understandable: is the indicator clearly defined? Does the indicator have a comprehensible and acceptable interpretation?
- Available data: are data available for a large set of subjects (countries in this case) within an acceptable term and at a reasonable cost? Can the indicator be updated on a regular basis?
- Reliable: do the data come from a reliable source? Have the data been collected in a scientific way?
- Comparable/coherent: is the indicator coherent over time (i.e. has the same definition, method, … been used) and over space (i.e. do the subjects apply the same definition, …)?
- Specific: does the indicator focus on a certain level? Is the indicator detailed enough?
- Sensitive: is the indicator capable of reflecting changes in risk over time? Do small changes manifest in another indicator value?

### *3.6.2 Indicator cards*

Choosing one indicator over another for monitoring a specific risk factor has major implications, for example different policy measures could be suggested. Therefore, it is advisable to justify the selected indicators by making an extensive overview of the main characteristics of each possible indicator candidate. Afterwards, the best indicators for each risk domain can be identified, leading to a diverse and useful set of road safety performance indicators.

The indicator card contains ten aspects which extensively describe the indicator and help in assessing its relative appropriateness. The indicator card shown in Figure 6 results from some changes made to the model presented in Hens et al. (2005). An elaborated example is shown in Appendix I for the indicator 'the percentage of persons wearing a seat belt in the front seats of a car or van'.

The first section gives some basic information about the indicator. More specifically, the risk domain which is measured by this indicator is given as well as a short definition and the measurement unit. Secondly, the indicator is framed in a broader entirety, namely it is indicated to which component of the DPSEAIEA framework the indicator belongs and with which other factors it has a link. The policy relevance is the subject of the third section. The degree of significance for policymakers is assessed, thereby taking into account target setting and prevailing regulations. Methodological notes are discussed next. In particular, it is described how the indicator is computed and which data are needed for this. The current measurement method (e.g. survey, observations) and the sampling design, collection frequency and data source are given. Possible limitations and recommended alternatives are also listed.

Next, section 5 discusses the degree to which the indicator meets each of the eight criteria identified in section 3.6.1 (criteria 5.1 is linked to section 3 of the indicator card). If data are available, the indicator performance can be shown over time and with respect to different countries. In case of frequent measurements each new value can be plotted against previous values. A graph showing all values in time even as warning lines indicating unsatisfactory performance (i.e. deteriorating performance or failure to reach targets) is valuable in this respect (Bird et al., 2005). On the contrary, a graph showing only a few data points (e.g. this year's and last year's result) may be misleading for reasons including regression to the mean. If possible, comparing with a recent average level or trend is a better idea. Based on the information in the first seven sections, the main strengths and weaknesses of the indicator can be identified, supporting the conclusion whether or not the indicator is suitable for monitoring performance in a certain risk domain. Finally, references related to the indicator are listed.

1. Name Safety Performance Indicator
1.1) Domain
1.2) Description and context
1.3) Measurement unit

2. Position in the general framework

3. Policy relevance
3.1) Applicability or relevance
3.2) Link with other indicators
3.3) Objective and values to aim at
3.4) Regulation (national, international)

4. Methodological description
4.1) Measurement method
4.2) Data needed, collection frequency, source
4.3) Limitations
4.4) Alternatives

5. Assessment of the Safety Performance Indicator
5.1) Relevant/valid
5.2) Measurable
5.3) Understandable
5.4) Available data
5.5) Reliable
5.6) Comparable/coherent
5.7) Specific
5.8) Sensitive

6. Evolution of the Safety Performance Indicator

7. Comparison between subjects

8. Positive and negative aspects
8.1) Strengths
8.2) Weaknesses

9. Conclusion

10. References

**Figure 6: Indicator card**

For an indicator with a number of negative aspects (for example not specific enough and unreliable data) its weaknesses, listed under 8.2, can be seen as points to improve. Moreover, as these strengths and weaknesses may vary in time up-to-date information is required in the indicator card. Indicators characterised by mostly positive aspects should be considered as best available indicators. In addition, best needed indicators also score well on most aspects, but have a (few) major shortcoming(s), i.e. no data available; data of inferior quality; or not comparable/ coherent. For (macro) studies assessing the relative safety performance of a large set of countries data might be a big issue. Therefore, the degree of availability and quality of road safety data in Europe is handled in section 3.6.3.

This section is concluded with an illustration of the two-yearly Belgian roadside survey methodology for drink driving (Vanlaar, 2005). The output is the percentage of drivers exceeding the legal alcohol limit during weekend nights, weekend days, weekdays and weeknights. Furthermore, it is checked if the differences between these periods are significant. The methodology is as follows: first, the road sites per region are selected at random by means of a geographical information system. Based on their field knowledge, policemen decide whether the road site should be replaced by another one due to efficiency or safety reasons. After completing the sampling of the road sites, each site is randomly linked to one of the four possible time frames. The sampling design is thus stratified in space and time. The flow of traffic is counted and this result is used to calculate weights. Then, during the months October and November, drivers of passenger cars are stopped at random and asked to do an alcohol test. The random stopping of drivers is realised by stopping as many drivers as possible and testing them all and sundry (without a distinction on observational criteria). Some agreements were made, such as checking for one hour maximum and intercepting drivers who try to escape. Furthermore, all sampled drivers had to participate in a short questionnaire with personal questions (age, sex, …) and road site questions (flow of traffic, proximity of a disco, …). In case drink driving results are compared across countries, one has to keep in mind that various data collection aspects may differ (such as the selection of locations, the selection of drivers, the duration of checking on one specific location, etc). In view of a coherent and comparable data set, best practices in terms of data collection need to be advocated. One could benefit from the manual developed at the European level, specifying the measuring of indicators and sampling designs (Hakkert and Gitelman, 2007).

### *3.6.3 Data availability and quality in Europe*

Data on the incidence and types of accidents as well as a detailed understanding of the circumstances that lead to accidents is required to guide safety policy (World Health Organization, 2004). Quantification is at the core of scientific understanding and requires data (Evans, 2004). In this section, existing road safety data sources are reviewed.

#### 3.6.3.1 National sources

In general, the collection of accident data on the national level is well-developed. Nearly all countries in the world record accidents. Since the beginning of motorisation, detailed information (i.e. the number of accidents, the number of casualties and their characteristics) has been gathered and inventoried on a regular basis. Despite this large amount of data, many questions remain unanswered because other factors of interest have not been recorded or the data are not sufficiently reliable, complete or conveniently accessible (Evans, 2004).

Police reports are the main source of accident information. Road traffic accidents on the public road resulting in injury have to be registered. When the police arrives an accident form is filled out specifying the circumstances and details of the accident. These forms are then collected centrally and the national statistical bureau annually publicizes the overall figures. Belgian data are available via www.statbel.fgov.be where yearly aggregated and disaggregated (e.g. per transport mode, municipality, …) accident and casualty figures are shown up to 2007. A comparison of data collection methods in countries of the European Union (Farchi et al., 2006) revealed that there are only small differences. The most commonly reported characteristics are related to the accident (location, time of occurrence, light conditions), the persons involved (age, sex, physical condition, use of safety devices, type of road user) and the vehicles involved (type). These accident data are sometimes linked to census data and exposure data to draw conclusions in terms of mortality rate, fatality rate and fatality risk.

The road safety problem could also be quantified using road safety data from hospitals or insurance companies. However, privacy issues among other things prevent their frequent use at this moment. For most countries, we may conclude that the reporting of accidents in official statistics is incomplete and inaccurate (Elvik and Vaa, 2004). Tessmer (1999) showed there is a problem of under-recording by the police in most countries. Some detailed information of the accident is lacking as policemen have limited medical or engineering background. These shortcomings in accident data in terms of underreporting, misclassification and under-recording should be kept in mind.

#### 3.6.3.2 International sources

Accurate data enable a country to diagnose its road safety problems and to select appropriate measures to apply. Beside national data sources, international databases provide essential information for easily carrying out cross-country comparisons over time.

In theory, the same definition for a variable should be used in all countries (e.g. most European countries apply the 'dead within 30 days' definition; otherwise a correction factor is applied), the data should have been collected from a reliable source and should refer to the same year. In recent years, efforts have been made to increase the comparability of accident data. However, information on the underlying safety performance indicators is required as well. In one of their deliverables (Vis and Van Gent, 2007a) the SafetyNet team states that in general it is difficult to compare the road safety performance of countries. The main reasons are lack of data (essential data are missing), suspicious quality of the data received from numerous authorities (affecting the validity of the results) or the incomparability of (seemingly similar) data due to different circumstances of measurement. Moreover, some EU countries have laws prohibiting the measurement of necessary data (e.g. alcohol and drugs substances in the road user population).

Some information desired for analysing road safety performance exists but is not publicly available. Fortunately, we can dispose of a number of relevant international databases and research reports. In the proposal of EuroRIS, i.e. the European Road safety Information System (SafetyNet, 2005a) the main road safety data sources for Europe are discussed. The information regarding CARE, EuroStat, ECMT, IRTAD, IRF, UNECE and WHO is given consecutively.

- The creation of a Community database on Accidents on the Roads in Europe (CARE) was agreed upon in November 1993. It was intended to identify and quantify road safety problems, evaluate the efficiency of road safety measures, determine the relevance of community actions and facilitate the exchange of experience in this field. A distinguishing feature of CARE is its high level of disaggregation. Fatalities and fatal road accidents are discussed per person class (driver, passenger, pedestrian), demographic class (age groups and gender), area type (inside or outside urban area), motorway (yes or no), junction type (crossroad, level crossing, not at a junction, roundabout, T or Y junction), weather conditions (dry, fog or mist, rain, snow/sleet/hail, strong wind), transport mode/vehicle group (agricultural tractor, bus or coach, car or taxi, heavy goods vehicle, lorry under 3.5 tons, pedal cycle, moped, motorcycle, other), month, day of the week and hour. National data sets are integrated into the CARE database in their original national structure and definitions. However, transformation rules are implemented in order to increase data compatibility. At the time of writing, yearly data are available in CARE for the period 1991-2006 for 10 countries (Austria, Belgium, Denmark, Finland, France, Greece, Portugal, Spain, Sweden and United Kingdom). For Italy, this is up to 2004, for Ireland and the Netherlands until 2003 and for Luxembourg until 2002. Moreover, in 2005, four new countries were added to the database, i.e. Estonia, Hungary, Malta and Poland. More information can be found via http://ec.europa.eu/transport/roadsafety/road_safety_observatory/care_en.htm. (SafetyNet, 2008).

- EuroStat contains information on a wide variety of transport related topics, from diverse sources and consequently with a varying quality. EuroStat cooperates with other organisations (like ECMT, IRF and UNECE) to collect data from the national statistical institutes of the countries concerned. The main publication of Eurostat data is the EuroStat Yearbook which gives data related to population, health (e.g. deaths from transport accidents), economy, etc in annual time series of 10 years. Additionally, EU Energy and Transport in Figures is an annual publication in cooperation with the Directorate-General for Energy and Transport of the European Commission. The latest publication (2008) (available on http://ec.europa.eu/dgs/energy_transport/figures/pocketbook/2007_en.htm) does not only contain information on 27 EU member states but enables a comparison with candidate countries (e.g. Croatia) and other countries (such as Norway, Switzerland, United States of America and Japan) as well.

- The European Conference of Ministers of Transport (ECMT) publishes the annual Statistical Report on Road Accidents in 26 European countries. Data for the four most recent years, and for 1975, 1980, 1985 and 1990 are provided on the number of fatalities, the number of casualties, the number of injury accidents and the number of motor vehicles in use. For the most recent years, some risk figures and a breakdown of fatalities and injuries per transport mode are shown for each country. Finally, the report also lists the main road safety actions and changes in regulation as given by the countries. Recently, the European Conference of Ministers of Transport has been transformed into the International Transport Forum (ITF). ITF is an inter-governmental organisation involving more than 50 Ministers of Transport. More information can be found via http://www.internationaltransportforum.org.

- The IRTAD database is maintained by the Organisation for Economic Co-operation and Development (OECD). The use of the database is strictly limited to members, but some general statistics can be obtained via http://www.irtad.net. The database has information for 28 countries on the number of injury accidents and on the total number of injured persons. The number of fatalities and the number of seriously injured persons are available disaggregated regarding age of the victim, transport mode and road type (and a few combinations of these aspects). Furthermore, the following background variables are available: number of inhabitants per age group (mostly 5 year intervals), network length per road type, area of state, vehicle fleet per type, vehicle kilometrage per vehicle type and per road type, occupant kilometrage by mode of transport and seat belt wearing rate per road type. Most data are available for a number of years (some even for 1965 and 1970 onwards). The data come from statistical (and other) organisations in the different countries.

  Recently, IRTAD and ECMT (now ITF) have joined their forces by forming a joint OECD/ITF transport research centre. Currently, individual country reports can be found for 39 countries on http://www.internationaltransportforum.org/jtrc/safety/targets/Performance/performance.html.

- The International Road Federation (IRF) publishes at the end of each year an overview with data on several aspects of traffic and transport for more than 100 countries. Data refer to the network length, the production and export of motor vehicles, the active fleet of motor vehicles, the vehicle kilometrage, taxes related to transport and the annual expenditure of the national government on transport. For each country, the data on road safety (i.e. the number of injury accidents, the number of casualties and the number of fatalities) cover the last five years. The European Union Road Federation (ERF) publishes information on 27 European countries (see http://www.irfnet.eu/en/2008-road-statistics).

- The Economic Commission for Europe of the United Nations (UNECE) in Geneva annually publishes a multitude of data among which traffic safety related data (http://w3.unece.org/pxweb/Dialog). The data elements consist of the total number of accidents, the number of fatalities, the number of casualties and are subdivided by type of location, month of the year and day of the week.
- The World Health Organization (WHO) set up a mortality database. Annual world health statistics containing information on causes of death can be consulted online via http://www.who.int/whosis/en.

The data sources discussed above contain overlapping information but are not entirely consistent. For example, a value that is missing for a particular year in one database or publication is present in another one. However, this might not be an official value. Furthermore, elements present in more than one publication do not necessarily have the same value nor do they have the same value as published by the official national institute. Therefore, it is essential to know where the data come from and which procedures lie at the basis of their collection and publication (SafetyNet, 2005a). In addition to the data sources discussed above, various other sources exist, some of them consisting of data related to specific road user groups or locations such as CHILD (children), ECBOS (coach and bus occupants), ETAC (truck accidents), MAIDS (motorcyclists) and RISER (highway accidents). More information on these databases is available at www.erso.eu/data/content/european_databases.htm.

#### 3.6.3.3 Other sources

In addition to national and international databases, international projects set up around a specific road safety related theme often have a data collection component. Relevant road safety information has been collected in SafetyNet, SARTRE, SUNflower (+6), PENDANT, IMMORTAL, ALCOLOCK, CRASH TEST DATABASE, etc. More information on these projects can be found via http://ec.europa.eu/transport/roadsafety/publications/projectfiles/alphabetically_en.htm. Here, we elaborate on the SafetyNet project as it is of major importance for this research. Moreover, the road safety PIN (i.e. performance index) of the European Transport Safety Council is briefly described.

The European Commission 6th Framework integrated SafetyNet project aims to accelerate the availability and use of harmonised road safety data in Europe. One of the main outputs of this project is the European road safety observatory (ERSO) website (www.erso.eu) which is a system designed for road safety professionals to bring together road safety related data and knowledge and provide access to this information. In the SafetyNet work package on road safety performance indicators, which is of most interest for our research, a set of indicators has been developed for which relevant data or information about their availability was obtained from 27 cooperating countries (25 member states plus Norway and Switzerland) (Vis and Van Gent, 2007b). On average, usable data for the calculation of safety performance indicators (as defined within SafetyNet) are available for two thirds of the countries (Vis and Van Gent, 2007a). Most of the information has been obtained via national experts, who filled in the questionnaire. However, there is still a lot of work to be done before the availability of high-quality and comparable safety performance indicator data will be a fact. The development of a manual (Hakkert and Gitelman, 2007) providing details on the procedures for gathering the required indicator data contributes to uniform data collection in Europe.

Finally, the European Transport Safety Council started in June 2006 with a road safety performance index, a policy instrument to help countries in improving their level of road safety. Data are collected by national experts in 30 countries (27 member states, Norway, Switzerland and Israel). Four times a year, PIN flashes are published, specifying the ranking of countries in terms of their performance in a certain road safety area, e.g. motorways, motorcyclists and drink driving (more information can be found on http://www.etsc.be/PIN-publications.php).

### *3.6.4 Selection of road safety performance indicators*

The European Transport Safety Council advised the European Union in 2001 to formulate and specify a set of relevant safety performance indicators that can be used on the European and national level as a means to determine trends in the level of safety and the success of casualty reduction programmes.

Seven main road safety risk domains identified on the European level (Vis, 2005) are at the centre of this research. Several indicator candidates exist for each risk domain. To select appropriate indicators the pros and cons of various indicators need to be weighted against each other. All relevant information concerning each indicator can be summarized on an indicator card, in which among other things a definition, some methodological aspects and the degree of satisfaction of the selection criteria are mentioned. In the evaluation of safety performance indicators, eight criteria are in our opinion essential to speak in terms of a good indicator. More specifically, a safety performance indicator should be relevant, measurable, understandable, have data available, be reliable, comparable, specific and sensitive (see 3.6.1).

The availability of reliable and comparable data is an aspect that has a major influence on the indicator selection. To overcome the current, partial lack of indicator information and to assure the creation and collection of necessary data for road safety policymaking in a longer time perspective, best available as well as best needed road safety indicators are listed below (European Commission, 2005). An ideal road safety performance indicator set can be formulated, irrespective of whether the required data are available, reliable and comparable over time and space. Judging each possible indicator presented in section 3.5 based on the following five, not data related selection criteria – relevant, measurable, understandable, specific and sensitive – a set of **best needed indicators** for the risk domains alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management can be deduced (see Appendix II for the detailed evaluation of all indicator candidates):

- the percentage of drivers with an alcohol concentration above the legal limit
- the average (free flow) speed per road type and vehicle type during daytime and at night
- the variation in speed per road type and vehicle type
- the seat belt wearing rate in front and rear sets of cars and vans, busses and trucks
- the (correct) usage rate of child's seats
- the helmet wearing rate of motorcyclists and moped riders
- the usage rate of daytime running lights per road type and vehicle type
- the age distribution of the vehicle fleet
- the percentage of road length with a wide median or median barrier
- the percentage of road length with a wide obstacle-free zone or roadside barrier
- the average arrival time of emergency medical services at the accident scene
- the share of road casualties who died during hospitalisation

Despite the fact that a large amount of information needed to compare countries on their level of road safety can be found in international sources (see section 3.6.3), some essential data especially on the level of intermediate outcomes (see Figure 1) are missing. The larger the set of countries, the fairer the comparison but also the larger the data issue. There is a constant need for high-quality and comparable data for the countries involved, over the studied time period.

In practice, problems regarding the set of countries, the period (or year) for which data are available, the indicator definition and the measurement method occur. Since we want to compare countries on their underlying risk factors and since we aim to aggregate the essential information in an overall road safety performance index (see chapter 4), databases covering more or less the same countries need to be considered. In addition, all indicator values should refer to the same time period. At the same time, inconsistent indicator definitions are found between countries (for example, the percentage of seat belt wearing in the front seats can bear on all persons sitting in front, only the driver or only the passenger in front). Moreover, the measurement method may differ. The observed average speed per road type provides valuable information while an indication of speed violation is influenced by the level of enforcement and an indicator specifying self-reported speeds is somewhat biased (e.g. linked to cultural differences) (European Transport Safety Council, 2001). Of course, these aspects influence the outcomes but proxies or estimates are often needed to create an extensive indicator data set (at least for now). More generally, the following indicator set (scoring best on all eight selection criteria; see Appendix II) can be considered to be the **best available** one at this moment:

- the percentage of surveyed car drivers disrespecting the alcohol limit
- the percentage of surveyed car drivers exceeding the speed limit on various road types
- the seat belt wearing rate of occupants in the front seats of a car or van
- the existence of a law – fully or partially – obligating the use of daytime running lights
- the share of the fleet of passenger cars per age class
- the motorway density
- the expenditure on health care as share of the gross domestic product

The above list shows that the unavailability of good data restricts the selection of the indicator set to some extent. Self-reported data are to be used for the alcohol and speed domain and for the roads domain there are no direct or indirect safety performance indicators in use in Europe at the moment (Hakkert et al., 2007). Moreover, the evaluation of the daytime running lights and trauma management indicators revealed that currently no reliable and comparable data are available. Therefore, proxies are to be used. However, as soon as new indicator values become available, the list with best available road safety performance indicators can be adapted.

It is important to note that the selection of appropriate indicators is a permanent process requiring regular revisions. Both the set of ideal and best available indicators need updating and refinement. For valuable indicators that are hard to measure for now the frequent collection of high quality data should be recommended. Depending on the risk domain, the best needed and best available category call for different kinds of development efforts relating to concepts, methodologies and data collection procedures (European Commission, 2005). The urgent need to improve the availability and quality of policy relevant road safety performance indicators data cannot be overemphasized. The indicators should be produced with adequate frequency to support decision makers in a systematic way, i.e. for identifying problems, monitoring implementation of measures and following-up their effectiveness.

## 3.7 Conclusion

In this chapter, a theoretical framework has been elaborated resulting in the selection of road safety performance indicators. First, the multidimensional road safety problem was described by decomposing it in its main components. Relevant contributory factors were identified and discussed. Based on literature, the following seven risk domains were considered to be essential: alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management. Their link with accident frequency and severity and the interrelationships were indicated. Moreover, the causal chain of road safety effects (i.e. the DPSEAIEA framework) was described. After having a clear understanding of the main risk domains, possible indicators were listed next. Due to collection costs and other practical limitations, only appropriate indicators should be considered. Several selection criteria can be used in this respect. Safety performance indicator candidates were judged on relevance, measurability, interpretability, data availability, reliability, comparability, specificity and sensitivity. Based on the information in the indicator card and more specifically the degree of meeting all required criteria, the best indicators can be selected. We aim for a diverse set of safety performance indicators suitable for measuring road safety risk in a country. As data unavailability currently limits the use of best needed indicators, clear recommendations in terms of consistent data collection should be made on a high (European) level. In the meantime, best available indicators should be used.

Countries can be compared on each risk domain or indicator separately. However, if a large number of performance indicators is available, some summarization is essential for the analysis (Bird et al., 2005). Therefore, in the next chapter the methodology for creating an overall road safety composite indicator or index will be discussed. As the index will incorporate all main risk domains, the overall road safety performance of a country can be assessed.

# 4 THE ROAD SAFETY PERFORMANCE INDEX

## 4.1 Introduction

A composite indicator or index joins individual indicators based on an underlying model. An index captures a multidimensional concept that cannot be measured by one indicator. In chapter 3, the complex road safety phenomenon has been decomposed in several risk factors, which are to be measured by appropriate performance indicators. In this chapter, the process of aggregating indicators in one road safety performance index (RSPI; the term road safety index referring to the same in this report) is discussed. A composite index score can then be computed for each country, thereby presenting the overall road safety performance picture.

During the last decade, many indexes have been developed, related to various domains. Al Haji (2005) makes a division according to the type of developer. A large number of summary indices are being created and presented with the cooperation of international organisations, for example the Human Development Index – United Nations; the Environmental Sustainability Index – World Economic Forum; Composite Leading Indicators – Organisation for Economic Co-operation and Development; and Overall Health System Attainment – World Health Organization. Some other international indices were developed within or in cooperation with universities and research institutes, such as the Growth Competitiveness Index – Harvard University; and the General Indicator of Science and Technology – National Institute of Science and Technology Policy of Japan. A review of these and other studies is reported in Saisana and Tarantola (2002), Sharpe (2004) and McArthur and Sachs (2001).

Compared to other domains, the development of a composite indicator for road safety is new (with very limited research, e.g. Al Haji (2005) focusing on this issue as well). Traditionally, road safety studies analyse final outcome indicators (e.g. the accident rate and the mortality rate). However, indicators on the level of intermediate outcomes (see Figure 1) are valuable as they can provide detailed information and support policy decisions. Each indicator or each risk domain can be studied separately, but a summary statistic in the form of a road safety performance index is of much benefit because the total picture is presented. The road safety index builds on the risk domains relevant to the overall goal of reducing the number of traffic casualties. A schematic overview of the components of the road safety index is presented in Figure 7. The general indicators (e.g. speed indicator 2) can be concretized by the set of best available or best needed indicators (see section 3.6.4), but here the general framework is given.

Each of the seven risk domains is measured by means of a few indicators. As stated before, the selection of best safety performance indicators may change in the future as new information becomes available. However, the principle of combining is still valid then. The road safety performance index can be obtained by applying the methodological process in which several indicators are presented in a summary indicator, several times. First, the methodology is used on the set of alcohol and drugs indicators to create a composite alcohol and drugs indicator. The same applies to the other six domains. Finally, the alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management index are joined in one overall road safety index. So in theory, the road safety index consists of seven domain indicators, each one being an aggregation of specific individual indicators. In this chapter, we present the methodology for creating a composite indicator.

The road safety index is a summary statistic of relevant road safety risk information. Once the index methodology has been applied the road safety performance index 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 a country can be assessed; for monitoring the evolution or progress towards targets in a country over time and making predictions; and for policy supporting purposes since targets can be set and measures justified. Best practices and policies in well-performing countries can serve as a basis for formulating effective country specific road safety actions.

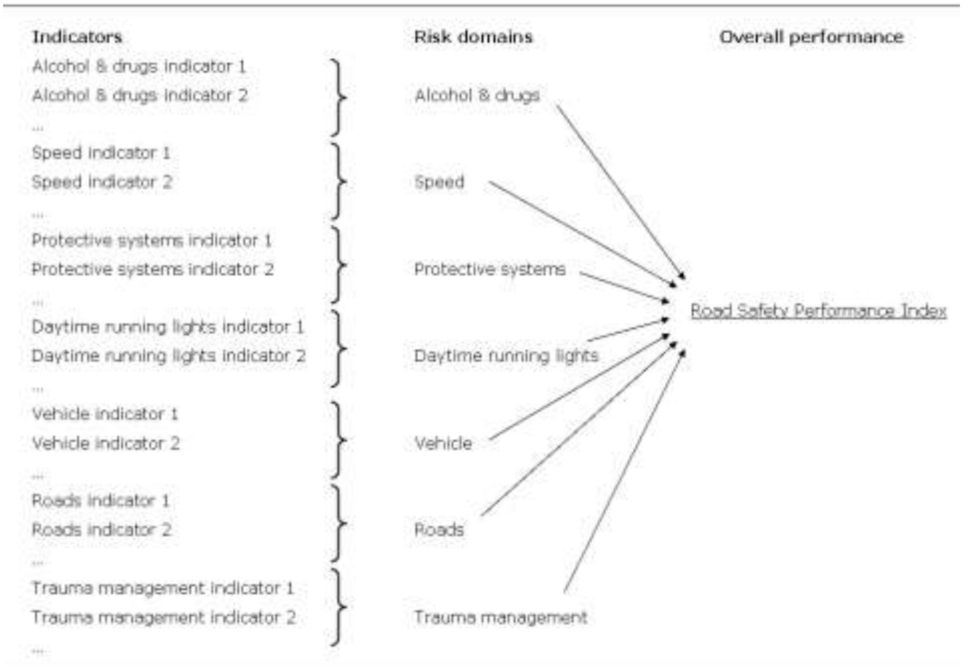


**Figure 7: Components of the road safety performance index**

This introductory section closes with an overview of the topics that will be handled in the remainder of this chapter. In the following section (4.2), some advantages and disadvantages of creating an index are discussed. Next, section 4.3 presents the methodology to construct a road safety index consisting of several individual indicators. First, the set of performance indicators to combine has to be decided on. The collection of indicator data as well as some univariate and multivariate analyses are topics of section 4.4. In section 4.5 we elaborate on the weighting and aggregating of indicators and discuss some common methods. Subsequently, we discuss the robustness of the index which can be assessed by means of an uncertainty and sensitivity analysis (section 4.6). The computation and evaluation of the final index values is the topic of section 4.7. The visualisation of the results is handled in section 4.8 and this chapter closes with the main conclusions regarding the road safety performance index (section 4.9).

## 4.2 Indexes versus indicators

In the indicator literature, a distinction can be made between aggregated indicators on the one hand (i.e. indexes or composite indicators) and non-aggregated indicators on the other hand (i.e. individual indicators). Two basic frameworks are available for aggregating indicators (Sharpe, 2004). The first one is a monetary framework in which variables are expressed in monetary terms first and then simply added (the gross domestic product is an example hereof). The second framework is the composite indicator approach in which domains represented by a set of indicators are combined using weights.

In Saisana and Tarantola (2002) and Tarantola et al. (2004) the main pros and cons of composite indicators are summarised. An index is characterised by the following advantages:

- It can summarise complex or multidimensional issues in view of supporting decision makers

- An index is easier to interpret than trying to find a trend in many separate indicators
- It facilitates the task of ranking countries on complex issues in a benchmarking exercise
- It can assess progress of countries on complex issues over time
- An index reduces the size of a set of indicators or includes more information within the existing size limit
- It places issues of country performance and progress at the centre of the policy arena
- It facilitates communication with the general public (i.e. citizens, media, etc) and promotes accountability

At the same time, the following disadvantages should be considered:

- An index may send misleading policy messages if it is poorly constructed or misinterpreted
- It may invite simplistic policy conclusions
- It may be misused, e.g. to support a desired policy if the construction process is not transparent and lacks sound statistical or conceptual principles
- The selection of indicators and weights could be the target of political challenge
- An index may disguise serious failings in some dimensions and increase the difficulty of identifying proper remedial action
- An index may lead to inappropriate policies if dimensions of performance that are difficult to measure are ignored

As the multidimensional road safety concept cannot be represented by one indicator, several relevant aspects are to be combined in an overall index. In case the methodological aggregation process is sound, transparent and clear the creation of an index over a set of indicators is worthwhile. Of course, the set of individual indicators provides an enormous amount of information. Nevertheless, as the different road safety risk aspects jointly affect the frequency and severity of accidents, it is valuable to study the set of indicators simultaneously and combine the information from several risk domains in one index.

The creation of indexes has largely progressed in recent years. Indexes developed in other domains and thereby using a particular methodology were studied as they are helpful in developing a sound road safety index. Some examples of composite indicators are the Internal Market Index 2004 (Tarantola et al., 2004); the European Innovation Scoreboard 2004 (European Commission, 2004b); 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 and Center for International Earth Science Information Network, 2005); the Index of Economic and Social Well-Being (Salzman, 2003); and the Meta-index of Sustainable Development (Cherchye and Kuosmanen, 2004).

The creation of a road safety performance index based on performance indicators is new. However, we will briefly elaborate on the road safety development index described in Al Haji (2003; 2005) as it is one of the rare studies dealing with this subject. In this study, nine dimensions are selected for explaining and predicting the accident situation in several countries: traffic risk, personal risk, health index, education index, vehicle safety index, roads situation index, road user behaviour, standard of living and urbanization. Notice that the human-vehicle-infrastructure decomposition is also used in this study. However, in our research, we study road safety performance indicators, situated on the level of intermediate outcomes in the target hierarchy (see Figure 1) and we consider traffic risk and personal risk as final outcomes and education, standard of living and urbanization as influencing factors but not performance indicators. Moreover, Al Haji compared the road safety situation and trends between ten Southeast Asian countries and Sweden and used a rather simplified methodology for combining the different dimensions. The methodology that we suggest for the road safety index is discussed in the next section.

## 4.3 Index methodology

The calculation of an index requires an extensive use of statistical modeling and analysis techniques. Since indexes have been and are still being developed in various research domains, several methodologies for combining indicators exist. In general, more or less the same issues are encountered: indicator selection, missing data treatment, normalisation, weighting, aggregation and performance testing. Other aspects can be added and the sequence of the different steps may change between studies. Based on a number of researches (Salzman, 2003; Nardo et al., 2004; Nardo et al., 2005b; Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006) we suggest the following steps for the creation of a composite road safety index.

1. <u>Developing the theoretical framework</u>: this first step involves the clear description of the phenomenon under study, the identification of the main underlying domains, paying attention to the interrelationships in a broader framework, listing possible indicators for each domain, evaluating indicators based on selection criteria (such as relevance and reliability) and obtaining a final set of best indicators.
2. <u>Collecting indicator data</u>: data need to be found for the indicators deduced in the theoretical framework. Ideally, time series data for the set of best needed indicators are easily accessible in reliable databases for numerous countries. However, in practice, a lack of reliable data and limited country coverage constrain the analysis. As the different risk domains require their own databases (i.e. one overall data source having information on all domains is nonexistent), indicator data from several sources need to be related to the same set of countries and the same time period.
3. <u>Univariate analysis</u>: based on the available indicator values, each indicator is studied separately. By means of basic summary statistics, an idea about the average indicator value and the degree of difference between the countries and/or over time can be obtained. Extreme values might need a closer look as they could become unintended benchmarks. Secondly, all data should be made comparable. This process is called normalisation. As the indicators might differ in magnitude, in the direction of their (expected) road safety impact, 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, proximity to target and ordinal responses. 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 imputation, regression imputation, expected maximisation imputation, nearest neighbour or multiple imputation.
4. <u>Multivariate analysis</u>: this step provides insight into the structure of the data set by studying the indicators simultaneously. Multivariate analyses are performed in order to find similarities and differences in performance between the countries. Moreover, a better understanding of the relationships between the indicators is obtained. The appropriateness of the data set for combination in an index is assessed by means of correlation analysis, principal components analysis, cluster analysis and regression analysis.
5. <u>Weighting</u>: the weight that is assigned to each indicator reflects its relative importance. 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 aggregation formula needs to be selected, i.e. the mathematical operation used for combining the indicators. 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. Arithmetic and multiplicative averaging can be tested as well as other aggregation operators.
7. Robustness testing: it is important to rigorously test the robustness of the index to the implicit and explicit assumptions and methodological choices made. The uncertainty in the final result with respect to the indicators included, the imputed missing values, the normalisation method chosen, the selected weighting technique and the applied aggregation formula can be quantified. Moreover, it can be indicated which factor implies the largest uncertainty and therefore requires additional research. This phase needs to be gone through several times until a satisfactory, robust index has been created.
8. Computing and evaluating final index scores: using the (imputed) normalised indicator data, the weights and the aggregation formula, an index score can be calculated for each country. By means of tests the final index scores could be compared to other related and published indicators or indexes.
9. Presenting the results: finally, the results should be visualised in a clear way. Rankings can be produced even as various types of graphs. The focus should be on the index scores, but the underlying indicators could be presented as well.

The theoretical framework (step 1) has been extensively described in chapter 3. The other methodological steps will be briefly discussed in the next sections. 'Section 4.4 Data preparation' relates to steps 2, 3 and 4; 'Section 4.5 Weighting and aggregating' handles steps 5 and 6; 'Section 4.6 Robustness testing' corresponds to step 7 and 'Section 4.7 Computation and evaluation of index scores' to step 8. Finally, step 9 is discussed in 'Section 4.8 Presentation of the results'.

## 4.4 Data preparation

Several steps in the index methodology relate to data. More specifically, for the set of indicators defined in the theoretical framework, data need to be collected (step 2), analysed in a univariate way (step 3) and by means of multivariate approaches (step 4). The three steps will be successively discussed.

### *4.4.1 Collecting data*

The road safety performance index will combine seven essential risk domains identified at the European level. Based on literature, a set of possible indicator candidates was obtained per risk domain (see section 3.5). An evaluation of these indicators using eight selection criteria resulted in a set of best needed as well as best available indicators (presented in section 3.6.4). For these indicators selected to be combined in the road safety performance index data need to be collected.

It is advisable to choose only data sets with sufficient coverage, data freshness and methodological consistency (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006). Moreover, the area of comparison should be assessed. In this respect, it is valuable to consider a particular region (e.g. Europe) with countries characterised by a similar level of motorisation and a comparable transport system. Nonetheless, a broader analysis on a worldwide scale would be interesting but possibly other indicators need to be considered then and data issues will play an even larger role. Beside a spatial boundary, the indicator data set will be limited in time. Because the concept of safety performance indicators is rather new no time series data are available for all indicators over some period of time. The most recent year for which all indicator data are available needs to be focused on. Progress towards postulated targets and relative success rates are to be studied in future research.

### *4.4.2 Univariate analysis*

#### 4.4.2.1 Summary statistics

Once the indicator data have been collected, some descriptive analysis will be performed for each indicator. Summary statistics can be presented, such as the mean, median, minimum, maximum, standard deviation and skewness. They will, in addition to a visual presentation of the data, provide insight into the range of values, the distribution of the values over the countries and depict which indicator shows most variability. Moreover, extreme values might become clear. One has to consider whether they represent real values or suspicious individual values that were erroneously entered into the data set. In the latter case, the data are subject to misunderstanding and may seriously distort final conclusions (Bird et al., 2005). Several statistical procedures aimed at detecting and dealing with outlier and aberrant observations exist. For example, the most extreme values may be equalized to the $5^{th}$ or $95^{th}$ percentile (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006).

#### 4.4.2.2 Normalisation

In theory, each indicator could be expressed in a different measurement unit and on a different scale. It is important to cancel out the differences in magnitude to ensure that no indicator dominates the final index score due to large raw values. Another objective of normalisation is to convey information about a country’s road safety performance in an easy-to-understand and meaningful way (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006). Furthermore, as we will compose one overall index based on several indicators, it is essential that all indicators point in the same direction. In other words, a high indicator value should always imply more (or less) accidents or casualties.

The normalisation method has to be chosen. From literature, several techniques can be selected, like ranking, standardisation, rescaling, distance to a reference, categorical scale, indicators above or below the mean, methods for cyclical indicators, percentage of annual differences over consecutive years, etc (Organisation for Economic Co-operation and Development, 2003; Nardo et al., 2005b). Each normalisation method may result in other index scores. In case a high, positive correlation exists between the differently normalised values, the results will not be influenced to a large extent by the normalisation method chosen. In general, the normalisation method should take the data properties as well as the objectives of the composite indicator into account (Pennoni et al., 2005).

#### 4.4.2.3 Missing values

After describing each indicator by some statistics and applying a normalisation technique, an unequal number of observations per indicator is handled next. In order to make a fair comparison, in which as many countries as possible are considered, we might come across some missing values. In case only a small share of the indicator information for a particular country is missing, imputed values could be used, thereby enlarging the data set. Nevertheless, missing data cause extra uncertainty in the index.

Several statistical methods exist for imputing missing values, each making some assumptions about the missing patterns (see Nardo et al., 2005b). Contrary to case deletion, single imputation and multiple imputation techniques consider the missing data as part of the analysis and try to come up with a realistic approximation to obtain a complete data set. In contrast with single imputation, several (more than one) values for each missing value are provided in case of multiple imputation, thereby better representing the uncertainty due to incomplete information. In the handbook on constructing composite indicators (Nardo et al., 2005b) the following imputation methods are suggested: mean/median/mode substitution, regression imputation, hot- and cold-deck imputation, expectation-maximisation imputation and Markov Chain Monte Carlo multiple imputation. Applying these methods requires knowledge and careful consideration of the strengths and weaknesses of the various techniques in light of the available data (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006).

### *4.4.3 Multivariate analysis*

The final data related step involves performing multivariate analyses on the whole indicator data set. The following multivariate analyses can be performed to gain insight into the structure of the data set: correlation analysis, principal components analysis, cluster analysis and regression analysis. Each topic is discussed below.

#### 4.4.3.1 Correlation analysis

A first multivariate analysis is based on correlations. Correlation coefficients for each pair of indicators are computed. Based on that information two indicators having a high correlation coefficient can be identified meaning they are partly showing the same aspect of the phenomenon under study (Nardo et al., 2004).

In addition, Cronbach coefficient alpha can be computed, i.e. the most common estimate of internal consistency of items in a model or survey (Nardo et al., 2005b). It measures the portion of total variability in the sample of indicators due to the correlation of the indicators. In case there is no correlation this alpha equals zero, while value one is obtained in case of perfect correlation between the indicators. A high value of alpha implies that the indicators are measuring the same underlying construct (Nardo et al., 2005b).

#### 4.4.3.2 Principal components analysis

Principal components analysis is a useful tool when investigating the relationships between the indicators. The goal of this type of analysis is to reveal how different indicators change in relation to each other and how they are associated (Nardo et al., 2005b). The indicators are grouped in a few principal components explaining a large part of the variance in the data. The optimal number of principal components can be deduced from the output. Moreover, a rotation of the components can enhance the interpretability as each indicator loading will be maximized on only one component. That way, insight is gained into the grouping of indicators.

#### 4.4.3.3 Cluster analysis

Beside grouping indicators by means of principal components analysis, clusters of countries can be identified. Cluster analysis refers to a rich collection of statistical classification methods used to determine similarities (or dissimilarities) of subjects in large data sets (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006). A hierarchical clustering method can be applied first from which an optimal number of classes can be dermined resulting in both a relatively small number of classes and a high level of similarity. This number of classes can subsequently be used in a non-hierarchical clustering method (e.g. *k*-means clustering) to obtain a classification of countries in homogeneous groups with a low within-variance and a high between-variance. Not only does this analysis provide information on the grouping of similarly performing countries, the cluster centres on each indicator can be plotted, thereby showing the main differences between several classes of countries. A cluster analysis can highlight good and bas aspects of each class.

Moreover, within each class, countries have a better basis for benchmarking their road safety performance as the group members are similar with respect to the data used to classify them (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006).

#### 4.4.3.4 Regression analysis

Subsequently, a regression analysis provides interesting information. Each safety performance indicator can be seen as an explanatory variable and for the road safety case, the number of fatalities per million inhabitants can be used as dependent variable. In case high indicator values represent good performance, the coefficients of the explanatory variables are assumed to be negative. The magnitude of the coefficients reveals the degree of importance while the goodness of fit value indicates the explanatory power of the indicator set.

#### 4.4.3.5 Concluding remarks

The main aim of performing multivariate analyses is to assess the appropriateness of the indicator data set and gaining insight into its structure. In addition, other road safety related variables could be involved in the multivariate analyses. In case data are available for the countries considered in the index study, these variables can be used as well. In fact, the following factors are believed to explain the difference in road safety between countries to some extent: demographic variables (e.g. population density, percentage of 15-24 years old, percentage of urban population), economic variables (e.g. percentage of unemployed population), geographic variables (e.g. location within Europe, number of wintry days), transport or mobility variables (e.g. share of passenger kilometres per transport mode), road safety outcomes (e.g. number of fatalities per transport mode or age class) and variables related to transport policy (e.g. legal alcohol and speed limit).

Finally, multivariate techniques such as correlation analysis and regression analysis can be useful in terms of indicator selection as well. For example, to select a limited number of speed indicators from a larger set of appropriate candidates, the indicator that turns out to be significant with respect to the dependent variable and that has a low correlation coefficient with the other speed indicators should be preferred. In the end, the set of indicators needs to be statistically balanced. Based on the results of the multivariate analyses, the selection of other indicators may be required. Selecting new indicators is justifiable as long as they fit within the theoretical framework.

## 4.5 Weighting and aggregating

The indicators are combined in an index by assigning a weight to each indicator and applying an aggregation method. In literature, several weighting and aggregation methods exist, none of them being the best technique to use in all circumstances. First, we determine weighting methods most often used in the construction of an index and valuable for the road safety context. Section 4.5.2 discusses the options related to aggregation.

### *4.5.1 Weighting methods*

By studying other indexes we obtain an idea about the most popular weighting methods. The e-business index 2003 (Nardo et al., 2004) explored three weighting schemes, namely equal weighting, budget allocation (qualitative method) and factor analysis (quantitative method). Al Haji (2005) used simple equal average, a principal components analysis, an assessment technique from experts’ opinions and an assessment technique from literature and theory review. Other examples can be found in Saisana and Tarantola (2002). In fact, it is common practice to experiment with various weighting techniques and compare the results. Nevertheless, the reasoning behind the choice of a particular weighting technique is often lacking in a study and simpler methods are more commonly applied than complex ones. In Booysen (2002) it is concluded that no weighting system is above criticism. Therefore, a thorough evaluation of the most relevant weighting methods for the topic under study is essential. In general, weights can be chosen to be equal, can be determined statistically, can involve the opinion of persons (e.g. experts) or can be optimized. Below, five common weighting methods – equal weighting, weights based on factor analysis, budget allocation, analytic hierarchy process and data envelopment analysis – are briefly explained.

- equal weighting: assigning the same weight to each indicator is the most simple method. This is the main reason why it is commonly used in indexes. Salzman (2003) states that this method reduces the subjectivity of weights, has an interpretive meaning and is transparent. On the other hand, the importance of an indicator is not reflected by its weight and there is a risk of double counting (Nardo et al., 2005b).
- weights based on factor analysis: factor analysis is a technique which can also be used to determine weights. More specifically, weights consist of the factor loadings of each indicator (after rotation) and the variance explained. Indicators with a strong capacity of explaining the variation in the data are expected to receive a relatively high weight (Pennoni et al., 2005).
- budget allocation: a group of experts is asked to allocate a budget of *N* points over the set of indicators, where more important indicators should receive a higher share of the budget. The share of the budget assigned to an indicator equals its weight. To obtain good results, a team of qualified experts needs to be found. The weights resulting from a particular expert could be considered for the analysis as well as a set of weights representing the opinion of all experts.
- analytic hierarchy process: this method uses experts' opinions as well. Each indicator is compared to another indicator and the expert decides which of the two is more contributing to the overall goal and indicates the intensity of the strength (Saaty, 1980). In case two indicators are considered to have the same contribution to road safety, a score of one is given whereas an extreme difference in contribution results in a score of nine. All scores are then transformed in weights, summing up to one.
- data envelopment analysis: in this case, the weights are endogenously determined from the data set as to obtain the best possible index score for a country. This means that higher weights are attached to the domains on which a country performs relatively well (Cherchye and Kuosmanen, 2004). Moreover, restrictions regarding the share of each indicator in the overall index score can be incorporated in the optimization problem to obtain more realistic weights. This method can result in optimal country-specific weights as well as one set of indicator weights that is the same for each country (like other weighting methods do).

For the road safety index, the advantages and disadvantages of the five previously described methods are worthwhile investigating. Each technique requires a profound examination.

### *4.5.2 Aggregation methods*

As is the case for weighting, aggregation is a potential area of methodological controversy in the field of composite indicator construction (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006). Various types of aggregators exist of which the selection should fit the purpose of the study and the subject being measured. In the handbook on constructing composite indicators (Nardo et al., 2005b) three aggregation methods are mentioned. Additive or linear aggregation sums the weighted indicators. Secondly, the non-compensatory multi-criteria approach guarantees the interpretation of weights as importance coefficients. This aggregation involves the creation of an outranking matrix.

Thirdly, geometric aggregation implies that the index is the product of its indicators to the power of their weights. Linear aggregation is the best-known way of aggregating. However, the suitability of this type of aggregation has been questioned (see e.g. Munda and Nardo, 2005).

Apart from the three aggregation types suggested for creating an index, aggregation is a very extensive research domain in which numerous types of operators exist. They are all characterized by certain mathematical properties and aggregate in a different manner. In general, aggregation operators can be roughly divided into three classes (Grabisch et al., 1999): conjunctive operators (AND), disjunctive operators (OR) and averaging operators. The third class possesses interesting properties and consists of mean operators, ordered weighted averaging (OWA) operators, fuzzy integrals, etc. Of these operators, OWA is an often used and comprehensible class of operators that is worthwhile testing. The attitude of decision makers in terms of the allowed degree of compensation between good and bad values can be reflected (Yager, 1996). That way, road safety professionals can express their aggregation policy in natural language (e.g. in case a country scores badly on more than a few indicators, its final road safety index score should be small). This guideline is then translated mathematically and index scores respecting the statements can be computed. By changing the parameters OWA can generate a wide spectrum of policy scenarios.

## 4.6 Robustness testing

So far, a number of steps in the methodological process of the creation of an index have been described. In the end, we want to develop a scientifically correct and acceptable road safety performance index. In this respect, justification of the methodological choices involved in the process and quantification of the impact of certain subjective decisions on the end result are of major importance. As can be intuited, a different method causes other outcomes. 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 during the index construction process. Methodological gaps or weaknesses in the design and creation of an index can lead to simplistic or misleading conclusions (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006). Furthermore, as the number of different methods in the various (e.g. normalisation, weighting and aggregation) steps of the index process is substantial, the end result can be manipulated relatively easy. Therefore, available methods should be thoroughly evaluated, the most justifiable methods related to the context applied to the data set and the robustness of the composite indicator assessed by means of a combination of uncertainty and sensitivity analyses.

Even though numerous composite indicators are developed in several domains, an uncertainty and sensitivity analysis accompanies only a small part of these indexes. However, the iterative use of uncertainty and sensitivity analysis contributes to the well-structuring 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 (Nardo et al., 2005a). A comprehensive description of uncertainty analysis and sensitivity analysis, applied to the technology achievement index is given in Saisana et al. (2005). 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. 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. In their handbook, Saltelli et al. (2007) present a step-by-step plan for performing a sensitivity analysis on a model.

Generally, the following questions can be answered by testing the robustness (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network, 2006):

- how do the ranks under alternative methodological scenarios relate?
- which methodological step accounts for the largest variability in the ranking?
- which countries have the most volatile ranks and why?
- what is the optimal set of methodological assumptions for a country?
- which are the confidence intervals for the country scores and ranks?
- by how much would the uncertainty in the index be reduced if a particular source of uncertainty could be removed?

As in other studies (e.g. Nardo et al., 2004) it would be interesting to observe through simulation how much the countries' ranking is affected by the chosen set of indicators to get an idea about the degree of sensitivity of the index with respect to each basic component. In case a data set is characterized by some missing values, the impact of the imputed values on the end result could be quantified. The same applies to the set of weights used in the construction of the index.

Although robustness testing is discussed as one of the last steps, it is important to note that this step is required several times as the iterative use of uncertainty and sensitivity analysis during the development of a composite indicator helps improving its structure. Ideally, all potential sources of uncertainty should be tackled: the inclusion and exclusion of indicators, the imputation technique, alternative normalisation schemes, different weighting methods and various aggregators. In case country ranks with unacceptably large uncertainty bounds are reported and this appears to be due to a large uncertainty in the weighting step, further research aimed at reducing this uncertainty is required. When a smaller set of relevant weighting techniques has been obtained (e.g. from a detailed evaluation study), the uncertainty and sensitivity analysis is performed again, possibly still leading to a too large uncertainty and requiring further research in another methodological aspect. Therefore, this step needs to be gone through every time a change in one of the previous steps occurred, until the index is robust enough. It is essential that the final index scores are only limitedly influenced by the methodological decisions taken during the index process.

## 4.7 Computation and evaluation of index scores

We reached the eighth step of the index methodology now. In the previous steps, the indicators to combine were identified, data collected, analysed in a univariate and multivariate way and weighted and aggregated. Moreover, the impact of several methodological choices on the end result is quantified. In case a robust index is obtained, the final index can be constructed and evaluated by means of some tests. More specifically, the final index scores can be computed and related to other index or variable values. In fact, the explanatory power of a composite indicator can be tested by means of these links (Nardo et al., 2005b). A high level of correlation indicates that the variation in the two data sets is similar. The intensity of the relationship between the road safety performance index and other indexes such as the corruption perceptions index (Lambsdorff, 2004), a cultural index (Hofstede, 1980; 2000) or a final road safety outcome index could be assessed.

## 4.8 Presentation of the results

Composite indicators should be able to quickly and accurately communicate a picture to decision makers and other end users (Nardo et al., 2005b). The previous steps in the methodology require a lot of research, resulting in a final road safety performance index score for each country. In case no clear presentation of the results is offered, all previous efforts will not attain full use. Several types of graphs can present the index values as well as the original indicator values.

There are interesting ways to display composite indicators, from simple tabular tools to more complicated multidimensional graphs and interactive software (Nardo et al., 2005b). For illustrative purposes, several ways of presentation used in other sources will be given below. While elaborating the road safety index, the most optimal type of visualisation needs to be determined. In this respect, the simplest mode of presentation that avoids being misleading and that is in accordance with the research objectives needs to be chosen (Bird et al., 2005). More specifically, presenting performance indicator or index data intended for public release should have intuitive appeal. Indications of variability such as confidence or uncertainty intervals may involve some statistical complexity in their determination but are usually adequately represented in a simple way. Furthermore, in case the results are for immediate action or discussion graphical methods are typically best; in case further analysis and comparison is involved a table may be preferred. When indicator or index data are plotted over time, the evolution can be shown. In addition, targets set for the future or the performance of benchmarks (i.e. best performing countries) could be indicated on the graph as well as warning lines providing signals for urgent action.

One of the most common ways of presenting information is by means of bar charts (see Figure 2). As the values are presented in increasing or decreasing order, the best, average and worst performing countries can be easily detected. In case we focus on the relative performance of one country with respect to a set of indicators, charts in which the indicator values corresponding to that country are connected are appealing. This is illustrated in Figure 8. Based on Figure 9, the strengths and weaknesses of each country can be easily seen as the bar charts indicate the performance on a normalised scale. Figure 10 presents an overall bar chart for the index as the bars of the 7 underlying dimensions of the commitment to development index are added together.

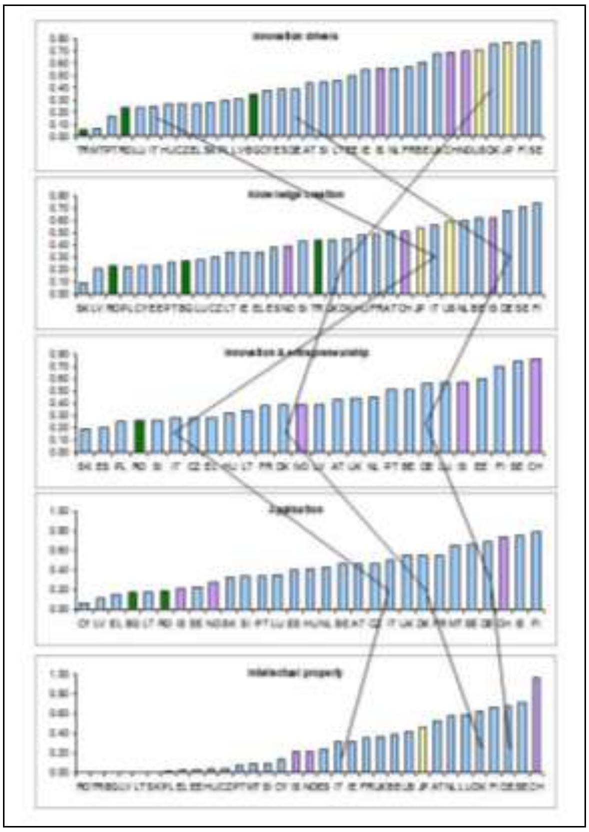

**Figure 8: Bar charts for 5 dimensions of European innovation performance (Dupont, 2005)**

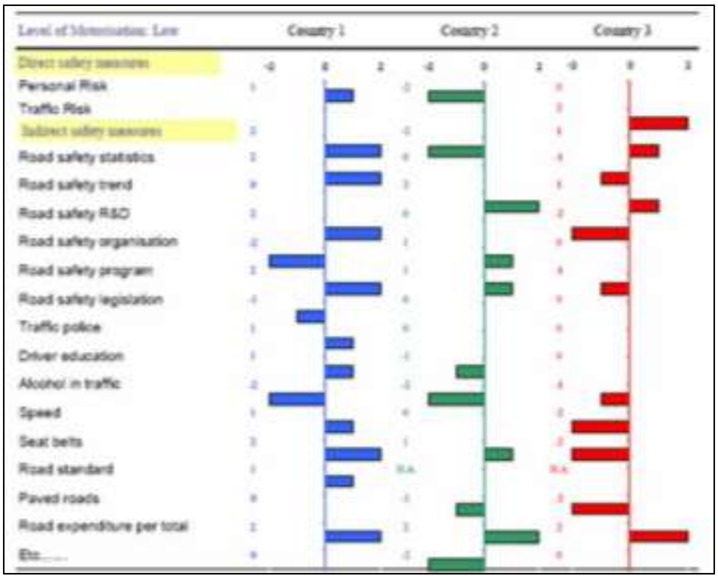


**Figure 9: Normalised bar charts for road safety dimensions (Asp and Rumar, 2001 in Al Haji, 2005)**

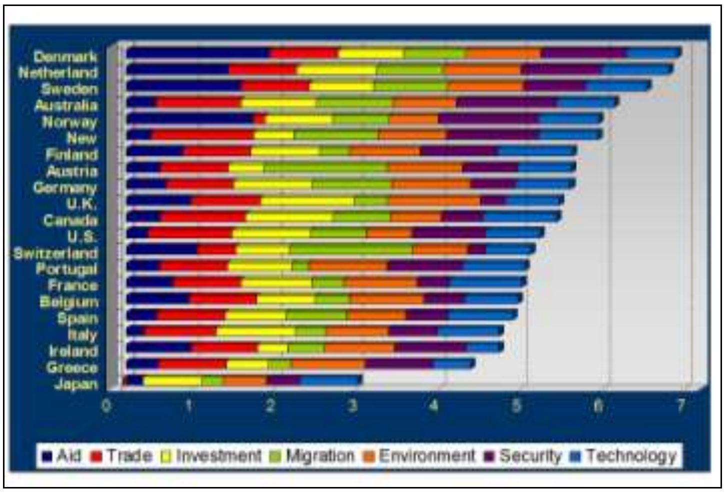


**Figure 10: Overall bar chart of the commitment to development index (Roodman, 2005)**

Spider diagrams or radar charts are a second group of interesting graphs. They can be used for presenting information on several factors related to one item (e.g. percentage of road fatalities per transport mode or age class; protective systems wearing rate for seat belts, helmets and child's seats; different dimensions of the overall index; etc). Spider diagrams have multiple axes along which all the variables can be plotted, as can be seen in Figure 11 (another example can be found in Morsink et al., 2007). Each variable is normalised between 0 and 100. In general, higher values, i.e. points near the edge, indicate good performance. To keep a clear overview the countries in the data set are often divided in several subgroups in order to visualise the performance of a few countries with respect to each other or to the average of all countries.

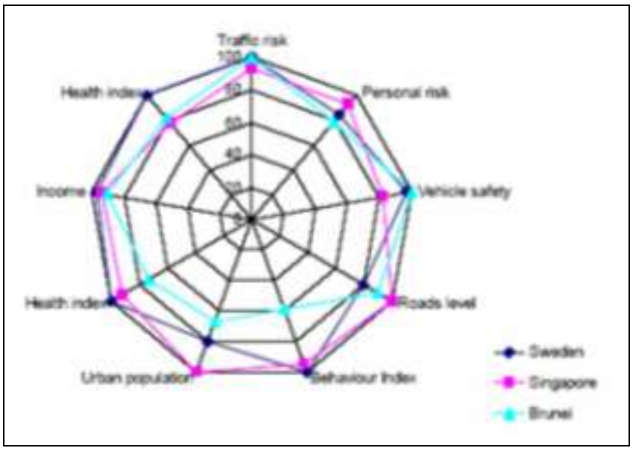


**Figure 11: Spider diagram with 9 dimensions of the road safety development index (Al Haji, 2005)**

The following graph shows the ranking of countries based on their technology achievement index score, starting on the left with the best performing country. As stated before, the amount of uncertainty linked to each position in the ranking should be provided to the end user as well. In Figure 12, 23 countries are shown with their light grey marked score on the original technology achievement index (2001), the median (black mark) and the corresponding 5$^{th}$ and 95$^{th}$ percentiles. It can be seen that under other methodological assumptions, countries like Singapore or Norway could obtain a totally different position in the ranking.

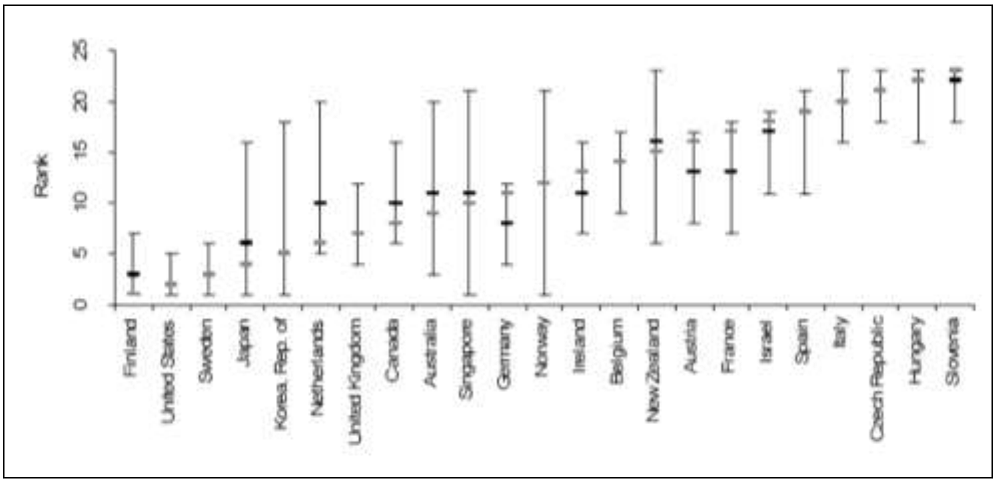


**Figure 12: Ranking of countries based on the technology achievement index (Nardo et al., 2005b)**

Next, presenting the performance of a country on two axes, the graph surface is divided into four quadrants. In Figure 13, countries are positioned on their summary innovation index score (Y-axis) in relation to the average growth rate (X-axis). Countries in the upper right quadrant are doing best as they are moving ahead. On the contrary, countries in the lower left quadrant score badly on both dimensions, thereby falling further behind. The upper left quadrant countries are losing momentum while the lower right quadrant countries are catching up. This information can also be visualised by means of a coloured map enabling the end user to see at a glance how a country is performing (Figure 14 & Figure 15).

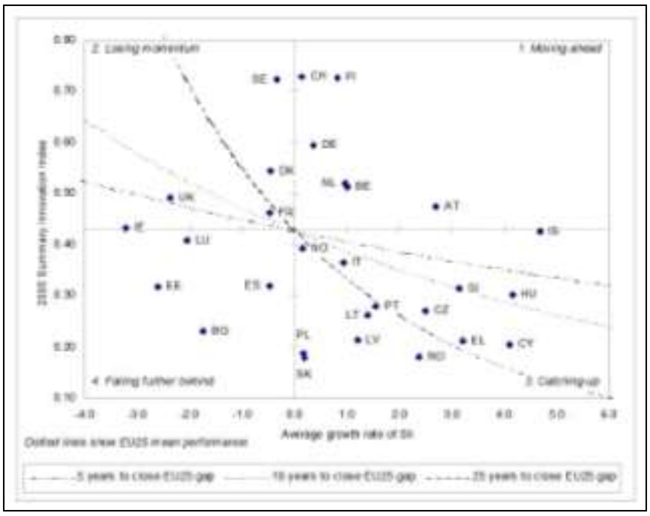


**Figure 13: Four-quadrant graph for European innovation performance (Dupont, 2005)**


**Figure 14: Coloured map for European innovation performance (Dupont, 2005)**

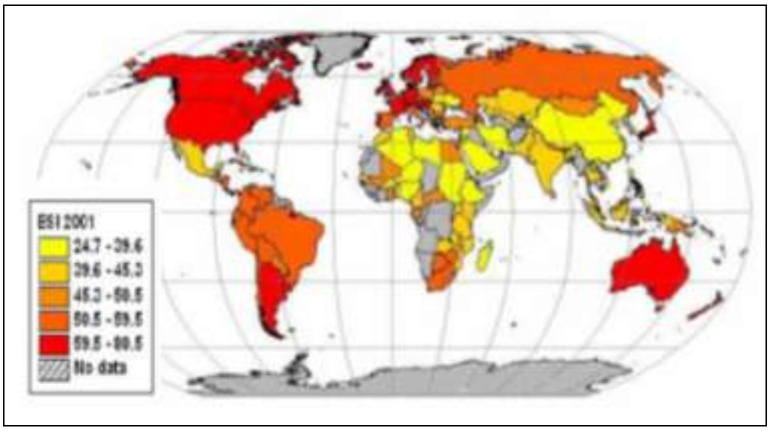


**Figure 15: Coloured map for the environmental sustainability index (Yale, 2005)**

The above graphs are useful tools for presenting road safety index outcomes. Although relevant road safety risk information is combined in one score, the decomposition in individual indicators might be of interest to some end users as well. The road safety index visualisation aims to indicate the relative performance of countries, the leaders and laggards. A (e.g. spider) diagram showing the performance of a country and its benchmark is useful to get insight in the risk factors needing urgent action. A more detailed look into the policies and practices of the benchmark can provide useful inspiration (see e.g. SUPREME, 2007). Moreover, it would be worthwhile visualising changes in road safety performance over time.

## 4.9 Conclusion

Creating a scientifically correct and valuable road safety index for monitoring and comparing road safety performance across countries (and over time) is a methodologically intensive process that needs considerable thought. In this chapter, the methodological process for constructing a road safety performance index has been discussed. Apart from studying indicators separately, an index combining relevant risk information in one score and thereby presenting the overall picture is a valuable tool for road safety policymakers and other end users. However, one can only benefit from an index if a sound, transparent and clear methodology is used for its development. The methodological process consists of several steps, which in fact are all research domains in itself. The theoretical framework should be developed, indicator data collected, univariate analysis performed, multivariate analysis performed, the issue of weighting handled, even as the issue of aggregation, the robustness tested, the final index scores computed and evaluated and the results presented.

The necessary theoretical basis for creating a road safety performance index is given in this chapter. An illustration of the methodology using real indicator data is outside the scope of the current report. In future research, a thorough evaluation of the different methodological steps is needed. From literature, possible (e.g. weighting) methods relevant for the road safety case could be identified. These methods should be evaluated, i.e. identifying the advantages, disadvantages, requirements and results of applying that particular method. Moreover, the methodological process is a continuous one that needs frequent updates as new methods may be worthwhile testing for the road safety case.

# 5 CONCLUSIONS

This report deals with road safety performance indicators. Three main objectives are postulated. First, to introduce the concept of road safety performance indicators. This involves summarising essential information on indicators in general and road safety performance indicators in particular. Second, to develop a set of (best needed and best available) safety performance indicators. The selection of these indicators results from the elaboration of the theoretical framework. Third, to describe the methodology behind the creation of an overall road safety index in which all indicator information is combined.

Indicators are tools for monitoring the status of a certain phenomenon. They express scientific knowledge in an understandable and relevant manner. Indicators can be used in a number of ways, such as measuring relative performance, drawing attention to problems, identifying trends, assessing the impact of policy measures as well as target and priority setting. From this, the value of indicators for the road safety domain becomes clear. In the road safety target hierarchy the essential elements of the safety management system are presented: social cost; number of killed and injured (final outcomes); safety performance indicators (intermediate outcomes); safety measures and programmes (policy output); and structure and culture (policy input). A road safety performance indicator can be seen as a measurement causally related to traffic accidents or casualties indicating the safety performance and offering a better understanding in the process leading to accidents. Safety performance indicators offer new insights to the road safety community. They allow benchmarking on a more detailed (and relevant) level and can reflect and prioritize main problem areas (e.g. speed). They enable taking necessary actions before the problem becomes visible in an increased number of accidents and casualties.

The road safety performance of a set of countries can be compared by means of an appropriate set of performance indicators. The selection of this indicator set results from the elaboration of the theoretical framework which involves the following tasks. First, the phenomenon that is studied should be clearly defined. As road safety is a multidimensional problem, better insight is gained in case this problem is decomposed into several components. From literature, some relevant classifications can be obtained, such as the human-vehicle-infrastructure decomposition or the exposure-accident risk-injury risk decomposition. Next, the main components or so-called road safety risk domains agreed upon on the European level are determined, i.e. alcohol and drugs, speed, protective systems, daytime running lights, vehicle, roads and trauma management. The DPSEAIEA framework (driving forces-pressure-state-exposure–accident risk-injury risk-effects-actions) for modeling the causal chain of road safety effects as well as the existing linkages between the seven risk domains are described in order to enhance the understanding of the overall concept. Next, possible indicator candidates for assessing the safety performance in each risk domain are identified from relevant literature sources. Due to collection costs and other practical limitations, only appropriate indicators should be selected. Therefore, it needs to be decided which criteria a good indicator should meet. Each indicator candidate is evaluated in terms of relevance, measurability, interpretability, data availability, reliability, comparability, specificity and sensitivity.

Following the discussion of road safety (performance) data availability and quality in Europe, a distinction between best needed indicators on the one hand and best available indicators on the other hand is useful in this case. A best needed indicator refers to an ideal indicator for which the concepts, definitions or data do not yet exist, for which data exist, but the quality is poor, unknown or does not allow publication or for which cross-country comparability is limited. A best available indicator is an indicator which can act as proxy for a best needed indicator and for which the available data are of sufficient quality. To assure the creation and collection of necessary data for supporting road safety policymaking in a longer time perspective, the following set has been identified as best needed road safety performance indicators:

- the percentage of drivers with an alcohol concentration above the legal limit
- the average (free flow) speed per road type and vehicle type during daytime and at night
- the variation in speed per road type and vehicle type
- the seat belt wearing rate in front and rear sets of cars and vans, busses and trucks
- the (correct) usage rate of child's seats
- the helmet wearing rate of motorcyclists and moped riders
- the usage rate of daytime running lights per road type and vehicle type
- the age distribution of the vehicle fleet
- the percentage of road length with a wide median or median barrier
- the percentage of road length with a wide obstacle-free zone or roadside barrier
- the average arrival time of emergency medical services at the accident scene
- the share of road casualties who died during hospitalisation

The evaluation of the indicator candidates revealed that the unavailability of reliable and comparable data restricts the best available indicator set to some extent. For the seven risk domains the currently best available indicator has been listed below.

- the percentage of surveyed car drivers disrespecting the alcohol limit
- the percentage of surveyed car drivers exceeding the speed limit on various road types
- the seat belt wearing rate of occupants in the front seats of a car or van
- the existence of a law – fully or partially – obligating the use of daytime running lights
- the share of the fleet of passenger cars per age class
- the motorway density
- the expenditure on health care as share of the gross domestic product

A comparison of country-specific values of each indicator separately could provide insight into the relative safety performance of a country and best-in-class countries with respect to a certain road safety aspect. However, in case a large number of performance indicators is available, some summarization is valuable. In other words, one overall road safety performance index score in which all indicator values are combined can be developed for each country. That way, information from all risk domains is studied at once. The development of indexes in research domains such as economy and sustainability is very popular. The road safety field could also benefit from a safety performance index as it can be a valuable tool for policymakers and other end users. The advantages of summarising a complex phenomenon in terms of policy and communication purposes (e.g. a ranking of countries based on a summary of relevant performance indicators instead of only the number of fatalities) counterbalance the disadvantages (such as misleading or simplistic policy conclusions) if a sound, transparent and clear methodology is used for developing the index. The methodology for creating an index – generally consisting of indicator selection, data preparation, weighting and aggregating, robustness testing, computing, evaluating and visualising the final scores – is indicated thereby briefly describing often used methods applied in other indexes which are probably relevant for the road safety case.

Based on this research, we conclude that road safety performance indicators on the one hand and a road safety performance index on the other hand are new but at the same time promising concepts. This report presented basic information on these topics. More specifically, essential concepts and indicator frameworks from literature have been described; the theoretical framework offered new information in terms of road safety decomposition, interrelationships, possible indicators, selection criteria and resulted in a set of best needed and a set of best available road safety performance indicators. In addition, the advantages of a combined index have been indicated, even as the resulting methodological challenges in terms of univariate analysis, multivariate techniques, weighting, aggregation, robustness testing, evaluation and visualisation. It should be noted that the final index results are influenced to a large extent by the set of indicator values used to create the performance index. In order to develop a valuable road safety performance index, the methodology as well as the data issue need future consideration.

The urgent need to improve the availability and quality of road safety performance indicator data cannot be overemphasized. In case the main road safety risk domains are captured by a set of best indicators which are correctly measured at regular intervals, useful policy information in terms of monitoring, evaluation and communication becomes available. The relative safety performance of subjects such as countries may be studied over time and with respect to other countries and regions. In practice, problems regarding the set of subjects and the period (or year) for which data are available, the indicator definition and the measurement method occur. Therefore, significant progress could be made in case all European member states would follow the same (best practice) guidelines (see the manual on safety performance indicators by Hakkert and Gitelman, 2007).

Further research is needed before we will be able to monitor road safety performance by this index. In the near future, data for the set of best available road safety performance indicators need to be collected for a large set of European countries and with respect to the most recent year. Univariate and multivariate analyses on the indicator data set are then to be applied followed by the issue of weighting and aggregating. The robustness of the index with respect to the different assumptions and choices can be assessed next. Finally, the final road safety performance index scores should be evaluated and presented. Based on the index scores, the relative rank of a country compared to other European countries in terms of road safety performance can be determined. Contrary to the traditional road safety research, this score takes several risk aspects into account. Furthermore, benchmark countries can be found serving as examples to follow. Indicator as well as index targets can be set and the progress can be monitored in case indicator data are collected in a systematic way.

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# 7 APPENDIX

## 7.1 Appendix I: Illustration of an indicator card

**1. Name: Percentage of persons wearing a seat belt in the front seats of a car or van**

1.1) Domain: protective systems

1.2) Description and context: the seat belt wearing rate of drivers and occupants in front of a car or van is determined. The indicator value is the share of persons wearing their seat belt in the total number of persons examined

1.3) Measurement unit: percentage

**2. Position in the general framework**

Protective systems in general can be seen as an injury risk factor since wearing a seat belt affects the degree of injury in an accident to some degree (e.g. World Health Organization, 2004). The effectiveness of seat belts depends on a number of factors such as the impact speed, the type of collision and the position of the occupant (Elvik and Vaa, 2004). In addition, risk compensation could occur implying that the driver (or occupant) accepts a higher level of risk (e.g. a higher speed) because (s)he feels more safe (see e.g. Gaudry and Lassarre, 2000).

**3. Policy relevance**

3.1) Applicability or relevance: seat belt wearing in front seats is compulsory in almost all countries. Measuring the wearing rate in practice is of relevance.

3.2) Link with other indicators: a positive correlation with the wearing rate in the rear seats of a car or a van can be expected, even as with the child's seat use. Furthermore, there may be a link with indicators from other risk domains, for example the age distribution of the car fleet.

3.3) Objective and values to aim at: the Federal Commission for road safety in Belgium instructs to increase the current seat belt objectives in order to obtain a seat belt rate similar to that of the best performing countries in Europe by 2010 (Federale Commissie voor de Verkeersveiligheid, 2007). The target figure for Belgium by 2010 is 95%. By means of various measures – such as campaigns focusing on the favourable effects or a higher level of enforcement – a lot of progress is possible.

3.4) Regulation: for Belgium, article 35 in the traffic regulations (www.wegcode.be) obligates the driver and passengers of cars and other motor vehicles participating in traffic to wear seat belts on the seats equipped with them. More specifically, seat belt wearing in front seats is compulsory since June 1975.

**4. Methodological description**

4.1) Measurement method: by means of observation the seat belt use of all persons in front of a car or van passing by the observation point will be assessed. In advance, the total number of vehicles to check needs to be determined even as the locations and times of observation. It is essential that these moments and locations are chosen randomly in order to obtain results that are representative for the entire population.

4.2) Data needed, collection frequency, source: the indicator value can be computed in case two figures are available, being the total number of observed persons and the number of persons wearing their seat belt. Under the authority of the Belgian road safety institute observational seat belt wearing studies are carried out in Belgium every year during May since 2003.

Drivers and passengers in the front seats of passenger cars are observed at 150 different locations selected according to region, speed limit and points in time (on a weekday at rush hour, on a weekday outside of rush hour, on a weeknight and during the weekend both day and night) (Godart, 2006).

4.3) Limitations: at locations characterized by high speeds and large intensities, it is impossible to assess the wearing rate of all persons passing by. Clear agreements are needed then. Furthermore, in Belgium about 25,000 passenger cars are currently observed (Godart, 2006) whereas the Federal Commission for road safety instructs to yearly check the occupants of at least 1,800,000 cars (i.e. one vehicle out of three) (Federale Commissie voor de Verkeersveiligheid, 2007).

4.4) Alternatives: applying the same measurement method in several time periods allows studying the evolution over time. A comparison with other countries is also relevant. In accordance with the European recommendations at least three integrated control actions need to be organised, each lasting two weeks (Federale Commissie voor de Verkeersveiligheid, 2007). In this respect, the guidelines for seat belt wearing measurement specified in the manual of SafetyNet (Hakkert and Gitelman, 2007) could be helpful.

**5. Assessment of the Safety Performance Indicator**

5.1) Relevant/valid: the indicator can be associated with a specific performance target and is action-oriented. Moreover, the indicator value provides a good picture of the protective systems domain.

5.2) Measurable: the indicator is computed as the ratio of two figures and thus quantifiable. In addition, the wearing rate can be measured in an objective way.

5.3) Understandable: the indicator has a clear interpretation and is defined in an understandable way.

5.4) Available data: assessing the wearing rates in front of a car or van is common in a number of countries implying an indicator value for a large set of countries. Moreover, the indicator can be updated on a regular basis and the data become available within an acceptable term and at a reasonable cost.

5.5) Reliable: the indicator values for Belgium are gathered using a scientific measurement method. However, the representativeness of the data could still be enhanced. Moreover, at this point, each country is collecting some data of which the reliability is difficult to assess.

5.6) Comparable/coherent: more or less the same definition is used for this indicator in most countries and over time. Therefore, some comparison is possible.

5.7) Specific: the indicator focuses on persons in front of a car or van and is characterised by a useful level of detail. A further division in specific road types could be valuable as well.

5.8) Sensitive: the indicator is sensitive enough; another indicator value implies a change in risk.

**6. Evolution of the Safety Performance Indicator**

The seat belt wearing rate of drivers and passengers in front of passenger cars in Belgium from 2003 onwards is shown in the graph below. Detailed wearing rates are also available, for example per maximum speed limit or region but here the overall figures are presented. Figure 16 shows an increase in the frontal seat belt wearing rate of cars in Belgium over the years 2003-2006. In case the target figures are met in the future, the percentage of persons wearing their seat belt in front of a car will approximate the level of 95% by 2010.

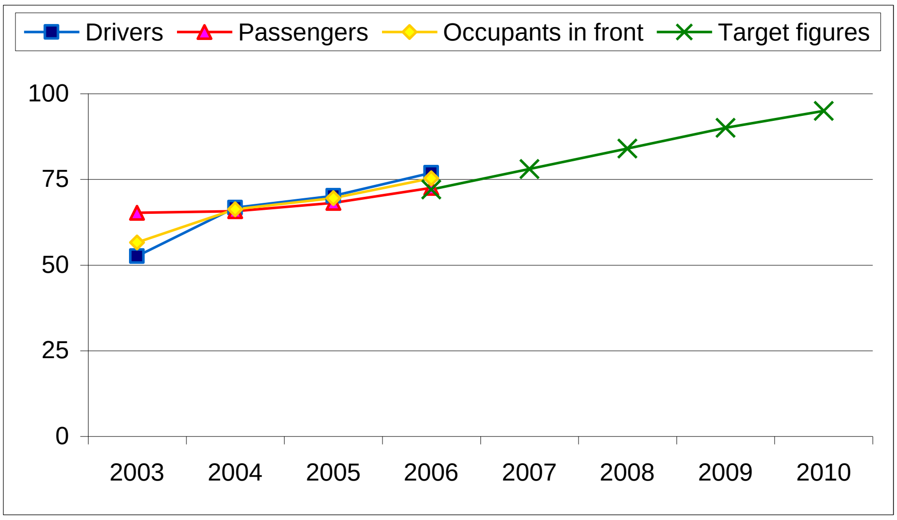


**Figure 16: Seat belt wearing rate in the front seats of cars in Belgium (2003-2006) and target figures until 2010 (Federale Commissie voor de Verkeersveiligheid, 2007)**

## 7. Comparison between subjects

In Finland, about 60,000 country-wide seat belt observations were performed in 2002 resulting in a frontal seat belt wearing rate of more than 80% inside urban areas and 93% in rural areas (Luukkanen, 2003). It was found that the wearing rate of vans compared to cars was 20 to 30 percent lower.

The European Transport Safety Council recently published – front aggregated, front driver, front passenger and rear seats – seat belt wearing rates for a large number of European countries (European Transport Safety Council, 2007). In 2005, Belgium had a frontal seat belt wearing rate of 71%. Countries performing very well on this indicator (i.e. ≥ 90%) are France, Germany, the Netherlands, Norway, Sweden and United Kingdom. The average percentage of persons wearing a seat belt in front of a car or a van for the 25 EU member states in 2005 is estimated at 86% (Vis and Van Gent, 2007a).

## 8. Positive and negative aspects

8.1) Strengths: for the risk domain 'protective systems' the seat belt wearing rate in front of cars and vans is a principal indicator. Within this domain, it is the most common indicator for which data are available in most countries for some time, thereby providing insight in relative performance and changes over time. Furthermore, the indicator scores well on the criteria under point 5 (i.e. relevant, measurable, understandable, etc).

8.2) Weaknesses: for this indicator occupants in the front seats of cars and vans are considered. As there might be a difference in safety behaviour between the two groups, it is important that both vehicle classes are incorporated when comparing the wearing rates across countries. The same holds for the persons checked (i.e. results differ in case both drivers and passengers in front are considered or only one class of occupants) and the locations considered (e.g. speed limit). Moreover, to avoid biased results measurements are needed at regular intervals, thereby testing a large share of vehicles. Guidelines are a prerequisite for a correct, comparable and representative measuring of wearing rates. In case all member states are willing to apply the guidelines developed on the European level within the SafetyNet project (Hakkert and Gitelman, 2007), more reliable indicator data will be obtained enabling better comparisons.

## 9. Conclusion

Based on the information above, we can conclude that the percentage of persons wearing a seat belt in the front seats of a car or a van is an appropriate indicator for monitoring the protective systems domain.

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## 7.2 Appendix II: Evaluation of indicator candidates

Based on literature, eight selection criteria were identified. Next, each possible indicator for a particular risk domain will be evaluated on these criteria. Meeting the criterion is indicated by a '+' sign, a '-' sign refers to the opposite, whereas '0' is the code for a score in between. Other possibilities are '0/+'; '-/0'; and '/' where the last symbol is used for rating reliability; in case no data are available, the degree of reliability is not applicable and not indicated (as a result only seven criteria are used then). To bring transparency in the subjective rating approach, some clarifications are given below the table for the first domain (alcohol and drugs) explaining why a specific code has been assigned. Although the evaluation of all possible indicator candidates is quite time-consuming, it is a necessary exercise as it has important implications.

From this analysis, a set of best needed indicators and a set of best available indicators will be deduced. Best needed indicators are ideal indicators with one or a few major shortcomings such as no data available, data of inferior quality (unreliable) or no comparable/coherent data. Therefore, only five criteria are used for computing the score for the best needed indicator (relevant-measurable-understandable-specific-sensitive), while all eight criteria are considered in the score for the best available indicator. Moreover, the signs attached to each cell in the table are quantified as follows: '+'=1; '0/+'=0.5; '0'=0; '-/0'=-0.5; '-'=-1. The indicator(s) with the highest best needed respectively best available score within each risk domain will appear in the final set of best needed and best available road safety performance indicators.

| **POSSIBLE ALCOHOL AND DRUGS INDICATORS** | Relevant/ valid | Measurable | Understan-dable | Available data | Reliable | Comparable/ coherent | Specific | Sensitive | Scores best needed (/5) | Scores best available |
|---|---|---|---|---|---|---|---|---|---|---|
| % of drivers with alcohol concentration > legal limit | + | + | + | 0 | 0 | -(5) | + | + | **5** | 4/8 |
| % of drivers with drugs concentration > legal limit | + | 0 | 0 | - | / | - | -/0 | + | 1.5 | ≤0 |
| % of surveyed (car) drivers disrespecting the alcohol limit | + | 0 | + | + | 0 | 0(6) | + | 0 | 3.5 | **4.5/8** |
| % of drivers impaired by alcohol or drugs | + | + | + | - | / | 0 | 0/+ | + | 4.5 | 3.5/7 |
| % of drivers impaired by alcohol and drugs | + | + | + | - | / | 0 | 0/+ | + | 4.5 | 3.5/7 |
| % of fatalities resulting from accidents with ≥1 driver impaired by alcohol | 0(1) | + | 0/+ | 0/+(4) | 0 | 0/+ | + | -/0(7) | 2 | 3/8 |
| % of fatalities resulting from accidents with ≥1 driver impaired by drugs | 0 | + | 0/+ | - | / | 0 | -/0 | -/0 | 0.5 | ≤0 |
| % of fatal accidents in which someone was drinking and driving | 0 | + | + | 0/+ | 0 | + | + | -/0 | 2.5 | 4/8 |
| % of road users involved in fatal accidents impaired by alcohol or drugs | 0 | + | + | 0/+ | 0 | + | 0/+ | -/0 | 2 | 3.5/8 |
| subjective risk of getting caught while driving under influence | 0(2) | 0 | 0/+ | 0/+ | 0 | 0 | 0 | 0/+ | 1 | 1.5/8 |
| attitude towards driving under influence | 0 | (3)- | 0 | 0 | 0 | 0 | 0 | 0/+ | ≤0 | ≤0 |

(1) not defined on the intermediate outcome level but on the final outcome level; therefore, not an action-oriented performance indicator

(2) not defined on the intermediate outcome level but on the policy level

(3) a concept that is difficult to measure and quantify

(4) in some countries only a small part is tested

(5) the limits differ between countries and changes in limits are possible over time; at present, the measurement method as well as the sampling design are not consistent

(6) there might be differences in self-reporting behaviour between countries

(7) a change in this indicator value might not be due to a better performance

| **POSSIBLE SPEED INDICATORS** | Relevant/ valid | Measurable | Understan-dable | Available data | Reliable | Comparable/ coherent | Specific | Sensitive | Scores best needed (/5) | Scores best available |
|---|---|---|---|---|---|---|---|---|---|---|
| % of drivers exceeding the speed limit on various road types | + | + | + | 0 | 0 | -/0 | 0/+ | 0 | 3.5 | 3/8 |
| % of surveyed (car) drivers exceeding the speed limit on various road types | + | + | + | 0/+ | 0 | 0 | 0/+ | 0 | 3.5 | **4/8** |
| average (free flow) daytime speed per road type and vehicle type | 0 | + | + | 0 | 0 | -/0 | + | + | **4** | 3.5/8 |
| average (free flow) speed per road type and vehicle type at night | 0 | + | + | - | / | -/0 | + | + | **4** | 2.5/7 |
| variation in speed per road type and vehicle type | 0 | + | + | - | / | 0 | + | + | **4** | 3/7 |
| median (or other percentile) of the set of observed speeds divided by the speed limit of the road class | + | + | 0 | 0 | 0 | 0 | + | 0/+ | 3.5 | 3.5/8 |
| median of the set of absolute differences between each of the observed speeds in the road class and the median of all observed speeds divided by the median of the set of observed speeds | - | + | - | - | / | 0 | + | 0 | ≤0 | ≤0 |
| % of drivers with an inappropriate headway on various road types | 0 | + | + | - | / | - | - | 0 | 1 | ≤0 |

| **POSSIBLE PROTECTIVE SYSTEMS INDICATORS** | Relevant/ valid | Measurable | Understan-dable | Available data | Reliable | Comparable/ coherent | Specific | Sensitive | Scores best needed (/5) | Scores best available |
|---|---|---|---|---|---|---|---|---|---|---|
| % of persons wearing a seat belt in the front seats of a car or van | + | + | + | + | 0 | + | 0/+ | + | **4.5** | **6.5/8** |
| % of persons wearing a seat belt in the rear seats of a car or van | + | + | + | 0/+ | -/0 | + | 0/+ | + | **4.5** | 5.5/8 |
| % of children <12 years (correctly) sitting in a child's seat in the front or rear seat of a car | + | + | + | -/0 | -/0 | + | 0/+ | + | **4.5** | 4.5/8 |
| % of persons wearing a seat belt in the front seats of a bus (>3.5 tons) or a truck | + | + | + | - | / | 0 | 0/+ | + | **4.5** | 3.5/7 |
| % of persons wearing a seat belt in the passenger seats of a bus | + | + | + | - | / | 0 | 0/+ | + | **4.5** | 3.5/7 |
| % of cyclists wearing a helmet | 0/+ | + | + | - | / | - | 0/+ | + | 4 | 2/7 |
| % of moped riders wearing a helmet | + | + | + | -/0 | -/0 | 0 | 0/+ | + | **4.5** | 3.5/8 |
| % of motorcyclists wearing a helmet | + | + | + | -/0 | 0 | + | 0/+ | + | **4.5** | 5/8 |

| **POSSIBLE DAYTIME RUNNING LIGHTS INDICATORS** | Relevant/ valid | Measurable | Understan-dable | Available data | Reliable | Comparable/ coherent | Specific | Sensitive | Scores best needed (/5) | Scores best available |
|---|---|---|---|---|---|---|---|---|---|---|
| total usage rate of daytime running lights | + | + | + | -/0 | -/0 | -/0 | 0 | 0/+ | 3.5 | 2/8 |
| usage rate of daytime running lights per road type and vehicle type | + | + | + | -/0 | -/0 | - | + | 0/+ | **4.5** | 2.5/8 |
| existence of a law – fully or partially – obligating the use of daytime running lights | 0 | 0/+ | + | + | 0/+ | 0/+ | 0 | -/0 | 1 | **3/8** |

| **POSSIBLE VEHICLE INDICATORS** | Relevant/ valid | Measurable | Understan-dable | Available data | Reliable | Comparable/ coherent | Specific | Sensitive | Scores best needed (/5) | Scores best available |
|---|---|---|---|---|---|---|---|---|---|---|
| % of cars failing the official vehicle inspection | 0/+ | + | + | 0 | 0/+ | 0/+ | 0 | + | 3.5 | 4.5/8 |
| EuroNCAP score: % of new cars obtaining 0 respectively 1, 2, 3, 4 or 5 stars in total # of new passenger cars | 0/+ | + | + | 0 | 0/+ | 0/+ | 0 | + | 3.5 | 4.5/8 |
| age distribution of the vehicle fleet: % of vehicles ≤5 years; between 6-10 years, between 11-15 years and >15 years in the total # of registered vehicles (focus on passenger cars) | 0/+ | + | + | 0/+ | 0/+ | + | + | 0/+ | **4** | **6/8** |
| composition of the vehicle fleet: % of cars, vans, buses, trucks and motorcycles in total # of registered vehicles | 0/+ | + | + | + | 0/+ | + | 0 | 0 | 2.5 | 5/8 |

| **POSSIBLE ROADS INDICATORS** | Relevant/ valid | Measurable | Understan-dable | Available data | Reliable | Comparable/ coherent | Specific | Sensitive | Scores best needed (/5) | Scores best available |
|---|---|---|---|---|---|---|---|---|---|---|
| share of network length per road type | 0 | + | + | 0/+ | + | -/0 | + | - | 2 | 3/8 |
| share of intersections per type | 0 | + | + | - | / | 0 | + | 0 | 3 | 2/7 |
| intersection density | 0 | + | + | 0 | 0 | + | - | - | ≤0 | 1/8 |
| network density | 0 | + | + | + | + | + | - | - | ≤0 | 3/8 |
| motorway density | 0 | + | + | + | + | + | + | - | 2 | **5/8** |
| EuroRAP road protection scores | + | 0/+ | 0 | -/0 | 0 | + | 0 | 0/+ | 2 | 2.5/8 |
| % of road length with a wide median or median barrier | + | + | 0 | - | / | 0 | + | 0/+ | **3.5** | 2.5/7 |
| % of road length with a wide obstacle-free zone or roadside barrier | + | + | 0 | - | / | 0 | + | 0/+ | **3.5** | 2.5/7 |
| % of road length with facilities for separation of slow vulnerable traffic and other motorized traffic | + | + | 0 | - | / | 0 | 0/+ | 0/+ | 3 | 2/7 |
| % of road network satisfying the safety design standard | + | 0 | 0 | - | / | -/0 | - | 0/+ | 0.5 | ≤0 |
| expenditure on roads as GDP share | 0/+ | + | 0/+ | + | + | 0 | - | 0 | 1 | 3/8 |

| **POSSIBLE TRAUMA MANAGEMENT INDICATORS** | Relevant/ valid | Measurable | Understan-dable | Available data | Reliable | Comparable/ coherent | Specific | Sensitive | Scores best needed (/5) | Scores best available |
|---|---|---|---|---|---|---|---|---|---|---|
| % of calls to emergency medical services due to a road accident | 0/+ | + | + | - | / | 0 | + | 0 | 3.5 | 2.5/7 |
| average arrival time of emergency medical services at the accident scene | + | + | + | - | / | -/0 | + | 0 | **4** | 2.5/7 |
| # of emergency medical services' staff per 10,000 citizens | 0 | + | + | 0 | + | 0 | + | 0 | 3 | 4/8 |
| # of hospital beds per 10,000 citizens | 0 | + | + | + | + | 0 | 0 | -/0 | 1.5 | 3.5/8 |
| average length of stay in the hospital after a road accident | 0/+ | + | + | - | / | 0 | + | 0 | 3.5 | 2.5/7 |
| share of road casualties treated in intensive care units | 0/+ | + | + | - | / | 0/+ | + | 0 | 3.5 | 3/7 |
| share of road casualties who died during hospitalisation | + | + | + | - | / | 0/+ | + | 0 | **4** | 3.5/7 |
| expenditure on health care as GDP share | 0/+ | + | + | + | + | 0 | 0 | 0 | 2.5 | **4.5/8** |