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Road Safety Performance Indicators Theory

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Project Co-ordinator:
Professor Pete Thomas
Vehicle Safety Research Centre
Ergonomics and Safety Research Institute
Loughborough University
Holywell Building
Holywell Way
Loughborough
LE11 3UZ

Organisation name of lead contractor for this deliverable:
SWOV

Editors for this deliverable:
Shalom Hakkert, Victoria Gitelman (TECHNION) and Martijn A. Vis (SWOV)

Report Author(s): Kerstin Auerbach-Hafen, Andrea Hasse, Markus Lerner (**BASt**); Roland Allenbach (**BfU**); François Riguelle (**IBSR**); Vojtech Eksler, Radim Striegler (**CDV**); Mouloud Haddak (**INRETS**); Péter Holló (**KTI**); Elisabete Arsenio, João Cardoso, Sandra Vieira Gomes (**LNEC**); Eleonora Papadimitriou (**NTUA**); Maarten Amelink, Charles Goldenbeld, René Mathijssen, Robert Louwerse, Peter Morsink, Chris Schoon, Alex van Gent, Sjoerd Houwing, Martijn Vis (**SWOV**); Victoria Gitelman, Shalom Hakkert (**TECHNION**); Terje Assum (**TØI**); Mariannne Page, Lucy Rackliff, Andrew Morris (**VSRC**)

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Executive Summary

This document provides details about the theory behind the development of Safety Performance Indicators (SPIs) in seven major areas which are central to the fields of activity in road safety in Europe. The fields of activity were selected as a result of reviews of national road safety plans in many of the EU countries and around the world and are considered the central themes of activity in road safety, necessary to bring about a significant improvement in road safety in the EU countries.

Within each field SPIs were developed which are directly related to that field of activity, can be quantitatively measured, can provide the basis for the assessment of the level of road safety in each country and can serve as an indicator to describe the level of activity in that field and country and can provide a yardstick for comparison. Comparisons can be before and after certain actions are taken or can be comparisons between countries.

As stated above, this document deals with the theory behind the development of each of the seven SPIs. It provides the rationale behind their development, the proofs for their relevance in the specific fields and the existing limitations that led to the adoption of the specific SPIs. The document provides also some recommendations for the possible improvements required to obtain better SPIs. Two companion documents are also being prepared. One is a manual which provides details on the procedures necessary to collects the required data for the development of each SPI in each country. The second document provides results on the data collected so far for each of the 25 EU countries and the SPIs developed so far, based on the data submitted by each of the countries. It can be seen that a lot of work still has to be done, both in collecting the necessary data and in improving the SPIs, once better and more detailed data becomes available.

Alcohol and drugs

Due to the limitations in the current state of accident data collection and data from surveys on the levels of alcohol and drugs in the driving population, three SPIs are proposed:

1. The number and percentage of severe and fatal injuries resulting from road accidents involving at least one active road user impaired by psychoactive substance (concentration above a predetermined impairment threshold);
2. The percentage of fatalities resulting from accidents involving at least one ***driver*** impaired by alcohol;
3. The percentage of fatalities resulting form accidents involving at least one ***driver*** impaired by drugs other than alcohol.

The first one is not yet possible to realise. Consequently the two latter ones are proposed as realisable for some countries at present.

Speeds

The speeds that are most relevant for safety purposes are spot speeds measured at various locations on the road network during periods when traffic can be considered free flowing, i.e not during periods of congestion when speeds are severely restricted. The SPIs developed are the mean speed, the standard deviation, the 85^{th} percentile speed and the percentage of drivers exceeding the speed limit. These indicators should be segregated by road type, vehicle type, period of day and period of the week, i.e week-days and weekends. For road types it is suggested to adopt the classification developed in the roads task. In the manual document procedures are developed and described to obtain statistically valid results on a national basis, calculated from the sample of sites at which speeds are measured.

Protective systems

The major protective systems in vehicles that are relevant for the development of SPIs are seat belts for adults and for children, in various types of vehicles and the use of safety helmets by cyclists, moped riders and motorcyclists.

The SPIs developed are:

Set I: Daytime wearing rates of seat belts

SPI A – Front seats – passenger cars + vans /under 3.5 tons/

SPI B – Rear seats – passenger cars + vans /under 3.5 tons/

SPI C – Children under 12 years old - restraint systems use in passenger cars

SPI D – Front seats – HGV + coaches /above 3.5 tons/

Set II: Daytime usage rates of safety helmets

SPI F – Cyclists

SPI G – Moped riders

SPI H – Motorcyclists

All the indicators should come from independent observational surveys carried out on an annual basis, according to sampling procedures described in the Manual and in-time stationary conditions. The values should be aggregated from the values for major road types in the country considered for each one indicator and weighted on the basis of traffic volume on each of these road types. Measurements should be classified according to motorways, other rural roads and urban roads.

SPIs for airbags have not been included at this stage because at present there is no Nationally available data on the number of airbags installed in vehicles.

Daytime running lights

DRL SPIs are usually considered in the form of the percentage of vehicles using daytime running lights.

The general indicator can be estimated for the whole sample of vehicles, which were observed in the country. Similar values can be calculated for different road categories and for different vehicle types.

The road categories to be considered are: motorways, rural roads, urban roads, and DRL-roads, where the term “DRL roads” implies the road categories where the usage of DRL is obligatory.

The vehicle types to be considered are: cars, heavy good vehicles (including vans), motorcycles and mopeds.

In countries, where the automatic DRL was introduced long time ago (e.g. Sweden, Norway), according to expert estimates, the DRL usage rate is close to 100%, thus the DRL usage rate as a behavioural safety performance indicator does not have practical implications any more. In general, once the option of automatic DRL is introduced Europe-wide the DRL indicators will lose their importance.

Following the general concept of the DRL SPIs and accounting for current practices on the DRL use measurements in different countries possible DRL SPIs can be considered.

In total, 9 DRL SPIs are recommended for application, which are: the total usage rate and the percentages of vehicles using DRL according to four road types and according to four vehicle categories.

To estimate the above SPIs, each country should perform an annual survey of the DRL use. The details of survey will be discussed in the “Manual” document.

Passive vehicle safety

EuroNCAP is widely used as an indicator of passive safety for individual vehicles to give consumers a guide to the crashworthiness of specific makes and models. However there is no current recognised measure of an entire vehicle fleet.

For passive vehicle safety the correspondents were asked to send data containing the entire vehicle fleet database according to vehicle type, make, model and year of first registration, as it stood in 2003.

EuroNCAP scores are only currently available for passenger cars, so the present analysis concentrates on those vehicles within the national fleet. For this study it was decided that a EuroNCAP score, although describing a specific model variant, would be applied to any vehicle of the same model, to ensure a larger sample size.

For each country a EuroNCAP score was attributed to eligible vehicles. An average figure was then calculated for each year and weighted by the number of vehicles present in the 2003 fleet from that year. An overall average EuroNCAP score was then awarded for each country and together, with the median age of passenger cars in the fleet, these two figures make up the SPI for each country.

In order to validate the SPI with real-world data, car occupant fatality rates in each of the countries were considered. The number of car occupant fatalities in 2003 for each country was divided by the number of passenger cars present in each 2003 fleet, to give a figure for the number of car occupant fatalities per million cars. The average EuroNCAP score for each country was weighted by the percentage of passenger cars in a country’s 2003 fleet, which were less than 10 years old. This figure for each country was then plotted against the car occupant fatality per million cars figure for each country.

Roads

There are no direct or indirect SPIs for road networks in use in Europe at the moment. The Dutch study on quality aspects of a sustainably safe road infrastructure presented a method to assess network and design quality aspects of a safe road infrastructure at the regional level. This method could be used to formulate road network SPIs. However, the method is not commonly used yet and needs more development for use in Europe.

Even for the assessment of detailed road design there are no direct SPIs in use at the moment. Two methods could be used to formulate indirect SPIs: The Road Protection Score (RPS) of EuroRAP and the Dutch Sustainably Safe Indicator (SSI). These methods score specific road design elements. This score can be used to formulate SPIs for road design. There is some overlap in the road elements that are considered in the two methods, however the way these elements are scaled differs a lot. Both methods pay attention to *homogeneity* of the road traffic and *forgiving* road environments. The SSI has strong roots in the Dutch Sustainable Safety vision, and therefore paying more attention to the *predictability* of the road environment and the *function* in the network of the distinguished sustainably safe road categories.

The RPS turned out to be more useful in the SafetyNet context because of two main reasons:

- all road design elements used are broadly accepted as relevant for road safety, and

- the method itself is worked out in detail and already in use in a lot of European countries.

At this stage it was considered more practical to adopt the RPS scores developed in EuroRAP as the basis for Road SPIs Europe-wide, this in view of the large amount of work already invested in the practical data collection for these RPS scores.

The assessment and weighting methods, to determine the RPS-score of EuroRAP are far more elaborately been worked out than the proposed SPI-method in the State-of-the-Art document [SafetNet 2005a]. EuroRAP has even designed a method to determine an aggregate RPS for a road. The scores for the four design elements are combined in proportion to the frequency with which the accident types matched to these design elements occurred, averaged across Sweden, Denmark, France, Hungary, Switzerland and Britain. Besides that, the potential data availability proved to be higher for EuroRAP than gathered from the questionnaire.

Therefore we propose to adopt the RPS protocol in the future so as to use and possibly share the same data as much as possible.

Nevertheless, there are three main obstacles to overcome:

- Details of the scoring and weighting methodology;
- Vulnerable road users (VRUs) are not yet included yet;
- A network approach is missing.

EuroRAP designed a method to calculate a final score for a road, expressed with one to four 'stars'. The scores on the several SPIs are weighted to calculate this final score. The magnitudes of these weights are based on accident statistics of a small and arbitrary group of European countries. Possibly these weights should depend on the distribution of accidents types in the country or region, or on the road type, where the RPS is applied. This weighting method should be as transparent as possible. SafetyNet could offer its assistance for improving this scoring and weighting method. Details of the scoring and weighing methodology are expected to be published soon.

Despite the fact that accidents with vulnerable road user are a main crash type, this item is not yet included in the RPS assessment methodology. SafetyNet could offer its assistance with defining this part of the SPI.

The 'SafetyNet Road Network SPI' enables a road authority to assess the extent to which a connection complies with the demands. EuroRAP assesses whether a road complies to design criteria. However, the EuroRAP RPS-score by itself does not indicate to which extent a road (or connection) complies with the requirements for that connection, arising from the function of the connection in the network. Therefore we propose to combine the RPS with a functional road categorization.

This will result in two aggregated network SPIs:

- Network SPI: percentage of appropriate road category (AAA-C) length per connection type (I-V);
- Road design SPI: distribution of stars (1-4) per road category (AAA-C).

Trauma management

The mechanism of post-crash trauma care (or Trauma Management – TM) comprises two types of medical treatment: that provided by emergency medical services (EMS) and that provided by permanent medical facilities.

EMS are those, which normally answer the emergency calls and deal with the next steps, like sending an ambulance to the scene of crash. EMS staff provides basic medical assistance to injured patients on the scene and during the transportation to a hospital. There are different forms of EMS, which depend on:

- the type of transport means (ambulance, helicopter);
- EMS vehicle equipment (mobile intensive care unit; basic life support unit; regular ambulance);
- medical staff arriving with the vehicle, which may include a physician, a paramedic, a "critical care" nurse, an emergency medical technician.

Further medical treatment can be provided at a regular hospital or at a specially equipped trauma centre/ the trauma department of a hospital, whereas minor injuries are usually treated by doctors/ other medical staff outside a hospital. The focus of the TM system is on patients who are hospitalized.

Based on the analysis of data available in the countries, a minimum set of the data items to be provided by the countries, was defined. These data enable the calculation of a ***Minimum set of Trauma Management SPIs*** that are necessary for an initial characteristic of the system's performance.

The minimum dataset covers seven data items as follows:

- Total number of EMS stations;
- Number of EMS staff in service (according to categories);
- Number of EMS transportation units in service (according to categories);
- The demand for a response time (min);
- Percentage of EMS responses which meet the demands for response time;
- Average response time of EMS (min);
- Total number of beds in permanent medical facilities (according to categories).

The minimum set of the TM SPIs, which can be estimated using this minimum data set, includes fourteen items as follows:

1. EMS stations per 10,000 citizens

2. EMS stations per 100 km length of rural public roads

3. Percentage of physicians out of the total EMS medical staff

4. Percentage of physicians and paramedics out of the total EMS medical staff

5. EMS medical staff per 10,000 citizens

6. Percentage of MICU out of the total EMS units

7. Percentage of BLSU, MICU and helicopters/ planes out of the total EMS units

8. EMS transportation units per 10,000 citizens

9. EMS vehicles per 100 km road length of total public roads

10.-11. Percentage of EMS responses which meet the demand for response time; to be accompanied by a data item "The demand for a response time, min".

12. Average response time of EMS, min

13. Percentage of beds in certified trauma centres and trauma departments of hospitals out of the total

14. Number of the total trauma care beds per 10,000 citizens

The above minimum set of TM SPIs enables to characterize both the scope and the quality of the post-crash care in the country, in terms of the EMS treatment potential (the availability and quality of resources), EMS response time and the treatment potential of permanent medical facilities (the availability and quality of resources).

According to our results, the TM system in a country can be characterized and the countries can be compared using the above described set of SPIs. However, comparing the countries it is frequently desirable to have a ***combined indicator*** which could provide an overall characteristic of the system.

Developing such a combined indicator we should emphasize that it is *limited* to the following considerations:

- We search for a qualitative indicator which would combine the TM SPIs' values, which are available for a country;
- A comparison by means of the combined indicator should be based on available data and then, provide an indication of "higher"/ "lower" level of the system's performance *relatively* to other countries in the sample;
- According to the meanings of separate SPIs, the combined indicator will tell us something about the level of the EMS treatment potential, EMS response time and the treatment potential of permanent medical facilities, i.e. the message is limited mostly to the availability of these services and, to a lesser extent, to the shares of higher-quality resources.

The combined indicator was developed by means of ranking the values of separate TM SPIs and weighting the results together. The following rules were applied:

- The combined indicator is estimated using the minimum set of trauma SPIs - 14 indicators.
- The values of each SPI should be consistent, i.e. higher values of SPIs should correspond to a better system's performance.

To avoid the dependency of the results on the estimation method and to check the sensitivity of results, three ways of ranking were applied and compared.

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1 General background

GITELMAN[A], V., HAKKERT[A], S.

[A]TECHNION

1.1 The scope of road safety problem in the EU countries

The Transport White Paper adopted in 2001 proposed the target of halving the number of road fatalities by 2010 (White Paper, 2001). This target was subsequently repeated in the European road safety action programme adopted in 2003 (EC, 2003).

In 2001, 50,000 people were killed on roads in the countries which today make up the European Union (EU). For the EU-15, the burden of road accidents and injuries was estimated as follows: 1,300,000 accidents a year, with 40,000 deaths and 1,700,000 injuries on the roads, which resulted in direct and indirect costs of 160 billion Euro or 2% of the EU GNP (EC, 2003).

The joint target proposed in 2001 and updated after enlargement in 2004 is that by 2010 there should be no more than 25,000 fatalities a year. The figures for 2005 showed that about 41,600 people were killed on roads (EC, 2006), a fall of 17.5% over 4 years. At the present rate, road deaths in the EU in 2010 are likely to stand at 32,500, and the target of a maximum of 25,000 will probably not be achieved (EC, 2006).

The trend over the last ten years demonstrates that (EC, 2006):

- Between 1994 and 2000, the number of people killed on the roads fell by an average of only 2% a year, while the number of accidents rose very slightly. The technical improvements made to vehicles would seem to be the main reason behind this trend.
- Between 2001 and 2005, the number of people killed on the roads fell by an average of 5% a year, and the number of accidents fell by an average of 4% a year, and 5% between 2003 and 2004; this parallel trend in the major safety indicators corresponds to the periods of entry into force of voluntary road safety plans in most of the Member States.

The road safety performance of the new Member States following the recent enlargement is not as good as the average situation in the EU before 2004. While some of these countries saw dramatic improvements in the early 1990s, their situation since 2001 has basically been the same as that of several of the EU-15 Member States. The problems are not specific to the enlargement countries. They are similar everywhere but with different degrees of progress over time (EC, 2006).

The major differences between the Member states, in terms of road fatalities' figures, can be described as follows (EC, 2006):

- The annual number of victims per million inhabitants varies from 50-60 (Malta, the Netherlands, Sweden, the United Kingdom) to more than 200 (Latvia, Lithuania), while the average for the EU-25 is 95;
- The annual number of victims per million private cars varies from 130-150 (the Netherlands, Sweden, the United Kingdom) to 600 (Lithuania), and 800 (Latvia), while the average for the EU-25 is 220;
- In terms of changes in the number of people killed between 2001 and 2004, nine Member States (Germany, Estonia, France, Italy, Luxembourg, Malta, the Netherlands, Portugal, Sweden) have reduced at a faster rate than the average for the EU-25 (-14%); in eight other countries (Belgium, Denmark, Greece, Spain, Ireland, Austria, Finland, the United Kingdom) there has been limited progress (a fall of at least 5% but less than the average rate); in six countries (Czech Republic, Latvia, Hungary, Poland, Slovenia, Slovakia)

progress was very slow or there has been a slight backward trend; the situation has got worse in Cyprus and Lithuania. However, these figures should be treated with caution, especially for small Member States where slight changes in fatal accidents greatly affect the national result.

1.2 The need for road safety management

The 2001 White paper and the 2003 European action programme encouraged Member States to adopt national road safety plans (especially those States which did not have them before). The EU therefore promotes putting road safety at the top of the agenda of the Member States' political concerns (EC, 2006).

A road safety plan typically includes a weighted combination of actions on improvements of road, vehicle and road user safety, at the before-, during- and after- accident stages, whereas the actions' priorities depend on the analysis of road safety problems in a specific country (OECD, 2002). The European action programme (2003) aimed to:

- encourage *road users* to improve their behaviour, in particular through better compliance with the existing legislation, basic and continuous training for private and professional drivers and by pursuing efforts to combat dangerous practices;
- make *vehicles* safer, in particular through technical harmonisation and support for technical progress including the aspects concerning electronic technologies ("eSafety");
- improve *road infrastructure*, in particular by defining best practices and disseminating them at the local level and by eliminating accident black spots.

The mid-term review (EC, 2006) indicated that the Member States' safety plans generally include the following topics:

- strengthening compliance with traffic rules, by means of controls and penalties;
- improvements of passive and active vehicle safety;
- improvements of road infrastructure;
- strengthening the legislation on driver education, training and standards of fitness for driving;
- protecting and educating users at risk and vulnerable users;
- monitoring road safety performance, etc.

Following the recommendations by the 2003 European action programme, the emphasis is typically put on involving different stakeholders and sharing responsibilities among the institutions (on the European, national, regional and local levels), private initiatives and the community.

A number of initiatives adopted since 2001 intend to promote the road safety plans performance in the EU countries, such as (EC, 2006):

- The recommendation 2004/345/EC, which is concerned with best practice with regard to monitoring the application of the rules on drink-driving, speeding and seat belts; it applies to all motorised transport, both private and professional.
- The Member States have adopted initiatives to combat driving under the influence of alcohol, drugs and medicines e.g. a lower maximum blood alcohol level (generally 0.2 mg/ml) for new drivers and professional drivers in some countries; stricter penalties for drinking and driving; legislative actions to prevent driving under the influence of drugs. Alcohol checks are now carried out more frequently and they are typically targeted, reliable and fast.

- Vehicles provide much better protection for their occupants today than a few years ago; safety has become a key commercial factor. The EuroNCAP programme for assessing the protection of occupants in new car models demonstrates the achievements made by industry and provides the information to consumers.
- It is now compulsory to wear a seat belt in all vehicles fitted with one and to use child restraints by children travelling in cars. Moreover, the proposals on fitting safety belts to all vehicles and on making a certification of heavy goods vehicles and coaches mandatory, are currently under negotiations.
- Concerning the road infrastructure, the legislation is currently limited to Directive 2004/54/EC on tunnel safety, which is aimed at reducing risk by means of preventive measures and, if an accident occurs, to minimise the loss of life. A recent evaluation demonstrated that on the roads of the trans-European network 12-16% of fatalities and 7-12% of accidents would be avoided through better infrastructure safety management.
- Initiatives such as EuroRAP (European road assessment programme) and EuroTAP (European tunnels assessment programme) are aimed at making road infrastructure safer by means of an information and transparency strategy.

As stated by the 2003 European action programme, the safety targets have to be periodically monitored to verify the progress made. Besides, monitoring is essential for adopting necessary changes in current safety plans, based on recent accident trends observed (OECD, 2002).

The European Transport Safety Council (ETSC) recently initiated a project of a close follow-up of the progress achieved in road safety by the EU-countries. The project is presented as a new policy instrument assisting to compare Member States' performance in promoting safe road user behaviour, infrastructure and vehicles, as well as sound and evidence-based policy-making (ETSC, 2006a). The main idea of the instrument is to compare the countries by means of the Road Safety Performance Index (so-called "Road Safety PIN") which is based on generally accepted road safety indicators including accident data and data related to road safety performance. For example, ETSC (2006b) compared the countries in terms of percentage of change in the national numbers of fatalities, over the years 2001-2005; background considerations of the causes to a remarkable progress made by some countries (e.g. France, Belgium, Luxembourg, Portugal, the Netherlands) accompanied the figures presented.

According to the 2003 European action programme, the use of performance indicators makes it possible to target actions in key areas systematically and to monitor implementation. These may concern particular groups of road users such as children, new drivers or professional drivers, or compliance with important safety rules such as seat belt wearing, or cover specific areas such as the urban road network, country roads or the trans-European network. Performance indicators for speed, drinking and driving, the use of restraint systems and safety devices, number of roadside checks are already used in some member States and therefore could be adopted by other countries (EC, 2003). The following stage is seen in the development of indicators in areas relating to the management of road network standards, the characteristics of vehicles on the roads and the emergency services provided (EC, 2003).

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2 Methodological fundamentals for safety performance indicators[1]

GITELMAN[A], V., HAKKERT[A], S., HASSE[B], A., LERNER[B], M.

[B]BASt, [A]TECHNION

2.1 Introduction: the role of safety performance indicators in safety management

Road safety can be assessed in terms of social costs of accidents and injuries. However, simply counting crashes or injuries is often an imperfect indicator of the level of road safety. Frequently, accidents and injuries are only the tip of the iceberg, because they occur as the "worst case" of unsafe operational conditions of the road traffic system. At the same time, road safety policymakers and analysts aiming at a higher level of safety need to take into account as many factors influencing safety as possible or, at least, those factors they are able to affect or control (ETSC, 2001). Additional safety performance indicators (rather than accident/ injury numbers) might provide a means for monitoring the effectiveness of safety actions applied.

ETSC (2001) details the reasons for the need in safety performance indicators, as follows:

- The number of road crashes and injuries is subject to random fluctuations, where a short-term change in the recorded numbers does not necessarily reflect a change in the underlying, long-term expected numbers;
- Reporting of crashes and injuries in official road accident statistics is incomplete. Thus, an observed change in the number of crashes could merely be a change in the propensity to report crashes by the police.
- A count of crashes sometimes says nothing about the processes that produce crashes. It is, to some extent, a matter of chance whether a hazardous situation or a near miss results in a crash or not. It is possible that in spite of risky conditions, luckily, no accident occurred.
- In order to develop effective measures to reduce the number of accidents/ injuries it is necessary to understand the processes that lead to accidents. Safety performance indicators can serve this purpose.

Safety performance indicators (SPIs) are seen as any measurement that is causally related to crashes or injuries and is used in addition to the figures of accidents or injuries, in order to indicate safety performance or understand the process that leads to accidents (ETSC, 2001). They also provide the link between the casualties from road accidents and the measures to reduce them (ETSC, 2006a).

As believed (ETSC, 2001; Luukkanen, 2003), safety performance indicators can give a more complete picture of the level of road safety and can point to the emergence of developing problems at an early stage, before these problems show up in the form of accidents.

Safety performance indicators help illustrate how well road safety programs are doing in meeting their objectives or achieving the desired outcomes. They are a means of monitoring, assessing and evaluating the processes and operations of road safety systems concerning their potential to solve the problems they are up against. They use qualitative and quantitative information to help to determine a program's success in achieving its objectives.

[1] Based on the Working paper developed by Hasse A., Lerner M., 2004-2006

They could be used to track progress and could provide a basis to evaluate and improve performance.

In order to properly perform their function, SPIs need to be relevant to the program's desired outcomes and objectives, and to be quantifiable, verifiable and unbiased.

Before the elaboration of SPIs for specific problem areas, it is important to define a uniform vision and common methodology for their development. The common approach should ensure the reliability and validity of SPIs, increase the acceptance and application of SPIs and at last get transparency for the potential users of SPIs.

2.2 The basic model

2.2.1 General

A model describing the place of safety performance indicators in road safety management system was shown by ETSC (2001) – Figure 2.1. This model allocated safety performance indicators on the level of intermediate outcomes. In general, the model is measure-oriented and follows in its logic from the bottom upwards. As the SPIs' target is to provide a picture of the road safety level and not of the road safety work or the implementation stage of a specific countermeasure, the dependence on interventions diminishes the potential of the model presented by ETSC (2001).

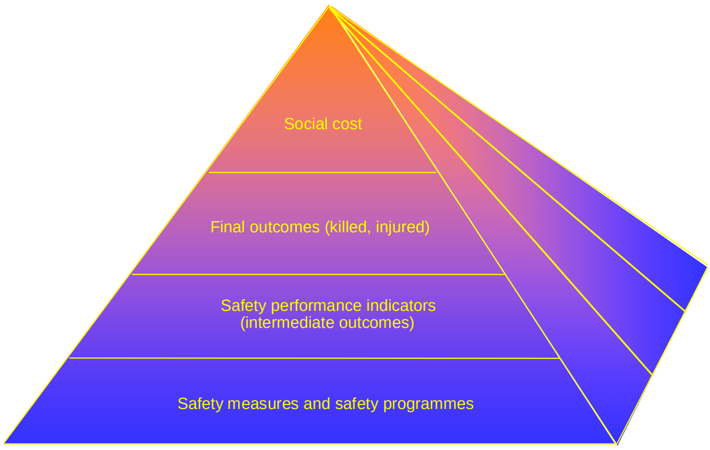


Figure 2.1 Essential elements of safety management system (ETSC, 2001).

A key point in the development of SPIs is that they should be able to reflect unsafe operational conditions of the road traffic system and therefore, be more general then direct outputs of specific safety interventions. In order to demonstrate a more general character of SPIs and their independence from interventions a further development of the model (see Figure 2.1) is required. To note, the model is not necessarily tied to the form of a pyramid. In general, it could also be presented as a chain of blocks. However, the pyramid enables to illustrate the interdependencies of the system, where the size (width) of a level indicates the quantity of factors influencing the next higher level (not the extent in means of monetized resources).

Further development of the basic model is presented in Figure 2.2 and Figure 2.3. The process is considered from the top to bottom, making the consideration problem-oriented (and not intervention-oriented).

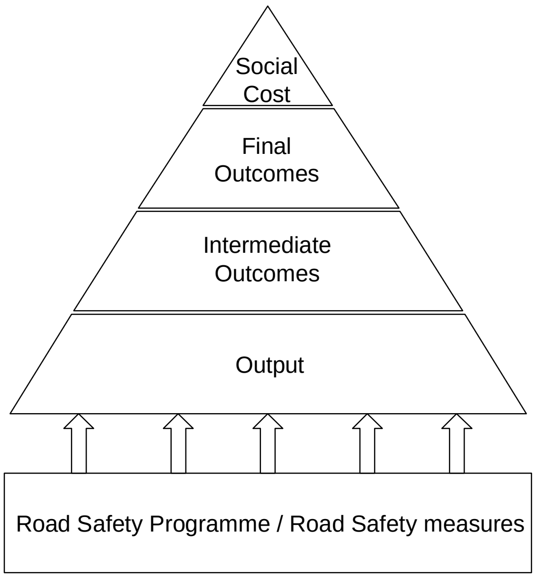


Figure 2.2: Development of model: independence from intervention.

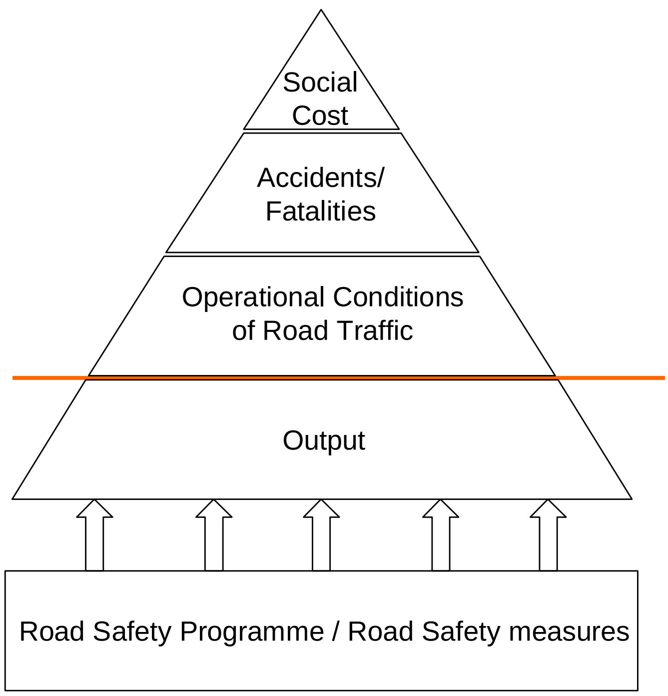


Figure 2.3: Further development of model.

Social cost, at the top level, is the monetary outcome resulting from the final (physical) outcomes at the next level, i.e. accidents/ fatalities/ casualties (see Figure 2.2 and Figure 2.3). The next deeper level are the so-called intermediate outcomes. Accidents are considered as the "worst case" of unsafe operational conditions of road traffic. Following this top-down logic, it is possible to present the intermediate outcomes as *operational conditions of the traffic system* and this way to reach an independence from safety interventions. Independent from any intervention, unsafe operational conditions of road traffic are responsible for accident/ injury occurrences. Unsafe operational conditions of road traffic may be pre-crash related (indicating a need for accident prevention measures), crash-related (meaning a need in injury prevention in case of an accident) or post-crash related (a need in post-crash injury treatment). At the same time, different safety measures/ interventions try to influence the operational conditions of the traffic system, where direct impacts of these interventions are presented as "output" (see Figure 2.3).

For example, in the case of alcohol-impaired driving, the "final outcome" may be the share of impaired killed drivers out of all killed drivers; the "intermediate outcome" may be the share of impaired drivers out of all drivers in traffic flows; whereas the "policy output" can be considered in terms of the number of random breath tests[2] (ETSC, 2006a).

Road safety interventions aim to influence unsafe operational conditions. Therefore, in order to identify unsafe operational conditions of road traffic, it is necessary to understand the process that leads to accidents. Only if the problem can be identified, interventions can be selected.

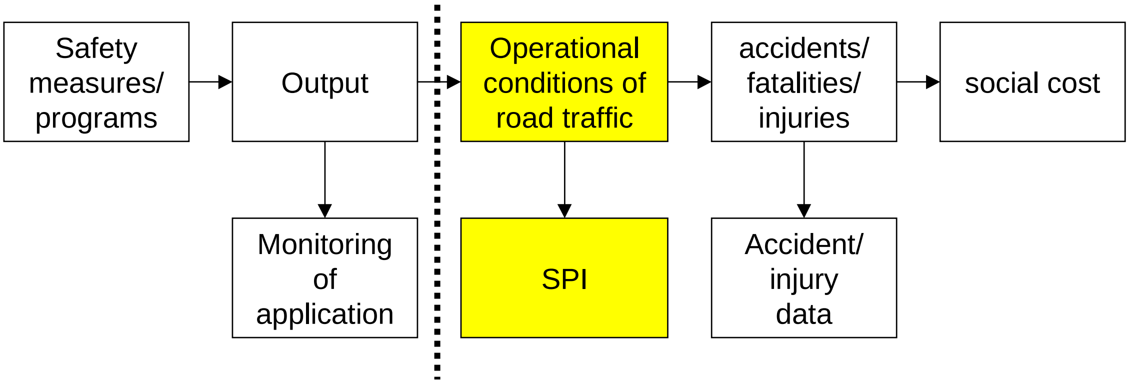


Figure 2.4: Road safety management system and its monitoring.

Besides, to distinguish between the system's conditions (physical process) and their reflection in data/ indicators, Figure 2.4 presents the same model in the form of a safety management system and data/ indices which are needed for its monitoring. Following the model, e.g., in the case of speeding, we can say that unsafe operational conditions of road traffic (speeding) are affected by the output from a road safety program in general or from a special road safety measure (e.g. speed enforcement). The output of a measure is the physical deliverable of the measure (e.g. speed cameras in use), whereas the outcome of the measure should be seen in improving the operational conditions (e.g. the level of speeding), which can be seen through the SPI. The improved operational conditions will result in accident or injury reduction, where the whole process should reduce finally the social cost.

2.2.2 Problem-related versus intervention-related components

The road safety system is divided into different areas referring to different key issues. The elements at the top (see Figure 2.3): social cost, final outcomes and operational conditions, are problem-related, while the lower elements - programmes/measures and output - are intervention-related.

Several interrelations between the different levels can be identified. The most important interrelation is located between accidents and operational conditions of road traffic, on the one hand, and between operational conditions and the selected countermeasures, on the other hand. This can be illustrated by the following examples.

Example 1:

> Accident analysis identified social cost due to speed-related accidents. Speeding accidents are the ”worst case“ of speeding behaviour. One form of the speeding

[2] Such an approach was suggested by the SUNflower projects.

behaviour is „inappropriate speeds“. Thus, one possible intervention could be speed enforcement. The output in that case would be e.g. speed cameras, which should affect „inappropriate speeds“. If the problem definition is correct and the intervention is effective, the intervention would reduce accidents and consequently social cost.

Another possible intervention could be Intelligent Speed Adaptation (ISA). Depending on some details of application, the number of ISA equipped vehicles would increase, which would also affect „inappropriate speeds“.

This example shows that one problem can be tackled by two different interventions. Both interventions affect the identified unsafe operational conditions of road traffic, but in different ways. Table 2.1 presents the components of example 1 in terms of road safety management process introduced in Figure 2.2 to Figure 2.4.

Social Cost	Social cost due to speeding accidents					
Final Outcome	Speeding accidents					
Operational Conditions	Inappropriate Speeds					
Output	Speed cameras	ISA equipped vehicles				
Road Safety Measure	1:Enforcement	2: ISA				

Table 2.1 Example of speed-related interventions in terms of road safety management model.

Example 2:

There are social costs associated with child injury in cars. Child injury as car passengers can be considered as the ”worst case“ of unsafe travel behaviour: non-use of child restraint systems. One possible intervention could be focused police enforcement. The output in this case would be e.g. the number of tickets issued or the number of cars checked. Another possible intervention could be public education, which impact is usually estimated by the level of public awareness to the problem (through public opinion surveys). There is an expectation that more dedicated enforcement and more efforts in public education will stimulate a more systematic use of child restraint systems, which, in turn, will reduce child injuries in cars and, consequently, social cost. Both interventions affect the identified unsafe operational conditions of road traffic, but in different ways. Table 2.2 presents the components of example 2 in terms of the road safety management process introduced in Figure 2.2 to Figure 2.4.

Social Cost	Social cost due to child injury in cars					
Final Outcome	Child injury as car passengers					
Operational Conditions	Unsafe travel conditions: non-use of restraint systems					
Output	Number of controls, tickets	Public awareness to the problem				
Road Safety Measure	1: Enforcement	2: Public education				

Table 2.2 Example of child injury in cars-related interventions in terms of road safety management model.

The above examples show that the SPI ideally should react to every change in the system. Otherwise, the indicator would possibly react to one intervention (e.g. speed enforcement), but not to another one (e.g. ISA). To react to all possible interventions the SPIs should ideally be completely independent from any road safety measure. Therefore the SPIs should be exogenous and the search for an optimal indicator has to go top-down.

The independence from interventions means that the SPIs must describe the scope of the identified problem instead of the scale of any intervention intended to force the problem. Speaking in terms of the model of the road safety system this means that the SPIs must be searched for above the dividing red line (see Figure 2.3).

The first and the key information which is needed is an exact definition of the problem. In other words, it should be determined, which operational conditions of road traffic are unsafe and lead to accidents or fatalities as the „worst case".

The second step is to put this key information into action, and to convert it into a measurable variable. At this point, one needs to answer the question: How can the identified problem (the unsafe operational conditions) be measured?

2.2.3 Definition of SPIs

Reflecting the theoretical considerations about the mode of operation of the road safety system, the following definition of SPIs can be given:

> *Safety performance indicators are the measures (indicators), reflecting those operational conditions of the road traffic system, which influence the system's safety performance.*

The purpose of SPIs is

- to reflect the current safety conditions of a road traffic system (i.e. they are considered not necessarily in the context of a specific safety measure, but in the context of specific safety problems or safety gaps);
- to measure the influence of various safety interventions, but not the stage or level of application of particular measures,
- to compare between different road traffic systems (e.g. countries, regions, etc).

2.3 Major areas of SPIs application

2.3.1 Examples in practice

ETSC (2001) considered a large number of factors which contribute to road accidents and injuries and therefore, might be potentially relevant for SPIs. For example, the aspects of road user behaviour that could function as SPIs include:

- speeding, with respects to mean speed, speed variance, percentage of speed limit violations;
- percentage of seat belts' and child restraints' use;
- percentage use of crash helmets;
- incidence of drinking and driving;
- failure to stop or yield at junctions or at pedestrian crossings;
- inadequate headways – close following;
- use of daytime running lights;
- use of reflective devices for cyclists and pedestrians;
- use of pedestrian crossing facilities by pedestrians.

Road and vehicle engineering can have a large influence on accident and injury reduction, by influencing behaviour and by offering crash protection. Possible SPIs in these areas are (ETSC, 2001):

1. pavement friction mostly in winter and on wet road surfaces;

2. percentage of new cars with the top star rating according to EuroNCAP;
3. percentage of technically defective vehicles;
4. percentage of road network not satisfying safety design standards.

Indicators of the quality of the post-crash care can be added to this list (ETSC, 2001).

As stated by ETSC (2001), the most commonly used SPIs for road transport in the EU are speed measurements, surveys on the use of seat belts and crash helmets, and surveys on the incidence of drinking and driving. However, the degree of detail of these indicators varies considerably. Besides, the different methodologies used for their estimation limit the possibilities of comparison between the countries.

Examples of SPIs' consideration were found in the Swedish national road safety programme for 1995-2000. For each policy objective of the programme a performance indicator was developed. Table 2.3 provides the definitions of these indicators and the progress made by 1998 towards their realisation. It can be seen that the indicators refer to different road safety fields: road user behaviour, road design, vehicle crashworthiness and the quality of emergency medical services. A system for monitoring progresses had to be set up for most of the indicators. Finally, the progress that has been made varies substantially between the indicators; actually, as of 1998, only the target set for a reduction in drinking and driving was realised (ETSC, 2001).

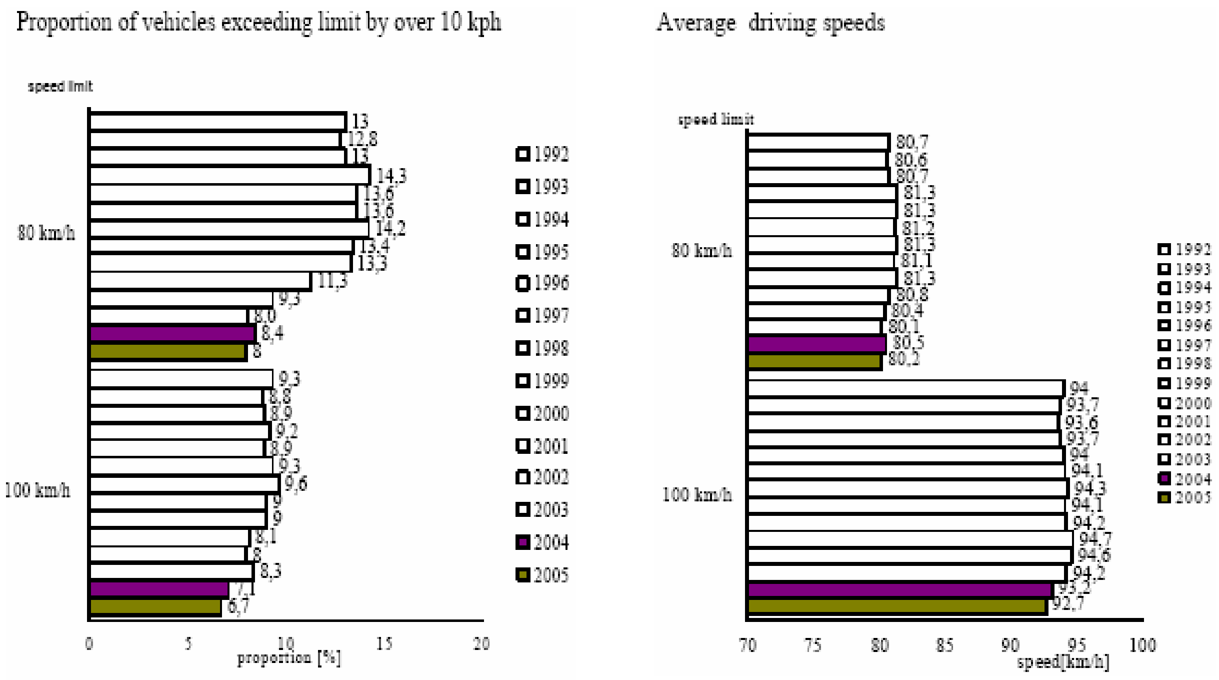
According to ETSC (2001), a number of European countries such as Sweden, Finland, the Netherlands and the UK have realised the importance and potential benefits of systematically monitoring driver behaviour and of creating safety performance indicators. Repeated measurements are performed on a regular basis, which enables the assessment of traffic behaviour trends and of the impacts of countermeasures applied/ the success of casualty reduction programmes. The most frequently covered areas are travel speeds, drinking and driving, use of vehicle restraint systems.

In Finland, the Traffic Behaviour Monitoring System was established in 1992, for the purpose of systematic data collection. Liikenneturva – the Central Organisation for Traffic Safety in Finland, maintains the system for the monitoring of traffic safety work (Luukkanen, 2003). The traffic behaviour measurements included in the system are: speeding, close following, drunk driving, seat belts' use, bicycle helmets' use, daytime running lights, direction's indication by vehicles, reflectors' use by pedestrians, red lights' compliance by pedestrians. Figure 2.5 and Figure 2.6 provide examples of the results of long-term behavior monitoring in Finland: SPIs estimated in the fields of speed and seat belt use, accordingly.

Policy reform	**Indicator**	**Target for the year 2000 compared to the situation in 1994**	**Results achieved by 1998 compared to 1994**
Valuation of road safety	Percentage of the population who regard road accidents as a public health problem	+30%	No measurements have been made
Drinking and driving	Percentage above the legal BAC limit	-27%	-40%

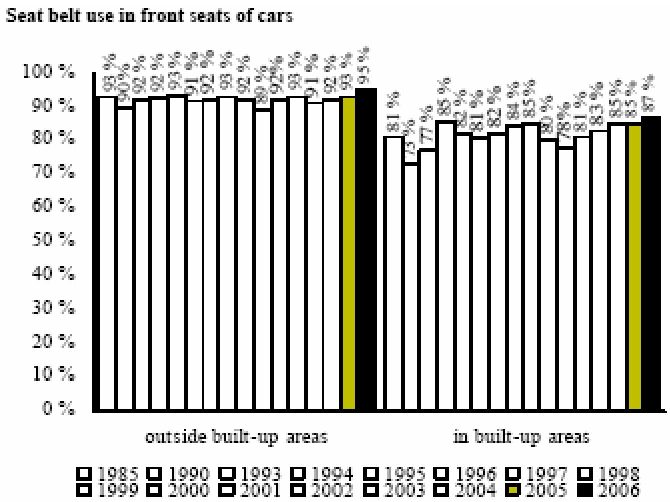
	in police checks		
Speeding	Percentage of all vehicle kilometres of driving exceeding speed limits	-35%	No change
Other violations	Percentage of vehicles following too closely	-50%	No change
Safer urban traffic environment	Proportion of streets that do not satisfy safety standards	Reduction	No change
Safer rural traffic environment	Proportion of rural roads that do not satisfy safety standards	Reduction	No change
Use of protective devices in cars	Percentage of car occupants using safety devices	95%	No change
Safer cars	Index for crashworthiness	+12%	No measurements have been made
Visibility in traffic	Percentage of pedestrians and cyclists using reflective devices	60%	No measurements have been made
Use of cycle helmets	Percentage of cyclists wearing helmets	80%	18% wore helmets in 1998
Emergency medical services	Average response time from alarm to treatment; knowledge of first aid	Shorter response time; improved knowledge of first aid	No change

Table 2.3 Road safety indicators and their monitoring in Swedish road safety programme for 1995-2000 (ETSC, 2001).



A B

Figure 2.5 SPIs of speeds on rural roads in Finland, in 1992-2005: (A) the proportion of vehicles exceeding speed limits over 10 kph and (B) average driving speeds, in 80 kph and 100 kph speed limit zones. (Figures taken from Liikenneturva 2006.)



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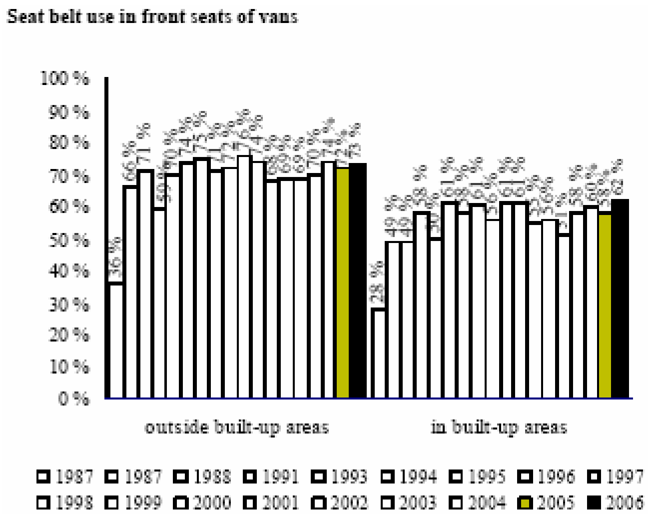

B

Figure 2.6 SPIs of the use of seat belts in Finland: (a) in front seats of cars, in 1985, 1990, 1993-2006; and (b) in front seats of vans, in 1987, 1988, 1991, 1993-2006. (Figures taken from Liikenneturva 2006.)

Main safety-related behaviour indicators which are monitored in Sweden are (Brude, 2005): seat belt use by car drivers, use of bicycle helmets, alcohol (in terms of drink-driving offences) and speeds (the proportion of vehicles traveling above speed limits on state-maintained roads). Values of indicators estimated in 1996-2004 are given in Figure 2.7.

SEAT BELT USE

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean 1996-98
Car drivers (%)	89,0	88,3	89,4	90,4	90,1	90,3	91,2	91,3	91,8				88,9

Note: Figures noted for 1992-1995 were 87,1, 87,9, 88,7 and 88,2 %
Source: VTI, Hans-Åke Cedersund

USE OF BICYCLE HELMETS

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean 1996-98
Totals (%)	15,2	16,1	17,7	16,1	16,0	15,4	17,1	18,0	*21,0*				16,3

Note: Figures noted for 1990-1995 were 6,4, 7,2, 7,4, 8,6, 10,7 and 13,5 %.
Source: VTI, Sixten Nolén

ALCOHOL (drink driving offence, drove after drinking more than low-alcohol beer)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean 1996-98
Drink driving offence	15023	13551	12127	*12356*	*12718*	14254	14924	15351	15549				13567
Note: Figures noted for 1990-1995 were 25508, 26100, 24563, 24298, 21011 and 17078							*Source: BRÅ*						
Drove after drinking	7,4	9,0	9,7	8,7	8,6	7,2	7,4	8,7					8,7
Note: Figures noted for 1990-1995 were 12,4, 11,8, 10,2, 11,6, 10,2 and. 9,0							*Source: Road Administration*						

SPEED (proportion of vehicle km above permitted speed on state-maintained roads)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean 1996-98
Cars without trailers (%)	53	52	53	52	53	56	56	57	55				52
Lorries with trailers (%)	65	68	72	72	73	73	74	74	76				68

Source: Road Administration

Figure 2.7 Road behaviour SPIs monitored in Sweden (Figure taken from Brude, 2005).

Following ETSC (2001), the SPIs for roads should concern three groups of issues:

1. Is there a safety norm or standard, e.g. a set of requirements for roads? If there is, how many injuries/ accidents would be saved had the standard been met?
2. Are there official plans to meet the norm/ standard and if there are, for which proportion of the road network is a plan defined for meeting the standards?
3. Which proportion of the road network actually meets the requirements?

As found by ETSC (2001), road SPIs are rarely included in safety management. However, several countries have started or plan to work with this kind of indicators. For example, the Start-up programme on sustainable safety in the Netherlands stimulated the extension of 30 kph zones inside built-up areas, from 10% to 50% by 2002; the introduction of a concept of 60 kph zones for minor rural roads – on 3,000 km by 2002, etc.

Besides, ETSC (2001) suggested to consider, for international comparisons, two types of road safety indicators. One of them is the proportion of accidents occurring at high risk sites compared to all accidents; however, it would require agreement on the exact definition of high risk sites. Another indicator is the difference in risk between the least safe and the "mean" road in each category, where the risk is estimated from the number of fatalities/ accidents and exposure (or road lengths). However, the applicability of such indicators depends on similarity of road categories defined in different countries as well as on homogeneity of roads included in the same category.

Concerning vehicle-related indicators, it was stated (ETSC, 2001) that regular vehicle inspections or vehicle defects are hardly suitable to serve as indicators due to their limited associations with crash causation. Instead, recognising a significant safety potential of the EuroNCAP crash test programme, it was suggested to consider as a vehicle SPI the frequency of number of stars for the vehicle fleet in each country.

Recognising the importance of the post-crash care by emergency services, compliance with the norms regarding response time and the availability of specialised trauma centres for treating severe injuries were suggested as the SPIs for development in this field (ETSC, 2001). However, as noted by ETSC (2001), indicators for response time are generally not used in road safety programmes.

In view of the large number of potentially relevant road transport SPIs, a selection of a small number of important indicators was recommended for the development and application (ETSC, 2001) – see Section 2.3.2.

2.3.2 Recommended areas for SPIs development

Following the recommendations of the ETSC report "Transport Safety Performance Indicators" (2001), seven problem areas were selected for the SPIs' development. They are:

1. Alcohol and drug-use
2. Speeds
3. Protection systems
4. Daytime running lights (DRL)
5. Vehicles
6. Roads
7. Trauma management

A closer examination reveals that these seven domains are related to different levels of the road safety system (Figure 2.8). While “alcohol” and “speeds” address "road safety problems" (or unsafe system conditions), “protection systems” and “DRL” reflect countermeasures which are intended to prevent accidents ("DRL") or to lower accident consequences ("protective systems"). The domains “roads” and “vehicles” are related to a wide area of road safety interventions, whereas “alcohol” or “speeds” are related to the area of human behaviour as cause of accidents. The domain "rescue services" (trauma management) presents an additional category of road safety issues.

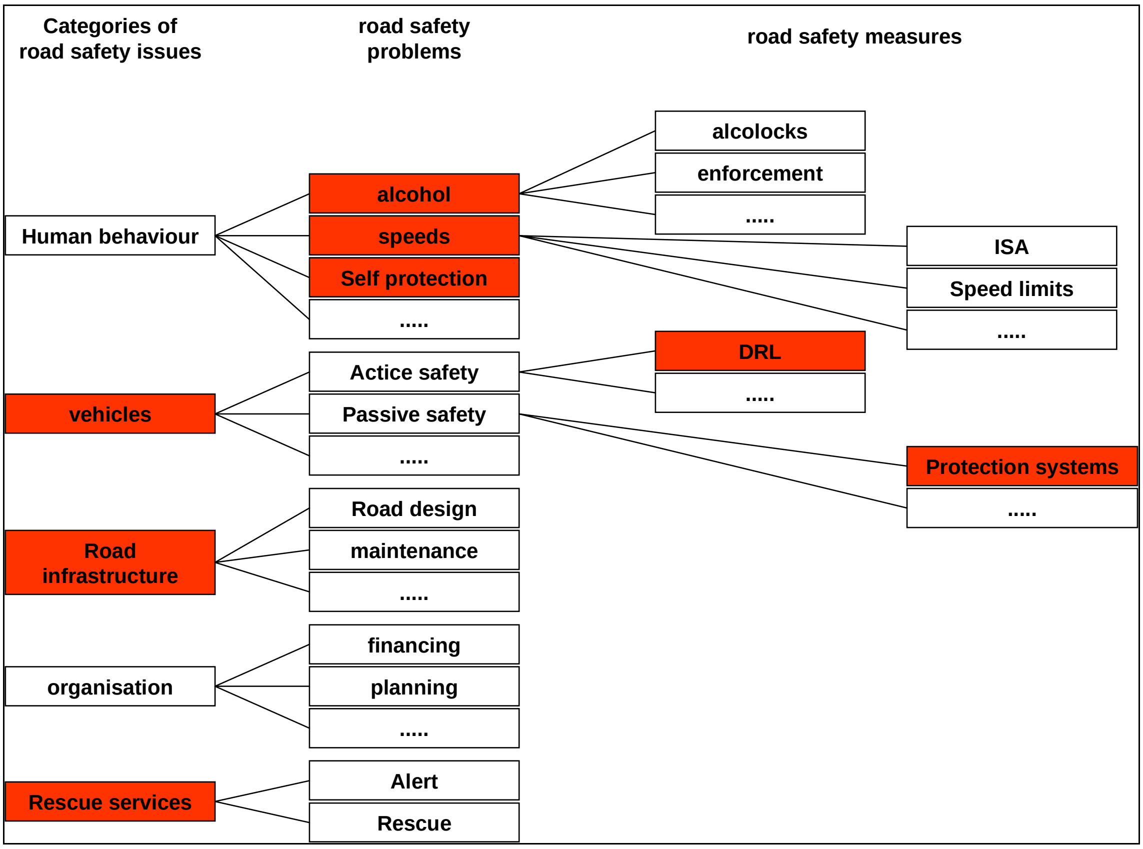

Figure 2.8 The place of the selected SPI domains in road safety system.

2.4 Requirements for SPIs

2.4.1 Quality levels of SPIs

Three quality levels of SPI can be identified:

- Direct measurement of the identified unsafe operational conditions is possible. In this case the indicator will cover the complete scope of the problem and will react to all possible interventions.
- Direct measurement of the identified problem is not possible. The identified problem can be seen as a latent variable. Describing the latent variable by several indirect variables as indicators will bridge this gap. This will be the normal case in the SPI development, where the solution should be in searching for several indicators, which are independent from interventions and describing the latent variable. Finding valid indicators to describe the latent variable would also reach the objective.
- Considering the expected availability of data and assessing the reasonable effort for data acquisition, in some cases it would be difficult or even impossible to develop an SPI independent from interventions. In this case one would have to cross the dividing line between operational conditions of road traffic and interventions, which are intended to improve the operational conditions (see Figure 2.3). Doing this means to give up independence from interventions and to bridge the gap by sub-dividing the problem.

For example, in the case of “speed-related accidents” we can identify the problem of ”inappropriate speeds“, which actually should be subdivided into two parts:

1. Inappropriate speeds below speed limits;

2. Exceeding speed limits.

Obviously, we do not have an indicator which can cover the complete scope of the problem (a direct measurement in not possible). For the characteristic of "exceeding speed limits" free-flow speed measurements can be defined and relevant speed measures (e.g. percentage of travelling over the speed limit) can be estimated; in other words, for this part of the problem, latent variables may be suggested. At the same time, "inappropriate speeds below speed limits" are not easily measurable; the scope of this part of the problem can be estimated by a number of indirect ways, e.g. through selected police accident files, in-depth accident investigations, engineering assessments, etc.

In the case of infrastructure-related accidents, due to the variety of problems, it is unrealistic to suggest one indicator which could reflect the scope of unsafe operational conditions. Instead, existing knowledge typically concerns the impacts (safety effects) of certain infrastructure improvements. This implies that we can have a series of intervention-dependent indicators. In this case, relevant questions are: (1) which part of the problem is covered by each indicator, and (2) how to combine the indicators together in order to characterize the whole problem.

Generally speaking, the stronger the dependence on interventions, the more sub-divided the problem is. Defining separate indicators it is important not to lose the transparency of what is measured.

The more an indicator is related to the area of interventions (i.e. the more the problem is sub-divided), the more the following questions are gaining in importance:

1) What should the intervention affect? What is the problem referred to by the SPI?

2) What should be achieved? How should the problem be solved?

3) How should the intervention work?

4) Which part of the problem is not covered?

5) Is one indicator sufficient and why? Are more indicators needed?
6) On which interventions does the indicator not react? Justify why this indicator is nevertheless suitable.

For the elaboration and derivation of a suitable set of SPIs, which is intended to describe the development and improvement of the most important problems of road safety in Europe, it is necessary to follow a common methodology, not least to give a general methodological framework for further indicators.

Providing politicians, decision-makers and the public with information about the level of road safety in European countries requires to ensure the reliability and validity of used SPIs as well as to make transparent what is measured. A common methodological framework can serve this purpose and herewith increase the acceptance and applicability of SPIs.

2.4.2 Elaborating the procedure

Developing a coherent set of SPIs one should start with the consideration at the same level of hierarchy (see Figure 2.3). Therefore it is necessary and useful to apply for every SPI domain the same procedure of elaboration.

The instrument for this elaboration procedure is the step-sheet as presented in Table 2.4. The step-sheet ensures consistency of the process and with that the use of a uniform methodology for the development of SPIs. The step-sheet describes the initial steps to be done and questions to be answered to come to a consistent set of SPIs.

Task number		**SPI**
0	**Level 0**	Describe:
	Key information: Exact definition of the problem; which operational conditions of road traffic are unsafe and lead to accidents or fatalities as the „worst case“	

1	**Level 1**	
a	Direct measurement possible?	Yes: Go to 1b / No: Go to 2
b	How can the identified problem - the unsafe operational conditions - be measured?	
		a) Query of availability. b) If it is predictable that the data performing this indicator would not be available, go to 2

2	**Level 2**	
a	Are there suitable indirect indicators to describe the latent variable?	Yes: Go to 2b / No: Go to 3

b	Which indirect indicators are suitable to describe the latent variable and how?	
		a) Query of availability. b) If it is predictable that the data performing this indicator would not be available, go to 3

3	**Level 3**	
a	Can the problem (level 0) be divided into sub-problems to get handled?	Yes: Go to 3b / No: Go to 4
b	The following questions have to be answered to explain the extend of the SPI referring to the problem (level 0):	
	To which interventions is the indicator related?	
	What should the intervention affect?	
	What should be achieved? How should the problem be solved?	
	How should the intervention work?	
	Which part of the problem is not covered?	
	On which interventions the indicator does not react? Justify, why this indicator is although suitable?	
	Is one indicator sufficient and why, or do we need more?	
		a) Query of availability. b) If it is predictable that the data performing this indicator would not be available, go to 4

4	**Level 4**	
a	No suitable SPI is available to indicate the problem (level 0) or the sub-problems (level 3)	Any measurement on a lower level can (only) indicate the application stage of a road safety measure.

Table 2.4 Step-sheet for elaborating SPIs.

The above procedure was applied, in a direct or indirect form, to the selected problem areas (see a list section 2.3.2). Relevant considerations are presented in Chapters 3 to 9.

2.4.3 Important considerations in creating SPIs

Safety performance indicators are the measures (indicators), reflecting those operational conditions of the road traffic system, which influence the system's safety performance. SPIs are comprehensible tools to provide a better understanding of current safety conditions and to monitor policy interventions.

The following aspects should be taken into account for creating SPIs:

1. target group;
2. optimal versus realizable SPIs.

The main target group of SPIs users are policymakers. By using SPIs, they can ensure that their actions are as effective as possible and represent the best use of public resources. Therefore, the indicators should be easy to understand for experts and the general public. Any indicator is an oversimplification and carries with it an inherent risk of misuse. That is why for users the knowledge of the intention, assumptions and limitations of different types of indicators and data are important. The intended meaning of the indicator should be clear, even when computational methods are not. A set of indicators should reflect all relevant objectives and not be too capacious. Using a large number of indicators can result in a lack of focus with the consequence of little influence on the decision making process of politicians. The arrangement of SPIs in categories like “most important” (should usually be used, a small number), “helpful” (should be used if necessary) and “specific” (should be used to reflect particular needs or objectives) can be useful for the SPIs' application.

Under normal circumstances the optimal indicator for a problem would be a direct indicator. Often this is not realizable. In that case indirect variables which describe the problem can be used as indirect indicators. If this is also not possible, the problem can be divided into several sub-problems and the indicator can be established for each of those. In this case the initial problem is not completely covered any more.

Indicators are useful to support efficient reporting on safety performance to the public and politicians. They provide conclusive information on the improvement or deterioration of safety performance and allow periodic refinement of programs by giving intermediate results. For this purpose it is important to identify the audience (e.g. a tool for policy makers to evaluate policies and programs or to assess trends) and exactly what the indicator is intended to communicate.

Constructing composite indicators is possible, but difficult, because any weighting process is value-laden and perhaps no longer neutral. General methodology on constructing composite indicators is described in a handbook OECD (2005).

Ideally, the developed SPIs should:

a) Be sensitive to significant changes in the system's conditions and over time, particularly in response to focused interventions such as policy changes; however, they should not be subject to manipulations.

b) Be invariant and independent from changes of non-focused circumstances.

c) Cover a meaningful range of changes in the systems' conditions. The message of the indicator and interpretation of changes of the value should be comprehensible, clear and simple.

d) Be sensitive to the influence of external factors like changes in population structure, in legal conditions of road traffic, traffic volumes or mobility behaviour in time or between countries.

e) Be estimated in a statistically reliable and valid manner and be of good and homogeneous quality.

f) Be comprehensible, because visualisation of results is important.

Finally, developing and applying SPIs one should recognize that some limitations are characteristic to this approach, as follows.

a) More general SPIs play mostly descriptive and not explanatory roles for "final outcomes" (accidents/ casualties). As mentioned above, an SPI may serve as a good visual tool to demonstrate the development of a safety-associated factor. However, as known, real accident/casualty changes typically stem from a range of factors, therefore, a direct interpretation of parallel changes in both an SPI and "final outcomes" should be avoided.

b) A comparison of SPI values is applicable for similar conditions only. For example, these should be similar road types, comparable traffic flow conditions, etc. Also, the conditions for which SPIs are estimated should be defined explicitly, where the remaining differences between the compared entities should be underlined. (For example, when comparing travel speeds on motorways existing differences in speed limits should be indicated; comparing the levels of DRL use, the differences in the related laws among the countries should be shown; etc).

c) Interrelations between different SPIs are possible. For example, a higher level of the vehicle fleet in the country will probably be associated with a better use of protective systems in cars and a higher level of DRL use; better characteristics of the road system may provide a quicker access for emergency services; etc. On the other hand, it is known from accident statistics that alcohol use and speeding may go hand in hand; etc. Such interrelations between different SPI groups are not considered in the current study.

2.4.4 Common structure for the presentation of SPIs in different domains

The next chapters of this report present the development of SPIs for seven problem areas which were introduced in section 2.3.2: Alcohol and drugs (Chapter 3), Speeds (Chapter 4), Protective systems (Chapter 5), DRL (Chapter 6), Vehicles (Chapter 7), Roads (Chapter 8) and Trauma management (Chapter 9).

Based on the methodological basics and tools for the SPI development, which were discussed in this chapter, a detailed presentation of the SPIs developed for each specific problem area will be given using the following common structure.

First, a relationship between the problem area and road safety is discussed. In this context, the scope of accident/ injury/ fatality reduction potential associated with better system's operational conditions (stemming from the improvements in a certain problem area e.g. lower speeding, better vehicle passive safety, etc) is presented. Based on a literature survey, available estimates of reduction potential are provided.

Second, a background for developing SPIs for the problem area is presented. In this context, characteristics of the system's performance, user behaviour, etc are analysed in order to select those of them which can be measured and quantified. A literature survey is presented to demonstrate the examples of SPIs in use by different bodies (countries, authorities) and/ or research studies.

Third, the way for developing the SPI concept in a specific problem area is presented. Such a way may stem from the structure of the area considered, from the available experiences with measurements of similar characteristics, or accounts for available databases, etc. The quality issues and the elaborating procedure (see Sec. 2.4.1-2.4.2) are sometimes explicitly discussed in this context. The initially developed SPIs are verified for their applicability based on the responses received on the SPIs' Questionnaire (details on the SPIs' questionnaire are given in SafetyNet, 2005). Finally, the suggested SPIs per area are presented in detail, in the form of a diagram.

Chapter 10 summarizes the SPIs suggested for different road safety domains.

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3 Alcohol and drugs

ASSUM[A], T., HOLLÓ[B], P., HOUWING[C], S., MATHIJSSEN[C], R.

[A]TØI, [B]KTI, [C]SWOV

3.1 Introduction

3.1.1 The problem of driving under the influence of alcohol and drugs

Driving under the influence of alcohol probably increases the risk of road accidents more than most other traffic law violations. The problem of alcohol and road traffic is described in ERSO (2006). The accident risk of drivers impaired by alcohol increases very much with the blood alcohol concentration (BAC) of the driver (Elvik and Vaa 2004, p. 975; ERSO 2006, p. 10-12) and this risk is higher for younger drivers than for middle-aged and elderly drivers. The accident risk of other road user groups such as pedestrians or bicycle riders impaired by alcohol is less known than that of motor vehicle drivers, but there may be reason to believe that the accident risk increases with the BAC for these road user groups as well.

The risk of driving under the influence of drugs is less known than the risk implied by alcohol, because the number of substances is large, and the most frequently used drugs vary over time and between countries. Moreover, drugs include legal, medical drugs in prescribed doses, illicit drugs, medical drugs in abuse doses, as well as combinations of drugs and alcohol. A report from the IMMORTAL project (Assum et al 2005) shows that the accident risk of a driver who has taken morphine or heroin is 32 times higher than the risk of driver with no drugs or alcohol, alcohol alone above 1.3 g/l gives a risk 87 times higher, and the combination of alcohol above 0.8 g/l and drugs gives a risk which is 179 times higher than that of a driver with no drugs or alcohol. Cannabis (marijuana) does not seem to increase accident risk significantly, according to this study.

More research is needed concerning the accident risk of the various drugs, as well as the doses and combinations of drugs. The new project DRUID – "Driving under the Influence of Drugs, Alcohol and Medicines" starting in November 2006, will continue this kind of research.

3.1.2 Scope of the reduction potential

As the risks implied by alcohol and drugs are quite high, the potential for accident reduction by reducing the use of alcohol and drugs among road users should also be quite high. However, reducing this problem may not be easy, but countermeasures such as adequate legislation and enforcement combined with information campaigns may be effective. For alcohol a low legal BAC limit for motor vehicle drivers is basic, a limit above which driving is illegal whether or not an accident is made. Most European countries have such BAC limits, but the enforcement of the legal limit may be increased in many countries.

Some countries, such as Germany and Sweden, have introduced legal limits for other substances than alcohol. The accident reducing effects of such countermeasures are not very well known. Legislation allowing for random substance testing without prior suspicion, such as most countries allow for alcohol, may be an effective countermeasure, especially as new screening devices to detect other substances are being developed, e.g within the DRUID and ROSITA projects.

3.1.3 Available estimates of reduction potential

Meta-analyses of the effects of blood-alcohol concentration legislation and drink-driving enforcement show substantial accident reduction potential. The introduction of drink-driving laws reduces fatal accidents by 26% and increasing the drinking age reduces fatal accidents by 24% on the average. Drink-driving enforcement may reduce fatal accidents by 9% (Elvik and Vaa, 2004, pp. 977 – 983). It seems reasonable to believe that similar reduction potentials exist for drugs implying accidents risks of the same magnitude as alcohol.

3.2 Background for developing SPIs

3.2.1 What can be measured and quantified

According to the theoretical framework of the SafetyNet project, the 'ideal' Safety Performance Indicator (SPI) of the alcohol and drug related road toll would be the prevalence and concentration of impairing substances among the general road user population. There are, however, major methodological problems associated with this SPI. Some of them are due to judicial impediments and others to practical obstacles.

One judicial impediment is the fact that in some countries (i.e. the UK and Germany) mandatory random testing of road users by the police is prevented by the constitution. In other countries random breath testing for alcohol is allowed, but random testing for drugs other than alcohol is not allowed. When random testing of road users – whether for all drugs or drugs other than alcohol – is not allowed mandatory testing of road users is only possible if they are *suspected* of alcohol or drug related impairment. In all other cases, testing is only possible on a voluntary basis, which will result in non-response rates that are (much) higher than the proportion of alcohol and drug positive road users.

Another judicial impediment is that in all EU countries pedestrians are excluded from mandatory testing by the police, because drink driving laws do not apply to them. This is a major drawback, as there may be reason to believe that the impairment of pedestrians may contribute to road accidents. The results of a study carried out by the British Transport Research Laboratory (TRL) show, according to the Sunday Times (d.d. 13 November 2005, p. 2) that, in 2003, 38% of killed pedestrians aged 16 and above who were tested for alcohol, had a BAC over the legal limit of 0.8 g/l. The proportion of killed car drivers with a BAC over the legal limit was significantly smaller, namely 22%.

A methodological problem resulting from practical obstacles is the difficulty of defining and taking a sample that is in all aspects representative of the general road user population of a country, even if pedestrians are ignored. Therefore, roadside surveys are generally focussing at the psychoactive substance use of one road user category (car drivers) often during selected time periods, such as weekends or night-time hours. Further limitations may regard road type, period of the year or certain parts of a country. These limitations may prevent a valid comparison between countries since, from one country to another, impaired driving may strongly vary by transport mode, road type, period of the year, day of the week and time of the day. Even within one country, the comparability over time may be questionable.

Moreover, the practical problems will only increase when all EU countries will have to agree on a common sampling and testing protocol. Simultaneous random testing for alcohol and drugs is not only very expensive but also time consuming which will result in relatively small road user samples or very high data collection costs.

Consequently, using the prevalence and concentration of impairing substances among the general road user population as the SPI for alcohol and drugs has been rejected.

When the “ideal” SPI cannot be realized, an SPI that may be less 'ideal' from a theoretical point of view, but more feasible in practice is needed. Such an SPI could be:

The number and percentage of severe and fatal injuries resulting from road accidents involving at least one active road user impaired by psychoactive substance (concentration above a predetermined impairment threshold).

The *number* allows assessment of the (societal) cost per country in absolute terms, but it is not suitable for comparison between years and countries, because it is very sensitive to other factors than psychoactive substance abuse that influence accident risk like the state of roads and vehicles, the quality of trauma care, etc. To compare between countries and over time the *percentage* should be used, i.e. the percentage of severe and fatal injuries resulting from road accidents involving an impaired road user among all severe and fatal injuries.

Even though this SPI is more feasible than the one discussed in paragraph 1, it cannot be realized as yet. However, it can be implemented step by step, starting with the BAC of fatally injured drivers and gradually extending to a larger set of psychoactive substances used by all active road users involved in severe injury crashes. The successive requirements for each step would be:

- Mandatory blood testing of all fatally injured drivers (who decease, e.g., within 12 hours after the crash), for a fixed set of psychoactive substances; blood sampling by coroner or hospital medical staff.
- Mandatory blood testing of all fatally injured active road users (who decease, e.g., within 12 hours after the crash), for a fixed set of psychoactive substances; blood sampling by coroner or hospital medical staff.
- Mandatory breath or blood testing of all active road users involved in fatal accidents, for a fixed set of psychoactive substances; breath testing by the police, blood sampling by police doctor, coroner or hospital medical staff.
- Extension of procedures mentioned under 1-3 to severe injury accidents, starting with testing severely injured drivers and resulting in testing all active road users involved in severe injury accidents. For comparisons between countries, the inclusion of severe injuries will require that the same definition of severe injuries is applied in all countries. There may also be a problem of unreported severe injuries which may vary between countries.

Presently some countries have reached step 1, 2 or 3 above, whereas others have no relevant data or do not reply to our questionnaires. To be able to compute an SPI now, we have to adjust the definition to the data available in at least some countries, i.e. we concentrate on the impairment of drivers, i.e. drivers of motor vehicles, disregarding impaired pedestrians and bicycle riders, as very few countries have data for impairment of involved pedestrians and bicycle riders. However, all road user categories, including passengers, pedestrians and bicycle riders, should be included among the victims.

Two supplementing SPIs are proposed:

1. The percentage of fatalities resulting from accidents involving at least one ***driver*** impaired by alcohol;
2. The percentage of fatalities resulting from accidents involving at least one ***driver*** impaired by drugs other than alcohol.

The difference from the ideal SPIs is that we limit impairment to drivers of motor vehicles, i.e. we leave out fatalities where the driver(s) are not impaired, but a pedestrian, bicycle rider or some other active road user is. Moreover, only fatal injuries are included. However, these SPIs are limited only to the involved drivers, but not to fatalities, i.e. all fatalities are included whether drivers, passengers, pedestrians, bicycle riders or other road user category.

The question has been raised whether all drivers under the influence should be included or only cases with “causer driver” under the influence. However, the question of who is causing the accident is likely to vary according to national legislation. In some countries, a driver above the legal alcohol limit will always be considered the “causer” no matter what else this driver or other road users have done, whereas in other countries other considerations will apply. Consequently, it is recommended that all fatal accidents involving an impaired driver be included. The problem with legal limits varying from 0.0 to 0.8 per mil between countries still remains. Harmonizing a limit for alcohol impairment is necessary in the long-term perspective to ensure comparability between countries.

3.2.2 Examples of SPIs in use (literature survey)

Outside the SafetyNet project efforts are under way in Europe to develop performance indicators in a number of safety areas. Collaboration between SafetyNet and these efforts might lead to improved SPIs also in the alcohol and drugs field.

Some countries have reliable time-series data for alcohol and/or drug prevalence in the general driver population, but most countries do not. Indicators such as the number of drink-driving convictions, police suspicion of impairment of drivers involved in accidents are also used. Most of them have flaws, and their validity and reliability depend on the data collection and analysis methods applied.

3.3 Constructing SPIs

3.3.1 Description of the way of developing the SPI concept in this area – the general concept

The fundamental question is whether the SPI should be related to the general road user population or limited to accident involved road users. As described in section 3.2 an SPI related to the general road user population may be theoretically correct, but is difficult in practice. An advantage of an SPI limited to accident involved road users, is that the SPI can be based on the *total* number of accidents, rather than a sample, Thus the uncertainty arising from statistical sampling is avoided. Another question which is also discussed in section 3.2 is whether the SPI should be concerned with all active road users or with drivers of motor vehicles only. As to the latter question a compromise is to start with the motor vehicle drivers and expand to bicycle riders and pedestrians later on. Other considerations are which? concentrations of alcohol and drugs should be considered and for the drugs, which kinds of drugs, medical, illicit or both. The use of drugs may vary quite a lot between countries, and a common drug in one country may be irrelevant in another. So far this issue has hardly been discussed. Very few countries have data for drug use. For those which have such data, any kind, number and concentration of drug that each country uses, is accepted, a fact calling for caution in comparison between countries. The most important question for comparability between countries is most likely the testing rate. To what extent are accident-involved drivers tested for alcohol and drugs in each country?

3.3.2 Responses to questionnaires as a means to examine applicability

Two questionnaires were sent to all countries with about a year inbetween. 19 countries replied to the first questionnaire, and 17 countries replied to the second one. However, judging from the data supplied by the countries, it is rather obvious that most countries had misunderstood what kind of data was needed. Except for two or three countries, it was necessary to follow up by e-mail once or several times to get the necessary data. Data for SPIs – at least in the field of alcohol and drugs – will have to be precisely defined, and an important question is whether a questionnaire is fit as a data collection instrument for this kind of data.

The most useful aspect of the questionnaire was to get a name and an e-mail address of a contact person to whom follow-up e-mail could be sent.

Of a total of 27 countries 23 countries provided data that could be used for the alcohol SPI and six countries provided data for the drug SPI.

3.3.3 Description of suggested SPIs

Three SPIs are proposed:

- The number and percentage of severe and fatal injuries resulting from road accidents involving at least one active road user impaired by psychoactive substance (concentration above a predetermined impairment threshold).
- The percentage of fatalities resulting from accidents involving at least one ***driver*** impaired by alcohol.
- The percentage of fatalities resulting form accidents involving at least one ***driver*** impaired by drugs other than alcohol.

The first one is not yet possible to realise. Consequently the two latter are proposed as realisable for some countries at present.

The SPI-alcohol has been computed for 23 countries of a total of 27. Only six countries have sufficient data for the SP-drug to be computed. The SPI for alcohol varies from 4.8% in the Czech Republic to 28.8% in France, disregarding the figures for Spain and Italy, which in the case of Spain is a slightly different statistic and in the case of Italy is likely to be an error. However, the French SPI result is likely to be an overestimation as it is computed on the basis of the fatalities for which the BAC level of the drivers was known. For Belgium the SPI is 8.2%, but it is estimated that only some 20% of drivers involved in fatal accidents are tested for alcohol. If this estimation is taken into consideration, the SPI for Belgium would have been 40.8%.

A fundamental question here is whether the variation between the countries is real or due to methodological variations. The blood alcohol concentration limit and the kinds of road users included vary between countries. If we study the data more deeply, additional differences between countries are likely to appear. The most important question, however, may be to what extent are drivers involved in fatal road accidents tested for alcohol and drugs, as the above example from Belgium clearly illustrates. Strict harmonization of definitions, data collection and data analysis methods is required to make the SPI results comparable.

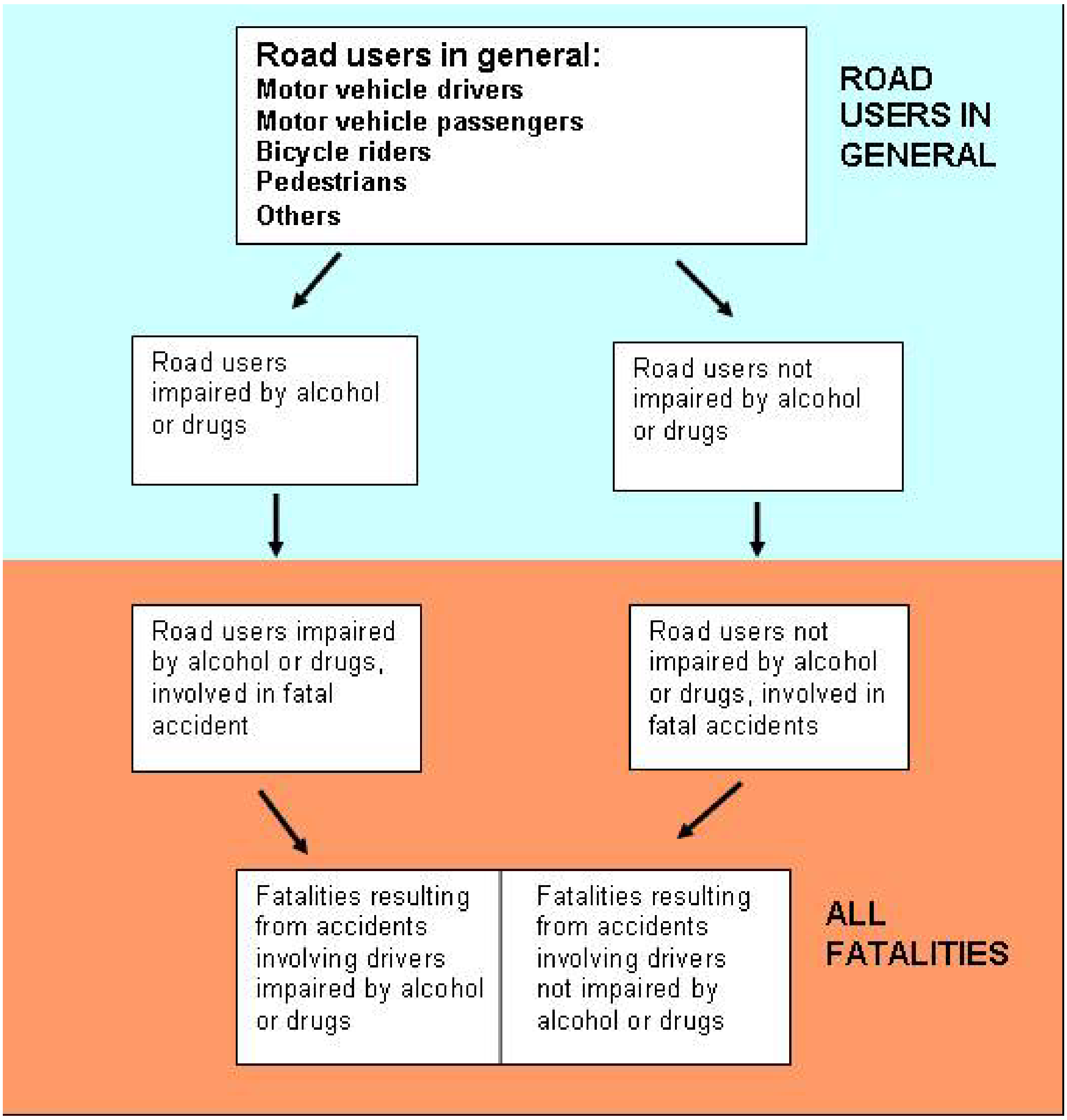

Figure 3.1 SPIs for alcohol and drugs.

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4 Speeds

RIGUELLE, F., GOLDENBELD, C.
[A]IBSR, [B]SWOV

4.1 Introduction

4.1.1 The problem

Speed is one of the main causes of accident and hence, a major issue for road safety. To some extent, speed is involved in all accidents: no speed, no accidents. More precisely, Bowie and Walz (1994) report that speed is cited as a related factor in 30% of fatal accidents and 12% of all accidents. The Transportation Research Board (1998) confirms that speed has been found to be a major contributory factor in around 10% of all accidents and in around 30% of the fatal accidents. Similarly, excessive speed for conditions was identified by Treat et al. (1977) as the second most frequent accident causal factor out of approximately 50 drivers, vehicle, and environmental factors.

The relation between speed and accident is abundantly studied in the literature. The following discussion is mainly based on Aarts and Van Schagen (2006) and Stuster, Coffman and Warren (1998) reviews of this literature.

Speed and the risk of accident

Speed affects the risk of getting involved in an accident. Higher speeds leave drivers less time to react to changes in their environment than lower speeds. The distance a vehicle travels while the driver reacts to a hazard and the stopping distance are larger at high driving speeds than at low driving speeds. Manoeuvrability is also reduced. Moreover, the other motorists, bicyclists or pedestrians have also less time to react to the arrival of a vehicle travelling at high-speed.

Several speed-crash studies looked at **absolute speed**, either at individual vehicle level or at road section level. All of them conclude that there is an increase of the accident rate with an increase in speed. However, there are some differences in the exact form of the function linking speed and crash rates. Studying individual vehicle speed, Maycock et al. (1998) and Quimby et al. (1999) found power functions while Fildes et al. (1991) and Kloeden et al. (1997; 2001) found exponential functions. In his famous study of 1982, Nilsson quantified the link between average speed at the road section level and the accident rate by means of several power functions (depending on crash severity levels). These functions have been widely used since and evaluated by Nilsson (2004) and Elvik et al. (2004) who confirm their reliability. So, the findings of all the above studies basically mean that the higher the speed, the steeper the increase in accident risk. Conclusions from Finch et al. (1994) conclusions were somewhat different. They stated that a speed reduction of 1 km/h corresponds to a decrease in crash rate of 3%, independently of the initial speed. However, it is very implausible that that a reduction of 1 km/h in average speed always results in an equal reduction in crash rate for all different reference speeds (Elvik et al., 2004; Aarts and Van Schagen, 2006). In a different type of study, Taylor et al. (2000) showed that the accident risk increases with the proportion of drivers over the speed limit. The accident risk grows by 10% if the proportion of offenders doubles.

The speed-crash rate relation is further complicated by the fact that crash rate is not only related to absolute speed, but also to **speed dispersion**. Indeed, if vehicles in the same lane travel at different speeds, the probability of an encounter is higher than if they drive at similar speeds (Hauer, 1971; Elvik et al., 2004). An increased risk of crash involvement results of the potential conflicts from faster traffic catching up with and passing slower vehicles.

A lot of studies emphasized speed variance, rather than absolute speed, as the primary culprit in the incidence of crashes, starting with the study of Solomon (1964). He found a U-shaped relationship between vehicle speed and crash incidence on rural highways. The accident rate increased with greater deviations above and below the mean speed. Further, Solomon reported that the results of his study showed that "low speed drivers are more likely to be involved in accidents than relatively high speed drivers". Cirillo (1968) found similar results than Solomon for interstate freeways, but she only studied accident involving two or more vehicles travelling in the same direction. Munden (1967) showed that drivers travelling more than 1.8 standard deviations above or below the mean traffic speed had significantly higher crash rates. In a more recent study, Garber and Gadiraju (1988) reported that crash rates increase with increasing variance on all types of roadways. Harkey et al. (1990) refreshed the U-shape relationship of Solomon on an American case-study.

These findings lead some researchers to argue that reducing variance of speed was more important for road safety than reducing mean speed. Hauer (1971) and Lave (1985) both claimed that an action should be taken against slow drivers as well as fast ones instead of only fighting against speeding. However, this conclusion raises several remarks. Firstly, lower-speed accidents are very common at intersections (where drivers have to slow down) or in congested conditions (when there are the more interactions between vehicles). These two types of accidents represent 89% of the lower-speed accidents in the study of Solomon (Frith and Patterson, 2001). In both cases, the slower speed is unavoidable (required by the manoeuvre or the traffic conditions) and is not reflecting the driver choice. The Research Triangle Institute (1970) recognized that vehicles slowing to negotiate a turn should be treated differently in the analysis than vehicles moving slowly in the flow of traffic. West and Dunn (1971), who report the results of the RTI study, notify that excluding the accidents involving turning vehicles greatly attenuated the factors that created the U-shaped curve characteristic of the earlier studies. Secondly, the link between speed variance and the accident rate is only relevant for vehicles travelling in the same direction and near to each other. Variance is irrelevant for roads with a small traffic flow.

Finally rather than trying to reduce the number of accidents, it is more important to reduce the number of dead and injured people, which is narrowly linked with absolute speed. That means that reducing mean speed is surely more crucial to safety than reducing speed variance.

Several **environmental factors** play a role in the relationship between speed and accident rates. Fildes et al, (1991) report that for the same increase in speed, the accident rate increases faster on urban than on rural roads. Aarts and Van Schagen (2006) draw similar conclusions by comparing Kloeden et al. (2001) and Kloeden et al. (2002) and by summarising Taylor et al. (2000). They interpret these findings to be a result of the amount of traffic interaction and traffic composition on the different road types. Roads that are designed for high speed are mostly characterized by wider lanes, fewer junctions, and sometimes even physically separated driving lanes to reduce encounters with obstacles and other traffic. Baruya (1998) gave some empirical evidence to that. He found that not only wide lanes and low junction density, but also low traffic flows greatly reduce the increase of crash rate with increasing speed. Garber and Gadiraju (1998) found that design speed has also an influence on speed and accident rate.

The possible effect of other factors, such as the effect of weather, obstacle density along roads, traffic composition, and 24-hour fluctuations in traffic flow, has not yet been quantified by good empirical results. These issues may be examined in future research.

Speed and the severity of accidents

Speed directly affects the severity of an accident. This is an undisputable relationship because purely based on the laws of physics. The amount of kinetic energy released in an accident depends on the masses of the colliding objects and the square of their (relative) velocity. Thus, at a higher impact speed, more energy is released when colliding with another vehicle, road user or obstacle. Part of this energy will need to be absorbed by the vulnerable human body. Generally, the more kinetic energy to be dissipated in a collision, the greater the potential for injury to vehicle occupants. And because kinetic energy is determined by the square of the vehicle's speed, rather than by speed alone, the probability of injury, and the severity of injuries that occur in a crash, increase exponentially with vehicle speed.

Solomon (1964) examined the relation between travel speed and the severity of accidents and concluded that crash severity increased rapidly at speeds in excess of 60 mi/h (96 km/h), and the probability of fatal injuries increased sharply above 70 mi/h (112 km/h). Bowie and Waltz (1994) showed that the risk of a moderate or more serious injury was less than 5% when the change in speed at impact was less than 10 mi/h (16 km/h) but increased to more than 50% when it exceeds 30 mi/h (48 km/h). Similarly, Joksch (1993) found that the risk of a car driver being killed in an accident begins to rise when the change in speed at moment of impact exceeds 30 mi/h (48 km/h) and reaches more than 50% when the change exceeds 60 mi/h (96 km/h). The probability of death from an impact speed of 50 mi/h (80 km/h) is 15 times the probability of death from an impact speed of 25 mi/h (40 km/h).

However, these studies concern car drivers. For vulnerable users, the relationship between impact speed and crash severity is even more unfavourable. Based on Schweizerische Beratungsstelle für Schadenverhütung (1976) and Ashton and Mackay (1979), the European Transport Safety Council (1995) reported that only 5% of pedestrians died when struck by a vehicle travelling at 20 mi/h (32 km/h) but that the proportion of fatalities increased to 45% at 30 mi/h (48 km/h) and to 85% at 40 mi/h (64 km/h).

Different factors can reduce the risk of injury or fatal accidents (vehicles engineering, seat-belt use, efficiency of emergency medical care, etc) but most of them do not apply for vulnerable road users.

4.1.2 Scope and extent of reduction potential

As explained above, reducing speed is the first thing to do to reduce both the number of accidents and the number of injured and dead people. In 1994, the IRTAD estimated that reducing average speeds by 5 km/h could save over 11,000 deaths and 180,000 injury accidents annually in the EU.

However, speed has a positive effect on travel time that is easily noticeable by drivers (and often overestimated). At the same time, negative effects, which mainly apply to the whole society, have less impact on most individual drivers. Thus, measures of speed management have to reduce the perceived advantages of excess and inappropriate speed, and increase the perceived disadvantages (ETSC, 1995).

Speed cannot be reduced with only one single method. Several combined actions have to be undertaken together to reach the objective of speed reduction, including actions on speed limits, road design, drivers' education and repression. We detail these different actions in the following sections.

Lowering speed limits

Speed limits are at the core of speed management. Research and international experience point to the effectiveness of speed limits, where perceived as realistic by drivers, in reducing the frequency and severity of road accidents and casualties.

Speed limits in EU are comparable on urban roads (30 and 50 km/h) and quite comparable on motorways (from 90 to 130 km/h, except in Germany), but differ much on inter-urban roads. A harmonisation is always desirable because it increases the credibility of speed limits and their knowledge by drivers. Both elements induce drivers to more compliance.

Tingvall and Howarth (1999) proposed the following guidelines for determining maximum speeds depending on different traffic situations (Table 4.1). These guidelines are part of the "Vision Zero" concept aiming to develop a system which produces no deaths or serious injuries.

Much lower speeds are appropriate at particular times and places, taking into account weather, traffic and road conditions. Hence the usefulness of actions towards variable local speed limits. Their implementation requires more technical and managerial efforts than uniform speed limits but it can be balanced by the benefits it brings to safety.

Road type/traffic situation	Safe speed (km/h)
Roads with potential conflicts between cars and unprotected road users	30
Intersections with potential side impacts between cars	50
Roads with potential head-on conflicts between cars	70
Roads where head-on and side impacts with other road users are impossible	≥100

Table 4.1:Optimal speed limits following Tingvall and Haworth (1999).

However, lowering a speed limit is not a magic formula to reduce speeds. Several studies confirm the lack of compliance of drivers with speed limits (see e.g. ETSC, 1995). In a review of international studies, Finch et al. (1994) found that lowering of a speed limit conducts to a change in average speed corresponding roughly to 25% of the change in the posted limit. Knowles et al. (1997) reported similar findings from observational before and after studies in Canada. Stuster et al. (1998) produced a review of studies evaluating the influence of a speed limit change on speed. Many of them were conducted in the US in relation to the hot topic that is the relevance of the raise of speed limits from 55 mi/h to 65 mi/h on freeways. The change in speed is consistently less than the change in the limit, even sometimes insignificant. Drivers are more inclined to keep to the posted speed limit when they perceive the speed limit as being realistic for the road. That means reflecting the function of the road, traffic composition and road design characteristics.

Nevertheless, even if the change in speed is small, crash-incidence and/or crash severity, generally decline when speed limits are lowered and increase when speed limits are raised. Again, we refer to Stuster et al. (1998) for a consequential review of studies quantifying this relation.

Road design

The road infrastructure should be designed in a way that discourages excess and inappropriate speed. The hierarchy between roads with different functions should be clear so that the road user knows on what type of road he is and what the acceptable speed is.

The transition between different types of road has to be highlighted, especially coming from a high speed road to a road where a smaller speed is required. Engineering measures can be used to create a gateway effect at the start of a low-speed zone for a built-up area.

Traffic calming techniques are rapidly expanding on European roads. They have the objective of transferring the costs associated with excessive speed from unprotected road users (i.e., death and injury of pedestrians and cyclists) to vehicle drivers and their passengers (i.e., discomfort, risk, damage to vehicle, longer travel time) (Stuster et al., 1998). Most traffic calming techniques do not need to go along with any enforcement because drivers already incur a penalty when they encounter a traffic calming system at excessive speed. However, it is difficult to evaluate the global effect of traffic calming techniques on the number of injuries and fatalities because most traffic calming projects result in changes in traffic volume. So, even if there are less injuries and fatalities on the road where the traffic calming technique have been implemented, some of them may have migrated to other roads.

Education and information

It is important to inform roads users about the consequences of speeding for road safety and about the reasons of countermeasures.

For this purpose, the first step is to inventory the attitudes which can partially explain that, in similar conditions, some people tend to drive faster than others. People have different perceptions about the risk associated with speed, speed limits and their driving ability comparing to other drivers. Elvik et al (1994) reported that people mentioned the following main arguments for intentionally driving over the speed limit: adapting their speed to the general traffic stream, being in a hurry, enjoying driving fast and being bored. A part of the European project SARTRE 3 (2004) was dedicated to attitudes related to speeding issues and it confirmed that enjoying driving fast is a very common argument to explain excessive speed (In 2002, 10 % of European admitted enjoying driving fast). However there is a decreasing trend since the last SARTRE study of 1996. Furthermore, the understanding by European drivers of the role of speeding in road accidents is increasing. However, SASTRE 3 reported that people usually associate the risk with the behaviour of other drivers but hardly admit that their own speeding can be a risk of accident.

These results prove that information and education can have an influence on people attitudes towards speeding. However, attitudes changes do not mean behavioural change on the road. It is very difficult to isolate the role of education campaign on road safety. Anyway, Stuster et al. (1998) argued that none attributed a significant reduction in speed, speeding, crashes, or crash severity to any campaign that was not closely tied to an enforcement or engineering program. Education and information campaigns must be seen as a prerequisite or a support for other measures.

Enforcement

We already mentioned that the level of compliance with speed limits is low. It means that road safety can be improved in a significant way by implementing measures aiming that drivers respect the regulation. As long as the other measures are insufficient, enforcement is needed.

The principle of speed enforcement is to penalise drivers who exceed the speed limit to incite them to more compliance. But even if a driver is not caught himself, his perception of the risk of being caught for speeding can bring him to slow down.

The level of enforcement varies very much across European countries. Due to the number of different available techniques, it is difficult to compare countries, but ETSC (2006a) evaluated that Austria and Netherlands were the countries where the most vehicles were checked for speed in 2004. ETSC further considered that the level of enforcement of legal speed limits in EU is insufficient.

The effects of speed enforcement are very limited to both time and place. When the enforcement stops, the effects will disappear within a few weeks (Vaa, 1997). The effects are largest in the immediate vicinity of the enforcement location, and fade away when distance increases (Christie et al., 2003). However, during the enforcement activities and on the enforced roads, the effects of speed enforcement can be very positive.

Most evaluation studies looked at automatic enforcement by fixed speed cameras. The best estimate is that automatic speed enforcement results in an accident reduction of 15 to 20% (Elvik and Vaa, 2004). Individual evaluation studies differ widely in the reported effects. For fixed speed cameras, the effects varied from a 5 to 69% reduction in accidents, a 12 to 65% reduction in injuries and a 17-71% reduction in fatalities (Pilkington and Kilra, 2005). The actual effectiveness depends on many factors, such as the enforcement effort, the initial speed and safety level and the type and amount of supporting publicity.

The effect of any speed enforcement initiative is substantially increased if it is supported by targeted information to the road users.

In-car technologies

New technologies also allow reducing speeds, and hence, accidents. Among them, the ISA (intelligent speed adaptation) systems have a great potential for road safety. ISA is an in-vehicle system that uses information on the position of the vehicle in a network in relation to the speed limit in force at that particular location. ISA can support drivers in helping them to comply with the speed limit everywhere in the network. This is an important advantage in comparison to the speed limiters for heavy good vehicles and coaches, which only limit the maximum speed.

Different types of ISA exist, with different degrees of interference with the driver. It goes from a simple warning about the speed limit to an adjustment of the speed by the ISA system itself. All experiences that were conducted so far, whether on field or with simulator, conclude of the positive effects of ISA on speed. The potential negative effects, including the loss of attention from drivers, need further research.

Some barriers to the implementation of ISA were identified, including the technical functioning, acceptability by the drivers, applicability to the whole network, benefits for the road users and liability issues. However, the ETSC (2006b) claimed that these barriers were overestimated and that it was time to make advances in the implementation of ISA.

4.2 Background for developing SPIs

4.2.1 Speed and its measurement

Road safety is not the only reason why speed or traffic data are recorded. These data can indeed serve several functions:

- Monitoring of the road network performance by road authorities;
- Enforcement by the police;
- Monitoring of clients behaviour by insurance companies;
- And, of course, safety research.

Even for safety research, we must distinguish between measures that have a very local goal (evaluation of the opportunity for an anti-speeding measure on one road or the evaluation of its effect) and the measures that are of interest in the framework of European safety: those that aim to give a global view of driver behaviour related to speed.

The different purposes of speed data collection imply different data and hence different methods of collection. However, the road safety researcher does not always benefit of data that were collected for a road safety purpose only.

A specificity of speed data is that they potentially comprise a massive amount of data of different vehicles, roads, seasons and times that can be disaggregated and analysed in various ways. This is why some measurement systems only produce aggregated data (e.g. average speed by one hour periods) while others stock individual data but only for small periods of measurement.

The ideal system would measure speed and the time headway, would allow determining the vehicle type with a high accuracy, would keep individual data for a long period of time and would not be expensive. However, in reality, there is a trade-off between, on one hand, data accuracy and precision and, on the other hand, the period of time that can be stored. With technological advances, we can expect that this trade-off will be less and less a problem. Some data recorders are already able to send data minute by minute to a large database by GRPS wireless communication technology. The fact that data are not stocked in the measuring system remove some constraints about the size of databases. But still, there must be a willingness to invest in powerful hardware for handling the data and in people to analyse them.

At this moment, speed data are recorded in many EU-countries by (visible or invisible) measurement loops attached to a data-recorder which classifies data according to a pre-specified format. Being not implemented for road safety purposes only, these loops are often put on high-trafficked roads and on motorways rather than on a representative sample of the national road network. Some countries complete the measurement loops system by other measuring systems.

4.3 Constructing SPIs

4.3.1 Developing the SPI concept

The relevance and quality of safety performance indicators not only depend on the choice of the indicators but also very much on how measuring locations and measuring periods are selected, which equipment is used and how data are processed.

Ideally, an SPI should stand for one clear theoretical entity. An SPI that is an aggregate of measurements of different traffic populations, and of different traffic circumstances, does not represent one thing but different things, and because of this it cannot have a clear relationship with road safety. Since traffic populations and traffic circumstances differ between road type, time of day (day vs. night), day of week (weekdays vs. weekend days), it is necessary to have different speed SPIs for different road types and different reference time periods. For example, simply aggregating speed measurements over the whole year can obscure the possibility that an extreme winter period has affected the measurement of average speed. Since EU countries may differ very much in how their winter season affects driving speeds, aggregation over the whole year impairs a fair comparison between countries.

The following sections list the main elements to be aware of in the process of constructing SPIs. It is not the aim of this document to go further than general concepts. For practical recommendations, we refer to the coming SPI manual.

Speed under normal conditions

Kloeden et al. (2002) establish a relationship between free travelling speed and crash risk. Thus, the speed SPI should represent driving under normal conditions, meaning that drivers feel comfortable to choose speed according to their own preference instead of being pressurised by exceptional or less than optimal traffic circumstances. If not, the SPI can be influenced by circumstances such as congestion, weather, special events, that may differ over time or differ between countries. Of course, congestion, weather, or special events, can have an impact on road safety, but those relationships should be part of separate study and should not confuse the meaning of the speed SPI and obscure the relationship between the speed SPI and safety.

Sampling requirements

It would be very impractical to continuously monitor the speed of all vehicles and impossible to store and analyse the resulting data. A selection of time slices, vehicles and places must thus be made by means of a sampling procedure. The validity of the final SPI is function of how the initial measuring locations have been chosen. An SPI that is representative of the speed for all national roads of one given type is only reachable if the locations have been chosen using a scientific sampling design. Otherwise, the SPI would represent e.g. speed on roads with a high traffic volume. The speed measurement system that is used greatly influences the size of the sample that is technically possible to produce.

Spatial representativeness

Theoretically, the speed population (in statistical terms) is constituted by the instantaneous speed of all the vehicles driving on the road network under normal conditions during the time period of interest. As we want to compute separate indicators for different road types, there are in fact as much different populations than there are roads types. In order to allow a practical sampling procedure, several simplifications have to be made.

- Instead of being considered as continuous, the road network for each road category has to be divided into an ensemble of small road segments. These segments should be the most internally homogenous as possible. In that way, the population becomes finite because the speed of a vehicle does not have to be measured continuously but only one time per supposedly homogenous road segment.

- Not all the road segments should be kept in the sampling frame. Indeed, in order to ensure comparability, only some kinds of road segments will be suitable for speed measurements: those where the influence of road design or environment on speed is small, meaning that the driver has to be able to drive at a higher speed than the speed limit. It typically means that road segments should present most of these characteristics:
  - Be on a straight section of road
  - Be far from junctions (>500 meters)
  - Be far from any speed calming device (> 500 meters)
  - Be far from road works (> 500 meters)
  - Be far from pedestrian crossings (> 500 meters)
  - Be far from any speed limit change or sign (> 1000 meters)
  - Be on a section with a small gradient (<5% on the preceding 500 meters)
  - Have a pavement surface in good condition

Other considerations must be added depending on the speed measuring device:

- The possible observer or the people who install the device should be able to work safely.
- The site should allow measuring speed unobtrusively.
- If each vehicle passage on each road segment was considered as the primary sampling unit, picking a simple random sample from this population would result in having to measure speed of some isolated vehicles on a multitude of different road segments, which is very impractical. The only realistic way to proceed is to concentrate on a smaller quantity of road segments and to measure speed of several vehicles on each of these roads segments. Theoretically, that means a clustered sample of the population.

However, for simplification, roads segments may be considered as primary sampling units. Indeed, speed measuring devices allow to easily measure a lot of vehicle speeds per road segments (with permanent measurement, all vehicles can even be measured). So, if we take for granted that devices measure speed correctly, the uncertainty on the average speed (or other aggregated indicator) for each road segment can be considered negligible. Considering the road segments as sampling unit thus allow simplifying the sampling problem as follow: taking a simple random sample of locations from the population of suitable road segments.

The statistical theory on simple random sampling can thus be applied to determine the number of measuring location that are needed for each road type according to the acceptable margin of error and the desired confidence level.

At this time, most countries have mainly an objective of time comparison when making their speed surveys. If the same locations are chosen every year, a small number of locations are then sufficient. But, in order to have representative sample for the whole country and make international comparisons possible, the number of selected locations has to be higher.

Time representativeness

It is known that both speed and frequency of accidents are time dependent. For instance, there may be large variations between day and night and to a lesser extent between weekday and weekend. Speed indicators should thus be disaggregated in time as it is often done for accident data. Having one indicator for each of the four period (weekday day, weekday night, weekend day, weekend night) would be the best but in a first step, countries should concentrate on producing a reliable indicator for weekday day.

In general, all the periods when speed is expected to be temporally modified should be avoided. A special attention must be allocated to weather conditions (avoid snow, heavy rain, freezing). So, one shouldn't plan to measure speed in winter because weather conditions are more likely to prevent valid speed measurements. Also holiday period should be avoided because of the changing behaviour of road users.

Road types

Speed can be seen as a central characteristic of how a particular road type performs. It is important to have a coherent classification of road types in order to be able to compare countries. Within the SafetyNet project the following functional road classification has been proposed (Table 4.2). It is recommended that countries arrange the analysis and reporting of national speed data according to this functional classification. We recommend measuring speed at least on motorways (road type AAA), single carriageway rural roads (road type A or B) and single carriageway urban distributor roads (road type D).

	Rural areas (outside built-up areas)					
SafetyNet road classes	**AAA**	**AA**	**A**	**BB**	**B**	**C**
	Motorway	A-level road 1	A-level road 2	Rural distributor road 1	Rural distributor road 2	Rural access road
Functional road category	Through-road (road with a flow function)			Distributor road		Access road
Separation of opposing directions	Dual carriageway	Dual carriageway	Single carriageway, preferable with lane separation	Dual carriageway	Single carriageway, preferable with lane separation	Single carriageway
Lane configuration	2x2 or more	2x1, 2x2	1x2, 1x3, (1x4)	2x1, 2x2	1x2, 1x3, (1x4)	1x2, 1x1
Obstacle-free zone	Very wide or safety barrier	Wide or safety barrier	Wide or safety barrier	Medium	medium	small
Intersections	Grade-separated	Preferable grade-separated	Preferable grade-separated	Preferable roundabout	Preferable roundabout	

	Urban areas (inside built-up areas)		
SafetyNet road classes	**DD**	**D**	**E**
	Urban distributor road 1	Urban distributor road 2	Urban access road
Functional road category	Distributor road		Access road
Separation of opposing directions	Dual carriageway	Single carriageway	Single carriageway
Lane configuration	2x1, 2x2	1x2, 1x3, (1x4)	1x2, 1x1
Obstacle-free zone			
Intersections			

	SafetyNet road classes		Functional road category	Separation of opposing directions	Lane configuration	Obstacle-free zone	Intersections
Rural areas (outside built-up areas)	AAA:	Motorway	Through-road (road with a flow function)	Dual carriageway	2x2 or more	Very wide or safety barrier	Grade-separated
	AA:	A-level road 1		Dual carriageway	2x1, 2x2	Wide or safety barrier	Preferable grade-separated
	A:	A-level road 2		Single carriageway, preferable with lane separation	1x2, 1x3, (1x4)	Wide or safety barrier	Preferable grade-separated
	BB:	Rural distributor road 1	Distributor road	Dual carriageway	2x1, 2x2	medium	Preferable roundabout
	B:	Rural distributor road 2		Single carriageway, preferable with lane separation	1x2, 1x3, (1x4)	medium	Preferable roundabout
	C:	Rural access road	Access road	Single carriageway	1x2, 1x1	small	
Urban areas (inside built-up areas)	DD	Urban distributor road 1	Distributor road	Dual carriageway	2x1, 2x2		
	D	Urban distributor road 2		Single carriageway	1x2, 1x3, (1x4)		
	E	Urban access road	Access road	Single carriageway	1x2, 1x1		

Table 4.2 Functional road classification.

For the same road types, speed limits vary inside and between countries. For comparisons it is essential to use roads with the same speed limits when constructing the indicator for a specific road category. Otherwise, aggregation will mask important differences and adjustment procedures for further comparison will be unpleasantly complicated.

Data processing and aggregation

In order to produce SPIs, data have to be aggregated from the road section level to the country level. However, the aggregation must be done in a way that preserves the representativeness of each of the inferior aggregation level. Let's consider that SPI_i is the value of the SPI for the road section *i,* which is part of the *n* sampled road locations and that W_i is the number of vehicles that have been measured at location *i*. The national *SPI* can be obtained as follows:

eq. 4.1
$$SPI = \frac{\sum_{i=1}^{n} SPI_i * W_i}{\sum_{i=1}^{n} W_i}$$

Equation 1 is only valid if the traffic has been measured for the same length of time in each location, thus allowing the comparison between traffic counts. If speed has been measured for different length of time T_i at the different locations, the relation becomes:

eq. 4.2
$$SPI = \frac{\sum_{i=1}^{n} SPI_i * \frac{W_i}{T_i}}{\sum_{i=1}^{n} \frac{W_i}{T_i}}$$

Some countries may also want to estimate speed at a regional level. It this case a stratified sample (with the regions being the strata) should be drawn and a minimum number of measuring locations per region fixed. Equation eq. 4.1 or eq. 4.2 can be used to calculate regional SPIs but then an exposure measure has to be taken into account for each region to aggregate to the national level. Ideally, the number of driven kilometres per region should be used. But practically, this variable is seldom known. The length of network in each region is a common proxy.

4.3.2 Questionnaire's responses as a means to examine applicability of safety performance indicators

The questionnaire was completely or partially filled by 19 countries out of 27 and most countries that did not respond do not have speed data. The included questions were useful to have a broad idea of the state of the practices in Europe but additional information had to be gathered by other sources to know more precisely if country methodologies were following SafetyNet task Speed requirements.

It should also be noted that confusion occurs sometimes between what can potentially be done with the technical possibilities of the devices used by a country and what is actually done. For example, with most traffic counters, it is possible to split out data by one hour periods but few countries publish hourly indicators. In that case some countries responded that data are split out by one-hour period because they can have these data while others that are in the same situation replied that data are not split out because they don't publish hourly indicators.

It appears that a lot of requirements are fulfilled by countries that have data. All the requirements, except for the fact of choosing measuring locations with a random sampling procedure, are satisfied by most countries. It is thus not unrealistic to ask all these requirements to countries in the process of construction of SPIs.

However, the situation is not so positive. Indeed, even if the requirements are fulfilled, there is a huge variability in the way countries do that. Two main problems must be mentioned:

Firstly, countries take the traffic conditions into account in very dissimilar ways. Some countries (e.g. Ireland, Austria) apply very strict rules to select free-flowing vehicles only. Others are satisfied with the solution of not measuring speeds during peak hours. Sometimes, speed data are aggregated over large periods of time without watching out for the traffic condition variations at all. The results of a speed survey may be very sensitive to the way traffic condition are taken into account, especially is measurements are carried out on highly-trafficked roads. The ways countries deal with traffic conditions should thus definitely be harmonised to allow valid comparisons.

Secondly, the locations chosen for speed measurement are often not representative of the national road network. Many countries do not use a sampling procedure to select their measuring locations and prefer to choose them on high traffic or high accident rate axes only. They are sometimes even not interested in a national estimate and concentrate on individual road analysis. Even if data are aggregated to the national level, it does not ensure that the resulting value is representative and comparable to other countries. In general, most countries use their speed data to make evolution studies. So, even if their speed monitoring methodology is imperfect, as long as they keep a constant methodology throughout time, they can make valid evolution studies. For example, Finland (Luukkanen, 2002) stated explicitly that their SPIs should only be used to compare one year to another but not considered as nationally representative.

On the other hand, the computation of our proposed indicators is not a big issue. All countries already compute at least two of them. All the indicators can be computed quite easily from the same datasets so there is no reason why countries would not be able to compute it. The only exception is Sweden where only journey times of vehicles over entire sections of roads are measured.

4.3.3 Suggested SPIs

In section 4.1, we reported that both absolute speed and the variability in speed influence the number of accidents at the road section level.

There is no reason why speed aggregated at the national level would not have such a link with road safety. However this is very complex to prove empirically due to the difficulty to measure the relation between speed and accidents all other circumstances being equal.

In normal driving conditions, speed data will be approximately normally distributed and the arithmetic mean, standard deviation, the 85th percentile speed and the percentage of drivers above the speed limit are the four main parameters describing the speed distribution. In terms of safety relevance, these indicators may perform differently under different circumstances. For example, changes in average arithmetic mean speed will have a strong relationship with safety on 30 and 50 km/hr roads whereas changes in standard deviation rather than changes in arithmetic mean may be a sensitive safety indicator for motorways. For evaluation of enforcement, the reduction in the number of offenders is especially relevant although this indicator may be less sensitive to safety than other indicators.

The definition of SPIs is complicated by the fact that there is no one-to-one relation between maximum speed limits and road category. For countries where there is more than one speed limit for one category of road, it is recommended to compute the SPI for the dominant speed limit (it is not convenient to aggregate data from roads with different speed limits). Along with the value of the SPI, clear information on speed limits should thus be supplied by countries. We prefer to have both the SPI and the information on the speed limit rather than one single piece of information (SPI normalised by speed limit) which is much influenced by how speed limits are decided.

Finally, we remind that SPIs should be disaggregated by vehicle types, road types, moment of the day and moment of the week.

Figure 4.1 (on the next page) summarizes the proposed indicators and their definition.

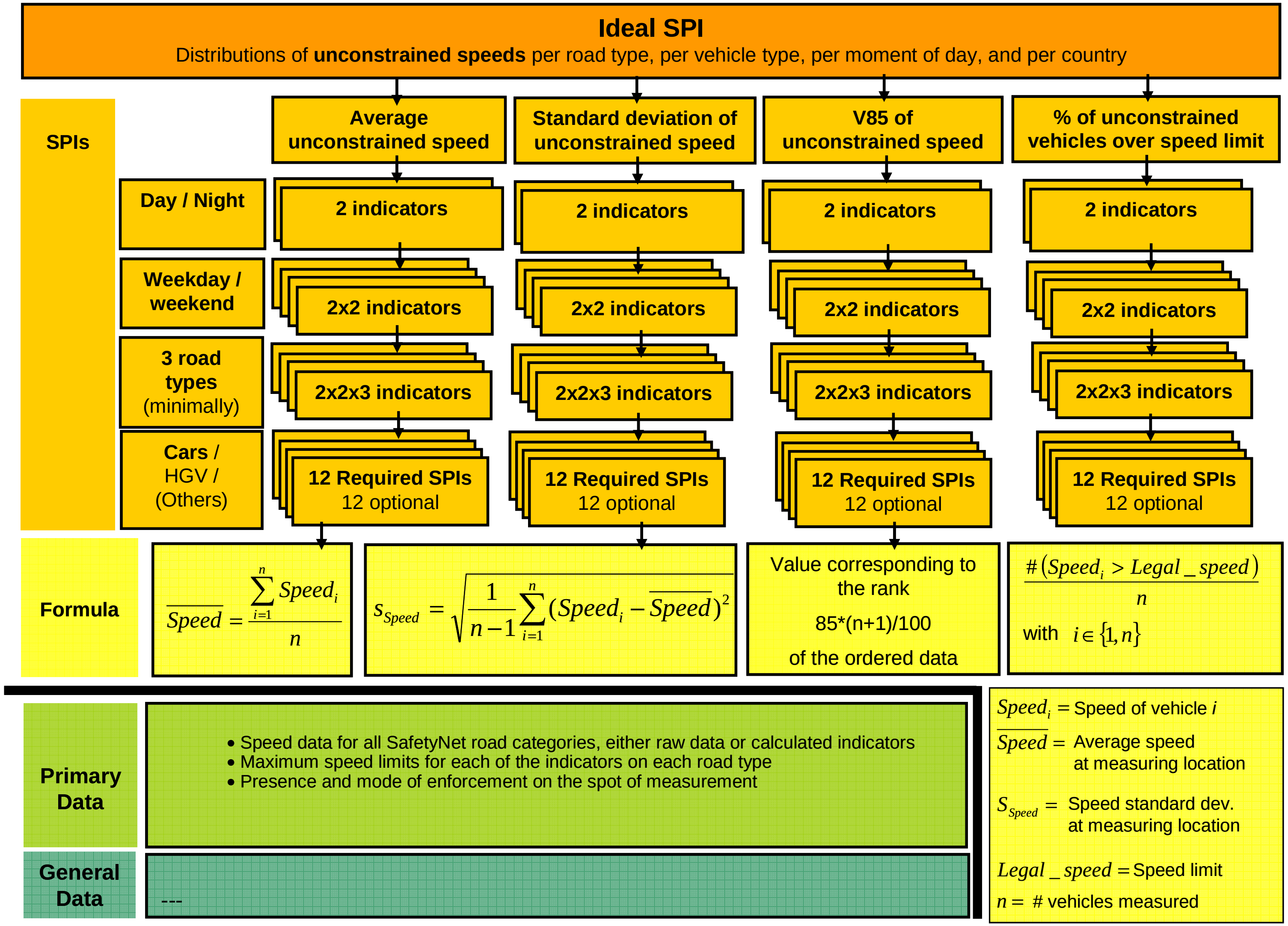

Figure 4.1: Schematic overview of the SPIs for speed and the required data.

4.4 References

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5 Protective Systems

EKSLER[A], V., ALLENBACH[B], R., HOLLÓ[C], P., SCHOON[D], C.

[A]CDV, [B]BfU, [C]KTI, [D]SWOV

5.1 Introduction

The use of various protective systems by road users in traffic has been assessed by numerous European countries since decades and belongs nowadays to widely accepted SPIs. For example, the use of seat belts has been regularly assessed in several European countries since 1970 (e.g. Switzerland, France, Germany) parallel to the introduction of seat belts related regulations (IRTAD, 1995). Nowadays, the use of seat belts is mandatory in all European countries, but the law continues to be broken by a significant proportion of traffic participants. In contrary, the legislation related to the use of safety helmets by pedal cyclists and moped riders varies considerably among countries and the rate of their presence in traffic comes mostly from users' awareness and country culture.

In this part all relevant protective systems used in road traffic are identified and a series of them is chosen as SPIs by investigating their contributions in eliminating outcomes of the road safety system (definition of a SPI). The former one comes from the analysis of known protective systems and their diffusiveness in traffic, while the latter one is demonstrated on the example of a seat belt for front seats passengers of a personal car. Last, but not least, the question of compatibility and reliability is discussed.

5.1.1 The problem

The human body is vulnerable and during road crashes is exposed to immense forces leading to injury or death. In case of vehicle related systems, passive safety of the vehicle itself, as an external form of occupants' protection in case of crash, cannot nowadays fully protect vehicle occupants against injuries. Here, the protective systems available for traffic participants play a vital role in protecting the most vulnerable parts of human body, i.e. belly and head against injury and considerably increasing the likelihood of surviving in serious crashes. Availability and appropriate use of protective systems are therefore fundamental items in developing related SPI(s).

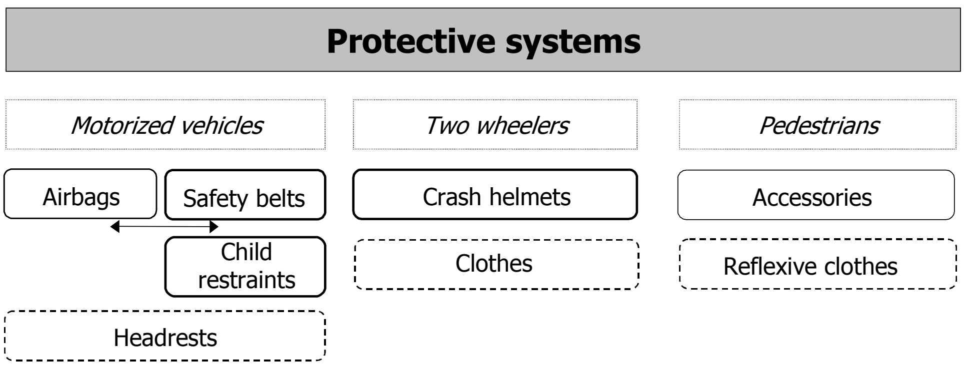

Figure 5.1: Overview of standard protective systems for road users.

Protective systems, defined as the devices mitigating the consequences of road crashes, concern three groups of road users, motor vehicle occupants, two-wheelers (both rider and passenger) and pedestrians (or roller skate riders).

Protective systems in vehicles (airbags and seat belts) work primarily by restraining and protecting their occupants in the event of a crash. Some other additional equipment of vehicles, which is elsewhere considered as protective system, e.g. headrest was a priori not included because of its insignificant safety effect and/or its extensive use/presence. The similar applies for protective clothes of motor bikers, where an argument of missing standard reference applies simultaneously.

Effectiveness (ability to prevent fatal injury of a road user involved in a road accident) of airbags and seat belts is strongly dependent on the speed that the vehicle with restrained occupants is travelling at and the type of the collision. Particularly, seat belts in vehicles are most effective in rollover crashes and front collisions, whilst their effectiveness strongly depends on the crash speed difference in a crash. (The speed difference (delta speed) is the change in speed that a vehicle (and its occupants or users) undergo as a consequence of crashing. It means the speed of the vehicle at the moment of crash against an obstacle, or the sum of two speed vectors of the two vehicles at the crash site.)

The effectiveness of seat belts is highest at low speeds at which a vast majority of unbelted fatally injured occupants would be saved by them and decreases almost linearly with increasing Δv. The effectiveness come near to zero at Δv>100 km/h. At a crash speed Δv>120 km/h the majority of occupants experience a mean acceleration in excess of 20xg what is the onset of irreversible injury, so the system looses its effectiveness and the probability of fatal injury converges to 100% (Michie, 1981). Continuously increasing level of vehicle passive safety does not influence significantly the effectiveness of the belt in general, although it shifts all curves representing the probability of fatal injury towards higher values of Δv. The relationship presented here further points to the fact that there is a relationship between the SPIs for speed and those for the use of protection systems in traffic. Thus they should be ideally addressed together when setting the fundaments of the new indicators.

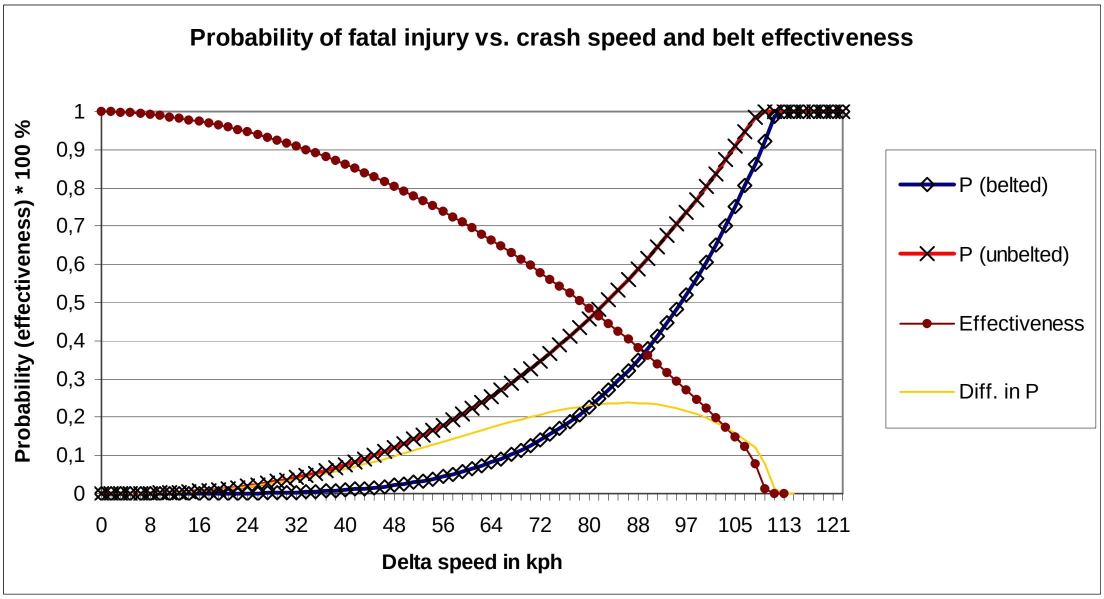

Figure 5.2 Effectiveness of seat belts on front seats of passenger cars vs. speed difference in crash (based on Evans, 1996).

Helmets for two-wheelers protect, in case of accident, the most vulnerable part of their users' body - the head - by absorbing a part of the kinetic energy. Their capacity of avoiding serious, or fatal injury is limited and strongly depends, beside collision type, on the speed at which the crash occurs. The latter applies also for cyclists, despite their travelling (impact) speed is significantly lower compared to the speed of motorized two-wheelers and consequently less energy has to be absorbed by the helmet. Besides, many cyclist accidents do not involve other road users but instead result in simple falls. Cyclist helmets are particularly effective in preventing head injuries in such accidents.

A large number of various protective accessories are nowadays available to protect other vulnerable road users such as *pedestrians*, especially those on rollers, scooters, etc. Beside, reflective materials could be also understood as a kind of protective system as they improve their users' visibility under bad weather conditions, what can help to avoid the crash to happen. However they do not mitigate the consequences of accidents once these happen, what makes them not suitable for a road safety indicator.

In general, there are no doubts on the definition of SPI in task 3, which has to address the use of protective systems in road traffic. Moreover, comparisons of protective system use rates have been for years an inseparable part of road safety policy in the EU. For illustration, data from recent ETSC study (ETSC, 2005), can be mentioned: the average seat belts wearing rate for EU15 countries in 2002 was estimated as 68% for front seats occupants and 37% for rear seats occupants. The wearing rates in the 10 recently accessed EU countries are expected to be slightly lower, with a greater difference for rear seats occupants. The problem with these data is their different origin (see par. 5.2.1) and quality making any international comparison complicated. A clear and precise enough picture of the situation is however essential for effective national road safety policies. Anyway, with regard to their safety potential, all possible measures have to be taken to assure their wider use with a target of at least 95%.

5.1.2 Types and definition of protective systems concerned

As mentioned above, within "Protective systems" we distinguish:

1. Airbags
2. Seat belts and child restraints
3. Helmets for two-wheelers
4. Protective clothes and accessories for pedestrians

Protective clothes, headrests and other protective systems were a priori excluded due to their extensive presence and/or their insignificant role/effectiveness in reducing fatal and serious injury.

Airbags

As an airbag, we understand a passive (idle) restraint system that automatically deploys during a crash to act as a cushion for the occupant. It creates a broad surface on which the forces of the crash spread, to reduce head and chest injury.

Airbags have been standard equipment on almost all vehicles in recent years. Airbags can be divided in frontal airbags (driver and passenger) and side airbags (curtain, tubular, seat-mounted, door-mounted, combo). Unlike other protective systems, the airbags protect passenger car occupants in all relevant accidents unconditionally on the occupant's behaviour. So their presence in the vehicle is essential for the protection of their occupants. At the national level, their diffusiveness among vehicles in traffic is then a crucial factor in the evaluation of the road safety potential of a country. The assessment of airbags' presence can be done in several ways: by surveys done in a representative sample and by the analysis of vehicle register data, or accident data.

Since the airbags are an inseparable part of vehicles and their activation does not directly depend on vehicle's occupants, they do not fall into the group of other behaviour-dependent protective systems. Other important argument for treating them separately comes here from the definition of EuroNCAP protocols for the evaluation of vehicle passive safety level (EuroNCAP, 2005). The protocol requires airbags to be activated during the test, so the safety rating of the vehicles takes into account the effectiveness of these devices. Anyway, the dummy is always buckled with seat belts, so any direct relation cannot be established between this protocol and the effectiveness of protective system. Since the definition of the SPIs in task 5 dealing with vehicle passive safety is based on the use of the EuroNCAP protocol, it seems appropriate, in the light of the arguments mentioned above, not to address their use (presence) within task 3. It is worth nothing that addressing the presence of the airbags in qualitative way would not take into account the great variety of airbags present nowadays on the market and within the vehicle fleet. It is likely that within some years the whole car fleet will be equipped with airbags, and then that this measurement will not be relevant anymore. Last but not least, there is a considerable proportion of cars in some European countries, in which airbags have been activated during a crash and have not been replaced by the new one, making the assessment of the airbag's presence even more complicated.

Seat belts and child restraints

Under the term seat belts, we understand a standard three-point lap-shoulder belt system regularly installed in passenger cars and light vans. Under the term child restraints, a crash tested and technically approved device that is especially designed to provide infant/child protection is meant.

Child restraints work in the same way as seat-belts. The presence of seat belts does not seem relevant anymore since they are mandatory fitted in vehicles since a long time and there is only few cars manufactured before 1989 in which no belts were fitted on the rear seats. However, in some countries, especially the accessing countries, the proportion of these vehicles in the whole fleet is still relevant. In all EU countries the following rule applies: if a seat belt is present, the use is obligatory.

Helmets for two-wheelers

Under the term helmet, we understand a crash/safety helmet designed for two-wheelers, whether motorized or non-motorized.

The helmets absorb, in case of crash, a large amount of kinetic energy and mitigate the seriousness of sustained head injury. The head is far the most sensitive and exposed part of body of riders and its protection is more important than the protection of any other part of the body.

Protection for pedestrians

Under the term protective systems for pedestrians' protection accessories, we understand both clothes and accessories for non-motorized, non two-wheeled persons in road environment.

In respect to their short number and rather negligible safety potential, they seem insignificant in the context of all protective systems mentioned previously. Moreover, the statistics on injuries of relevant road users suffers often from incompleteness.

<u>General note:</u> Misuse of protective systems is also a relevant issue, especially concerning child restraints (the child and/or the seat is fixed too loose, the device is not appropriate for the size of the child, etc.) and helmets (not using the chin strap; the strap is too loose; helmet damage; etc.).

5.1.3 Effectiveness of protective systems

When searching for the set of optimal SPIs, we focus, first of all, on the effectiveness and life saving potential of particular devices both at European and national level (top level of the road safety pyramid). Under the effectiveness of a protective system, we understand the proportion of lives that would be saved if the system were used. More generally, it is defined as the percent reduction in some specified level of injury that would result if a population of occupants changed from (all) not using particular systems to (all) using them, all other factor remaining unchanged [Evans, 1996]. Particular protective devices have different effectiveness; moreover there is some interaction between them, e.g. the effect of safety belt will further increase in case of simultaneous use of (an) airbag(s).

Airbags

The effectiveness of front airbags in traffic crashes depends on a simultaneous use of seat belts. According to NHTSA, the effectiveness of a front airbag alone is around 13% (i.e. 13% of those drivers killed in the car without front airbag would have been saved if their vehicle would have been equipped with it). Older estimates, such as made by Evans (1990), Zador and Ciccone (1993) and Braver et al. (1997) estimated the effectiveness of front airbags in frontal and near-frontal crashes as 18%, 28% and 20% respectively. On the other hand, the new recently introduced types of airbags as curtains can slightly increase estimated effectiveness. The effectiveness of front airbag used together with lap-shoulder belt is much higher and reaches 50%. (In an 'optimal' type of crash, i.e. in front collision, the safety effect might be up to 61%.) Front airbags effectiveness in crashes is likely to be more sensitive to the type of crash than in case of seat belts. More precisely, unlike for seat belts, there is little or no benefit of frontal airbags for crashes other than direct-frontal crashes.

Seat belts and child restraints

The use of *seat belts* is the single most effective means of reducing fatal and non-fatal injuries in motor vehicle crashes. According to TRL research, it reduces the death rate of car occupants by at least 40% (ETSC, 2001). More recent estimates of TRB based on FARS data reconfirm the agency's earlier estimates of fatality reduction by manual 3-point belts: 45% in cars and 60% in light trucks (Kahan, 2000). One of the most sophisticated studies in the field, published by Evans (1986), estimates the effectiveness of seat belts in preventing fatalities to drivers and right front passengers by applying the double pair comparison method to 1974 or later model year cars coded in the FARS as 43±3%. The NHTS uses for its “Lives saved estimations” the effectiveness of 48% for the occupants older than 4 years. The considered effectiveness of the three point belts in conjunction with airbags is 54% for occupants over 12 years. According to GDV (Die Deutschen Versicherer) the effectiveness of belts is 50%, but with simultaneous activation of frontal airbag 65% (up to 80% in frontal crashes.) The lack of consensus on the effectiveness of seat belts, when used, is remarkable given that belts have been standard equipment in passenger cars for more than 30 year (Robertson, 2002). The inconsistency and poor reliability of reported rates in fatal accidents is to be claimed here and would be definitively solved by a possible extensive use of black boxes in passenger cars. Until this will become the reality, an additional research should address this problem area.

The effectiveness of front seat-belts in a frontal collision is reduced by the rear loading caused by unrestrained passengers in the back seats and has not been born out by empirical evidence. This phenomenon of rear loading can cause severe chest injuries to the occupants of front seats.

Note: Only lap/shoulder belts are considered here, as the old lap belts have been gradually being replaced and their occurrence is rather marginal in cars. However, the situation might be different in case of heavy vehicles and coaches. The effectiveness varies significantly for both types according to TRB, which carried out a study targeting rear seat passengers in cars, for whom the lap belts might be still in use. Back seat lap belts are 32% effective in reducing fatalities and lap/shoulder belts are 44% effective in reducing fatalities when compared to unrestrained rear seat occupants in passenger cars (Morgan, 1999).

There is only limited knowledge on the effectiveness of *child restraints (CRS)* due to their construction variability, different national conditions and the fact that reliable data sets are lacking for relevant analysis. According to the TRB report, child safety seats are 71% effective in reducing fatalities in children under the age of 5, but misuse is a critical problem (TRB-TRIS, 2000). Arbogast et al, 2003 estimated, that the risk of serious injury was 78% lower for children of 12-47 months of age seated in forward facing restraint system in the back row of vehicles than for children using seat belts. Kahane, 1986 estimated that correctly used child safety seats reduced the risk of fatality by 71% and the risk of serious injury by 67%. Safety seats reduce infant deaths in cars by approximately 71% and deaths of small children by 54% (198 cases). According to the NHTSA the estimated fatality reducing effectiveness of child restraints is 71% for children under 1 year old and 54% for those between 1 and 4 years old. Here we should note, that several studies reports on a very high level of wrong use of CRS reaching up to 60% (UK, CH, DE), which can considerably decrease their effectiveness in case of road crashes.

Helmets for two-wheelers

There are few studies on the effect of *motorcycle and moped helmets*, and they are not very recent. Hurt et al. (1981) surveyed over 900 injured motorcyclists, of which 60% were non-helmet wearers and 40% wore a helmet and concluded from that the risk of death is more than halved if a helmet is worn. In his conclusions Hurt (1981) further stated that "helmeted riders and passengers showed significantly lower head and neck injury for all types of injury at all levels of severity". Otte, Jessl & Suren (1984) studied 272 motorcyclists injured in road crashes around the Hanover area. Non-helmeted riders accounted for 72.5% of the total injuries and yet this group was outnumbered (by how many is not stated) by the helmet wearers. Overall (including figures from a previous study) Otte et al. (1984) claimed that 70% of non-helmeted riders suffer head injuries whereas only 45% of helmeted riders sustain head injuries. Research opportunities on the effectiveness of motorcycle helmets in the EU are limited due to the fact that helmet-wearing rate reach almost 100%. In various States in the USA there has been much research into the effect of the helmet use law repeal. However, this type of study evaluates the effect of the repeal of helmet use laws on the motorcycle fatality rate (De Wolf, 1986). It does not evaluate the effectiveness of motorcycle safety helmets because there is no direct comparison between helmeted and unhelmeted riders. This is largely true of all such studies and, for that reason, they are not discussed here except to say that in almost all cases of law repeal the incidence of head injury, fatal and otherwise, increased. The NHTSA uses the 37% effectiveness estimate in her studies.

The effectiveness of crash *helmets for cyclists* has been studied for decades, and they are known to reduce the risk of severe head injury by about one-third. The most careful, conservative estimates from trustful studies show that the reduction in risk of head injury to a bicyclist as a result of wearing a helmet is in the order of 45%. In other words, at the very minimum, a helmet halves the risk of head injury. Other estimates from controlled studies give even higher risk reduction figures. Depending on the type of impact and the severity of injury, the reduction in the risk of head injury as a result of wearing a helmet has been shown in several studies from all over the world to be in the range of 45% to 85% (Henderson, 1995). In a widely quoted article by Thomson et al. (1989), who carried out a case-control study in hospitals in Seattle, it was concluded that cyclists who do not wear a helmet have a 6.6 times greater probability of sustaining a head injury and are 8.3 times more likely to suffer brain injury than cyclists who do wear a helmet. According to this data, a reduction by a factor of eight in the annual number of cyclist victims with brain injury could be achieved if all cyclists wore a helmet. Royles (1994) reviewed a number of studies addressing the issue of how many bicycle related deaths and head injuries could be prevented if cyclists wore helmets. In Sweden, Lind and Wollin (1986) carried out a questionnaire survey, and concluded that more than 70% of the crash victims for whom the head injury was recorded, as the main site of injury would have benefited from the use of a helmet. Olkkonen (1993) investigated the injury severity of bicycle crash victims in three Finnish provinces from 1982-1988, and estimated that almost 50% of the 200 fatal injuries could have been prevented if a helmet had been worn. According to the meta-analysis on bicycle helmet efficacy made by Attewell et al. (2000), the combined effectiveness is 27% for fatal injury, but more than 40% for other type of injuries.

5.1.4 Scope of reduction potential

Based on CARE and IRTAD data for 2002, the rough estimation of the lives saved in EU25 can be made using the NHTSA methodology (Glassbrenner, 2003). The lives saved are here estimated as follows: If D_s people die using a safety device that has an effectiveness e (i.e. that reduces fatalities in settings in which people would otherwise die by $e \cdot 100\%$), then one can infer that a total of $D_s /(1-e)$ used the device in a setting in which they would otherwise die (the potential fatalities), $D_s(e/(1-e))$ of which were saved by the device. This is the number of lives saved as a result of the current level of usage of the safety device. The number of cases in which seat belts failed to save lives provides the key to how many lives they actually saved, for a given e.

In addition to calculating the number of lives saved, one might also be interested in the additional number of lives that would be saved if occupants who currently do not use the protective device were to use them. This value is simply given by D_0e.

In 2004, the EU25 road toll of 43359 was distributed among road users approximately as follows: 20800 (800) passenger car (vans) drivers and front seat passengers, 4300 passengers on rear seat of passenger cars and vans, 1500 HGV and bus occupants, 7200 motorized two-wheelers and 2500 pedal cyclists. (Other road traffic participants, e.g. pedestrians are not mentioned here, as they do not pertain to any of protective system defined above.) From available data, the weighted estimates of wearing rates can be calculated, from which in turn the wearing rates by fatalities can be estimated.

Using 0.52 as a conservative overall estimate of seat belt effectiveness for front seats and extrapolating our estimates out of sample to the set of all road fatalities, we calculate that the lives of 16781 front seats passenger cars and vans occupants were saved by seat belts in 2004 alone. Lives saved by airbags are substantially lower. Similarly, the number of lives saved by crash helmets among two-wheelers is relatively low, as it does not exceed 2000 lives annually. Table 5.1 offers a ranking of protective systems according to their contribution to the lowering road toll in the EU as can be seen from potentially lives saved calculated, but the figures presented should be considered with certain precaution, since for several countries, the fatality counts per road users were estimated from the total road tool.

SPI	Type	e	Y	R_t	R_{fa}	D_0	D_S	N_s	N_p
A	Passenger cars front seats	0.52	20800	86	73	5705	15095	16353	2967
	Vans front seats	0.52	800	66	49	404	396	429	210
	Together							16781	3177
	Airbags	0.15	21600	70	70	6480	15120	2668	972
B	Rear seats passenger cars	0.48	3800	68	52	1839	1961	1810	883
	Rear seats vans	0.48	500	58	41	294	206	190	141
C	CRS	0.60	800	70	55	360	440	660	216
D	HGV+bus front seats	0.48	1350	30	25	1013	338	312	486
E	Bus passengers	0.45	150	5	3	146	5	4	65
F	Pedal cyclists helmets	0.50	2500	15	12	2200	300	300	1100
G	Moped helmets	0.50	2700	85	76	648	2052	2052	324
H	Motorcycle helmets	0.40	4500	94	90	450	4050	2700	180
e=effectiveness, Y=fatalities, R_t=usage rate in traffic daytime, R_{fa}=use rate by fatalities, D_0=Nr.persons not using system, D_s=Nr. persons using system, N_s=Nr.persons saved by device, N_p=Nr. persons potentially saved if 100% use									

Table 5.1 Rough estimates of lives saved by protective systems in EU25 in 2004.

5.2 Background for developing SPIs

5.2.1 What can be measured and quantified

From the definition of the SPI, the SPI for Protective systems should be the measures reflecting those operational conditions of the road traffic system, which influence the system's safety performance.

Their purpose is threefold:

- They reflect the condition of the road safety system;
- measure the effect of interventions;
- and allow comparison in time and space.

Hereby we define appropriate SPI for Protective systems as the use (wearing) rates of protective systems.

There are several ways how the value of the indicator may be obtained: Police reported rates, self-reported rates, roadside survey rates and accident rates. Although all these rates refer to the same indicator, their values vary considerably.

The police reported rates are usually largely overestimating the real rates, as they often come from the statistics of general roadside controls, which primarily focus on other, more serious offences. Beside, the presence of the police can have deterrent effect leading the person to try to buckle up before being checked or observed for seat belt wearing.

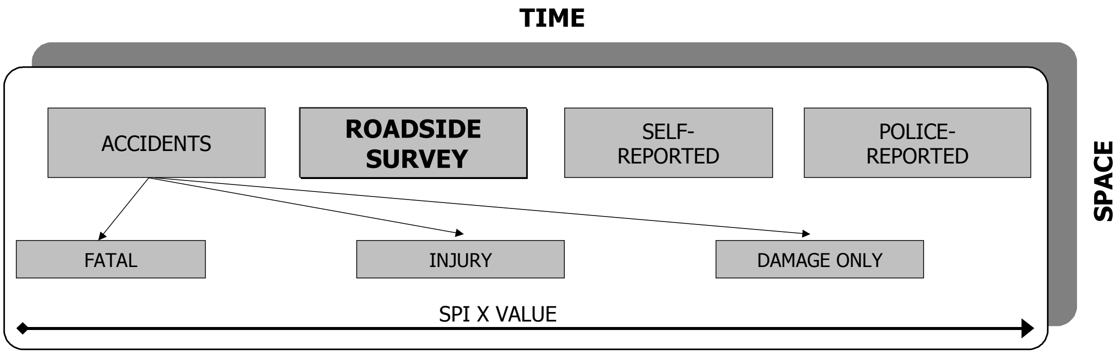

Figure 5.3 SPI values according to their origin.

Self reported rates overestimate rates compared to observational surveys of the same population. For example, in case of seat belts, Streff and Wagenaar (1989) mention that self-report measures overestimate observed belt use by 8.9 to 19.4 percentage points or by a factor of 1.2 to 2 and their best estimate is that self-reported seat belt use rates be discounted by 12 percentage points to estimate actual belt use rates.

This does not apply in all countries, as shows the example from Sweden. Here the seat belts wearing and other behavioural aspects of driving have been monitored by the National road administration since the 1980's through a special road safety questionnaire distributed among almost 7000 road users of age 15-84. Here, thanks to the nature of the questionnaire (probability based) and other factors, a good correspondence can be found between seat belt wearing rates observed in traffic and those reported by road users. Specifically, front (rear) seats self reported rates were 95.4% (85.2%) in 2005, while those observed in 2004 were 95 and 83% respectively.

The SARTRE project (Cauzard et al., 2005) is a unique source of self-reported rates of protective systems use in Europe covering 21 member states. Comparing survey results with the results of observation studies from the IRTAD database for the year 2002 (9 countries for urban areas, 8 for motorways), a strong correlation between the two data sets can be identified (0.89 for both road environment), however, the two sets differ significantly from each other. E.g. Self-reported seat belt wearing rates in urban areas in Ireland are some 17% higher than rates coming from observation survey, while 13% lower in case of Slovenia, etc.

Rates observed in accidents vary considerably depending on the seriousness of the injuries. In case of fatal or serious injury, the rates are lower than rates from observational survey. There are at least three factors influencing the size of this difference: Effectiveness, differences in characteristics of road users using and not-using protective system and inconsistencies in data definitions and possible biases of the two datasets. Particularly for seat belts, a number of models have been developed to describe the relationship between the day-time (roadside survey) rates and the rates recorded in fatal accidents (Glassbrenner, 1995, Kahane, 1986, Salzberg et al. 2000, Wang and Blincoe, 2003).

The rates observed in slight injury accidents are usually only little lower compared to observational surveys values, but strongly depends on reporting circumstances, insurance practices and legislation. In damage only accident, the rates are usually higher than observed, as the drivers and passengers can have an interest in referring that they complied with traffic rules.

Figure 5.3 summarizes all data assessment methods on the use of protective systems: police data, self-reported data, observational survey and accidents. It further illustrates that SPI values have two dimensions, time and spatial. Firstly, there are considerable differences between rates recorded in daytime and night-time. Generally, the rates are lower during the night, as the road user spectrum changes. Beside, there are obvious difficulties in assessing the rates during the night. Secondly, the rates vary in space. This can be related to different nature of journeys and socioeconomic characteristics of night-time road users (NHTSA, 1996).

Direct indicators

It was possible to find a direct indicator, as it was already identified in few studies and beside that, there is a current praxis in new EU countries, which historically have some experience with the use of this SPI. Under the direct indicator we understand

The day-time wearing (use) rate of protective systems in traffic.

The SPI directly measures the use of protective systems, which mitigate crash consequences on the health of road users (outcomes of road system).

Indirect indicators

It is also possible to find indirect indicators, from which the direct indicators can be derived. They are well described in the literature and are moreover regularly used in many European countries. The first indirect indicator relates to:

The use of protective systems by fatally injured accident participants recorded by Police. (1)

The second one concerns

The presence of the systems, or their availability in general. (2)

(1) The police records are an important source of accident related data for the development of SPIs protective systems as it is the only one indicator available in many countries. However, there is a lot of difficulties related to the use of accident data. The reliability varies much as the legislative background differs, so that the reporting might be influenced by external factors. For example, insurance companies can be interested in the problem etc., so we cannot rely on the self-reporting, or police-reporting data. Accepting this presumption, only wearing (use) rates among road fatalities are of interest. They are not biased, at least not as much as in the serious accident the use of a protective system at the moment of a crash is easily recognisable by a policeman.

Regarding seat belts wearing rates, it is generally possible to develop a model describing the relationship between the day-time wearing rates and wearing rates for the fatalities in accidents, based on the data from the countries, in which both figures are available. In the U.S., the NHTSA uses since many years a model, which allows to predict the use of seat belts among potential fatalities from known day-time wearing rates. The most recent version of this model is $UPF(x) = 0.47249 x^2 + 0.43751 x$, where x denotes belt use in the front seat during daytime and UPF(x) denotes the belt use among potential fatalities when daytime front seat use is x. (Wang and Blincoe, 2003).

(2) The presence, or the availability of protective systems among road users, or in vehicles, is a very rough indirect indicator, as it does not have a clear relationship with the wearing rates in traffic. Further it loses its importance with time, as the availability is almost reaching 100% in most of the cases (e.g., presence of seat belts in front seats of passenger cars).

Further consideration

One important feature of SPIs in task 3 is that the use of protective systems is related to a wide range of factors, such as:

- Individual factors
  - Demographical (age, sex)
  - Behaviour (drinking, smoking, sport activities)
  - Attitudes, personality, awareness
- General factors
  - Environment (infrastructure)
  - Social

So the assessed SPI values are not homogenous and vary in space and time, as shown in Figure 5.2. So for example, the night-time use is lower than the daytime use and the use on higher-level roads (supposing long trips) is higher than the use on urban roads (with typically short trips). While the former one can be related to a different demographical structure of daytime and night time road users and to a generally lower level of police enforcement, the latter one is likely to be exclusively related to the perception of risk in different environments by road users.

Building-up the SPIs is based on the general philosophy described above. Analysis on the effectiveness of protective systems foreshadows, how the SPI should be defined and which should be used in praxis. Although the detailed knowledge on wearing rates is important from many points of view, identification of the overall rates describing the national road safety condition is preferred, e.g. the rates for children, front and rear occupants in all road environments will be analysed. Similarly for two-wheelers, the overall wearing rates for particular riders might be analysed in different ways. This simplification can shadow some discrepancies hidden behind national statistics, but we do believe that their effect is marginal.

As the technical features of protective systems may vary, implying different safety effects, all the differences in their quality should be assessed in theory. Examples to be mentioned for seat belts are: the shoulder-height seat-belts adjusters which allow a comfortable fit for occupants of varying height, seat-belt retractors which lock the belt automatically in a crash or severe deceleration, or pre-tensioners minimising the amount of slack belt and consequently reducing the risk of a front-seat occupant hitting the steering wheel or dashboard. However, it doesn't seem to be necessary to address all these particular issues, since they don't influence the final safety effect as much as the use of a seat belt of any quality. As the wearing rates depend on many external variables, the scope of the questionnaire did concentrate on: Vehicle types, Age groups, Road types, Gender of occupants, and Seating position.

Regarding vehicle types, ideally all vehicle types would be addressed, including further subdivision for cars (such as taxi, police, etc.). However, this is not possible in the frame of this project. It was therefore decided to focus on the vehicle types representing the majority and having the highest possible safety capability (see 5.3.1).

Regarding road types considered, all road types existing in Europe were distinguished by using the IRTAD definitions [3] (IRTAD, 1998). As the methodology determines the quality and interpretability of the data, the way the wearing data are assessed was of a great interest assuming the four basic data sources: Insurance companies, Statistical offices, Police, Others. The regularity of the surveys is assessed as well.

[3] All public roads comprise urban roads, rural roads and motorways.

Categorizing road users, and particularly children into the sub-groups according to their age in order to identify differences between ages not seems to be effective as well, since several different age categories exist throughout the EU and such differences should be better targeted by dedicated surveys.

5.2.2 Indicators currently in use

It has been a practice in several European countries to assess the use of protective systems in traffic for many years. In the following text, the overview of data related to each of the protective systems SPIs in the EU is presented. In general, two important sources of protective systems use data are available:

	SPI	EU countries	Since	By
IRTAD	Belts, CRS	14	1983	Annually
ETSC	Belts	15 / 25	1998	2002 / 2004

Table 5.2: Availability of data on protective systems use in the 25 Eu member states.

The data on in-traffic use of seat belts and child restraints in passenger cars have been an integrated part of IRTAD database since 1993. The study on the availability of seat belt wearing data in OECD member countries prepared by the members in 1995 is the first and most sophisticated approach to the assessment and harmonisation of protective systems use data (IRTAD 1995). It offers, among else, an overview of data availability in 14 European countries, but also definitions and details on data proceeding.

Following the most important conclusions of this report (quoted):

1. "Most countries reported that data on the wearing of seat belts for car drivers on motorways and urban and rural roads was available."
2. "Variations in national methodology are likely to be large enough to make precise quantitative comparisons of wearing rates difficult."
3. "The supplementary survey indicates substantial variation in sample size, national representation, and periodicity. These are real limitations to international comparability; nevertheless, wearing data may provide a useful background for comparing road accident fatalities between countries and also a platform for the improved collection of data on the wearing of seat belts."

Besides, some data are available also for indirect indicators on passenger cars (percentage of killed front seats occupants wearing seat belt). Data from 10 countries are available here, though; in many cases likely to suffer from underreporting and biases. The lack of data on this subject was also highlighted in the report of Clifford & Chance, where the percentage of killed car occupants not wearing seat belts was presented for 11 EU countries for the year 2000.

The European Transport Safety Council (ETSC) has been gathering information on protective systems use in European countries through the network of its correspondents since 1998 (ETSC, 2003 and 2006). Most recently, the information of seat belt use were collected separately on front and rear seats in passenger cars for 15 EU countries in 2003 and 25 EU countries in 2004. The ETSC did not particularly investigate data background, such as data sampling and procedures; therefore it is very likely that some data presented can be unreliable or incomparable.

There is one obvious difference in presented data. While IRTAD seeks for disaggregated values for three road types, ETSC prefers aggregated values. The aggregation procedures as well as sampling methods in the background remain unknown and very likely differ between countries. Some doubts raise regarding data reliability once comparing the values of direct and indirect indicator as they do not always fit to the empirically established exponential curve describing the relationship between the both indicators.

In general, there is a large room for improvement of the indicators in most of the countries recently using them on the one hand and on the other hand for the introduction of the use of indicators to those countries not using them yet.

		ETSC (2004)		IRTAD (2002)			
Country	**Code**	A	B	A (urban)	A (rural)	A (motorway)	A (fatalities)
Austria	AT	77	56 a	70	77	77	52 d
Belgium	BE	66	NA	50*	58*	63*	N/A
Cyprus	CY	NA	NA				
Czech Republic	CZ	75 d	NA	43	63	81	
Denmark	DK	84	63				N/A
Germany	DE	94 d	90 a				31 d
Estonia	EE	75	21				
Spain	ES	86 o	42 o				34/41
Finland	FI	89	80	81	93		39 d
France	FR	97	68	95	95	97	23
Hungary	HU	59	20 o	45	49	62	
Ireland	IE	85 o	46 o	69	74		30/22
Greece	IL	40 o	15 o				42/53
Italy	IT	NA	NA				N/A
Lithuania	LT	NA	NA				
Luxembourg	LU	88 d	72				53
Latvia	LV	NA	NA				
Malta	MT	95 d	43				
The Netherlands	NL	86 o	63 o	74*	86*	87*	
Poland	PL	71	49	76			
Portugal	PT	88	25	86**	95**		27
Sweden	SE	92	79	88	90	98	40
Slovenia	SI	?	?	92	94	96	
Slovakia	SK	?	?				
United Kingdom	UK	93 d	83				N/A

Note: a Adults only; o Data from 2003, otherwise 2004; d Only for driver; * 2000; ** 2001

Table 5.3: Referred values of protective systems use in EU countries.

5.3 Constructing SPIs

5.3.1 SPI concept for protective systems

The safety performance indicators for protective systems are the wearing and use rates of protective systems by road users in road traffic. As the importance of particular devices derives mostly from their fatality preventing potential at national and European level, they may vary significantly among each other. The choice of the appropriate ones should be based on sophisticated research knowledge and their potential to save lives on European roads. The factors such as accessibility and measurability should be understood as subordinate. In general, the detailed knowledge on the use of protective systems covering all system types, road types, and users would be considered as a best basis for a series of SPIs. The indicators in this row can be called “ideal indicators”,and can be ranked in respect to their safety efficiency. However, one must think about the realizable indicators. Those that are actually available in most countries.

The process of identifying the appropriate SPI is illustrated above in section 5.2.1. The schemes presented there show how the indicator might be aggregated from the particular indicators. However, aggregation may not be desired, as it may decrease the reliability and representativeness of indicators. Appropriate indicators are therefore chosen with regard to the former research findings and current practices as follows:

Set I: Daytime wearing rates of seat belts and CRS

A – Front seats – passenger cars + vans /under 3.5 tons/

B – Rear seats – passenger cars + vans /under 3.5 tons/

C – Children under 12 years old - restraint systems use in passenger cars

D – Front seats – HGV + coaches /above 3.5 tons/

E – Coaches – passengers

Set II: Daytime usage rates of safety helmets

F – Cyclists

G – Mopedists

H – Motorcyclists

We suggest addressing exclusively daytime use of protective systems for a number of practical reasons, such as sample availability, observation costs etc., despite their measurement under night time conditions is feasible (TRB, 2005).

Comments:

- All data disaggregation would inevitably lead to higher demands on sample size and complexity of the sampling procedure used.
- Measuring driver and front passenger seat belt wearing rates separately does not make much sense, given the purpose of the indicator. According to the questionnaire responses, the overall wearing rates in 16 countries were 81% (driver seat) against 75% (front passenger seat). In crashes, however%, 76 against 67%.
- Wearing rates for different road types as well as gender should be aggregated since the disaggregated rates are more important for in-depth analysis studies and probably not available in all member states (e.g. not all road types are present in some countries).

Assessing vans occupant seat belt wearing rates separately is not reasonable, as they fall into the same driving licence vehicle category as cars and it should be left voluntarily to countries to disaggregate proposed category.

- The values given should be representative for the total road network; therefore one hopes that the countries calculate them from their aggregated data. The formula was provided and can be found in Appendix A.
- One should consider wearing rates for coach occupants, despite the fact that these data are rarely available and assessable without difficulties.

- Seat belts wearing by front seat occupants in heavy vehicles and coaches might be addressed through a common indicator.
- Some indicators, such as helmet wearing rate among motorcycles [H] should be understood as an indicator for the near future only in some countries, as it has already reached almost 100% level (Norway, Germany).

We suggest not using the presence or activation of airbags in vehicles as an SPI for protective systems, because they are an integrated part of vehicles and their activation in accidents is automatic, therefore independent from behavioural attitudes and other external factors, such as enforcement (see also 5.1.2).

Misuse of child restraint systems has been recognized as a prevalent and potentially life-threatening problem with possibly deadly consequences. Margolis et al. (2002) argue that 63% of children placed in child restraint systems were incorrectly restrained. We therefore suggest addressing in case of SPI-C also correct use of systems.

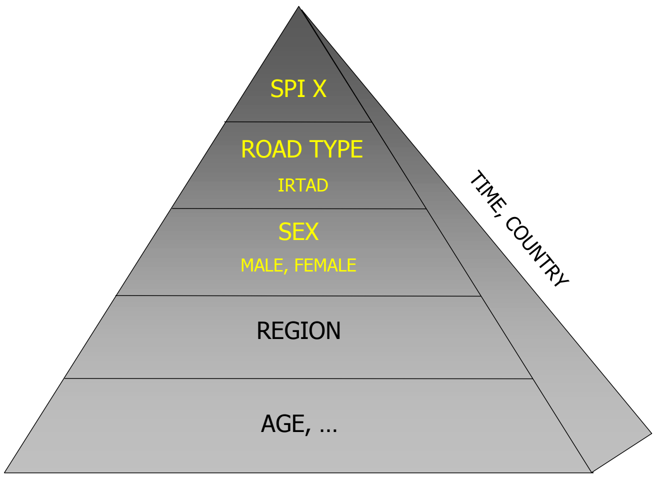

Figure 5.4 Aggregation of SPI values illustrated by a pyramid.

The way how to derive SPI is described in diagram in Appendix A, whilst Figure 5.4 is meant to illustrate possible disaggregation process. At the top of the pyramid the the values of indicators A - H can be found as defined in section 5.2.1. These may be aggregated from the values pertaining to the different road types, which can be further disaggregated for men and women, for different regions, different ethnic group, or for different age groups. The pyramid illustrates the hierarchy of the values and sheds light on how chosen SPIs are defined.

It should be stated here that the aggregated value of indicator conforming to requirements on precisions, as defined in the Manual, is preferred against disaggregated values. (More strata is considered in sampling procedure, for which the value of indicator should be obtained separately, more complex sampling design required leading to a very large sample and observation costs.)

5.3.2 Questionnaire responses

In order to obtain as much information as possible, but at the same time keep the questionnaire short, the questions posed were formulated in such a way as to allow simple, or two words answers to most questions. The only exception was the part regarding the methodologies used to gather data on wearing rates, as it was desired here to learn many particularities.

The purpose of the questionnaire was twofold:

1. To get an overall picture on data availability and related legislation;
2. To get the values of currently used indicators and their character.

The questionnaire did not aim at assessing methodological details related to data sampling and proceeding since this was viewed as too much complicated and large issue to be addressed by this questionnaire.

Basically, the questionnaire was divided into four parts. Two of them dealt with seat belts, one with airbags, and one with helmets. For each part, the set of question was formulated in such a way that the respondent not possessing data could skip the next questions. Figure 5.5 illustrates the reasoning behind the questionnaire for protective systems. Where it was appropriate to ask for the legislative background, the question on current law in the country was positioned at the beginning. Furthermore, the respondents were generally asked if in their country the data on wearing rates existed. If yes, they were advanced to the more detailed questions assessing the scale of data collection and methodology used.

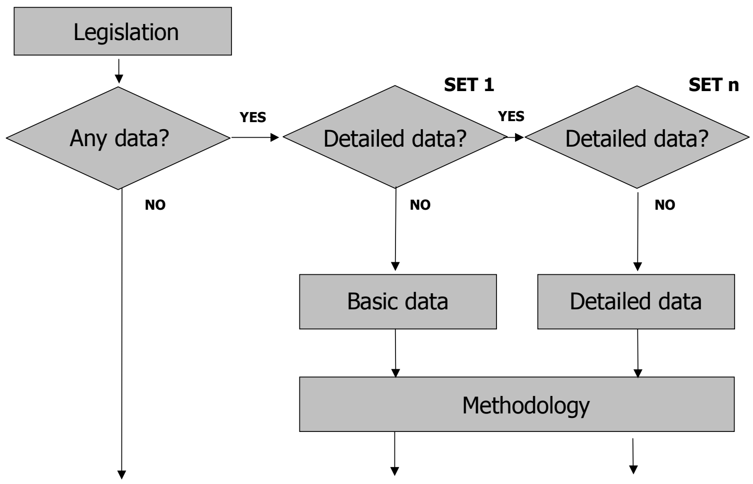

Figure 5.5: Diagram used for questionnaire.

As the aim was to gain as much data on wearing rates for different road users, road types, and gender as possible, some questions were prepared in the form of tables allowing the same question for several variables. When investigating the helmet wearing rates of cyclists and children restraint system use, the space has been left for defining the specific age, or weight categories and specification of the appropriate protective system type.

National Responses

The lessons learnt from analysing the responses of particular countries are not very surprising: there exist important variations in terms of quality and availability of data needed to realize suggested SPIs on protective systems. In certain countries, no information is available; however some of them have recently started with its collection. National respondents have, for the most part, well understood the questions asked and answered in a correct way. The first part of the questionnaire, dealing with the presence of seat belts in vehicles, caused them some difficulties, as some of them understood this question as a request for wearing rates. Some others perhaps left the question unanswered. However, the lesson learnt from their responses regarding this part is clear enough (there is no data on airbag presence in the vehicle fleet in the EU).

From the responses concerning the wearing rates, out-of-date information was forwarded in some cases, moreover some respondents probably haven't understood the importance of data source choice for their reliability as they provided with the rates coming from police observation, or mailing questionnaires responses, despite the regular research observations having already been established in their country. Here, another general problem must be mentioned: some of the experts filling in their national questionnaires obviously did not have access to the research databases or failed to use this sort of data. The problems might lay in the independency of some research institutes and resulting difficulties of the state administration to obtain their data. As obvious further from the national responses, the countries interested in data collection on using protective systems are often looking at the same indicators, while using IRTAD definitions for road types, using distinctions for different occupants' seats and vehicle types as well. It allows for comparing and merging data among countries. Nevertheless, the quality of the comparison is influenced by the fact that the year for which the expert sent the relative data/most recent data is not always the same, i.e. there is data from 2004, 2003 and 2002. In few cases, the quality of data received was influenced by the way the questionnaire was constructed at some places: a choice 'zero', or 'none' was missing in the roll-down menu and the respondent had no other choice than to answer in the wrong way.

5.3.3 Suggested SPIs

Based on the discussion presented above, the following SPIs for protective systems are proposed:

Set I: Daytime wearing rates of seat belts

A – Front seats – passenger cars + vans /under 3.5 tons/

B – Rear seats – passenger cars + vans /under 3.5 tons/

C – Children under 12 years old - restraint systems use in passenger cars

D – Front seats – HGV + coaches /above 3.5 tons/

E – Coaches – passengers

Set II: Daytime usage rates of safety helmets

F – Cyclists

G – Mopedists

H – Motorcyclists

All the indicators shall come from an independent observational surveys carried out on an annual basis, according prescribed and in-time stationary conditions. The values should be aggregated from the values for major road types in the country considered for each one indicator on the basis of traffic volume on each of these road types. (Basically distinction between motorways/ rural/ urban roads).

5.3.4 Implementation

The application of the indicators proposed for Protective systems allows to

1. Monitor spatial and time variation and development;
2. Measure the effect of intervention;
3. Figure out social costs of prevented accidents as well as figure out reduction potential behind increased rates.

Development in time is evaluated by the mean of the two following indicators:

- **Year to year increase (annual increase)** as the difference of SPI value (use-rate) from last year (i-1) to present year (i)

eq. 5.1 $$AI_t = -((SPI_{t-1}) - (SPI_t)) = (SPI_t) - (SPI_{t-1})$$

- **Conversion rate** as rate of decrease of non-use from last year (i-1) to next one (i)

eq. 5.2 $$CR_t = \frac{(100 - SPI_{t-1}) - (100 - SPI_t)}{(100 - SPI_{t-1})}$$

Conversion rates provide a better measure of improvement than percentage point or percentage increases in use as it shows the percentage of belt nonusers converted into users each year, so they assess improvements in a way that does not penalize regions or other categories that already exhibit high user rate. Note also that the conversion rates are negative when use declines. The user/nonuser categorization is a bit simplistic, since most of vehicle occupants are part-time users. However the use/nonuse categorization is helpful for thinking about conversion rates.

As discussed earlier, it is possible to estimate the number of lives saved in a country (region) using the methodology proposed by NHTSA. (If D_s people die using a safety device that has an effectiveness *e* (i.e. that reduces fatalities in settings in which people would otherwise die by $e \cdot 100\%$), then one can infer that a total of $D_s/(1-e)$ used the device in a setting in which they would otherwise die (the potential fatalities), $D_s(e/(1-e))$ of which were saved by the device. This is the number of lives saved as a result of the current level of usage of the safety device. The number of cases in which seat belts failed to save lives provides the key to how many lives they actually saved, for a given *e*.)

In addition to calculating the number of lives saved, one might also be interested in the additional number of lives that would be saved if occupants who currently do not use the protective device were to use them. This value is simply given by D_0e.

One can imagine performing similar calculations for the severity of accidents, once the calibration is done through detailed accident studies.

Using valid monetary estimates of life one can, once estimating life saving potential, perform a cost-benefit analysis of various interventions, such as impact of increased rates due to media campaigns, Police enforcement actions, or wider implementation of seat belt remainders.

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6 Daytime Running Lights

HOLLÓ[A], P., GITELMAN[C], V., AMELINK[B], M., SCHOON[B], C.

[A]KTI, [B]SWOV, [C]TECHNION

6.1 Introduction

6.1.1 The problem of daytime visibility

Many traffic crashes occur because road users do not notice each other in time or do not notice each other at all. This is true not only for traffic crashes in the dark but for traffic crashes in daylight as well. Vehicle visibility is therefore one of the factors which affects the number of crashes (Attwood 1981; Rumar 1980; Helmers 1988; Elvik and Vaa 2004).

The eye reacts to contrasts and changes in contrast in the field of vision. When light conditions are particularly difficult, such as at dusk, in rain, or in fog, it becomes difficult to see all traffic elements (Elvik and Vaa 2004).

Use of daytime running lights (DRL) for cars in all light conditions is intended to reduce the number of multi-party accidents by increasing the cars' visibility and making them easier to notice (Elvik and Vaa 2004). Besides the DRL use could increase the reliability of the estimation of other motorised road users' moving direction, distance and speed.

Koornstra et al (1997) evaluated all the earlier experiments regarding visual perception, road user behaviour, and DRL. Their most important conclusions were as follows.

Conclusion 1

> Vehicles with DRL are **more visible** than vehicles without DRL.
>
> With regard to the hypothesis that DRL increases visual contrast between vehicles and their background, and therefore conspicuity /visibility; subjective assessments have shown that, in general – both depending on the level of ambient illumination and DRL intensity – vehicles with DRL are more visible than vehicles without DRL.

Conclusion 2

> DRL results in **increased detection distance** and angle.
>
> The detection experiments have shown that detection distance is greater for vehicles with DRL when compared to unlit vehicles (under relatively low ambient illumination levels). Moreover, vehicles in the periphery of the visual field are earlier detected with DRL than without.

Conclusion 3

> DRL probably results in some **'safer' judgements.**
>
> Regarding the hypothesis that DRL results in more accurate or 'safer' judgments, it has been shown that vehicles with lights on are estimated to be closer than unlit vehicles; and in overtaking situations the minimal gap acceptance is greater when DRL is used than when lighting is not used. The acceptance of a larger gap and estimating a vehicle to be 'closer' can be interpreted as a 'safer' performance with respect to the situation without lighting. However, the results of studies concerned with gap acceptance in situations other than overtaking are less clear-cut.

Besides, Brouwer et al. (2004) performed experiments to examine suspicions on possible negative effects of DRL, e.g. a poorer conspicuity of other road users in the vicinity of vehicles with the DRL switched on. They found no evidence that the conspicuity of other road users, as measured by the speed with which their presence was detected, suffered from the DRL using vehicles.

6.1.2 Accident reduction potential of the DRL use

Elvik and Vaa (2004) summarized the results of about 20 studies, which evaluated the effects on accidents of DRL-equipped cars. The studies were carried out in different countries such as USA, Canada, Sweden, Norway, Denmark, Israel, Austria, Hungary, and considered two types of effects: the effect on the accident rate for each car of using DRL and the effect on the total number of accidents in a country where the DRL use is mandatory – Table 6.1. The researchers found that the DRL use reduces the number of multi-party accidents by around 10-15%.

Percentage change in the number of accidents			
Accident severity	**Type of accident affected**	**Best estimate**	**95% confidence interval**
Effect for each car which uses daytime running lights			
All levels of severity	Multi-party accidents in daytime	-13	(-18; -8)
Mandatory usage of daytime running lights (increase in use from around 35-40% to around 85-90%)			
Injury accidents	Pedestrians hit by cars	-15	(-17; -13)
Injury accidents	Cyclists hit by cars	-10	(-15; -5)
Injury accidents	Front- or side collisions	-10	(-12; -8)
Injury accidents	Rear-end collisions	+9	(+5; +14)
Injury accidents	Multi-party accidents in daylight	-8	(-9; -7)

Table 6.1 Effects of daytime running lights for cars on accidents (percentage change in the number of accidents).

The problem of visibility is especially pertinent to mopeds and motorcycles. Poor visibility was indicated as a contributing factor to many accidents involving these vehicle types. The DRL use is accepted to be one of the ways of increasing moped and motorcycle visibility (Elvik and Vaa 2004). 12 studies, from the USA, Australia, Great Britain and Malaysia, considered the effects on accidents of using DRL on mopeds and motorcycles. Summing up their findings, it was stated (Elvik and Vaa 2004) that mopeds and motorcycles using DRL have a 10% lower accident rate than those not using it. However, this estimate is considered as uncertain, because the confidence interval of the summary value was very wide making the result statistically insignificant. The recent study commissioned by the EC involved a meta analysis of 41 studies of the effect for cars and 16 studies of the effect for motorcycles (Elvik et al., 2003). This showed that for cars DRL reduced the number of daytime injury crashes by 3-12%, and for motorcycles by 5-10%. For both results we should mention that the results found per individual study (may) differ greatly. The reduction refers to daytime crashes in which more than one road user was involved. A greater effect on fatal crashes may be estimated. Motorcyclists in the Netherlands, who nearly all have their headlight on during daytime, sometimes express the fear that their conspicuousness lessens if cars also have their lights on during daytime. The TNO laboratory experiment (Brouwer et al., 2004) showed that the subjects saw both motorcycles with their lights off and motorcycles with their lights on sooner if cars also had DRL. However, motorcycles with DRL were spotted faster. Wildervanck (1994) already explained this phenomenon. By having his headlight on a motorcyclist separates himself from the static surroundings and thus is noticeable as a moving vehicle. And that is what it continues to be, even if the surrounding vehicles also have their lights on. European motorcycle organizations (FEMA, British Motorcyclists Federation en Motorcycle Action Group UK) strongly criticize the recent EU study. Although nearly all points of criticism could be refuted, these organizations are expected to continue opposing DRL.

The only accident type which shows an increase is the rear-end collision. A possible explanation for this is that when the taillights are on, it might be more difficult to recognise the brake lights (Attwood 1981; Elvik 1993). According to Hungarian research results (Hollo 1998), following the introduction of mandatory DRL use, the number of frontal and crossing collisions decreased without a simultaneous increase in rear-end collisions: the latter number has changed not significantly.

Probably the possible increase in the rear-end collisions will not be a problem anymore in the future due to the presence of the extra high-mounted stop lamps. These lamps are obligatory for new cars in almost all European countries since 1998.

6.2 Background for developing SPIs

6.2.1 What can be measured and quantified?

The basic idea in developing the SPI for Daytime Running Lights (DRL) is the stated relationship between the level of DRL use and road safety. According to Elvik, Christensen, Olsen (2003), we can talk about the effects of DRL for each vehicle using it (intrinsic effects) and the effects of laws or campaigns that lead to an increased use of DRL in a country or part of a country (aggregated effects).

Koornstra et al (1997) found a relationship between the intrinsic DRL effects and latitude as presented in Figure 6.1.

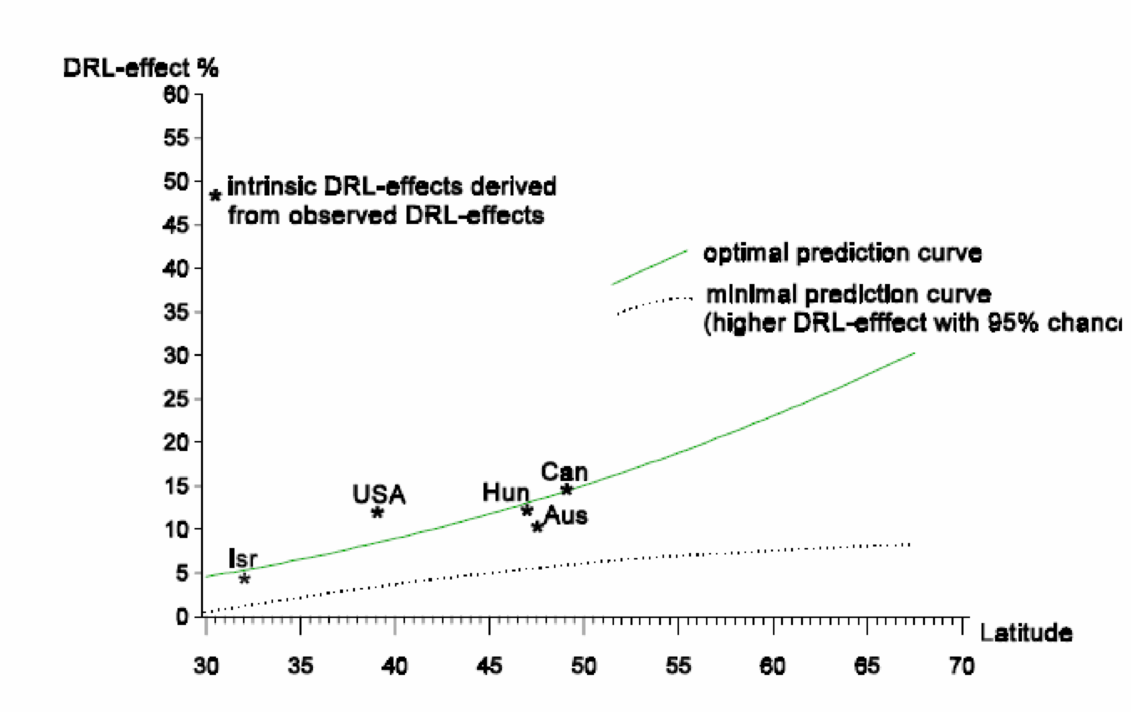

Figure 6.1: Prediction curves for intrinsic effects of DRL on all multi-party daytime accidents in different countries: an optimal and a minimum prediction curves (with a 95% confidence interval). (Figure taken from Koornstra et al. 1997.)

Later, Elvik et al. (2003) examined the above relationship and stated that there is hardly any relationship between the latitude and effects of DRL. Their results can be seen in Figure 6.2. It can be concluded that there is no general agreement in literature on the relationship between latitude and the effect of DRL.

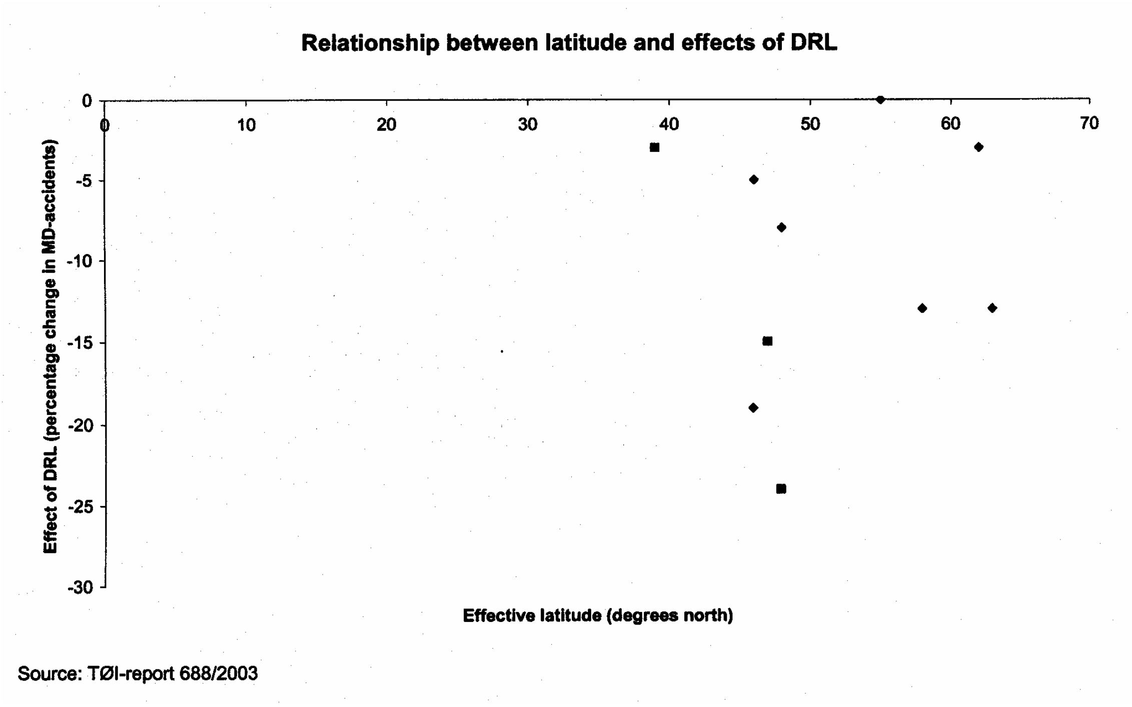

Figure 6.2: The relationship between geographical latitude and effects of DRL for cars (Figure taken from Elvik et al. 2003.)

Besides, the daytime visibility of motor vehicles cannot be measured directly but the level of DRL use can. In other words, an indicator of the DRL use can be considered as an indirect indicator for visibility.

On the basis of both literature survey and the current practices, the DRL SPI was suggested in the form of the percentage of vehicles using daytime running lights.

6.2.2 Examples of SPIs in use (literature survey)

An examination of the literature reveals that the DRL use is generally discussed among the road accident preventive measures. For example, a recent publication by ETSC (2003) provided a cost-benefit analysis of a number of road safety measures which can be considered as the most promising for the application in the EU. A legal obligation for all motor vehicles to drive with low beam headlights or special DRL lamps during the whole year was evaluated in this context.

Later, an extension of the DRL use was included in the test cases of the EU project ROSEBUD which developed the efficiency assessment tools for road safety measures (Winkelbauer and Stefan, 2005). In this project, the test cases were selected accounting for interest to these measures in different EU countries. The economic evaluation of safety benefits of the DRL application (for the whole year) was performed for two countries: The Czech Republic and Austria.

Increasing the DRL use frequently appears among the measures which are parts of the national road safety programs. For example, the Austrian Road Safety Programme 2002-2010 supports the mandatory use of DRL in rural areas during winter period and expects safety benefits from this measure, e.g. the annual potential reduction of up to 30 fatalities by the year 2010.

Despite a wide use of the DRL as a safety measure, the use of DRL indicators are not common in the road safety decision-making practice. Elvik et al. (2003) performed a quality assessment of 41 studies from different countries which quantified the effects on accidents of the DRL use by cars and motorcycles. One of the criteria for assessing the studies was the availability of information on DRL-use. It was found that more than half of the reviewed studies provided no information on the DRL use. In the studies providing such data, the indicator usually had a form of the proportion of vehicles using DRL.

Examples of the use of DRL indicators can be found in traffic behaviour monitoring systems. One of the most comprehensive systems of this kind exists in Finland. The system was launched in 1992. Presently, Liikenneturva – the Central Organisation for Traffic Safety in Finland – maintains the system for monitoring traffic safety work. Traffic behaviour data are annually collected using the same methods and the same measuring points. The use of daytime running lights is among the ten behaviours which are monitored by the system (Luukkanen, 2003). Annual DRL observations cover more than 21,000 vehicles over the country. A DRL indicator applied is the percentage usage rate, inside and outside built-up areas, where the rates are estimated by proportioning the number of observations to the population of the provinces to which they refer to (Luukkanen, 2003). Figure 6.3 presents the monitoring results for the years 1993-2002.

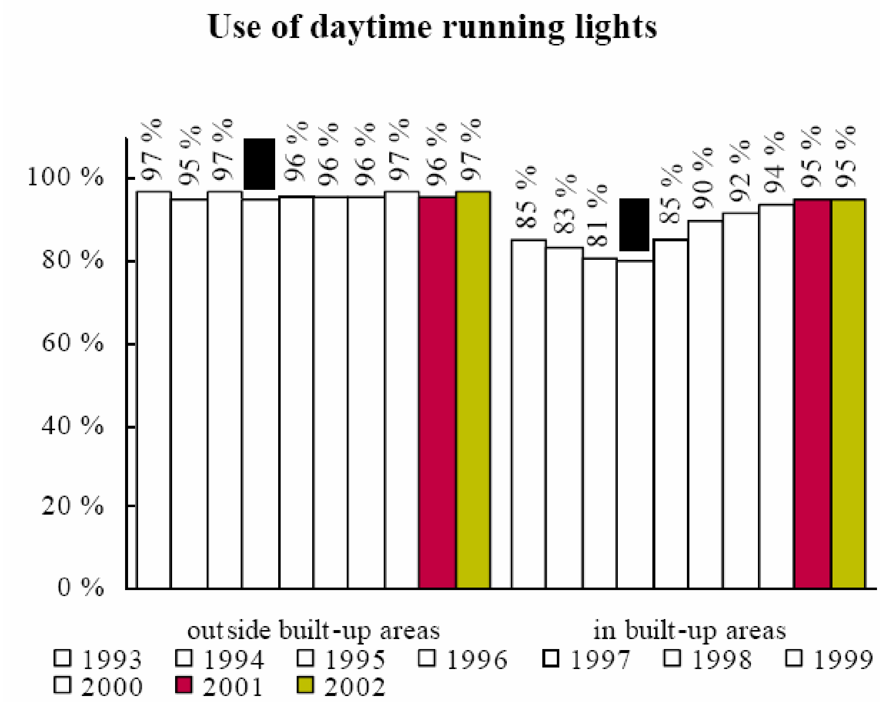

Figure 6.3: Use of daytime running lights in Finland - Results of systematic surveys in 1993-2002. (Figure taken from Luukkanen 2003.)

In Hungary the DRL usage rates have been observed since 1993, the year of the introduction of this measure. Each year more than 10,000 vehicles are being observed during the surveys. In Figure 6.4 the DRL usage rates can be seen according to road categories. (In Hungary DRL is obligatory outside built-up areas only.)

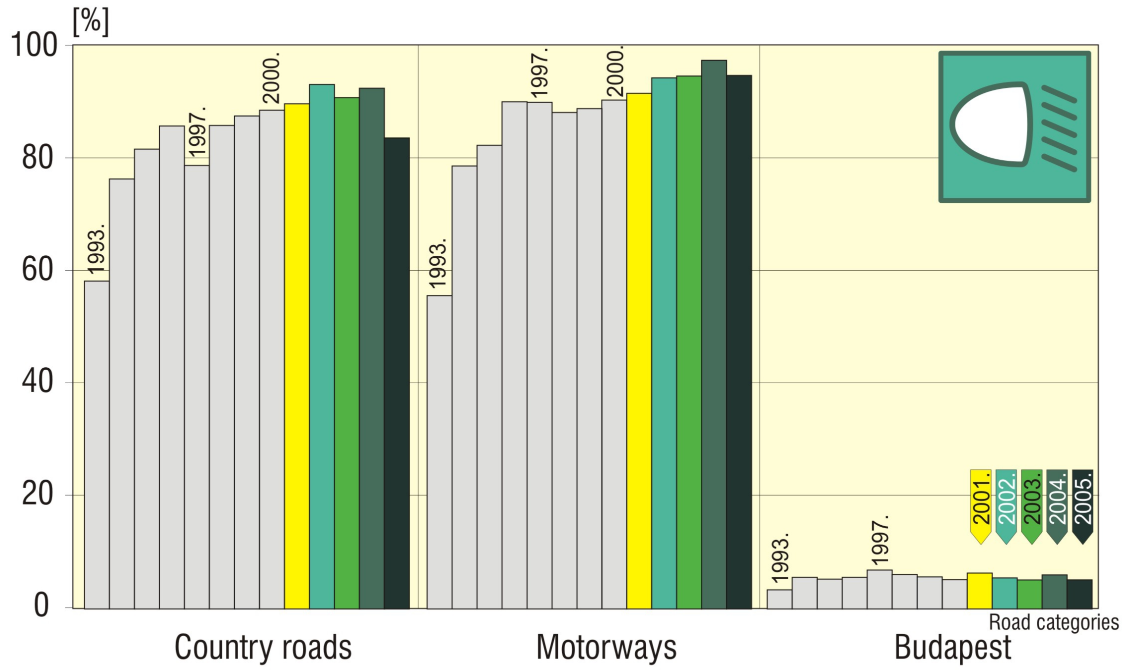

Figure 6.4: Use of daytime running lights in Hungary - Results of systematic surveys from 1993 to 2005.

6.3 Constructing SPIs

6.3.1 General concept

DRL SPIs are usually considered in the form of the percentage of vehicles using daytime running lights.

The general indicator can be estimated for the whole sample of vehicles, which were observed in the country. Similar values can be calculated for different road categories and for different vehicle types.

The road categories to be considered are: motorways, rural roads, urban roads, and DRL-roads, where the term “DRL roads” implies the road categories where the usage of DRL is obligatory. For example, in Hungary, DRL roads are ones, which are outside built-up areas.

The vehicle types to be considered are: cars, heavy good vehicles (including vans), motorcycles and mopeds.

Besides, the background information on the DRL legislation is essential for a correct interpretation and comparison of the results. For example, comparing the countries' DRL usage rates it is reasonable to take into account whether the countries have a law/ regulation on obligatory use of DRL and if they do, how long. Besides, DRL usage rates cannot be interpreted practically in countries where the lights are switched on automatically.

In countries where the automatic DRL was introduced long time ago (e.g. Sweden, Norway), according to expert estimates, the DRL usage rate is close to 100%, thus the DRL usage rate as a behavioural safety performance indicator does not have practical implications any more. In general, once the option of automatic DRL is introduced Europe-wide (e.g. by means of a scenario: “The use of DRL is required by all motor vehicles from a certain date", where “new cars sold after the same date are required to have dedicated DRL that are switched on automatically"), the DRL indicators will lose their importance.

6.3.2 Questionnaire responses as a means to examine applicability

To consider the context of the DRL use in different countries as well as to examine the potential for the application of DRL SPIs, a DRL questionnaire was built and distributed to national safety experts in the European countries. The questionnaire was composed in a way enabling to obtain information on a wide spectrum of issues, which are relevant to the DRL use in a country.

The main issues on which the information was collected are:

1. Legislative background, i.e. whether the DRL use is obligatory in a given country, and for which vehicle types; whether the automatic switch on was introduced, when, in which form and what is the current state of usage; sanctions for non-use of the DRL.
2. Surveying circumstances of the DRL usage rate, i.e. the frequency and the structure of the DRL survey (if applicable); sampling rules and available results.
3. Evaluation details of the DRL usage rate, i.e. how the DRL survey data are processed; whether the DRL use rates are available for separate road types and vehicle categories.
4. State of the application of means for increasing the DRL use, i.e. whether information and/ or enforcement campaigns on the issue are carried out; whether special road signs are applied to stimulate the DRL use.

In total, the information on the DRL use related issues was provided by experts from 20 (out of 27) countries, which are Belgium, Czech Republic, Denmark, Germany, Estonia, Greece, Spain, France, Cyprus, Latvia, Hungary, Malta, Austria, Portugal, Sweden, the United Kingdom, Norway, Poland, Switzerland and the Netherlands.

Considering the information provided by the countries it was found that:

a) A law or regulation concerning the use of DRL exists in 15 countries out of 20. Such countries as Greece, Cyprus, Malta, the United Kingdom and the Netherlands do not have a law on obligatory use of DRL. Austria has recently introduced the obligatory use of DRL.

b) The majority of countries with the DRL use related law/ regulation apply them for the whole year, where some countries have different rules. For example, Czech Republic applies the law for winter time only; Spain defines special suppositions for obligatory lighting, as follows: "there is a legal obligation to use the lighting under adverse weather conditions as fog, hard rain, snowfall, smoke or dist clouds, or under similar conditions".

c) In many cases, the DRL law/ regulation has specifics for motorcycles. For example, in Czech Republic, Germany, France, Hungary the obligation is valid for motorcycles on any road or for the whole year, where for regular vehicles the DRL use is obligatory only for winter period or only for some road categories.

d) In the majority of countries with a law/ regulation for the DRL use for cars, DRL should be used for the whole year and everywhere (on any road type). However, in some countries, the DRL law concerns certain vehicle types or certain road categories.

e) At least five countries such as Denmark, Estonia, Sweden, Norway, Switzerland, reported that the majority of the vehicles have lights that are automatically switched on when starting the engine. All these countries have a law concerning the use of DRL, which is applied for the whole year and all vehicle types.

Surprisingly, a regular DRL survey is obligatory in one country only (Latvia) and is recommended in another one (Estonia), where in all other countries, including the countries having a DRL law, it is not even recommended.

DRL usage rates are available for six countries: Czech Republic, Estonia, France, Hungary, Switzerland, and the Netherlands. However, for the Netherlands the data are old, from the years 1990-1993.

All six countries (Czech Republic, Estonia, France, Hungary, Switzerland, the Netherlands) delivered data on the DRL usage rates according to road categories. The Czech Republic and Switzerland also provided DRL usage rates according to vehicle types. Each country, except for the Netherlands, has its specific DRL legislation for types of vehicles and types of areas.

6.3.3 Suggested DRL SPIs

Following the general concept of the DRL SPIs (section 6.3.1) and accounting for current practices on the DRL use measurements in different countries (section 6.3.2), possible DRL SPIs can be considered as presented in Figure 6.5.

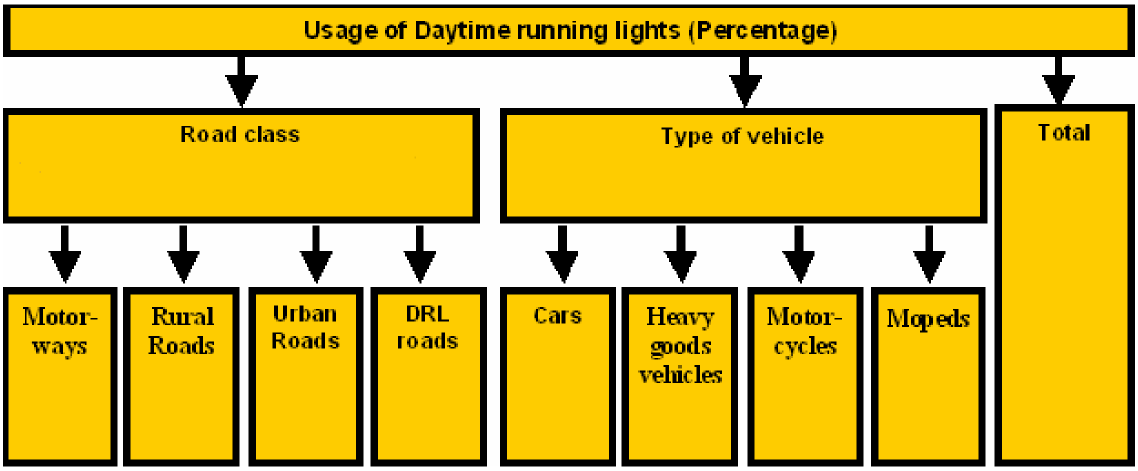

Figure 6.5 Schematic overview of possible SPIs for DRL.

In total, 9 DRL SPIs are recommended for application, which are: the total usage rate and the percentages of vehicles using DRL according to four road types and according to four vehicle categories.

To estimate the above SPIs, a country should perform an annual survey of the DRL use. The details of survey will be discussed in the document "Manual".

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7 Vehicle passive safety

RACKLIFF[A], L., HADDAK[B], M., MORRIS[A], A. PAGE[A], M., VIS[C], M.A.

[A]VSRC, [B]INRETS, [C]SWOV

7.1 Introduction

7.1.1 The influence of vehicle passive safety

Safety performance indicators (SPI) are policy tools which describe the extent of insecure operational safety conditions within traffic systems. These SPIs represent the presence within a country's vehicle fleet, of vehicles that may not effectively protect an occupant in a collision.

The potential of the vehicle to prevent (or indeed cause) injuries in the event of a crash can determine whether the outcome is a fatality or something less serious. Unlike an SPI such as speeding, passive safety measures do not influence the occurrence of crashes. The specific hazard can therefore be defined as the presence within the fleet of a number of vehicles which will not protect the occupant well in a collision. What is needed is a variable that will tell us the significance in each member state.

It is important to remember that each SPI is concerned with only one area of road safety: In this case, the passive safety performance of the vehicles which make up the fleet. Issues such as how fast a vehicle is driven, whether the seatbelt is used or the quality of the road infrastructure will affect injury outcome, however, they do not affect the proportion of a country’s fleet that protects occupants well in the event of a crash.

Private cars make up the majority of traffic in most EU countries. Private cars can be described by many different characteristics; age, weight, size, type of use, wheelbase, height, power for example. The availability of a wide range of different types of information about private cars, and the fact that they make up the biggest proportion of the fleet makes private cars the most logical starting point in an assessment of the overall performance of the fleet.

Passive safety performance can be assessed by looking at the crashworthiness of a vehicle; that is how it performs in a crash situation. The design of many aspects of a modern car interior is based on the tolerance of different parts of the human body to violent impacts. Passive safety devices such as airbags and seatbelts have been highly effective in reducing injury severity. The European Transport Safety Council (1999) estimates that 50% of all unbelted car occupant fatalities would have survived if they had been wearing their seat belt, while Kirk et al (2002) indicate a strong reduction in the severity of head injuries when an airbag is activated. Frampton et al (2002) attribute a significant fall in the rates of killed and seriously injured car occupants to the coincident introduction of airbag/pretensioner restraints. Thomas et al (2003) indicated that a large portion of the reduction in driver fatalities in newer cars was due to vehicle safety measures. Research presented at this year’s SafetyNet conference stated that an occupant was 10 times more likely to be killed in a 30 years old car than in a crash with a new vehicle.

The increased protection offered by newer vehicles can be attributed to two main factors:

- Newer vehicles are much more likely to be equipped with state-of-the-art safety technology and are likely to be designed from a structural point of view to be more ‘crashworthy’ in the event of a crash. This implies that in modern vehicles, crash-energy is managed more efficiently by the vehicle structures thereby reducing the risk of energy-transfer and hence injury potential to the occupant.

- Older vehicles are more prone to rust and therefore do not generally perform as well in the event of a crash since the crash-energy is 'managed' much less efficiently by the vehicle with greater associated risk of injury.

The age of the vehicle represents a proxy for improvements in automotive engineering designed to resist the effect of crashes, suggesting that, as the vehicle ages, vehicular damage will increase. Conversely, more recent vehicles are equipped with costly technology that improves automotive performance or passenger comfort, a feature that may increase the relative amount of damage sustained by newer passenger cars or four-wheel vehicles.

7.1.2 The influence of fleet composition

Few studies refer to the vehicle fleet when explaining a country's road safety performance. The reason is that a country's vehicle fleet, whether it is its composition or its age, is a combined result of a number of exogenous factors (Langley 2001):

- geographical factors: the size of the territory, level of urbanisation;
- economic factors: road network density, road infrastructure conditions, availability of public transport, car ownership and economic development levels;
- socio-demographic and human factors: age pyramid, the population's mobility needs and habits, driver behaviour, different road users and ways of life.

Transport policy choices can, to varying degrees, influence both fleet composition and user behaviour:

- Polices could more or less favour road haulage instead of other freight transportation modes such as rail, water or mixed;
- Likewise, with a diverse and adapted public transport policy or by favouring non-motorised means of transport (such as walking and cycling) policies could to some extent, dissuade motorcyclists or car drivers from using their vehicle. These policies could lead to a decrease in the use of private vehicles (at least in town) or even a reduction in the level of car ownership. A low level car ownership, whether it is through positive choice or not, results in different road conditions from high levels.

As described above the fleet composition is the result of many different, sometimes contradictory, factors from which it is difficult to identify the specific effect on a country's road safety record.

The fleet composition can be considered as a first rough indicator of risk exposure on the road which must be fine tuned while taking into account the characteristics of road traffic and the behaviour of road users. Bearing in mind that these are rough indicators only, it could be said that:

- the relative share of motorcycles in use in the fleet is an indicator of the proportion of vulnerable road users since motorcyclists are on average at greater risk of serious accidents;
- likewise, the share of heavy goods vehicles (HGV), light goods vehicles (LGV) or sports vehicles and other sport utility vehicles could be an aggressiveness indicator towards other road users;
- and inversely, the relative share of public transport, through the rate of bus and coach use related to the number of motorised vehicles, would be an indicator that represents the proportion of protected users and therefore how safe the road traffic is. Based on the number of kilometres travelled, public transport is the safest means of transport amongst motorised road vehicles.

7.1.3 Scope of the improvement potential

One of the main problems with many of the national vehicle fleets in Europe is the proportion of old vehicles. Changes have already begun to be observed in this area, often due to schemes such as Member States using fiscal incentives to encourage the purchase of new cars, for example in Greece. The changes are already being observed in the SPI analysis and will be seen to greater effect in the future. However, these changes themselves may present future problems. The UK appears to be moving in the right direction with only a very small proportion of passenger cars remaining from before 1994. However, these vehicles are now potentially at a greater risk of involvement and the occupants at greater risk of injury, in a collision with a newer and therefore stiffer and heavier vehicle. Work carried out by Martin et al (2003) suggests that in a collision, the driver of the lighter car is at an increased risk of injury. Countries such as Sweden are at a transition stage where the balance is changing to newer cars. In Latvia, the majority of passenger cars are older and therefore likely to be less crashworthy.

Passive safety is still a developing area and more and more technologies are being introduced as standard in vehicles. EuroNCAP currently gives extra points if a vehicle contains seatbelt reminders and side and curtain airbags are becoming more common on vehicles. Fiscal incentives also exist to encourage use of more advanced safety technologies. For example, Denmark gives an incentive to cars equipped with a combination of ABS, airbags and ESP. Manufacturers have shown a desire to build cars that will satisfy the requirements of the EuroNCAP tests, and the consumers have shown a demand for cars offering a higher level of protection. According to EuroNCAP the test results ‘provide the public with independent, realistic and accurate information about the safety performance of individual car models.’ In the UK, for example, EuroNCAP test results now form a high profile part of vehicle marketing. Cars are increasingly marketed on their ability to withstand impacts, rather than on engine performance.

Compatibility between passenger cars is also an important issue for discussion with regard to potential safety improvements. Currently, EuroNCAP divides vehicles into nine different vehicle classes. These broadly relate to the size and weight of the vehicles. Scores are only directly comparable between different cars in the same class. For example, the latest Ford Fiesta scores 25 points. This is only a valid indication of its capacity to protect when in collision with a vehicle of the same class, such as a Renault Clio. There is work beginning by companies such as IDIADA in Spain to develop methods of testing the crashworthiness of a vehicle model against collision partners of different weight and stiffness.

The issue of pedestrian safety is not a new concern for public health practitioners and vehicle designers. For pedestrians there is extensive literature outlining the characteristics of friendly vehicle exteriors; many current models of cars are exhibiting some of these properties but better agreement on an optimum specification for the car's exterior is still required.

Pedestrian injuries have declined in recent years, mainly due to factors such as speed limit enforcement, public education and improved vehicle aerodynamic design. However they are still a major public health concern in most developed countries where pedestrian injuries account for a significant portion of traffic fatalities.

In order to perform well in EuroNCAP tests, manufacturers have tended to make the front of their cars stiffer. This may have implications for pedestrians. In terms of the limitations of the crash tests themselves, pedestrian protection is a notable exception from the analysis here. EuroNCAP does assess vehicles for this, but it was felt that these tests were not, as yet, sufficiently well validated for them to be used to calculate an SPI. In the past, manufacturers tended to focus on occupant protection and have paid less attention to pedestrian protection. However, with the introduction in 2010 of new directives setting out design standards for pedestrian protection, this is beginning to change; the first (and so far the only) award of 4 stars for pedestrian protection was made in 2005 to the Citroen C6. Pedestrians need to be considered as a major compatibility risk and the recent rise in vehicles such as MPVs and SUVs exaggerates the problem. Research by Gabler et al (2006) showed in the US, that the number of pedestrians killed by SUVs and vans had increased by 10%. 4.5% of pedestrians struck by a car were killed but the figure rises to 7.8% when hit by a small SUV and 11.5% when hit by a large one. The vehicle compatibility SPI needs to extend to pedestrians and different types of passengers cars, not only looking at cars against HGVs and motorcycles.

7.1.4 Available estimates of improvement potential (literature survey)

The Cars21 project addresses the issue of vehicle age and overall fleet renewal by countries. According to the Final Report (April 2006):

"The last 30 years have seen a tripling of traffic on European roads while the number of casualties has halved during the same period. Industry has contributed significantly through improved occupant protection (passive safety). For example, the combination of EU legislation for crash test standards and improved consumer information through the EuroNCAP programme has substantially raised the survivability of vehicle occupants in a crash. The issue of fleet renewal should also be given consideration by policymakers as it can have important environmental and safety implications. A vehicle fleet with a high average age of vehicles tends to have a negative effect on road safety and the environment and if vehicle owners retain their old vehicles for longer periods the market penetration of new better performing vehicles is slowed down."

(http://ec.europa.eu/enterprise/automotive/pagesbackground/competitiveness/cars21.htm)

EuroNCAP claim that the tests have been 'responsible for a dramatic change to overall car safety.' This is not necessarily a universal view, however the rationale behind offset frontal and side impact tests proposed by the EEVC Working Group 11 was extensively researched and validated using both data from dummy tests and real world crash configurations [Lowne, 1994, 1996]. EuroNCAP is supported by a number of partners comprising governments, insurers and research groups. Other studies have looked at trends in real–world collision data and the correlation with improvements in EuroNCAP scores. Lie and Tingvall (2000) reported that 'cars with three or four stars are approximately 30% safer, compared to two star cars.' More recently Newstead et al. (2005) stated that 'design priorities for vehicle safety encouraged by the EuroNCAP scoring process are leading to improved real world crash performance on average.' There has been some work which has examined the link between EuroNCAP ratings and injury outcome. Lie and Tingvall (2000) conclude that 'there was a strong and consistent overall correlation between EuroNCAP scoring and risk of serious and fatal injury.' EuroNCAP is therefore seen in this case as a valid measure to use as a link between advances in passive safety and injury severity reduction.

There is also evidence which suggests that newer cars offer better protection in the event of a collision. Hägg et al. (1999) stated that 'there are 5 times higher risk of fatalities for cars introduced in the early 70s compared to cars introduced in the end of 1990s.' This is important when assessing the crashworthiness of an entire fleet, as only a percentage of vehicles are EuroNCAP-tested, therefore vehicle age becomes an important factor in the safety offered by the fleet as a whole. In addition, Frampton et al. (2002) used national casualty figures from the UK showing an 18% decrease in fatalities in newer cars.

7.2 Background for developing SPIs

7.2.1 What can be measured and quantified

From the data provided in the vehicle fleet databases from each country, a number of factors contributing to vehicle passive safety can be assessed as SPIs:

- Vehicle crashworthiness;
- Vehicle age;
- Fleet composition and compatibility.

The purpose of the vehicle crashworthiness SPI was not to develop a new method for assessing crashworthiness. Instead it was to take a recognised measure which gives an indication of the protective capacity of vehicles and apply it to the whole fleet of each country. In this way it was hoped to draw conclusions about the general level of crashworthiness across the entire fleet, and the degree to which consumers seem to prioritise safety. Passive safety performance can be assessed by looking at how vehicles perform in a crash. It was therefore necessary to select a measure of crashworthiness that was already well developed, could be applied to a significant proportion of the vehicles registered in Europe, and had been subject to scientific scrutiny. Initially two different types of measure seemed possible; those based on real-life crash outcomes, and those based on crash-tests. In the former category, the crashworthiness ratings derived by Newstead et al (2004), Hägg et al (1999) and those used by the UK Department for Transport (2003) were considered. However, there were a number of problems with these, including:

- The time lag between the introduction of a model and its involvement in a sufficient number of collisions to make robust conclusions about crash performance possible. This is particularly problematic when attempting to rate countries with a very high number of new registrations each year.
- Different models may have a different distribution of collision severity, which will bias the results of the safety ratings.
- The characteristics of drivers differ across vehicle models, which will also bias the safety ratings. A particular model may be preferred by older drivers, whose physical frailty makes them more vulnerable to serious injury. According to Broughton (1996), in the UK one third of drivers of Toyota Carinas are at least 55 years old, compared to only one twelfth of drivers of older Fiat Pandas.
- These ratings are relative, not absolute, so while they will give an indication of the position with regard to safety of one make and model over another, they will not offer any insight about the evolution of a model (in terms of passive safety) over time. Equally, they compare each model with the average, but do not provide any information that allows us looking at how the “average” level of passive safety may have changed.

It was decided to use the results of the EuroNCAP crash tests as the basic measure of crashworthiness to be applied to each fleet. Whilst there are limitations to these tests, it was felt that EuroNCAP had a number of advantages including:

- Crash testing is a reliable method of assessing the relative level of protection a vehicle offers in certain crash types;

- It offers the potential in the future for integration with other SPI areas, for example, infrastructure provision based on European Road Assessment Program (EuroRAP) results;
- It offers a global methodology that can easily be extended beyond Europe, through the use of NCAP results in Australia, USA and Japan;
- Frontal and side impact results for over 170 models are widely available and frequently updated.

One major limitation concerns the fact that not all vehicles have been subjected to EuroNCAP tests and the contribution that these vehicles make to the accident constellation is unknown. Until national fleets contain 100% of vehicles which have been tested, it is difficult to see how this can be overcome. Assumptions have therefore been necessary in order to assess a country's fleet as a whole.

Another factor which influences the safety of the fleet is the proportions of vehicles of different types and weights that make up the total fleet. The composition of the vehicle fleet gives an indication of the likely compatibility problems, which result from collisions between vehicles of different mass and/or geometry. These problems lead to well-recognised effects on occupant outcomes in crashes, with (in general terms) occupants of smaller or lighter vehicles being more at risk from severe injuries in the event of a crash. For example, there may be greater numbers of car-to-truck/bus crashes in Member States that have a higher proportion of truck/buses in the fleet.

In vehicle-to-vehicle collisions, the protection of all occupants in the subject and other vehicle should be considered. Compatibility means that passenger vehicles of disparate size provide an equal level of occupant protection in car-to-car collisions.

Vehicle crash incompatibility is defined as design differences between vehicle types (or by extension road user category) which result in disproportionate damage patterns to the vehicles involved in a collision (Kopits and Cropper, 2005). The incompatibility is induced by the difference in the mass (Lassarre, 2001), stiffness, geometry of both vehicles and other parameters such as angle of impact (Trawen et al, 2001). Vehicle mass is one of the most significant factors affecting driver injury in car-to-car accidents, and an incompatible vehicle induces high risk for the occupants in the other vehicle, which can be defined as 'aggressivity' (Kent et al, 2002).

The heterogeneity and the diversity of a country's fleet are key determining factors of their vehicles' road safety performance. Vehicle categorisation and inventory of the different vehicle categories vary greatly from one country to another. For example mopeds and scooters with a capacity of less than 50ccs are not systematically registered in all countries and it is therefore difficult to include them in the study. A similar problem is encountered for buses, LGVs and HGVs.

Therefore analysis will focus on the three most common categories; passenger cars, motorised two-wheelers and HGVs.

For countries where the vehicle type has been provided, some analysis can be done looking at the different proportions of the three main vehicle types identified. This will give an indication of the compatibility of the fleet (in terms only of average vehicle mass.

There is also compatibility of vehicles with pedestrians to consider. The behaviour of the pedestrian and the severity of injury can be affected by vehicle mass, geometry and stiffness.

For the purpose of EuroNCAP tests, passenger cars are broken down into 9 vehicle groups, based on weight:

- Supermini;

- Small Family Car;
- Large Family Car;
- Executive Car;
- Roadster;
- Large Off-Roader;
- Small Off-Roader;
- Large MPV;
- Small MPV.

For countries that have provided make and model data, the proportions of each vehicle group in the fleet can be determined and the use of EuroNCAP scores for pedestrian impact can be considered. However, since only the more recent crash tests have considered impact with pedestrians the sample size is small and can only be used as an indication of the fleet.

7.2.2 Examples of SPIs in use

EuroNCAP is widely used as an indicator of passive safety for individual vehicles to give consumers a guide to the crashworthiness of specific makes and models. However there is no current recognised measure of an entire vehicle fleet.

Projects such as SUNflower and SUNflower+6 are comparative studies of road safety policies, programmes and performances in 9 European countries. The projects use road safety ‘footprints’, representing the road safety status of a country. Passive safety areas of a footprint include:

1. Crashworthiness;
2. Compatibility ratio;
3. Fleet age;
4. Fleet composition;
5. Vehicle inspection frequency.

“Footprint based benchmarking is mainly meant to show how a country deviates from a reference. This especially concerns those deviations that indicate a worse performance than the reference.”

7.3 Constructing SPIs

7.3.1 Description of suggested SPIs

For vehicles (passive safety) the correspondents were asked to send data containing the entire vehicle fleet database according to vehicle type, make, model and year of first registration, as it stood in 2003. Initially 17 countries sent vehicle fleet data, a response rate of approximately 63%. However, there were variations in the level of detail and degree of accuracy between different countries. Common problems included: the failure in some countries to remove all scrapped vehicles from the database; the lack of detailed information about vehicle make and/or model in some countries; the use of database from a year other than 2003, leading to compatibility problems.

Vehicle crashworthiness and age

EuroNCAP scores are only currently available for passenger cars, so this analysis concentrates on those vehicles within the national fleet. For this study it was decided that a EuroNCAP score, although describing a specific model variant, would be applied to any vehicle of the same model, to ensure a larger sample size.

For each country a EuroNCAP score was attributed to eligible vehicles. An average figure was then calculated for each year and weighted by the number of vehicles present in the 2003 fleet from that year. An overall average EuroNCAP score is then awarded for each country and, together with the median age of passenger cars in the fleet, these two figures make up the SPI for each country. These two figures have been plotted on a graph to show a direct comparison between countries in both areas.

eq. 7.1 $$SPI = (ave.EuroNCAP, median\,age)$$

In order to validate the SPI with real-world data, car occupant fatality rates in each of the countries were considered. The number of car occupant fatalities in 2003 for each country (www.prismproject.com) was divided by the number of passenger cars present in each 2003 fleet, to give a figure for the number of car occupant fatalities per million cars. The average EuroNCAP score for each country was weighted by the percentage of passenger cars in a country's 2003 fleet, which were less than 10 years old. This figure for each country was then plotted against the car occupant fatality per million cars figure for each country.

eq. 7.2 $$Combined\ RSPI = ave.EuroNCAP * \left(\frac{\sum cars > 1994}{\sum cars} \right)$$

Fleet composition and compatibility

In the case of compatibility, the goal is to develop a safety performance indicator related to vehicle fleet composition. The value of an appropriate indicator is directly related to the degree to which road safety is influenced by the composition of a country's vehicle fleet. Furthermore, the indicator should be such that it allows for the comparison of countries.

Here, fleet composition indicates the size of vehicle types within the total fleet. More particularly, for the development of the indicator three types of vehicles are taken into consideration: passenger cars, heavy good vehicles (HGVs), and motorcycles. These three types are chosen because they represent the most incompatible vehicle types within a fleet. Incompatibility is the phenomenon that one vehicle absorbs more energy that the other in a crash, due to its characteristics. One of the most important characteristics here is vehicle mass. The vehicle with the lower vehicle mass generally has greater damage, and this is reflected in the severity of injury suffered by the occupants.

The safety performance indicator should take into account the distribution of the vehicle types within the fleet, together with the countries' relative severities of vehicle crashes.

The severity of vehicle encounters

Vehicle characteristics other than mass can yield a difference in the severity of injuries in the case of a crash for different vehicle types. For example, motorcycles are inherently less safe than passenger cars, since the vehicle itself offers no protection to the rider. This can be seen from Table 7.1 which shows for The Netherlands the number of fatal accidents due to a crash between two vehicles of any of the three types, divided by the total number of accidents between these vehicle types, normalised on the value for crashes between passenger cars.

This table, which demonstrates the severity of incompatibility in a crash, shows for example that a crash between two motorcycles is 17.33 times 'more severe' than a crash between two passenger cars. Risk resulting from vehicle incompatibility can be seen from the non-diagonal values. Except for the motorcycle-to-vehicle crashes, they are larger than the corresponding diagonal values.

	HGV	PC	MC
HGV	4,04	4,47	39,65
PC		1	8,01
MC			17,33

Table 7.1 Relative severity of a possible encounter between two vehicles of any three vehicle types (PC: passenger vehicle; HGV: heavy good vehicle; MC: motor cycle). Data from The Netherlands (1970-2005).

Note that, since the relative severities in Table 7.1 were calculated from accident data, aspects other than vehicle characteristics are included in the values. For example, helmet wearing rate heavily influences the severity values related to crashes involving motorcycles. Therefore, although Table 7.1 does clearly show the problem due to vehicle incompatibility, the measure used here to calculate the severity is not the optimal one for the development of safety performance indicators related to fleet composition.

An optimal measure for severity relates to vehicle characteristics only. The most obvious – and only practically feasible – vehicle characteristic for this is vehicle mass. In Appendix B a correct measure for relative severity is derived from mechanical considerations.

Derivation of the safety performance indicator for fleet composition

The safety performance indicator should depend on the number of possibilities of two vehicles of any of the three vehicles types meeting. This number is dependent on the number of vehicles on the road at any time.

Not all vehicles will be on the road at any time. It will first be derived how many vehicles of a given type are on the road at any time, and this number will be used to derive an appropriate safety performance indicator. After that, it will be shown how the assumed unavailability of some of the data necessary to calculate the number of vehicles leads to the use of a simpler value.

Let

i indicate vehicle type i (1: passenger cars – PC; 2: heavy good vehicles – HGV; or 3: motorcycles – MC)

k_i indicates the amount of kilometres driven per year by vehicles of type i

v_i indicates the average velocity of vehicles of type i on all road types (in km/h)

Then the average number of vehicles of type i on the road at any time, M_i, can be calculated as follows:

eq. 7.3
$$M_i = \frac{k_i}{v_i \cdot 24 \cdot 365}$$

Note that the average vehicle velocity is multiplied by the number of hours per day and the number of days per week, so that the unit of the denominator is km/year. This makes M_i dimensionless.

The number of possibilities of two vehicles of types i and j meeting, $X_{i,j}$ is:

eq. 7.4 $X_{i,j} = M_i \cdot M_j$ if $i \neq j$, and

eq. 7.5 $X_{i,j} = \binom{M_i}{2} = \frac{M_i!}{2! \cdot (M_i - 2)!}$ if $i = j$.

Note that $X_{i,j} = X_{j,i}$ for all i, j, so that the total number of possible meetings can be calculated as:

eq. 7.6 $$X = \sum_{\substack{i,j=1 \\ j \geq i}}^{3} X_{i,j}$$

Now assume that the probability, $P_{i,j}$, of a crash between two vehicles of types *i* and *j* is proportional to the number of possibilities of two vehicles meeting, and that the proportionality is independent of the vehicle type. With the latter assumption, and realising that the proportionality factor is unknown, for the development of a performance indicator, the number of possible meetings, $X_{i,j}$, can be used instead of $P_{i,j}$.

The overall severity of all crashes between and within all (here: three) vehicle types can now be calculated if the relative severities between single crashes between any two vehicles of any two vehicle types is known. Let $g_{i,j}$ be the severity of a single crash between two vehicles of type i and type j, relative to the severity of a crash between two passenger cars (a correct measure for relative severity is derived in Appendix B). Then the total severity of all crashes relative to the crash between two passenger cars can be calculated by:

eq. 7.7 $$G = \sum_{\substack{i,j=1 \\ j \geq i}}^{3} g_{i,j} \cdot X_{i,j}$$

This number could be used as a safety performance indicator related to fleet composition for individual countries. Its development can be monitored in time to see if the situation improves. It is, however, not suitable for the comparison of countries, yet, since it strongly depends on the total number of possible meetings, which in turn depends on the number of vehicle kilometres, which strongly depends on the fleet size. Here we assume that a country's fleet size is roughly proportional to the number of vehicle kilometres driven.

To be able to compare different countries, the total severity *G* should be normalised on the total number of possible meetings *X*, yielding the normalised total severity $\overline{G}$:

eq. 7.8 $$\overline{G} = \frac{G}{X}$$

The normalised total severity can be used as a safety performance indicator comparing different countries.

Note that the country's road length is not taken into account here. Although the road length strongly influences the vehicle density at a given fleet size, and hence influences the probability of two vehicles meeting, it is reasonable to assume that it does not influence the effect of fleet composition on road safety. Two countries with similar fleet composition and similar severity values should have the same safety performance score with respect to fleet composition, irrespective of their road length. Of course, the size of the road network will influence the eventual number of road deaths, but this in turn is irrespective of fleet composition.

Coping with unavailability of necessary data: appropriate and feasible safety performance indicators

The normalised total severity would be a good indicator, but we realise that some of the data needed to calculate it is not available in most of the countries. In particular, this holds for the number of vehicle kilometres driven (per vehicle type).

We therefore propose to use the number of vehicles per vehicle type as a surrogate, under the extra assumption that the average number of kilometres driven per vehicle of a given type is the same for all countries. In that case, M_i in eq. 7.4 and eq. 7.5 can be replaced by N_i, the number of vehicles of type i in the country's fleet.

Example

The following bar chart shows the fleet compositions for five countries, together with the number of vehicles per vehicle type. Note that the fleets in countries 2-5 are variations on the fleet of country 1, to allow a sensitivity analysis of the method. In particular, note that the fleet of country 2 has the same composition of that of country 1, but is twice as big.

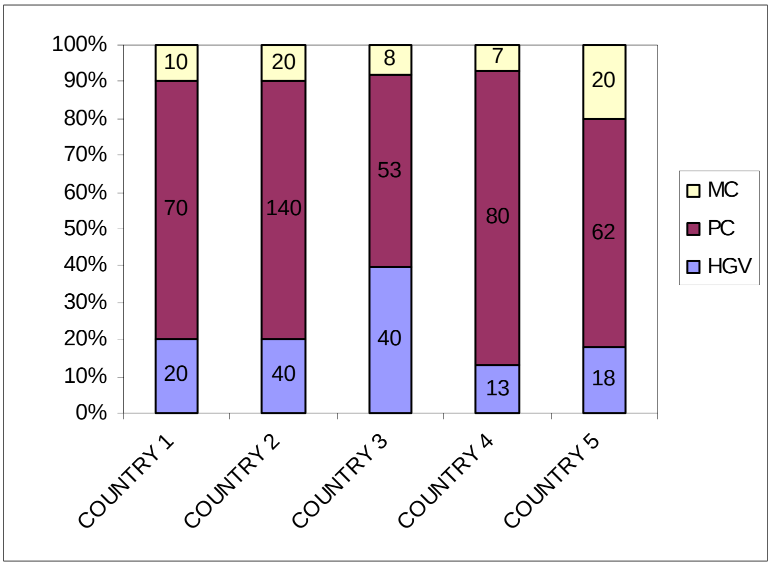

Figure 7.1 Fleet size and composition of five different countries.

The following table gives the relative severity of crashes of two vehicles of either the same or different type, according to the measure derived in Appendix B.

	Relative severity of possible encounter between two vehicles		
	HGV	**PC**	**MC**
HGV	1,00	1,68	1,98
PC		1	1,88
MC			1,00

Table 7.2 HGV: heavy good vehicles, PC: passenger cars, MC: motorcycles.

To show the validity of the method, both the total severity and the normalised total severity were calculated for each country on basis of the data above. The following table shows the outcomes, together with the fleet data.

Country	HGV	PC	MC	Total severity	Normalised total severity
COUNTRY 1	20	70	10	6715,456	0,67
COUNTRY 2	40	140	20	26961,83	0,67
COUNTRY 3	40	53	8	7183,625	0,70
COUNTRY 4	13	80	7	6240,332	0,62
COUNTRY 5	18	62	20	7149,69	0,71

Table 7.3 Total and normalised total severity for each of the 5 countries.

The outcomes are also graphically shown in the following figures.

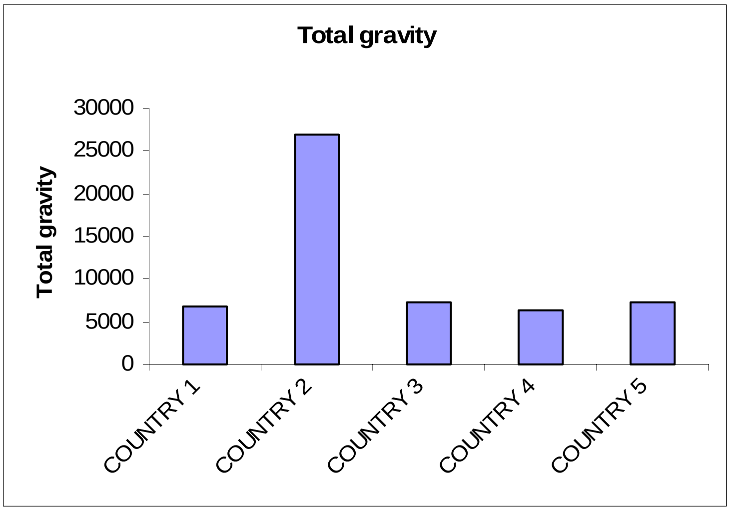

Figure 7.2: Total severity for all 5 countries.

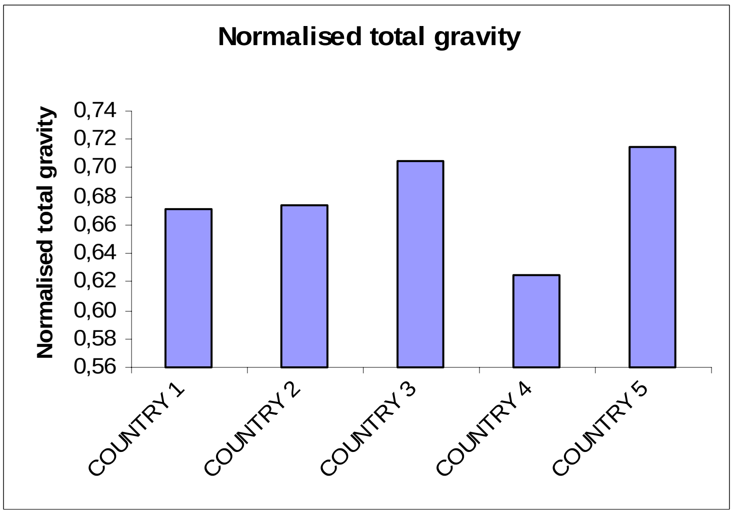

Figure 7.3: Normalised total severity for all 5 countries.

Notice that the normalised total severity is a better safety performance indicator than the total severity. This follows from the following observations:

- The countries that have the same fleet composition (1 and 2) have the same score.
- If the fleet has relatively more HGVs (3 vs 1) or motorcycles (5 vs 1) while the composition of the other two vehicle types remains the same, the score is higher. These are situations where the incompatibility within the fleet is increased.

- If the fleet has relatively more passenger cars (4 vs 1), the score is lower. This is a situation where incompatibility within the fleet decreases.

Different measures of relative severity

Using the method derived in Appendix B to determine the relative severity, collisions between two vehicles of the same type always yields a relative severity equal to 1 (see Table 7.2). This suggests that for road safety, a collision between two motorcycles is as undesirable as a collision between two passenger cars. This is clearly incorrect, since, due to the difference in the characteristics between the two vehicle types, a motorcycle is inherently less safe than a passenger car (see also Table 7.1).

For the above example, however, using the values in Table 7.1 as relative severities does not change the position of the countries in the ranking. This can be seen in the following figure, which is similar to Figure 7.3, but calculated using the values in Table 7.1 as relative severities, thus basing the relative severity on accident data.

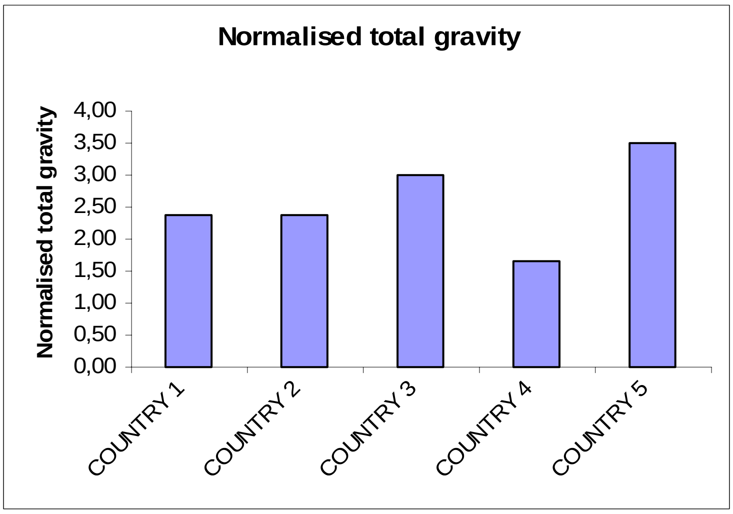

Figure 7.4 Normalised total severity for all 5 countries, now using the values in Table 7.1 as relative severities.

It can be seen from the figure that, although the values for the normalised total severity are different than in Figure 7.3, the score of the countries is qualitatively similar.

Severities could also be determined in yet different ways, for example by taking KSI crashes instead of all crashes. Note that the severities will probably differ per country. For example, for countries were helmet usage rates are low, the severity for accidents involving motorcycles may then be (much) higher. In the example, the relative severities were equally applied to all countries.

The role of road length

As explained above the country's road length is not taken into account. The safety performance indicator should score the influence of fleet composition, leaving unrelated aspects out.

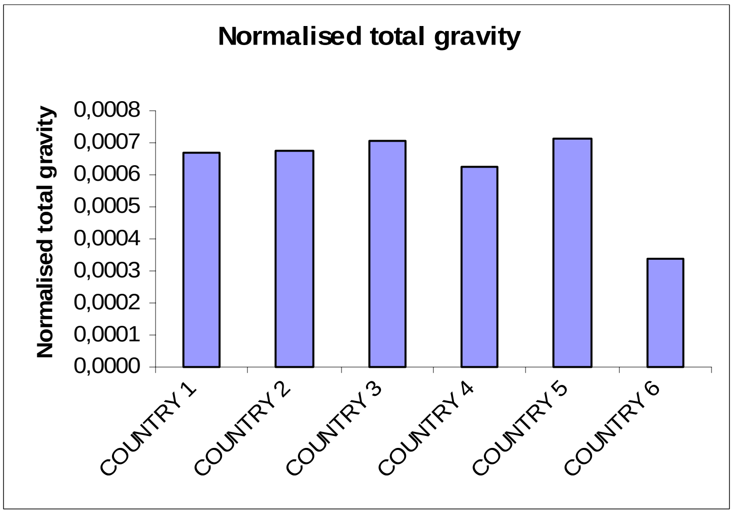

Figure 7.5 The values for the developed safety performance indicator (normalised total severity) as before, but now allowing influence of road length.

Figure 7.5 shows what happens if a country's road length is taken into account in the safety performance indicator. In this case, the number of possible encounters between two vehicles is divided by the country's road length. Country 1-5 have the same road length, so that the relative performance is the same as in Figure 7.3. Country 6, however, has exactly the same fleet size and composition, but its road length is twice as big. The resulting score for the safety performance indicator is lower than any of the other countries. This shows that a safety performance indicator that takes road length into account in such a way, is not appropriate. Namely, two countries with similar fleet composition and similar severity values should have the same safety performance score with respect to fleet composition, irrespective of their road length. Of course, the size of the road network will influence the eventual number of road deaths, but this in turn is irrespective of fleet composition.

Discussion on the performance indictor for fleet composition

There are a number of assumptions which may compromise the validity of the safety performance indicator.

- There is also incompatibility within each of the three vehicle types themselves. A bigger variation of vehicle mass within the group of passenger cars is more disadvantageous than a passenger car fleet that has a more homogeneous mass distribution. This could be accounted for in the indicator by using relative severity weights for the three groups. A country that has more incompatibility in one of the vehicle types will automatically use a higher severity weight value for that vehicle type, since the incompatibility is reflected in the severity of the accidents in which this vehicle type is involved.
- No disaggregation is made for road type. This could be necessary, because the amount of vehicle kilometres driven and the average velocity per vehicle type will differ per road type. It is highly unlikely, however, that it will be possible to get these necessary data for most of the EU member states.
- Since we expect that vehicle kilometres driven will not be available in most of the countries, we use the fleet data to calculate the safety performance indicator. This is under the assumption that the average number of kilometres driven per vehicle of a given type is the same for all countries. Of course, this may not be true.
- Using the method derived in Appendix B to determine the relative severity, collisions between two vehicles of the same type always yield a relative severity equal to 1 (see Table 7.2). This suggests that for road safety, a collision between

two motorcycles is as undesirable as a collision between two passenger cars. This is clearly incorrect, since, due to the difference in the characteristics between the two vehicle types, a motorcycle is inherently less safe than a passenger car (see also Table 7.1).

Conclusions on the performance indicator for fleet composition

A safety performance indicator related to fleet composition was developed. It seems to behave as we would expect: if incompatibility or relative severity of a vehicle type increases, the score increases, while the fleet size is accounted for. The indicator is therefore suitable for comparisons between different countries on the aspect of their fleet composition and risk resulting from vehicle incompatibility within the fleet.

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8 Roads

MORSINK[A], P., ARSENIO[B] E., CARDOSO[B], J., EKSLER[C], V., GITELMAN[D], V., HAKKERT[D], S., LOUWERSE[A], R., PAPADIMETRIOU[E], E., STRIEGLER[C], R., VAN GENT[A], A. , VIEIRA GOMES[B], S.

[A]SWOV, [B]LNEC, [C]CDV, [D]TECHNION, [E]NTUA

8.1 Introduction

8.1.1 The problem of road (un)safety in relation with road infrastructure

Infrastructure layout and design has a strong impact on the safety of the road transport system. Many ongoing practises in infrastructure research apply sampling of casualty data for safety assessment (a posteriori). In addition, crash prevention can be improved by early (a priori) assessments of safety hazards e.g. by monitoring the physical appearance of the road environment and the operational conditions of traffic. This is what Safety Performance Indicators (SPI) dedicated to roads are aiming at. This chapter describes considerations for the development and definition of SPIs in the roads domain.

The safety performance of the road transport system is the result of the (right) combination of the functionality of the network, homogeneity, and predictability of the road environment and the traffic involved. The road environment also has to be forgiving when an accident occurs. Relevant questions that arise are: is the right road placed at the right place in the network from a functional point of view? Do the physical appearance and characteristics of a road comply with its functionality? And as a consequence, is traffic safety sufficiently guaranteed? To answer these questions, the safety problem has to be organized in at least two levels: the road network and individual road design. In order to develop or find suitable SPIs, quantitative relations between road network, road design elements and road safety have to be known sufficiently well. However, knowledge is still lacking, although it is known that conflicts and related crashes can be prevented by choosing the right elements or facilities in the road network or individual roads. Based on these elements and facilities, SPIs will be proposed.

The road network

In many cases roads and streets nowadays fulfil simultaneously more than one function. This phenomenon contributes (greatly) to making roads less safe. That is why, in a sustainably safe road network, each road should only have one ***function***. Functionality refers to the use of the road network. The road network should consist of a small number of road types or road categories. Each of these road categories should have its own and exclusive function with its own and exclusive requirements regarding use and behaviour. This is what we call, monofunctionality. In a sustainably safe traffic system the road network should be functionally subdivided into three main road categories. The two 'extreme' road categories are through-roads (which allow traffic to flow) and access roads (which provide access to destinations). The third type is the distributor road, to literally and figuratively connect the two 'extreme' road types. Because flow and access traffic functions are often mixed on distributor roads (and no strict monofunctionality exists), this road type has relatively high crash risks.

Three road categories are distinguished:

- Through-road with a flow function, for long distance travel, at high speeds and, generally, for large volumes;

- Distributor road, opening up districts and regions containing scattered destinations;
- Access road, enabling direct access to properties alongside a road or a street.

Together, these three road categories form a network that (schematically) can look like Figure 8.1. The actual category must, of course, be consistent with the traffic function of the connection. If this is not the case there will be an insecure operational condition at the road network level.

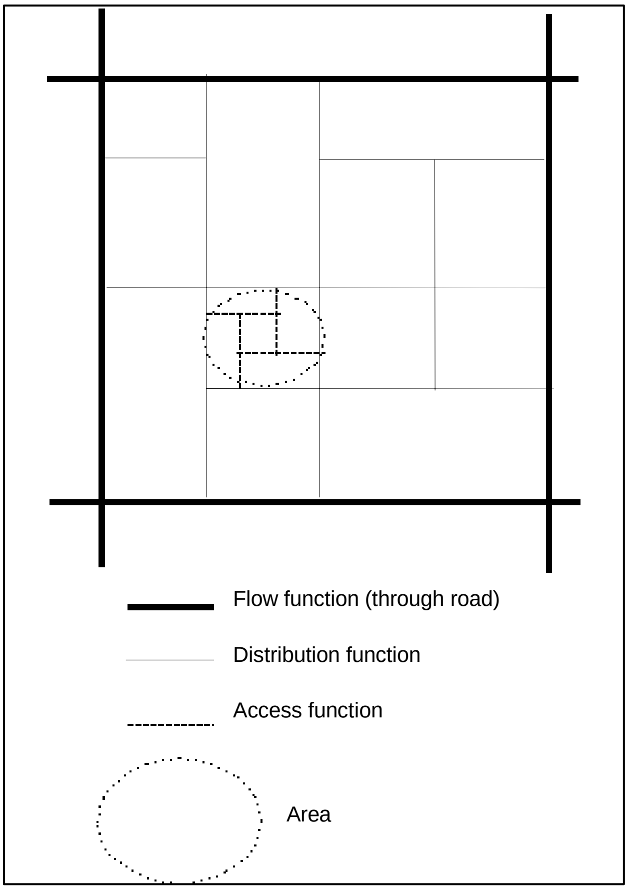

Figure 8.1: Traffic functions assigned to the different road classes in the road network.

Road design

Road design and construction determine many of the conditions in which road users have to act. Therefore, a road designer should design with safety in mind in order to create optimal conditions for the road users. However, the knowledge about relations between road design elements and (the resulting) road safety is still growing and by far not completed.

In sustainably safe road transport, the human road user is the measure of all things. This means that traffic, its surroundings and rules (the traffic and transport system) must be adapted to the limitations and possibilities of the road users. This is an efficient approach since over 90% of crashes result from human errors. Much effort should be put into preventing crashes and in case of unavoidable crashes, the crash severity must be reduced to the absolute minimum. This means that e.g. the infrastructure should be ***forgiving***, both to the occurrence of human error and to the consequences of remaining error.

A high level of ***homogeneity*** is aimed at in sustainably safe traffic. This means that a mix of road users with different speed and characteristics (mass, protection and motorization) should be prevented. For this purpose, infrastructure has to be set up and designed such that there will be small speed and mass differences between transport modes that can collide. Table 8-1 shows the exceptional position of cyclists and pedestrians which are much more vulnerable than e.g. occupants of buses and lorries. In this chapter the term vulnerable road users (VRU) is used for these non-motorized means of transport.

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Motorized
(high speed)</th><th>Non-motorized
(low speed)</th></tr>
<tr><th>Protected</th><th colspan="2">Non-protected</th></tr>
<tr><td rowspan="3">Mass</td><td>Big</td><td>lorry
bus
tram</td><td>-</td><td>-</td></tr>
<tr><td>medium</td><td>car
van</td><td>motor cycle</td><td>-</td></tr>
<tr><td>small</td><td>-</td><td>moped</td><td>bicycle
pedestrian</td></tr>
</table>

Table 8.1: Differences between traffic participants in mass, physical protection and motorization.

8.1.2 Scope of the reduction potential

In 1999 the Organisation for Economic Co-operation and Development (OECD) reports that each year, more than 75 000 people are killed on rural roads in OECD Member States [OECD 1999]. According to this report the relative importance of rural road fatalities in relation to total road fatalities has increased from less than 55% in 1980 to more than 60% in 1996. Because OECD countries have experienced a reduction in the total number of road crash fatalities, it is clear that motorway and urban road safety improvements have been more successful than those on rural roads.

Around 80% of all crashes on rural roads falls into three categories: single vehicle crashes, especially running off the roads (35%), head-on collisions (23%) and collisions at intersections (19%, average of France, Switzerland, Hungary and Denmark [OECD 1999]). Driver behaviour and road infrastructure are the key contributing factors to these types of crashes. Rural crashes are scattered over the entire rural road network. A main conclusion from the OECD report is that the rural road system itself has inherent characteristics that significantly contribute to the high number of crashes and the high risks.

In the EuroRAP project Lynam et al. [2003a, 2003b] identify four main crash types on rural roads in six European countries. In addition to the three crash types of the OECD study, Lynam also identified crashes with vulnerable road users (VRU). These four crash types lead to 80%-90% of all fatal crashes on these roads (average of six EU countries: France, Switserland, Hungary, Denmark (OECD 1999) plus Britain and Sweden (Lynam 2003b); see Table 8-2). The crash distribution differs on different road types and in different circumstances.

Accident type	France	Switzerland	Hungary	Denmark	Britain	Sweden	Average
Single vehicle Run-off road	40%	51%	23%	25%	26%	30%	32%
Head on collision	21%	16%	31%	26%	19%	34%	24%
Side impact at Intersection/other	18%	21%	8%	27%	27%	12%	19%
VRU*	6%	3%	22%	11%	9%	13%	11%
sum	84%	91%	84%	89%	81%	89%	86%
	OECD (1999), table II.7 p 26				Lynam (2003b), table 6.2 p 36		

Table 8.2: Percentage of fatalities on (rural) roads by accident type and country. Four main crash types lead to more than 80% of all fatal crashes on rural roads in the six EU countries: France, Switzerland, Hungary, Denmark plus Britain and Sweden (= vulnerable road users = cyclists and/or pedestrians).*

8.1.3 Available estimates of reduction potential

The OECD and EuroRAP data gives a first specification of frequently occurring safety problems in the roads domain. Unfortunately there are no statistics available concerning the road network–safety relation. Especially in rural areas, road infrastructure related safety problems are eminent. To obtain a starting point for the definition of SPIs a distinction is made in four crash types: run-off-the-road crashes, head-on crashes, side impact crashes at intersections, and crashes with involvement of VRU. These crash types count for a substantial part of all fatal crashes on rural roads.

In this section, a concise series of studies, concerning safety related to the quality of the road design is discussed. It is not meant to give a complete overview of all relevant progress in this working field, but rather to identify expected effects on road safety.

Run-off road accidents

In the SAFESTAR report Criteria for roadside safety of motorways and express roads, Schoon [1999] takes the perspective "injury prevention at off-the-road incidents", and makes suggestions for European design norms to ensure safe shoulders.

In the SAFESTAR report a strategy is described to design a safe roadside for motorways and express roads. The report also proposes 'European standards' for Roadside Safety. To summarize, it can be stated that possibilities exist to reduce the relatively high percentage of serious crashes involving obstacles and dangerous zones. The safest way is to create obstacle-free zones or safe slopes where vehicular manoeuvres are possible. If there is a need for dangerous objects, such as lighting poles, to stand in this (otherwise) obstacle-free zone, they can be made to yield easily in case of a collision. Isolated rigid obstacles can be shielded with a crash cushion. The use of safety barriers is the next best solution, given that a collision with it is less dangerous than hitting the obstacle itself. Because of this safety barriers are often involved in crashes; in some European countries in approximately 20% of all injury crashes on motorways.

According to FHWA (report RD-87-008 quoted in Neuman 1992), the effect of constructing a soft shoulder of 0.6 m, 1.2m or 2.4m will be a reduction of 14%, 25% or 46% accidents. Hedman (1990, quoted in Ogden 1996) confirms this positive effect of widening the roadside. Schoon [2000] estimated a reduction of 75% casualties after a combination of (semi) hard shoulders (=not paved) and a obstacle-free zone along 80 km/h-roads. A reduction of 20% is the effect when the road is only equipped with (semi) hard shoulders of 0.45m - 2.45m (without an extra obstacle-free zone). Newstead & Corben (2001) estimated a reduction of 51% casualties of roadside accidents after constructing a hard shoulder with normal edge marking and removing the obstacles. The effect of only removing the obstacles will be less.

Wijnen [in preparation] estimated the effect of (semi) hard shoulders: 15% reduction of al casualties (killed and injured) on rural Distributor roads in the Netherlands. In the same study, they estimated the effect of obstacle-free zones of 4.5 - 6m wide: 35% reduction of al casualties (killed and injured) on rural Distributor roads in the Netherlands. This road category has a speed limit of 80 km/h.

Head-on collisions

Safestar (1997) estimated that only 10% of the head-on collisions were related to overtaking manoeuvres. It can be concluded from this that the effect of facilities that prevent overtaking will be at the most 10%.

Schoon (2000) estimated the effect of building both obstacle-free zones, (semi) hard shoulders and physical separation of carriageways (either wide median or barrier) on 100 km/h-through-roads: 50% accident reduction.

Side impact collisions at intersection

Schoon & Minnen [1993] and Dijkstra [2004] estimated the effect of constructing urban roundabouts: a reduction of 69% casualties. According to a study in the Dutch Province of South-Holland (Overkamp 2000) the effect of replacing a rural signalized intersection by a roundabout will be 60% casualty reduction. In the case of reconstructing a priority intersection to a roundabout this will be even 80%.

Schoon (2000) estimated the effect of extended urban speed humps (plateaus) at 35%. These plateaus can be situated just in front or even on the intersection square. According to Overkamp (2000) the effect of building plateaus on rural intersections will be 25% casualty accident reduction. Fortuijn et al. (2005) estimate the effect of plateaus on intersections of 80 km/h-roads at 30% casualty reduction, based on a before an after study of 40 signalized an 29 priority intersections outside build-up areas.

Wijnen [in preparation] estimated the effect of plateaus: 35% reduction of al casualties (killed and injured) on rural Distributor roads in the Netherlands.

Vulnerable Road Users

Laboratorial crash tests prove that when a passenger car collide with a pedestrian the survival probability of the pedestrian dramatically decrease if the speed increase above 30 km/h [Ashton & Mackay, 1979]. At that speed 'only' 5% of the pedestrians will be killed, whereas at a speed of 50 km/h already 45% and at a speed of 65 km/h even 85% will die. Because of this fact vulnerable road users should use their own, separated infrastructure when the speed of other road users exceeds 30 km/h.

Elvik & Vaa (2004) and SWOV (2004) stated that there is no proof of a significant effect of separated bicycle paths/tracks in urban areas, yet. In general, there is a reduction of accidents on the road section (of the cycle path), but also an increase of accidents at intersections. The number of crashes can be reduced by additional measures at intersections: priority regulations, speed bumps, and plateaus

Separated bicycle paths along road sections are safer than bicycle lanes on the carriageway. Roads with these bicycle lanes on the carriageway are less safe than roads with no bicycle facilities, according to Welleman & Dijkstra (1988). However, in Denmark, Herrstedt et al [1994] evaluated new bicycle lanes on the carriageway and concluded a reduction of 35% accidents involving bicycles.

SWOV (2004) stated that bicycle facilities that separate motorized traffic from vulnerable road users are necessary in a sustainably-safe traffic environment. Schoon (2000) estimated the effect: 23% reduction of casualties among cyclists. In the Netherlands, cyclists are involved in 9% of the accidents on rural Distributor roads. Schoon concluded that the effect of separated bicycle paths is 2% reduction of al casualties on rural Distributor roads in the Netherlands.

8.2 Background for developing SPIs for Roads

8.2.1 What can be measured and quantified

As a start, the identification of suitable SPIs has been inspired by the literature review of the State-of-the-Art report (SafetyNet 2005a) and crash data analysis described in the previous section. They help to understand the processes that lead to road-related crashes. For the identification of SPIs, a distinction is made in two groups according to Lerner (2004). The first group concerns road networks, the second concerns road design characteristics. The network group deals with 'higher level' problems. It aims at giving a description of the road network in terms of functional road types and their actual use. Subsequently, road design characteristics go into more detail for each road type.

According to the methodological fundamentals for the development of SPIs [Lerner 2004] a distinction can be made between direct and indirect SPIs.

Was it possible to find *direct* indicators? No

A direct indicator of safety performance of road networks and road design in each Member State could not be attained and so inferences have to be made. This is because it is not possible to make direct measurements of the insecure operational conditions.

Was it possible to find *indirect* indicators? Yes

The identified safety problems on road network level and road design level can be seen as latent variables. Certain road network and road design characteristics could be the indirect variables that can describe the latent variable. These characteristics are more or less independent from interventions.

8.2.2 Examples of SPIs in use (literature survey)

The literature review presented in the State-of-the-Art report (SafetyNet 2005a) demonstrated that there are no SPIs for road networks in use. However, in the Dutch study: “Quality aspects of a sustainably safe road infrastructure”, Dijkstra (2003b) discusses a method to assess network and design quality aspects of a safe road infrastructure at the regional level. This method could be used to formulate road network SPIs and will be discussed in this section.

Even for road design there are no direct SPIs in use at the moment. In this section two methods are discussed, which are in line with the indirect SPIs formulated in the previous section: the Dutch Sustainably Safe Indicator and the Road Protection Score. One of these methods should be used to formulate indirect SPIs for road design.

Dutch Sustainably Safe Indicator

During the last decade, the Sustainable Safety concept has become the leading traffic safety philosophy in the Netherlands [Wegman & Aarts 2006; Wegman & Elsenaar 2001; Hummel 2001]. The question still is to what extent a greater road safety improvement in the Netherlands can be achieved if a higher quality implementation of a sustainably safe infrastructure had been achieved.

The goal of the Sustainably Safe Indicator (SSI) is to provide a method and an instrument with which the designer or road authority can determine whether planned or existing traffic infrastructural provisions meet sustainably safe requirements [Dijkstra 2003a]. The SSI supports the designer or road authority by processing the input data and carrying out the test.

A national working group [CROW 1997] has set up twelve so-called functional requirements for each of four sustainably safe principles: functionality, recognition/predictability, homogeneity and forgivingness. The principles are based on theories from traffic planning and engineering, biomechanics and psychology.

These twelve requirements cannot be directly linked to traffic features and traffic infrastructure elements. Indicators show which variables and features are important for the testing of the sustainably safe requirements. The (draft) indicators for each requirement are given in Table 8.3.

Requirement, according to CROW (1997)	Indicators
Functionality	
1 Realization of as many possible joined residential areas	area and shape
	number of dwellings
	journey production
	maximum traffic intensities
	supply of daily provisions
2 Minimum part of the journey along unsafe roads	number of category transitions per route
	risk per (partial) route
	crossroads distances
3 Journeys as short as possible	length of fastest route divided by straight line
	Distance
4 Shortest and safest route should coincide	overlap of shortest (in time) and safest route
Recognition and Predictability	
5 Avoid searching behaviour	presence and locations of signposting
	indication of ongoing route at choice moments
	street lighting at choice moments
6 Make road categories recognizable	presence and type of alignment marking
	presence of area access roads
	presence of emergency lanes
	obstacle-free distances
	presence of bus and tram stops
	construction form of crossroads
	speed limit
	colour and nature of road surface
	presence and transverse position of bicycle, moped, and other 'slow traffic'
7 Limit and standardize the number of traffic solutions	number of structurally different crossroad types
	number of different cross-over provisions and category transitions
	number of different right-of-way regulations (per route)
Homogeneity	
8 Avoid conflicts with oncoming traffic	degree of protection of oncoming traffic
9 Avoid conflicts with crossing and crossing-over traffic	degree of protection of crossing and crossing-over traffic
	number of possible conflict points
10 Separate vehicle types	degree of protection of bicycle, moped, and other 'slow' traffic from motor vehicles
11 Reduce speed at potential conflict points	degree of speed reduction per conflict point
Forgivingness	
12 Avoid obstacles along the carriageway	presence and dimensions of profile of free space,
	obstacle-free zone, and plant-free zone
	presence of bus and tram stops, break-down
	provisions and parking spaces

Table 8.3: The indicators for each requirement [Dijkstra 2003a].

Sustainably safe makes demands on functionality which require the individual road user to choose a route that is safe, also for others. So a journey may not go through a residential area. Driving along an unsafe road for too long is also not desirable. A large residential area is safe for internal traffic; one prevents too many cross-overs by slow traffic of the surrounding through roads. An area that is too large leads to too much internal traffic; one that is too small leads to too many crossings-over the surrounding through roads.

The recognition and predictability requirements aim at orderly traffic surroundings: unification of measures, road signs and signposting. In Sustainable Safety, the limitation of the number of road categories produces a large contribution to the recognition. This assumes that the differences between the categories are large, and within each category are small.

The homogeneity and forgivingness requirements are mainly the result of accident analyses and based on biomechanical theories. Many accidents could be prevented by making certain conflicts impossible and separating different vehicle types. Accident severity decreases considerably with lower speeds and obstacle-free zones.

Quality aspects of a sustainably safe road infrastructure

The Dutch sustainably safe principles of functionality, recognition/ predictability, homogeneity and forgivingness are the starting points for the layout of road segments and intersections. However, the functionality also contains a dimension to be found at the network level of the traffic infrastructure. Dijkstra (2003b) has formulated a number of additional requirements. These additional requirements concern among others the function of a connection in an area and can be traced back to the requirement that certain conflicts on a sustainably safe road category should not occur. If a conflict cannot be avoided, only small speed differences are permitted. Dijkstra attempts to investigate the extent to which the current and planned road infrastructures meet the sustainably safe requirements. To do this, both the network features (road categorization) and the road sections and intersections features have been tested in a region in the Netherlands (part of the southern province of Limburg). Dijkstra shows that, to a large extent, the tested network meets the requirements made. Based on this sample, there is, at the most, an indication for the situation in the whole country.

The EuroRAP Road Protection Score (RPS)

The European Road Assessment Programme (EuroRAP) was designed as a complementary activity to the European New Car Assessment Programme (EuroNCAP), developed in the 1990s. EuroNCAP involves crash tests of new cars and awards each vehicle with a star rating depending upon the protection given. According to EuroRAP (Lynam et al 2003a, 2003b) a similar rating system for roads should help optimize the combined effect of road and vehicle safety. EuroRAP was therefore piloted to rate Europe's various roads for safety.

'Besides the so-called risk mapping, the EuroRAP programme contains a direct (visual) inspection of road quality. The aim of this survey is to produce a score for each route section that enables it to be compared with other sections. The Road Protection Score (RPS) focuses on the road design and the standard of road-based safety features. "Protection" in this sense describes protection from crashes (elements of primary safety) and protection from injury when collisions do occur (secondary safety).'

The classes or values that are used for the scoring of each road characteristic are speed limit, median treatment, hard obstacles or barriers (type and placement), road site areas (cut and embankment), junctions and intersections (type and access) - see further Table 8-6. The RPS appears to relate to the same type of philosophy that is being aimed at in SafetyNet SPIs for Roads.

According to EuroRAP four types of crash contribute about 80% of all fatal and serious crashes on major roads outside urban areas. The four types are single vehicle run-off-the-road crashes, head-on 'meeting' crashes, crashes at intersections and crashes involving vulnerable road-users (VRU)[4]. The total percentage is common to many countries, but the distribution of the crash proportion between the four types differs according to the existing nature of the road network and the traffic patterns in each country (see also Sec. 8.1.2 above).

The RPS-scoring process is described in the (pilot) protocol on scoring methods (Lynam et al 2003a, 2003b, 2007, Lynam in preparation). The main RPS is based on scoring separately the protection provided in relation to three of the four main accident types, and then combining their scores into an overall score of 1-4 stars. The combination of the component scores is weighted in proportion to their average occurrence across a range of European countries. An extension to the RPS is envisaged for protection provided to vulnerable road users, but that requires further development.

The score for each accident component is based on a family of risk curves reflecting the speed limit for traffic on the road and the potential variations in road design relevant to that accident type.

Conclusions

There are no direct or indirect SPIs for road networks in use in Europe at the moment. The Dutch study "Quality aspects of a sustainably safe road infrastructure" presented a method to assess network and design quality aspects of a safe road infrastructure at the regional level. This method could be used to formulate road network SPIs. However, the method is not commonly used yet and needs more development for use in Europe.

Even for road design there are no direct SPIs in use at the moment. Two methods could be used to formulate indirect SPIs: The Dutch Sustainably Safe Indicator (SSI) and the Road Protection Score (RPS) of EuroRAP. These methods score specific road design elements. This score can be used to formulate SPIs for road design. There is some overlap in the road elements that are considered in the two methods, however the way these elements are scaled differs a lot. Both methods pay attention to *homogeneity* of the road traffic and *forgiving* road environments. The SSI has strong roots in the Dutch Sustainable Safety vision, and therefore pays more attention than the RPS to the *predictability* of the road environment and the *function* in the network of the distinguished sustainably safe road categories.

The RPS are assumed to be more useful in the SafetyNet context because of two main reasons:

- all used road design elements are broadly accepted as relevant for road safety and…
- …the method itself is worked out in detail and already in use in a lot of European countries.

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[4] The International Road Assessment Programme (iRAP) is extending the VRU definition to include motorcycles, taxis and public transport users in places such as Africa where clearly these users are much more vulnerable and at risk of injury than car occupants. There are iRAP pilot studies using the Road Protection Score (with both protection and crash likelihood measures) in low- and middle-income countries like Chile, Costa Rica, Malaysia and South Africa and iRAP will extend to 20 more countries over five years. More than 100,000 km of road has now been surveyed on six continents using (slight different) RPS techniques (including sister programmes in Europe, Australia and the US)

8.3 Constructing SPIs

8.3.1 Description of the way the SPI concept is developed

Development of road network SPIs

The type of connection (road class) between residential areas and business districts depends on the number of people (in vehicles) using the connection, e.g. two main (regional) cities should be connected by a motorway, while a village should be connected to a main city by a minor rural road. Our assumption is that a road network is performing safely when the actual road classes (including the facilities in an area) fit the types (or level) of connection following from the size of each area or centre. This size will be expressed by the number of inhabitants, since population is assumed to determine to a great extent the number of journeys to and from a centre.

For five centre types, five different sorts of connection are possible - see Table 8.4. Each type of connection has its own position in the road network and a characteristic traffic volume. The (sustainably safe) road categories must fit the desired capacity and must be consistent with the traffic function of the connection.

It is recognised that (residential) centres differ from each other in many ways. The German guidelines for road categories (FGSV 1988), apply functions to each centre in an area in order to divide the centres into four classes (government, laws, culture, service). In between, there are various types of connections that fit the traffic that is the result of these functions (production/attraction of people and goods). This method could be an alternative for using population as the only distinctive factor.

Table 8.4 specifies the type of connection between different types of urban areas. The urban area types 1 to 5 are defined according to their number of inhabitants. Type 1 is a big city, type 5 is a village, and 2 to 4 are in-between. The type of connections is specified by road type I to V. These road types will vary between different countries, although some basic overlap will be present. For example a type I road is a road with a 'flow function', allowing for relatively high traffic volumes and relatively high speeds. Type V is a road with an 'access function' e.g. giving access to a residential area or one's own property. The network function of a road in a country or region can then be displayed in a uniform way by specifying what urban centres the particular road connects, according to Table 8.4.

In the chosen system there is no need for direct connections between type 1 and 4, between type 1 and 5, and between type 2 and 5 centres; these connections (may) run via larger centres. In any case, such connections can already be present in practice, or be considered necessary for other reasons (than intended here).

Urban area	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 5**
Type 1	I	I	II	indirectly	indirectly
Type 2		II	II	III	indirectly
Type 3			III	III	IV
Type 4				IV	IV
Type 5					V

Table 8.4: Connections between different types of urban areas. Connection types I -V depend on the number of inhabitants (city size) and might differ per country or region (example: Urban area type 1 > 200.000 inhabitants, type 2 = 100.000-200.000, type 3 =30.000-100.000, type 4 =10.000-30.000, type 5 < 10.000; connection type I & II = flow function, III& IV = distribution function, V = access function).

The testing of the connections occurs in a number of steps: at every step we determine a search area in order to search for a municipality of centre type N, within which municipalities of centre type N+1 are looked for. A search area is circle-shaped, whereby the radius is dependant on the distance to the nearest municipality of centre type N (Figure 8.2).

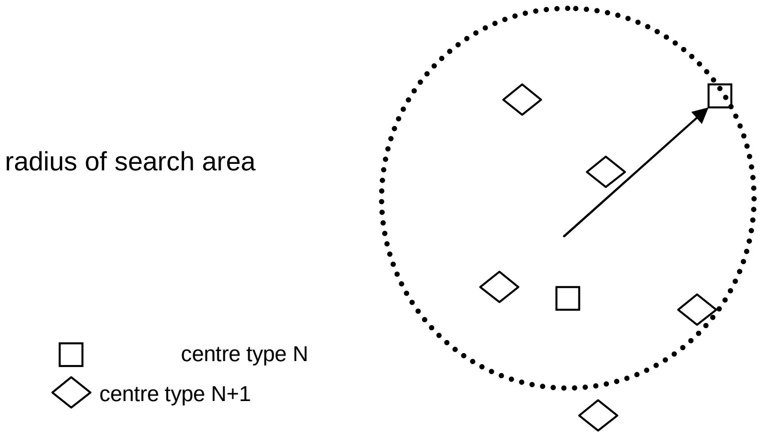

Figure 8.2: Search area for a centre type.

Figure 8.3 shows an example of theoretical network connections in the north part of the Dutch province of Limburg. Each type of urban area (city) or road connection has its own colour.

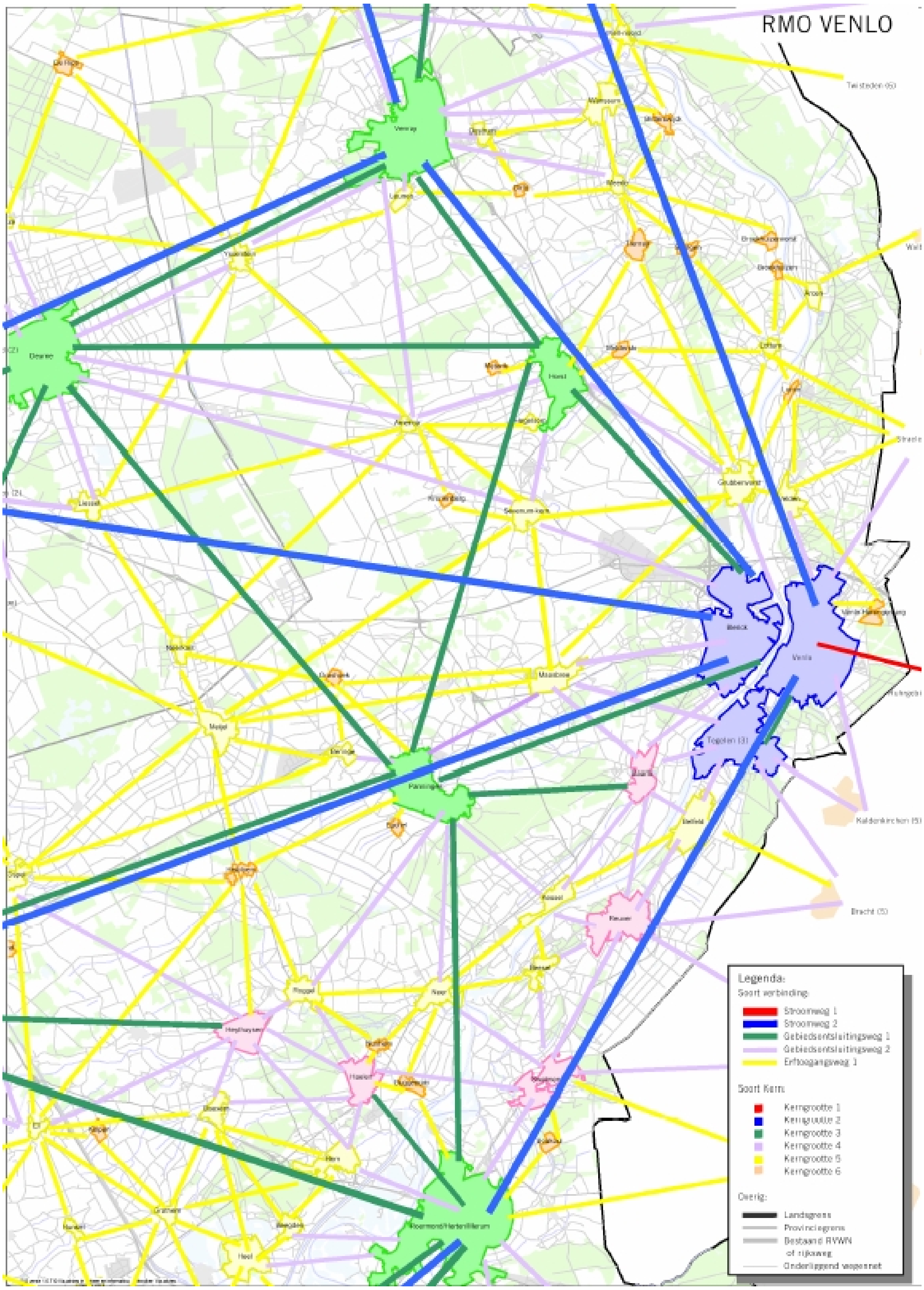

Figure 8.3: Theoretical network connections: functional road types connecting different types of urban areas. Example of north part of the Dutch province of Limburg, (source: Via Traffic Care, The Netherlands). Key to symbols: red = connection type I (motorway); blue = connection type II (A-level road); green = connection type III (distribution road 1); purple = connection type IV (distribution road 2); yellow = connection type V (access road).

Functional road categorization

To obtain SPIs on the network level that allow for international comparison, an internationally harmonized road categorization is needed. The international IRTAD database can be a starting point. However, for a safety assessment of road networks, the current IRTAD categorization is too superficial. At least a further specification of 'A-level roads' and 'other roads' is needed to monitor the functional specifications and actual use of roads.

A first indication of the proposed functionality of a road is given by the actual position of the road in the road network. To further link this to safety assessment, a harmonized description of road types is needed, in which functionality has been translated to the design and physical appearance of the road. For this purpose, the functional road classification presented in Table 8.5 has been used. As explained before, it has been restricted to rural roads and motorways.

	Rural areas (outside built-up areas)					
Connection type (table 8-5)	I	II	II	III	IV	V
SafetyNet road classes	AAA:	AA:	A:	BB:	B:	C:
	Motorway	A-level road 1	A-level road 2	Rural distributor road 1	Rural distributor road 2	Rural access road
Functional road category	Through-road (road with a flow function)			Distributor road		Access road
Separation of opposing directions	Dual carriageway	Dual carriageway	Single carriageway, preferable with lane separation	Dual carriageway	Single carriageway, preferable with lane separation	Single carriage way
Lane configuration	2x2 or more	2x1, 2x2	1x2, 1x3, (1x4)	2x1, 2x2	1x2, 1x3, (1x4)	1x2, 1x1
Obstacle-free zone	Very wide or safety barrier	Wide or safety barrier	Wide or safety barrier	medium	medium	small
Intersections	Grade-separated	Preferable grade-separated	Preferable grade-separated	Preferable roundabout	Preferable roundabout	

Table 8.5: SafetyNet Functional road classification.

Three main functional road categories have been distinguished:

- Through-road; road with a flow function enabling high speeds of long distance traffic and, many times, high volumes.

  Motorways and A-level roads have been assigned to this category. AAA refers to motorways. The characteristics of this road category are a dual carriageway; a wide obstacle-free zone or a safety barrier, and grade-separated junctions. AA and A refer to A level roads according to the IRTAD definition: roads outside urban areas that are not motorways but belong to the top-level road network. AA is a dual carriageway road; A is a single carriageway road with a kind of separation of opposing driving directions, preferably in a way that makes overtaking impossible. Other main characteristics of these last two road categories are an obstacle-free zone or at least a safety barrier and preferably grade-separated junctions. In EU Member States they are often known as primary roads, national roads, semi-motorways or non-interstate arteries.

- Distributor road: serving districts and regions containing scattered destinations.

  Here a distinction is made between BB and B roads. The BB-road typically is a dual carriageway road, whereas a B-road typically is a single carriageway road, preferably with a kind of separation of driving directions to discourage overtaking. Obstacle-zones and intersections occur in various layouts among the various countries. Preferably, they should have medium obstacle-free zones and roundabouts.

- Access road: enabling direct access to properties alongside a road or street.

  This type of road, indicated as category C, typically is a single carriageway road with one driving lane or two lanes separated by access marking only.

For some cells it is relatively straightforward to specify the information of concern. For other cells, it appears impossible to give a specification beforehand for all countries, a preferable measure is recommend instead.

Figure 8. shows an example of a functional road categorization in the north part of the Dutch province of Limburg. Three main road types are connecting different urban areas based on the theoretical network connections of Figure 8.3.

The European project Ripcord-Iserest (Sixth framework programme of the European Commission) aims to draw up a proposal for a European road categorization in 2007. This categorization will be more detailed - e.g. with regard to cross-section and intersection design - than the functional road classification described in this section. Therefore we propose to adopt the Ripcord road categorization when it will be available.

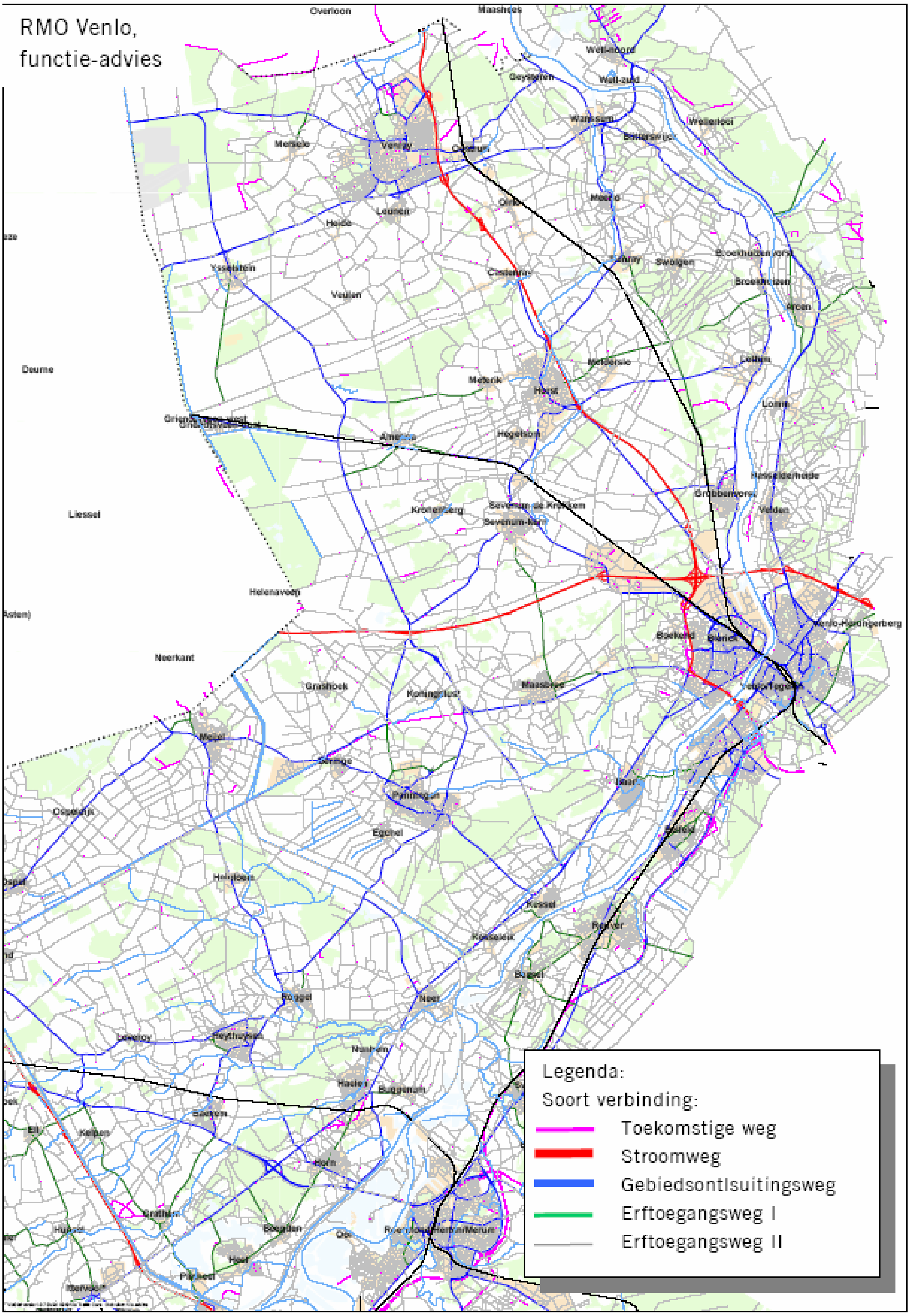

Figure 8.4: Functional road categorization: Three main road types are connecting different urban areas based on the theoretical network. Example of north part of the Dutch province of Limburg (source: Via Traffic Care, The Netherlands) Key to symbols: red = motorway or A-level road); blue = distribution road 1 or 2; green and grey access road (type 1 and 2).

Suggestions for road networks characteristics as a basis for SPI

Based on Table 8.4 and Table 8.5, the following road network SPI might be extracted (if a European agreement on a limited series of road categories can be achieved):

The degree of compliance of road network use with the functionality of the road network. A rating should be developed for this, e.g. taking into account the share of 'correct connections': the share of appropriate road type(s) related to the connection type (for each connection). At a more aggregated level, this could be formulated as: the share of appropriate road types per connection type in a region or country.

Development of road design SPIs

Once the network characteristics have become clear, an assessment can be made of road design characteristics. This assessment will then show if these roads are indeed suitable (safe enough according to current knowledge) for the type of function they have been assigned to in the road network.

In general, SPIs will be the share of total road length which has certain (safe) design characteristics. By adopting the RPS of EuroRAP, it will be possible to express the road design SPI as the distributions of the stars along the network.

The classes or values that are used by EuroRAP for the scoring of each road characteristic are given in Table 8.6.

Road characteristics	Classes/values
Speed	50, 60, 70 etc.
Barrier (placement)	Right, left, middle etc.
Barrier (CEN approved)	Yes/No
Median (width)	0-4 meter, 4-10 meter etc.
Hard obstacle point/stretch (distance)	0-3 meter, 3-7 meter etc.
Hard obstacle point/stretch (placement)	Right, left, etc.
Side area cut (placement)	Right, left etc.
Side area embankment (placement)	Right, left etc.
Side area embankment (type)	Gentle, steep
Junctions (not signalized)	3 of 4 arms with or without left turn lane
Junctions (signalized or roundabouts)	Traffic lights, roundabouts
Intersection merging	Long/short
Intersection access	Yes/No

Table 8.6: The classes or values that are used for the scoring of each road characteristic to obtain the RPS during a drive-through inspection, (EuroRAP in preparation; Mobycon 2006).

At the moment, the main RPS is based on scoring separately the protection provided in relation to three of the four main accident types. These scores are being combined into an overall score of 1-4 stars (Lynam et al 2003a, 2003b, Lynam in preparation). The combination of the component scores is weighted in proportion to their average occurrence across a range of European countries: Denmark, France, Hungary, Switzerland, Sweden, and Britain (Table 8.7).

Three main accidents types	**Weighting factors**
run-off road	43%
head-on impacts	31%
severe impacts at intersections	26%
Total	*100%*

Table 8.7: Weighting factors used by the RPS to scale the three accident types (without VRU) [EuroRAP in preparation]. These factors are based on the average of six EU-countries: Denmark, France, Hungary, Switzerland, Sweden and Britain.

An extension to the RPS for vulnerable road users is under development. The combination of the four component scores will be weighted then as shown in Table 8.8.

Four main accidents types	**Weighting factors**
run-off road	38%
head-on impacts	28%
severe impacts at intersections	23%
VRU	11%
Total	*100%*

Table 8.8: Weighting factors used by the RPS to scale the four accident types (with VRU) [EuroRAP in preparation]. These factors are based on the average frequency of occurrence of six EU-countries: Denmark, France, Hungary, Switzerland, Sweden and Britain.

The score for each accident component is based on a family of risk curves that are illustrated in Figure 8.5 to Figure 8.7, and can be transformed into risk matrices (Table 8.9) with accompanying number of stars (Lynam 2003a).

Median treatment	**Relative risk for different speeds**					
	120 km/h	**110 km/h**	**100 km/h**	**90 km/h**	**80 km/h**	**70 km/h**
Barrier not CEN approved						
Barrier CEN approved	1	1	1	1	1	1
Median > 10 m.	1	1	1	1	1	1
Median 4 – 9.99 m.	3	3	3	3	2	1
Median 1 – 3.99 m.	19	15	10	7	4	1
1 m. Rumble strip	34	25	16	7	5	1
1 m. Marked strip	41	30	19	8	6	1
Double centre lines	46	33	21	8	6	1
Single centre lines only	48	35	22	9	7	1

	4 stars
	3 stars
	2 stars
	1 star

Table 8.9: Assumed relative risk of fatal and serious head on accidents by speed and by median treatment (transcription of Figure 8.3) [Mobycon 2006].

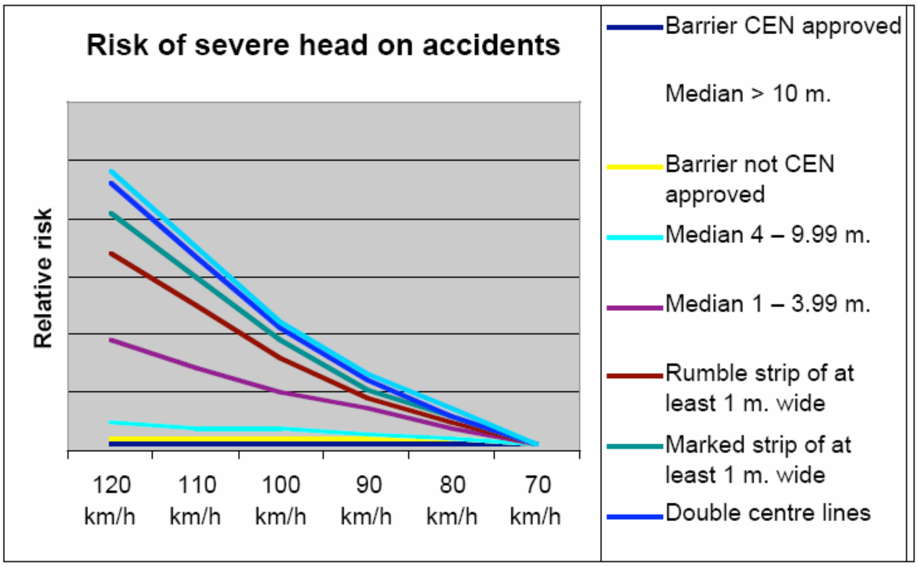

Figure 8.5: Assumed relative risk of fatal and serious head on accidents by speed and by median treatment [Figure taken from Lynam 2003a].

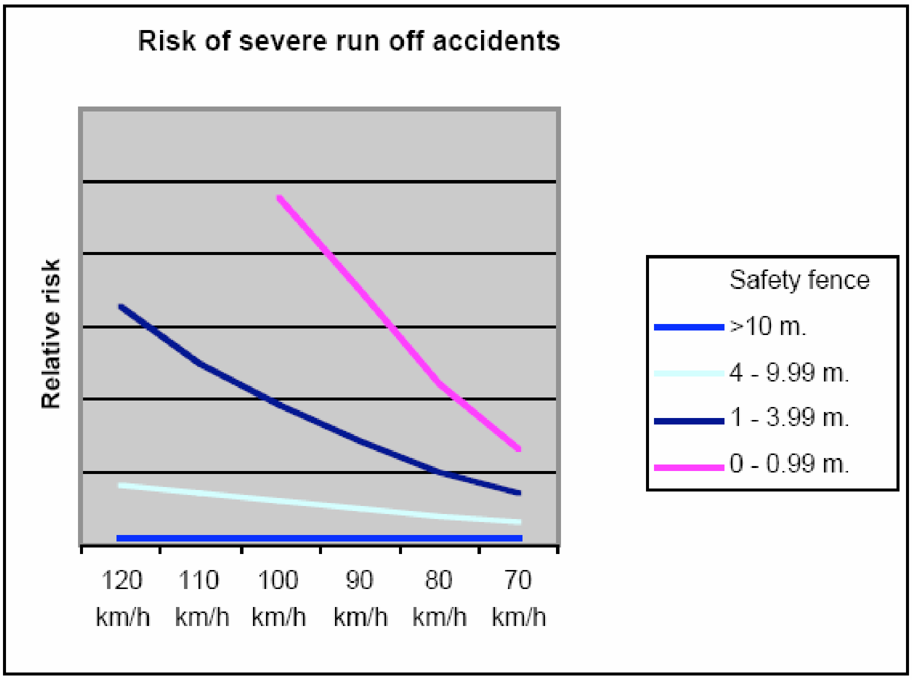

Figure 8.6: Assumed relative risk of fatal and serious run off accidents by speed and edge of road treatment [Figure taken from Lynam 2003a].

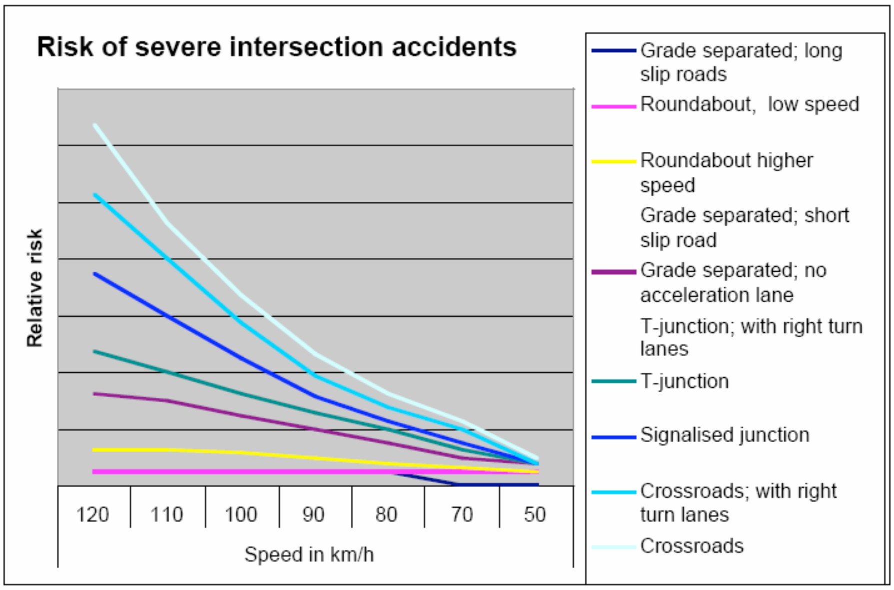

Figure 8.7: Assumed relative risk of fatal and serious intersection accidents by speed and intersection type [Figure taken from Lynam 2003a].

There is scientific indication of a relation between Design Consistency characteristics and road safety (Messer et al 1979). Estimates of consistency indicators are difficult due to the need for detailed design characteristics that are often not available, and difficult to obtain with drive-through inspections. Therefore it has been concluded, in the State-of-the-Art document (SafetyNet 2005a), that Design Consistency is not suitable as SPI in this context, for the time being. EuroRAP has also expressed the wish to develop indicators for bends and road curvatures, so Design Consistency will find its place in the RPS and with that in the SPIs for roads, in the future.

SPI overview and hierarchy

In the previous section we discussed which road and road network design characteristics or features are suitable to use as SPI. In the State-of-the-Art report (SafetyNet 2005a) a first attempt has been made to draw up hierarchical schemes to give an overview of SPI development. In place of the previous SPI schemes presented in the State-of-the-Art report, new schemes are drawn in this section as a consequence of adopting the EuroRAP RPS. The top layer of the scheme is presented in Figure 8.8.

At the road design level four road safety problems have been distinguished for which SPIs could be formulated. They are related to measurements to prevent crashes on road sections and junctions/intersections.

At the road network level two sub-levels are proposed: the highest level is the total road network in a region or country. The second sub-level deals with individual connections.

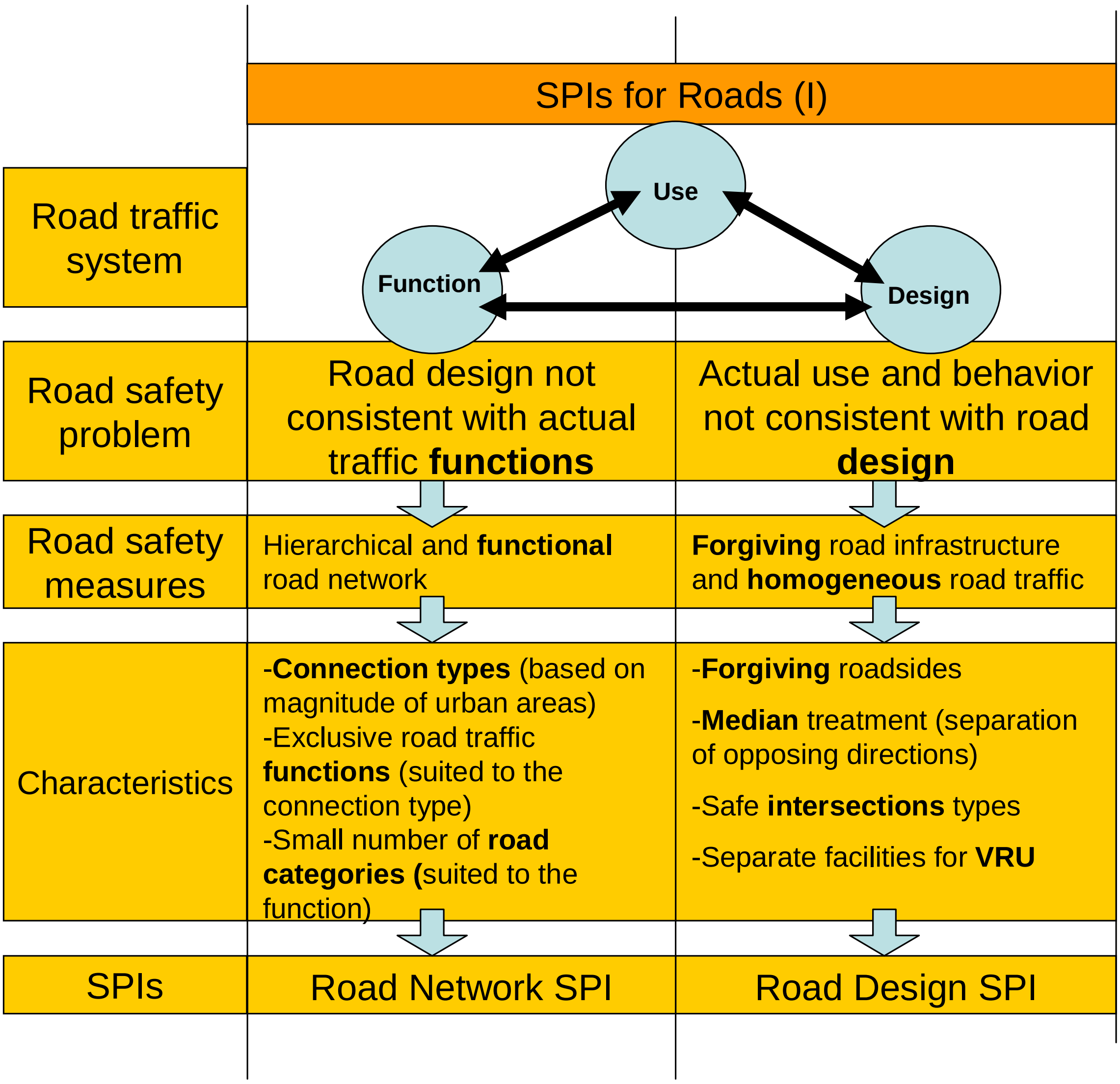

Figure 8.8 SPI scheme (I) for road network and road design (see also section 8.3.4. SPI Diagrams).

8.3.2 Questionnaire's responses and EuroRAP data as a means to examine applicability

In the State-of-the-Art (SafetyNet 2005a) and Results report the national responses on the questionnaire of the 25 European countries and 5 partner countries have been presented as far as available at that stage of the project. The presentation showed which country had sent a response and if this response was correct. The quality of the data was examined as well. On the basis of the response and of the data quality, an attempt was made to conclude whether (part of) the SPIs are realisable or not.

For at least 8 countries, it should be possible to collect data of good quality. For 5 of them the response contained only data for main roads. Only 5 of the 8 'good' responses gave a (more or less) complete answer on the requested data.

The questionnaire data set has been used as a pilot to test a previous set of SPIs for usefulness and reliability. The assumptions and SPIs had to be modified because of the poor responses to the questionnaire and the poor quality of the received data. This was one of the main reasons to adopt the EuroRAP RPS.

At the conference in the Netherlands (Den Haag, May 2006) EuroRAP has presented the RPS of the road network of the Dutch province of South-Holland. A total road length of 751 km, mainly "Distributor" and "Through" roads have been scored during drive-through inspections. In Figure 8.9 the RPS-stars are represented by colors (Mobycon 2006).

The inspected road network of the Province of South-Holland has got an average score of 3 stars. The distributions of the stars along the network is the following:

4 stars: 31%,

3 stars: 51%,

2 stars: 17%,

1 star: 0% of the road length.

In the case that this had been the score of one road category (instead of two or more) the Road Design SPI could be represented by this distribution. These Dutch scores and the raw RPS-data are currently being analysed and an attempt is made to apply the new SPI-method to it. The first results will be supplied in the next deliverable 'Manual for SPIs'. New pilot projects in an East and South European country are preferred to be performed as well.

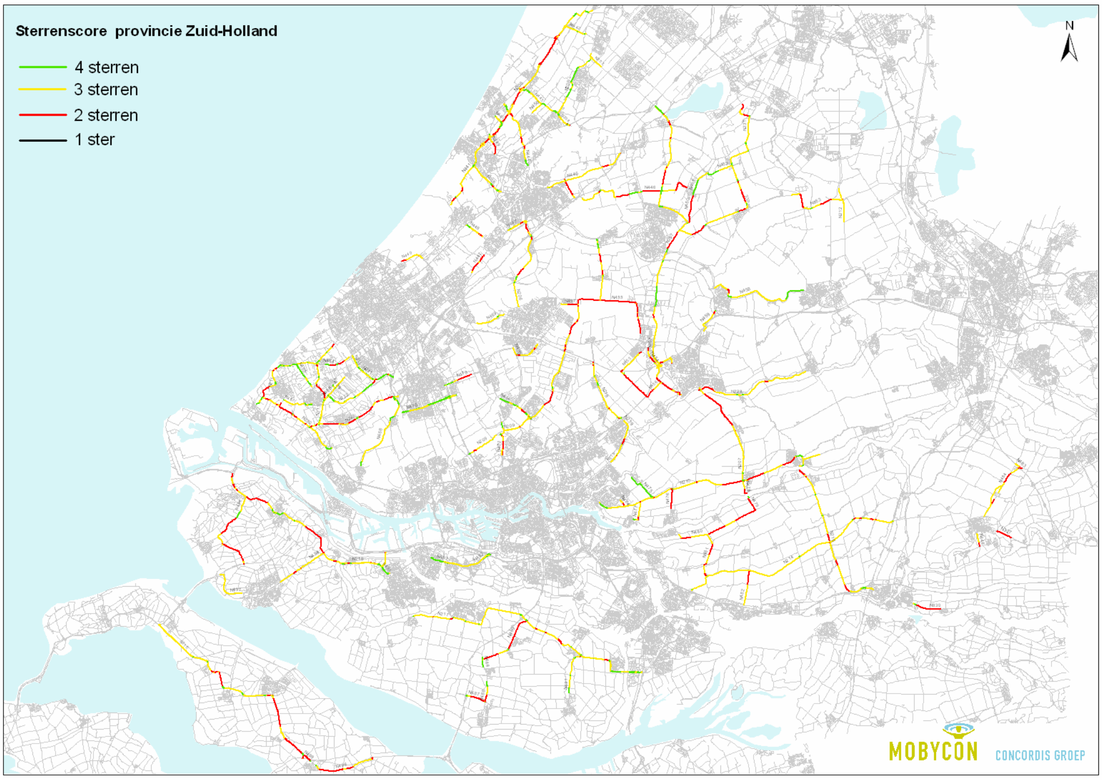

Figure 8.9: RPS of 751 km road in Province of South-Holland (mainly Distributor and Through roads). Stars are represented by colors. [Mobycon 2006].

8.3.3 Description of suggested SPIs

The assessment and weighting methods to determine the RPS-score of EuroRAP have been worked out far more elaborately than the proposed SPI-method in the State-of-the-Art document (SafetNet 2005a). EuroRAP has even designed a method to determine an aggregated RPS for a road. The scores for the four design elements are combined in proportion to the frequency with which the accident types matched to these design elements occurred, averaged across Sweden, Denmark, France, Hungary, Switzerland and Britain. Besides, the potential data availability proved to be higher for EuroRAP than gathered from the questionnaire.

Therefore we propose to adopt the RPS protocol in the future, so as to use and possibly share the same data as much as possible.

Nevertheless, there are three main obstacles to overcome:

1. details of the scoring and weighing methodology
2. VRUs are not included yet
3. a network approach is missing (i.e. no functional road categorization).

EuroRAP designed a method to calculate a final score for a road, expressed with one to four 'stars'. The scores on the several SPIs are weighted to calculate this final score. The magnitudes of these weights are based on accident statistics of a small and arbitrary group of European countries. Maybe these weights should depend on the distribution of accidents types in the country or region, or on the road type, where the RPS is applied. This weighting method should be as transparent as possible. SafetyNet could offer her assistance for improving this scoring and weighting method. Details of the scoring and weighing methodology are expected to be published by Lynam and EuroRAP soon.

Despite accidents with VRUs being a main crash type, this item is not yet included in the RPS assessment assessments currently being conducted in Europe[5].

'SafetyNet Road Network SPI' enables a road authority to assess the extent to which a connection complies with the demands. EuroRAP assesses whether a road complies to design criteria. However, the EuroRAP RPS-score by itself does not indicate to which extent a road (or connection) complies with the requirements for that connection, arising from the function of the connection in the network. Therefore we propose to combine the RPS with a functional road categorization (the one described in Table 8-5 or later on the Ripcord road categorization).

This will result in two aggregated SPIs:

- Network SPI: percentage of appropriate road category (AAA-C) length per connection type (I-V);
- Road design SPI: distribution of stars (1-4) per road category (AAA-C).

The State-of-the-Art report [SafetyNet 2005a] contains the complete schemes, based on the theoretical framework (Lerner 2004), including the formulas and data needed to calculate the SPIs. In place of the previous SPI schemes presented in State-of-the-Art report, new schemes are drawn in this section as a consequence of adopting the EuroRAP RPS. The figures 8-10 to 8-12 show these new SPI schemes (see also Figure 8-8 SPI scheme (I) for road network and road design).

[5] Vulnerable Road Users are being included in the models for surveys currently being conducted in the iRAP pilots in Chile, Costa Rica, Malaysia and in South Africa.

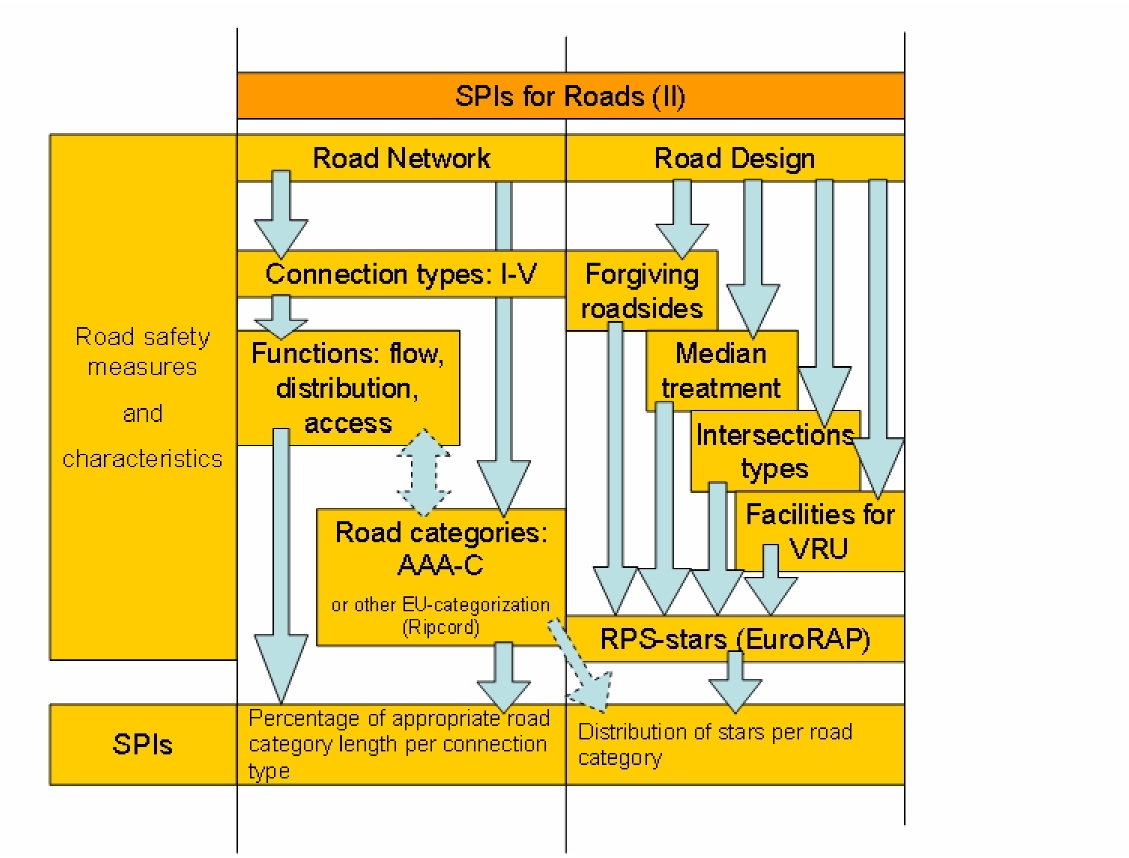

Figure 8.10 Scheme (II) of Road Network and Road Design SPIs.

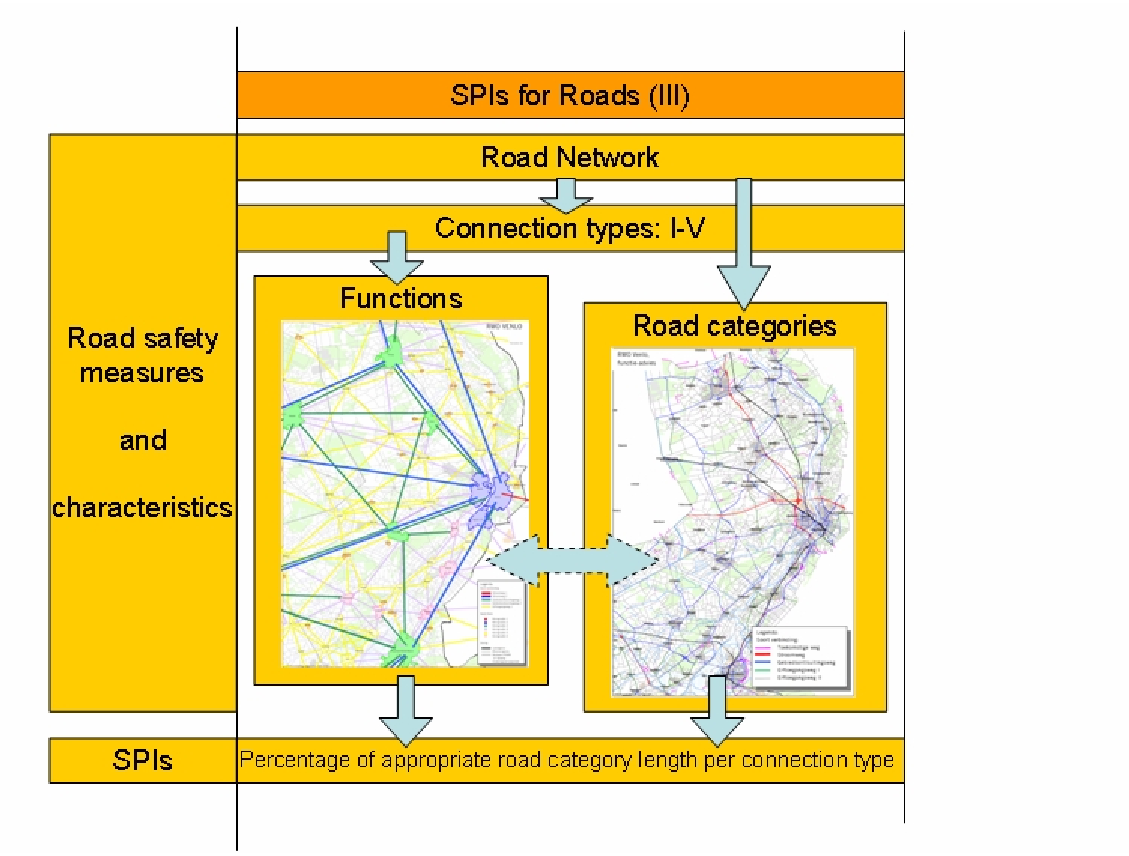

Figure 8.11 Scheme (III) of Road Network SPI.

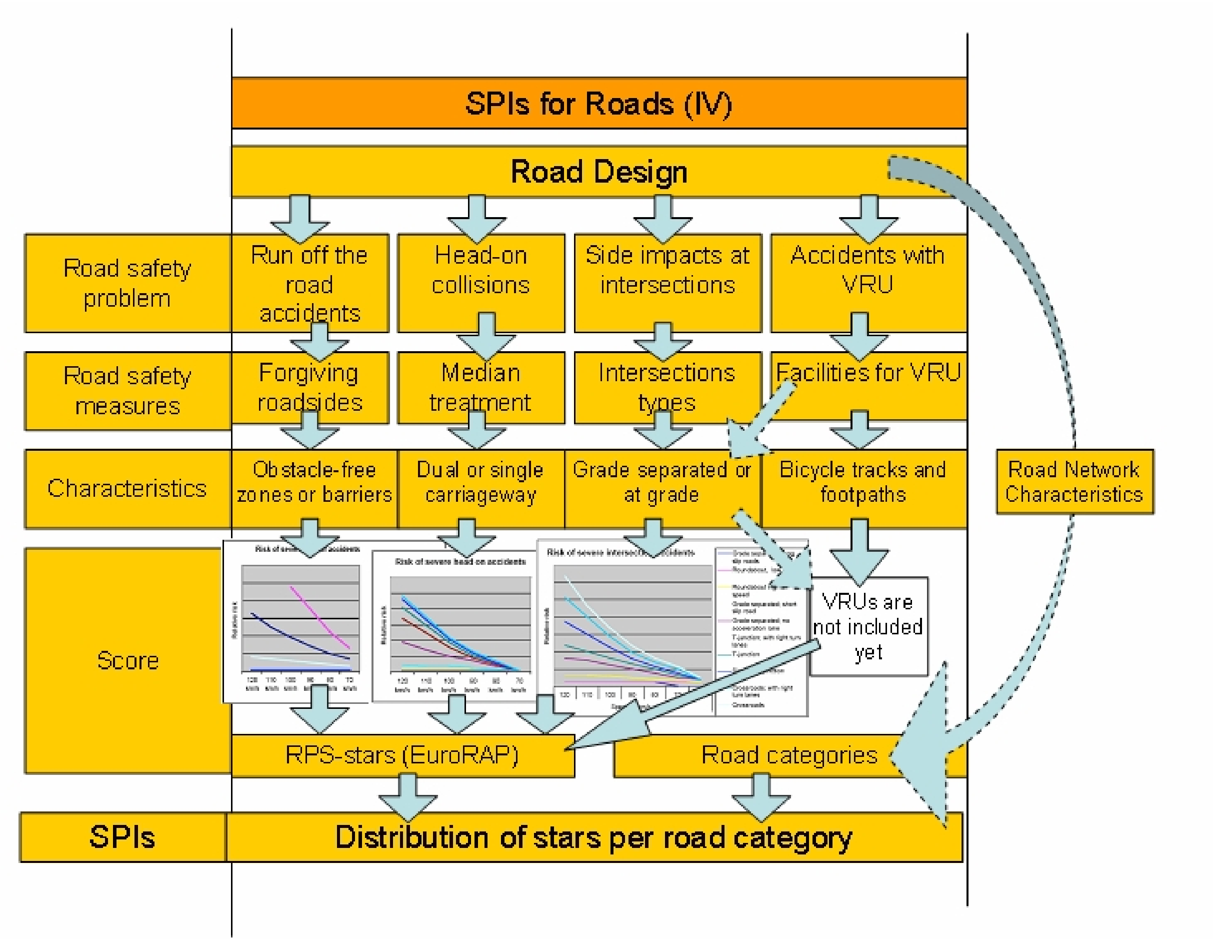

Figure 8.10 Scheme (IV) of Road Design SPI.

8.3.4 Conclusions

In the development process of SPIs for 'Roads' the following observations have been made so far:

- The domain 'roads' is related to a wide range of road safety issues. At the highest level, a distinction can be made between road network and road design issues. A clear identification of road-related safety problems is necessary as a basis for finding suitable SPIs. The following problems have been identified: the road network layout is not optimized in terms of safety (right roads are not at the right place); at individual road level four types of crashes are eminent: run-off-the-road crashes, intersection crashes, head-on crashes and crashes with involvement of vulnerable road users.
- Crashes related to road characteristics appear to be more eminent in rural areas than in urban areas. Furthermore, international diversification of road types is assumed to be less important for rural roads and motorways than for urban roads. Therefore, for this task, the focus will be on rural roads and motorways. The four crash types mentioned before, account for a substantial part of all fatal crashes on these rural roads and motorways.
- A methodology for network description and (safety related) road classification has been developed, that is assumed to be suitable for international harmonisation. As a basis, the functionality of a connection (consisting out of one or more road types)

and a systematic combination of present (safety related) characteristics have been used. This methodology needs to be worked out in more detail.

- A road network is performing safely when the actual road classes in an area fit the types of connection according to the function of the road. This Road Network SPI should be applicable and realizable yet at this stage, but the method needs to be worked out in more detail.
- The degree of presence (or absence) of relevant characteristics gives an indication of the safety level of a road section or intersection. Related to the four crash types, one Road Design SPI could be formulated at the road design level by adopting the EuroRAP Road Protection Score.
- EuroRAP has expressed the wish to develop indicators for separated facilities for pedestrians and cyclists, so VRU will find their place in the RPS and with that in the Road Design SPI soon.
- SPIs at a detailed level, such as based on Design Consistency characteristics, are considered not applicable and realizable yet at this stage. EuroRAP has expressed the wish to develop indicators for bends and road curvatures[6], so Design Consistency will find its place in the RPS and with that in the SPIs for roads, in the future.

8.4 References

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9 Trauma management

GITELMAN[A], V., AUERBACH-HAFEN[B], K., EKSLER[C], V.

[A]TECHNION, [B]BASt, [C]CDV

9.1 Introduction

9.1.1 The role of Trauma management

The term "Trauma Management" (TM) or "Post-Crash Trauma Care" refers to the system, which is responsible for the medical treatment of injuries resulting from road crashes. In the general complex of road crash preventable actions, which considers before the crash (active or primary safety), during the crash (passive or secondary safety) and post crash (rescue services, medical treatment and rehabilitation, or tertiary safety) stages, TM covers the majority of issues of the post-crash treatment.

To explain the role of trauma management, a typical post-crash chain of events can be considered (Figure 9.1). A concept describing the sequential functions in the process of preclinical care ("chain of survival") was introduced in the late 1960s by Professor Ahnefeld in Germany. Presently, this concept is generally accepted and has validity in all European countries.

According to the typical post-crash chain of events (see Figure 9.1), when a crash occurs, first aid is sometimes provided by a bystander. Usually, an emergency call takes place, which is responded to by Emergency Medical Services (EMS). The EMS arrive at the scene of the crash and provide initial medical treatment at the scene and during the transportation to a permanent medical facility (hospital, trauma centre). The permanent medical facility takes further medical care of the injured patient. In this chain of events the authorities of medical care are involved in steps 4-7 (see Figure 9.1), which, then, compose the mechanism of the post-crash trauma care (or TM) in the country.

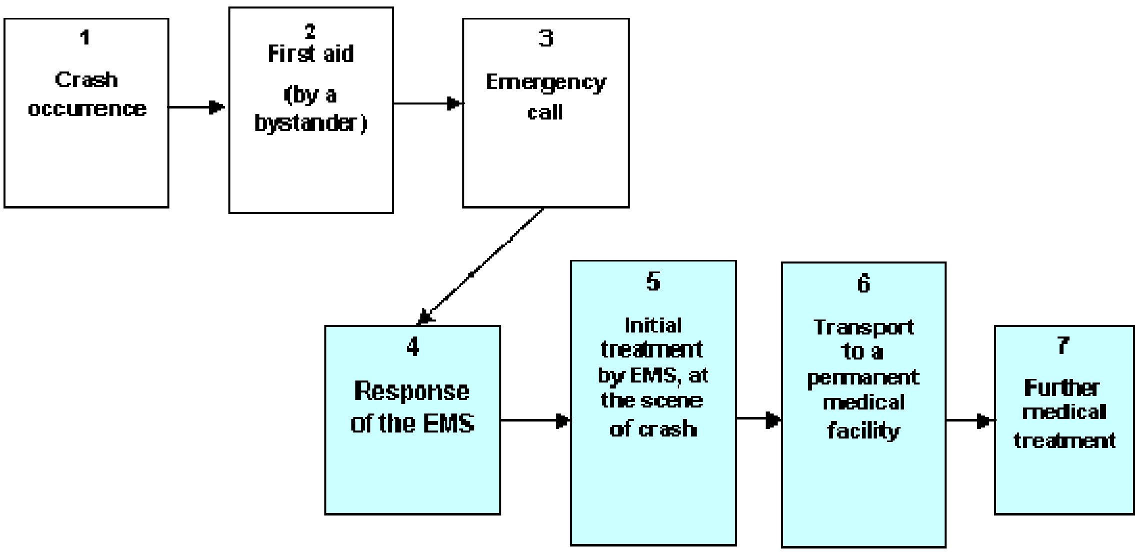

Figure 9.1 Post-crash chain of events.

ETSC (1999) defines a more comprehensive chain of the post-impact care, starting with action taken by the victims themselves or more commonly by lay bystanders at the scene of the crash, then the EMS involvement, access to the pre-hospital medical care system, trauma care at permanent medical facilities and, finally, helping road crash victims to re-integrate into work and family life (rehabilitation). The rehabilitation programmes are typically individually tailored and work with small amount of participants. Besides, no systematic information on the health of survivors is routinely available in the EU countries (ETSC, 1999). Thus, being aware of the importance of rehabilitation phase for certain types of injury, we leave it out of the scope of TM consideration (at least at this stage of SPIs development).

There is a consensus in the professional literature that the appropriate management of road casualties following the crash is a critical determinant of both the chance of survival and, on survival, the quality of life (ETSC, 1999; ETSC, 2001). Conversely, improper functioning of the post-crash care system leads to more fatalities and severe injuries, which could be avoided. Following a more comprehensive vision of the post crash care (as mentioned above), ETSC (1999) stated a more general ultimate goal of the post crash care which is, on the one hand, to avoid preventable death and limit the severity of injury and, on the other hand, to ensure optimal functioning of the crash victim and their re-integration into the community.

9.1.2 Crash reduction potential of improved trauma management

Two recently published summary reports underlined the potential of improved TM for the reduction of road crash fatalities and injuries: OECD (1999) and ETSC (1999). The OECD report "Safety strategy for rural roads" (1999) showed the importance of emergency services by indicating differences between the survival in severe (fatal and serious) crashes in rural versus urban areas. The ETSC report "Reducing the severity of road injuries through post-impact care" (1999) highlighted evidence-based actions for the organisation of optimal trauma care in the EU. A recent European Commission report CEC (2003) stated that several thousands of lives could be saved in the EU by improving the response times of the emergency services and other elements of post impact care in the event of road traffic crashes.

As stated by ETSC (1999) and other studies, rigorous experimental evidence in trauma care is often lacking. The following summary of the literature provides some evidences of the crash reduction potential from improved TM.

Considering the issue, one should remember that there are survivable and unsurvivable injuries. Not all fatalities in road crashes die instantly at the scene. Typically, there are three time periods in which death from road trauma can occur. The first period comes immediately in the seconds and minutes that follow the injury. Death is usually due to disruption of the brain, central nervous system, heart, aorta or other major blood vessels. Only a few of those patients can be successfully treated and then only in large urban areas where very rapid emergency treatment and transport is available. The second period occurs in the one to two hours after the incident (“golden hour”). Death in these instances results from major head injuries (subdural and extradural haematoma), chest injuries (haemopneumothorax), abdominal injuries (ruptured spleen, lacerated liver), fractured femur and pelvis, or multiple injuries associated with major blood loss. Survival rates during this period are clearly dependent on early and appropriate medical intervention (OECD, 1999). The third death period occurs during several days or weeks after the initial injury. Major causes of death include brain death, organ failure and overwhelming sepsis. Improved survival rates during this period mainly depend on the quality of hospital treatment.

Similarly, Sasser et al (2005) defines three phases of deaths from severe injury: phase 1 when deaths occur immediately or quickly as a result of overwhelming injury; phase 2 when deaths occur during the intermediate or sub-acute phase, i.e. within several hours of the event and are frequently the result of treatable conditions; phase 3 when deaths are delayed, i.e. occur days or weeks after the crash and are the result of infection, multi-system failure or other late complications of trauma.

Thus, the potential to reduce fatalities by means of an early and appropriate medical treatment (in the form of emergency medical help and further hospital treatment) is given at least for the patients in the second and third periods after the crash.

International studies estimated the shares of road crash fatalities, which refer to different time periods after a crash. For example, Australian data showed that death at the scene occurs in 57% of rural fatal crashes, and in 44% of urban fatal crashes (OECD, 1999). Likewise, on the basis of a full-scale survey in Hungary (Ecsedy and Hollo, 1994) it was found that in the case of fatalities, about half of all the victims are taken to a hospital before they die. A Swedish study (Henriksson et al, 2001) concluded that 48% of those who died in fatal road traffic crashes, sustained non-survivable injuries.

For the purpose of international comparisons of fatality data, the United Nations adopted a figure of 65% of fatalities, who died at the scene of a crash or on the way to the hospital (UN, 1994). The ETSC report (1999) also states that about 50% of deaths from road traffic crashes occur within minutes at the scene or in transit and before arrival at hospital; some deaths (15%) occur between 1-4 hours after the crash but the majority (35%) occur after 4 hours.

This implies that 35%-50% of cases are “treatable”, i.e. occur during the second and third after-crash periods, and therefore, can be influenced (partly reduced) by an improved TM system. The chance to survive depends heavily on emergency help provided at the crash scene, on the way to the hospital and at the hospital.

A summary of available estimates on crash reduction potential of improved TM is presented below. Additional but indirect evidences on the effects of improved TM, i.e. of lower response time, more qualified emergency staff, better equipped emergency vehicles, on the frequency of fatalities and (sometimes) severe injuries can be found in literature review (see SafetyNet, 2005).

A 1995 study of 155 fatalities in 24 rural counties in the State of Michigan, USA, concluded that about 13% of the fatalities could be determined to be definitely preventable or possibly preventable (Maio et al, 1995) if rapid emergency treatment and transport were available.

A Swedish study into survivability in fatal road traffic crashes concluded that out of the group who sustained survivable injuries, 12% could have survived had they been transported more quickly to hospital and other 32% could have survived if they had been transport quickly to an advanced trauma centre (Henriksson et al, 2001).

A UK study estimated that 12% of patients who had sustained serious skeletal trauma went on to have significant preventable disabilities (McKibbin et al, 1992).

In Germany, with a highly developed EMS system, it was estimated that every tenth person killed in a traffic crash could still be alive if only he/she could have been rescued more quickly and thus been placed under more qualified medical care, and that each 30 minute delay in the start of therapy triples the death rate (Pegler, 1989).

It was shown in France that the consequences of a crash could be reduced by 1% for every minute saved in the arrival of first aid (Bernard-Gely, 1998).

To summarize, at least 10% of the fatalities can (probably) be prevented due to improved TM; a similar figure is also relevant for serious injuries. The reduction potential of the measures will definitely be higher in those countries with a lower initial state of the TM system.

9.2 Background for developing SPIs

9.2.1 TM system: what can be measured and quantified

As introduced in section 9.1.1, the mechanism of post-crash trauma care comprises two types of medical treatment: that provided by emergency medical services (EMS) and that provided by permanent medical facilities.

Emergency Medical Services are those, which normally answer the emergency calls and deal with the next steps, like sending an ambulance to the scene of crash. EMS staff provides basic medical assistance to injured patients on the scene and during the transportation to a hospital. There are different forms of EMS, which depend on:

- the type of transport means (ambulance, helicopter);
- EMS vehicle equipment (mobile intensive care unit; basic life support unit; regular ambulance);
- medical staff arriving with the vehicle, which may include a physician, a paramedic, a “critical care” nurse, an emergency medical technician.

(Definitions of terms which are used for the characteristic of TM system are given in *Glossary* at the end of this Chapter).

Further medical treatment can be provided at a regular hospital or at a specially equipped trauma centre/ the trauma department of a hospital, whereas minor injuries are usually treated by doctors/ other medical staff outside a hospital (ETSC, 1999). The focus of the TM system is on patients who are hospitalized.

Based on the state of the art review of post crash care (ETSC, 1999) and other sources, better performance of the TM system is associated with the following factors:

- *Shorter response time by EMS*, which can be stimulated by a uniform emergency notification number (112 in the EU); an efficient call receiving system; an emergency medical dispatch system which can be automatic or priority-based. In the latter case, a trained dispatcher is required in order to qualify the urgency (speed of response) and the type of response needed (e.g. type of EMS vehicle, level of EMS staff). The system should be criteria-based or protocol-driven. Some potential for a reduction of arrival time is seen in Automatic notification system (eCall) which is currently under development in the EU.
- *Higher level of the EMS staff*. In this context, a significant role of specially trained emergency medical technicians is indicated, and a need in establishing minimum trained standards for the EMS staff at the EU is underlined.
- *Standardization of the EMS vehicles*, which should enable to provide basic life support or advanced life support medical care (see *Glossary*). The majority of cases are treated by land ambulances whereas for helicopters mostly regional and secondary responder role is recommended. Concerning the type of pre-hospital care, essential treatment should be given so there is no unnecessary waste of time. Basic life support care such as providing a free airway and techniques used to aid breathing is generally considered as sufficient, whereas the efficiency of most advanced interventions have not been proven as significant.
- *Adequate hospital trauma care*. Many literature sources highlight the necessity for appropriate mechanisms to transport severely injured victims to proper hospitals and the requirement for adequate medical equipment and personnel at the hospital. However, a higher level hospital may be distant, thus the consideration should account for the type of injuries, levels of hospitals and comparative distances to reach each one of them (on-site triage). On this issue, ETSC (1999) doubts the

applicability of uniform rules across the EU and recommend a standardized regional approach.

- *Establishing a national trauma system*. A prerequisite for high-quality hospital trauma care is the existence of a strategy for the organisation and provision of a national trauma system. Such a system provides research-based guidelines, standards and general advice about the treatment of trauma victims; defines the minimum thresholds of basic clinical capabilities to establish a hierarchy of hospitals for trauma care; dictates the rules for education and training of trauma teams; etc. (ETSC, 1999) The highest level of trauma care hospital which has the necessary trained personnel and appropriate facilities for treating poly-traumatised patients is recognized as a trauma centre. Best practice arrangements in Europe with regard to composition and availability of clinical care are outlined in Figure 9.2.

<u>In-house 24 hours a day</u>:
Emergency Medicine
Anaesthesiology
General Surgery and any life saving surgery (such as urgent external fixation for pelvic fractures, vascular surgery)
Radiology: a mobile X-ray apparatus should be located in the resuscitation room and the other X-ray facilities such as CT-scan should located near the emergency department

<u>On call promptly available</u>:
ESSENTIAL:
Anesthesiology (2nd team)
General Surgery (2nd team)
Neurosurgery (2nd team)
Orthopaedic Surgery
Maxillo facial Surgery
Interventional Radiology

DESIRABLE :
Pediatric Surgery
Vascular Surgery
Urologic Surgery
Plastic Surgery
Thoracic surgery

<u>Facilities and resources: available in-house 24 hours a day</u>:
X-ray and Ultrasonography
CT-scan
Trauma operating room with staffed personnel
Clinical laboratory service
Blood bank with adequate storage facilities
Rehabilitation team for the acute trauma phase

The facilities and medical instruments for every clinical procedure must be recorded on dedicated checklists which are monitored every day by trained nursing staff overseen by the trauma coordinator.

Figure 9.2 Minimum threshold of basic clinical capabilities to be provided by trauma centre (ETSC, 1999).

There are evidences from the literature, which came in the form of panel reviews of preventable deaths, hospital trauma registry studies and population-based studies, that general improvements in the trauma care system are associated with a reduction in medically preventable deaths or overall trauma mortality (Mock et al, 2004). As found in the US states, the effect of the TM systems was not usually evident until 10 years after its implementation and reached a maximum at 16 years (Nathens et al, 2000a; Nathens et al, 2000b).

A general assumption is that the quality of the post-crash trauma care has a direct implication on the condition and the number of crash injuries. To reduce the severity and the number of road crash victims, *the TM system should provide rapid and adequate initial care of injury, combined with sufficient further treatment at a hospital or trauma centre*. Improper functioning of the post-crash care system implies a lack of treatment and/or improper treatment of injuries (at any stage of the treatment).

The trauma management SPIs intend to qualify and quantify the performance of the post-crash care system in the country. In order to do this, *the speed and the quality of the post-crash care, both initial and further, should be estimated*.

9.2.2 Trauma care performance indicators in the literature

According to the concept of the "chain of survival" and to the legal, technical, and organizational conditions of the trauma care in the country, different indicators can be applied to measure the quality of the EMS system, the quality of treatment provided by permanent medical facilities, or to characterize the whole trauma care system. A literature study was undertaken to review various trauma care performance indicators which were applied by empirical studies carried out in different countries for the analysis of systems /forms of post-crash care. The studies which considered a relationship between the trauma care performance and the outcomes (i.e. changes in mortality rates or in patients' quality of life) were of particular interest. The findings of the literature study are given in SafetyNet (2005). A brief summary of the results is as follows.

Studies analyzing the relationship between the performance of the trauma care system and road crash outcomes, are not frequent. There is evidence concerning the effects of improved EMS care on the frequency of fatalities and/ or the state of severe injuries. The improved EMS care is measured in terms of lower EMS response time, higher rate of qualified emergency staff and/ or higher rate of better equipped emergency vehicles which arrive at the scene of accidents. The state of former severe injuries is estimated upon discharge or some period later, and is measured by means of standard protocols, which rank the capabilities of a person to carry out basic life functions. The outcome indicator usually has a form of percentage of those patients who satisfy the protocol's demands.

In general, trauma care performance is characterized by shares/rates of different forms of treatment, with the emphasis on higher levels of treatment and on percentages of correspondence to the demands of medical protocols (for the care to be supplied). The values of EMS response time and the time values of treatment at the hospital are frequently in use. The inputs of the medical systems (EMS and hospitals/trauma centres) are typically considered together with the outcomes, which are the state of the patients treated. The mortality or survival rates (i.e. the percentage of those who survived or died out of the sample considered) and the length of stay in hospital/ intensive care unit are frequently used for comparison of different forms of initial treatment.

Indicators, which are frequently applied to the characteristics of medical treatment at permanent medical facilities, are the length of stay in hospital, the length of stay in intensive care unit, times of waiting for certain treatments, mortality rate and the quality of life of the former patients. For a comparison of the level of in-patient treatment between hospitals/ countries, an indicator of mortality rate due to poly-trauma was also applied.

Comparing both EMS and hospital treatments, a correction for injury severity is necessary as the effects of treatments can reasonably be compared only for groups of patients with similar severity levels. Besides, age and gender differences among the compared groups should be controlled for.

For a specific trauma program, a wide range of clinical indicators is usually in use, which typically presents a mix of time values with percentages of different medical treatments applied to the controlled sample of patients.

Some national-scope studies which sought to establish a connection between the improvements in medical care and reductions in traffic-related fatalities, applied proxies of medical cares such as: the average length of in-patient stay in the hospital, the per-capita level of National Health Service staff, the number of people per capita waiting for hospital treatment, infant mortality rates, physicians per capita, average acute care days spent in the hospital. However, these indices seem too general and not suitable to characterize the performance of trauma care system.

Based on the literature considered, a summary of the evaluation parameters may be as follows:

At the EMS Level -

- Type of training that EMS teams receive: Basic Life Support versus Advanced Life Support (see *Glossary*);
- Type of evacuation to trauma centre: self, regular ambulance, mobile intensive care unit, helicopter;
- Time values: arrival at scene, treatment in the field, arrival for definitive treatment in hospital;
- Type of field treatment provided;
- Treatment implementation according to protocols, to the extent that protocols exist.

At the Hospital Level -

- Level of coverage: to what extent do critical patients arrive at trauma centres and not at hospitals of other levels?
- Severity of injury according to ISS (see *Glossary*) and according to part of body injured (Barel Matrix) with emphasis on head, chest and stomach injuries;
- Performance of specific surgical procedures and evaluation of outcomes, comparisons of treatment in specific procedures;
- Speed of treatment in the hospital, speed of arrival to Emergency Rooms, extent of work according to protocols.

For outcomes –

- Death rates,
- Hospitalisation in intensive care units,
- Total length of hospitalisation.

To note, the indicators estimated are typically based on data from medical databases such as hospital files, trauma registry, or from national mortality files.

9.3 Constructing SPIs for Trauma Management

9.3.1 General TM SPI concept

As stated in Sec. 9.2.1, TM SPIs intend to estimate the speed of the initial treatment by EMS and the quality of the initial (by EMS) and further (by a permanent medical facility) post-crash care. Therefore, the three major characteristics of the trauma care system, which should be explored, are:

- time values associated with the initial treatment;
- quality of the initial treatment, on the scene and in transportation;
- quality of further treatment in a permanent medical facility.

As we intend to measure both the speed and the quality of the treatment, no single SPI will be suitable to this purpose but a group of indicators is to be developed.

Estimating the TM SPIs, two ways are possible (ETSC, 2001): examining the correspondence of actual performance to the demands; and considering actual values of SPIs. Both ways are essential because, first, the system functions in accordance with the legal norms established in the country and, officially, can be judged in accordance with these norms only. However, as we aspire to know the actual performance of the system (being able to compare different systems as well), the actual values of SPIs are also important. For example, an EMS response may be stated as "rapid" when it is within 15 min in one country but within 10 min in another country. Then, a 14-minute average value of the response time would be judged as satisfactory in the first case and as unacceptable in the second, whereas the actual EMS performance is similar in both countries.

Beside the indicators dictated by the mechanism of post-crash treatment, a group of general indices may be considered whose purpose is to evaluate the general level of trauma care in the country.

In general, we admit that in the TM case, a direct measurement of "unsafe operational conditions" (see Chapter 2), i.e. of improper functioning of the trauma care system, is impossible. Thus, the evaluation should be based on understanding and measuring of the real TM processes in the country, applying a set of indirect indicators.

Further in this section (9.3.1), a general concept of the TM SPIs, based on the aforementioned approach, is presented. This concept served as a basis for the development of Trauma questionnaire, which was distributed to the EU countries. Then, based on the questionnaire's responses (a summary is given in Section 9.3.2) and further data analysis, the concept was updated; the updated concept of TM SPIs is detailed in Section 9.3.3.

Following the general concept of the TM SPIs, types of TM SPIs can be defined as presented in Table 9.1.

SPI groups	**Ways for estimating SPIs**	
	(a) correspondence to demands	**(b) actual values**
(1) Time values of the initial treatment	Group A	Group B
(2) Quality of initial treatment	Group C	Group D
(3) Quality of further treatment	Group E	Group F
General indices	--	Group G

Table 9.1 General concept of trauma management SPIs.

Based on the SPI types (Table 9.1), state of current practices in selected countries[7], and the literature study (section 9.2.2), the following TM SPI groups were initially considered:

Group A A percentage of EMS responses meeting regulations for response time

Group B Characteristics of EMS time values, e.g. average response time

[7] Based on the results of a preliminary survey of trauma management systems in three countries: Germany, Israel, and the Czech Republic (July-August 2004).

Group C e.g. percent of cases meeting regulations/law for the type of EMS care of severe injuries – cannot be estimated. Reason: no official demands are available on the issue

Group D Presentation of the scope and the forms of EMS activity:

the number of EMS dispatching centres and EMS stations;

distribution of EMS transportation means: total figures and shares of different types;

distribution of medical level of EMS teams: total figures and shares of different types;

annual number of EMS calls;

annual number of EMS rides: in total and shares of different EMS transportation units and different EMS teams;

average time for treating a case at the scene;

average time for arriving to hospital.

Group E e.g. percentage of cases meeting regulations/laws for the type of medical facility for care of severe injuries – cannot be estimated.Reason: no official demands are available on the issue.

Group F Presentation of the possibilities of further treatment and the actual treatment applied. As to the possibilities, the types and the numbers of permanent medical facilities to deliver injured patients (with the number of beds) should be presented.

To characterize the actual treatment provided for road crash injuries, the best way is to apply to a Trauma Registry, estimating indicators such as:

share of those treated at a higher level of hospital (e.g. certified trauma centre);

mean lengths of stay in the hospital;

share of those who died during hospitalisation;

share of treated in intensive care units;

average number of days in intensive care unit;

share of those who were in surgery rooms;

share of transferred to rehabilitation facilities upon discharge.

Group G General indices of the level of trauma care in the country such as:

the number of EMS units per 10,000 population or 100 km road length;

the number of trauma centre beds/trauma department beds per 10,000 population.

Following comments are essential for estimating the above SPI groups:

- The intention of group D indicators is to present the scope of EMS activity *in the service of road crashes*. However, as known, the EMS treats various kinds of injury as well as diseases. When the source of information is the national EMS statistics, where specific figures on serving road crashes are unavailable, general EMS figures should be presented with an indication of the share of activities related to road crash injury, e.g. a percent of road crash injuries out of total patients treated by EMS.
- An additional way for estimating the quality of initial treatment provided for road crash injuries (group D) is using a Trauma Registry (TR), where such a system exists. For example, among motor vehicle injuries registered by the TR, it is possible to see the share of those delivered by different types of EMS transportation units.

- For a better understanding of the scope of data presented by the TR (group F), the characteristics of actual treatment should be accompanied by: (a) the share of severe cases (e.g. with ISS≥16) among the road crash casualties treated; (b) the relation between the number of cases presented by the TR and the total number of road crash injuries reported in the country.
- The idea of the group G indicators is that, beside the absolute figures of the initial and further trauma care (which we have in group D and group F), for comparisons between the countries and over time, the values should be presented in the context of the area served. The area served can be characterized by the population, the total road length, or the size of traffic (vehicle kilometres travelled).
- It is also important to see the share of activity of the trauma care system associated with road crash injury, e.g. share of EMS journeys associated with road crashes out of total journeys; share of injuries treated by permanent facilities with the initial diagnosis of MVA (motor vehicle crashes) out of total injuries treated. For a better understanding of the scope of EMS activity with regard to road trauma, a relation between the number of road crash casualties treated by the EMS and the total number of road crash casualties reported in the country (based on the police statistics) should be considered.

To note, the above concept of TM SPIs accounts for the suggestions by ETSC (2001) in the part of TM related indicators, and extends them significantly.

9.3.2 Questionnaire's responses as a means to examine applicability of TM SPIs

Emergency medical care has developed independently in each European country, and even within cities and regions of a country, resulting in a variety of definitions, legislations, and systems (Bossaert, 1993). Recently, efforts to facilitate planning and organisation of EMS with the objective to improve the standards of the EMS in Europe were made by the Council of Europe and the World Health Organisation. Despite of these efforts, the cooperation and uniformity of the different EMS systems are still inadequate. Great variety of definitions is used to describe the EMS systems and their components, in different countries. These definitions should be known in order to interpret the structure and the activities of individual EMS systems. A similar lack of uniformity is characteristic for in-hospital trauma care. Thus, the TM questionnaire was built aiming at two purposes: (a) to describe the mechanism of the post-crash trauma care system in the country, and (b) to provide available data on the TM system's performance. In accordance with the post crash care mechanism the questionnaire consisted of two main parts: "EMS" and "Further medical treatment".

Concerning EMS, the questionnaire asked for a description of operational procedures, legal norms and regulations, staff and equipment in service, time values of initial treatment, numbers of patients treated and the quality of initial treatment.

Concerning further medical treatment, the questionnaire asked for a description of operational procedures, Trauma Registry (TR) and indicators of trauma care based on the TR data (if available), other injury databases, and trauma management indicators in use.

The questions cover all the data, which are required for the evaluation of TM SPI groups (as introduced in Sec. 9.3.1). Besides, general data on the country were requested, e.g. total population and the share living in urban areas, the length of public roads, vehicle numbers, and vehicle distance travelled, to enable calculating rates and estimating correction factors for comparison of SPIs from different countries.

Formal questionnaire's responses arrived from 18 countries: BE, CZ, DK, DE, EE, EL, ES, CY, LV, HU, MT, AT, PT, SE, UK, NO, CH, NL where ES, UK, CH provided general data only, with no information on the trauma care system in the country. Additional information arrived in the forms of:

- data on the TM system in Great Britain (provided by VSRC);
- updated general data for the countries (population, etc) – from IRTAD;
- further information provided by national experts as clarifications on the questionnaire's responses and responses on short feedback reports[8] distributed to the countries;
- characteristics of the EMS in selected EU countries, based on Pohl-Meuthen et al (1999);
- characteristics of the TM systems in the CEE-countries, based on a survey performed by CDV.

In total, for a detailed examination of the TM systems and the development of TM SPIs the data were available from 17 countries, which are: BE, CZ, DK, DE, EE, EL, CY, LV, HU, MT, AT, PT, SK, SE, UK, NO.

A detailed examination of the information received revealed that:

In ***general***:

- the information on the post-crash care in the country is typically provided by a medical expert or a researcher and not by a representative of road safety authorities;
- more data are available on EMS than on further medical treatment;
- in the majority of countries that responded, the definitions of injury (fatality, serious injury, slight injury) are similar to the general one (see *Glossary* – Sec. 9.5).

Concerning ***the EMS Legal norms and regulations***:

- In all countries EMS are working 24 hours a day, 7 days a week.
- Estimates of notification time are usually unavailable.
- Demands for response time exist and quantitative values of the response time can be provided by the majority of countries. The most frequent general demand is that the response time should not exceed 15 min (in 95% of cases).
- Typical EMS teams are provided by all countries. In some countries, two levels of EMS teams exist: a paramedic and/or emergency technician (or a nurse) attends in regular cases, where for severe cases an emergency physician joins the team. The team members usually have a special medical qualification/ passed special trainings in emergency medicine.
- In the majority of countries, specially equipped ambulances are in use. Typically, several equipment levels are defined. Concerning the ambulance equipment, some countries mentioned a correspondence to the European Norms EN 1789 (see *Glossary*). Two countries (Germany and Czech Republic) apply a RVS ("Rendezvous system") where the emergency physician arrives at the crash's scene by a separate car. Some countries mentioned the use of helicopters/ planes for delivering patients to hospitals.

[8] For each country, which originally responded the TM questionnaire, the national safety expert received, for comments, a "Short feedback report: data availability and estimated TM SPIs".

- Policy for treating injuries on scene: a mix of "scoop and carry/load and go" and "stay and play" policies is presented.
- Medical treatment at the scene: in the majority of countries BLS (see *Glossary*) is usually applied at the scene of crashes; ALS is applied if necessary.
- In all countries, EMS vehicles usually transport the patient to the hospital and an EMS team member accompanies the transportation.
- EMS database: usually unavailable, although some countries stated that they have such a database. However, the data from such a database are for internal medical use only and cannot be provided.

Concerning the ***EMS Staff and equipment in service***:

- The number of EMS dispatching centres and the number of EMS stations in service are reported by the majority of countries.
- The numbers of EMS medical staff and of the EMS transportation units are provided by most countries (for the whole country or for a selected region).
- The annual numbers of emergency calls and of EMS rides are known for the majority of countries, whereas the share of road crashes out of these calls/ rides is known for some countries only.

Concerning the ***Response Time of initial treatment***:

- The percentage of responses meeting the demands on response time and the average value of response time were provided by half of countries. Both values based on the results of estimations performed by the countries.
- The value of average time for treating a case at the scene and the average time for transportation are frequently unknown.

Concerning the ***Quality of initial medical treatment*** (i.e. the treatment which was actually applied):

- The total number of crash injuries treated by EMS is usually unknown. An estimate was provided by Germany only.
- The types of transportation units applied and the types of EMS teams involved are typically unknown, and were detailed by one country only (Germany).
- According to the responses, different medical scales (see *Glossary*) are used by the EMS for a qualification of the level of injury.

Concerning the ***Operational procedure of further medical treatment***:

- A mix of trauma centres, trauma departments of hospitals and regular hospitals are in use for treating the road crash injuries, in the majority of countries.
- Selecting a facility to deliver the injured person, a combination of two criteria is usually applied: the hospital's proximity to the crash scene and its suitability for treating the injury considered.
- The number of beds in the available facilities was provided by seven countries.
- For the characteristic of the level of injury, permanent medical facilities typically apply medical scales. The most widespread scales in use are GCS and ISS (see *Glossary*). Some countries apply several scales.

Concerning ***Trauma Registry***:

- A TR database is available in some countries. Germany and Greece provided data for selected hospitals. In Norway, a national database is to be established in 2006.

Some countries (e.g. the Netherlands) stated that trauma centres/ selected hospitals have databases.

- Data from the TR databases were provided by Germany and Greece, such as: values on the annual number of road crash injuries registered in the database; the number of severe injuries; the share of road crash injuries out of the total injuries; the types of transportation units, which brought the patients to the hospitals; details on the quality of medical treatment provided by permanent medical facilities - the average length of stay, the share of mortality among hospitalized injuries, the average stay in intensive care unit, etc. (All the values should be considered accounting for the selection rules applied to the cases included into the databases).

Concerning ***other injury databases and trauma management indicators in use***:

- Other injury databases on road crash injuries treated by medical facilities are unavailable for immediate application.
- No country reported on the use of any trauma management indicators.

Based on the information collected, it was concluded that EU countries generally have EMS norms and regulations, but these differ among the countries and, sometimes, between areas within a country (e.g. in federal states). The norms regarding EMS response time exist, in a certain form, in half of the countries. Compliance with these norms is assessed from time to time. Recent estimates of EMS response times are available in half of the countries.

EMS databases were stated as existing in many countries but their data are not easily accessible and are typically not linked to other crash databases, i.e. police crash files or other medical databases.

In the majority of countries, the composition of EMS teams, types of medical treatment provided at the scene, and the type of medical facility to transport the patient are regulated by internal rules. However, the quality of initial treatment provided or the extent of following these rules usually is not estimated.

TR or other medical databases exist in some countries, but these typically cover selected hospitals only or specially defined types of injury. The major problem is that available medical databases are generally not linked to the road safety research and management activities. As stated by ETSC (1999), ETSC (2001), mapping the trauma data and integrating them with the road safety data would lead to significantly improved decision making in emergency medical treatment of road crash casualties.

Part of the requested data were systematically lacking in some countries, especially that referring to further medical treatment. This means that these data are not collected in a systematic way in that country and that, presently, we cannot estimate the whole set of the initially considered SPIs for all countries.

Most of the data provided characterise the *availability* of trauma care services where the quantitative data on the *performance* of EMS and further medical treatment of crash injuries, are typically lacking. The state of the data is not uniform among the countries, therefore a further subdivision of SPIs on more common (and presently realisable for the majority of countries) and less common (i.e. unrealisable for the majority of countries, at least in the near future) should be applied.

In many countries, data on the performance of post-crash trauma care are not in use in the current decision-making practice and therefore, are not easily attainable. This means that special efforts will need to be applied to provide the data requested for the calculation of TM SPIs.

9.3.3 Suggested TM SPIs

Original set

Based on the general TM SPIs' concept (section 9.3.1) and information received from the countries (section 9.3.2), the original version of TM SPIs was as follows.

We suggested two sets of SPIs:

Set A - an initial (reduced) SPIs set, including indicators for which the data are available in the majority of countries. This set provides an initial characteristic of the post crash trauma care in the country, with mostly general figures on the availability of the services;

Set B - an extended set, including both set A and the indicators for which the data are available in selected countries only. This set enables the creation of a comprehensive picture of the post crash trauma care in the country, with both general figures of the availability of services and characteristics of the quality of the treatment supplied.

A scheme of the original set of TM SPIs is given on Figure 9.3. The concept of TM SPIs consists of two major topics: “Speed and Quality of Initial Treatment by Emergency Medical Services” and “Quality of Further Medical Treatment”. The first topic is divided into three sub-topics, which are “Staff and Equipment in Service”, “Scope of Activity” and “Time Values”. The second topic is represented by “Facilities in Service”. Thus, Set A covers four themes as follows:

- EMS: Staff and equipment in service;
- EMS: Scope of activity;
- EMS: Time Values of Initial treatment;
- Further medical treatment: facilities in service.

Other essential characteristics to assess the quality of the initial and further treatment are provided by Set B. Set B includes, in addition to the indicators of Set A, two groups of indicators, which cover the following themes:

- EMS database: Quality of treatment.
- Further medical treatment (Trauma Registry): Quality of treatment;

In total, Set A includes 20 SPIs and Set B includes Set A plus additional 12 SPIs which are estimated based on the TM data and general information provided by countries – see Figure 9.3.

To explain the difference between Set A and Set B, we should remind that for the majority of countries the information on the *availability* of trauma care services usually can be obtained, and sometimes on the scope and characteristics of EMS activity. This means that presently we can learn mostly about the *possibilities* of trauma care to be provided for the road crash injuries. If we are interested to estimate the quality of the medical treatment, which was *actually applied*, e.g. in terms of EMS units which treated the casualties or the ways of treatment in the hospital, this information is usually unattainable. In an ideal case, such information could be obtained from the hospital databases, had it been properly collected. However, presently, it is not the situation in any country, and the best information on the actual treatments provided for the road crash injuries, is from the TR databases.

As known, TR databases exist in selected countries only and they typically work with injury samples, not covering the entire phenomenon. Nevertheless, TR databases present a valuable source of information on actual treatment of road crash injuries, both today and in the future. For example, among motor vehicle injuries in the TR, it is possible to see the share of those delivered by different types of EMS transportation units, or in other words, to indicate which share of road crash casualties was actually treated by a higher level of EMS units. Concerning medical treatment provided by permanent medical facilities, using the TR it is possible to see the share of injuries treated by intensive care units, the share of those who were operated on, the rate of mortality during hospitalization, etc. (see Figure 9.3), i.e. parameters which typically characterize the quality of medical treatment.

Due to the limitations of TR databases, the estimated characteristics of actual treatment should be considered in a relevant context, i.e. to be accompanied by a share of severe cases among the road crash casualties that appeared in the database, and by a relation between the number of cases presented by the TR and the total number of road crash injuries reported in the country.

The TR data and the information from a database on actual performance of the EMS (if such an EMS database is available in the country) are considered as a basis for Set B of the TM SPIs (see Figure 9.3). At present, the data for the Set B indicators are available in a few countries only. Therefore, today we can consider an application of Set A of the TM SPIs only, where the application of Set B should be postponed to the future.

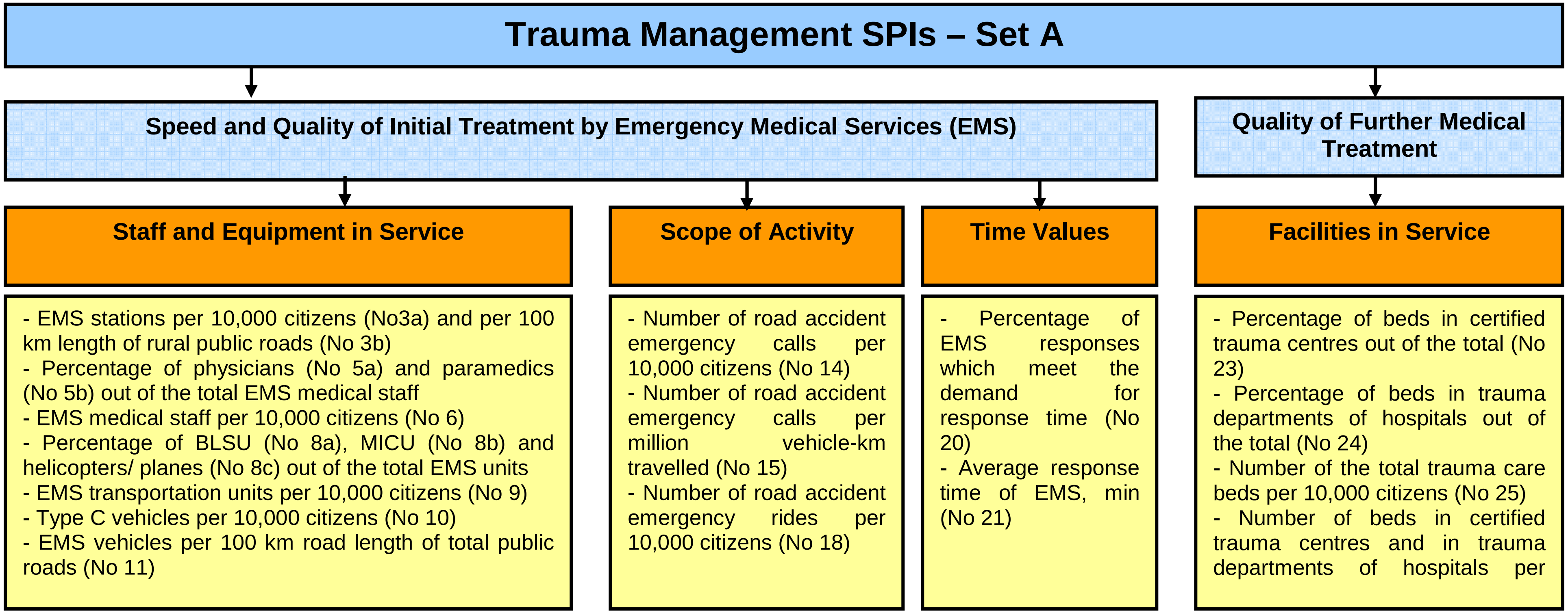

Figure 9.3 Trauma management SPIs - original set.

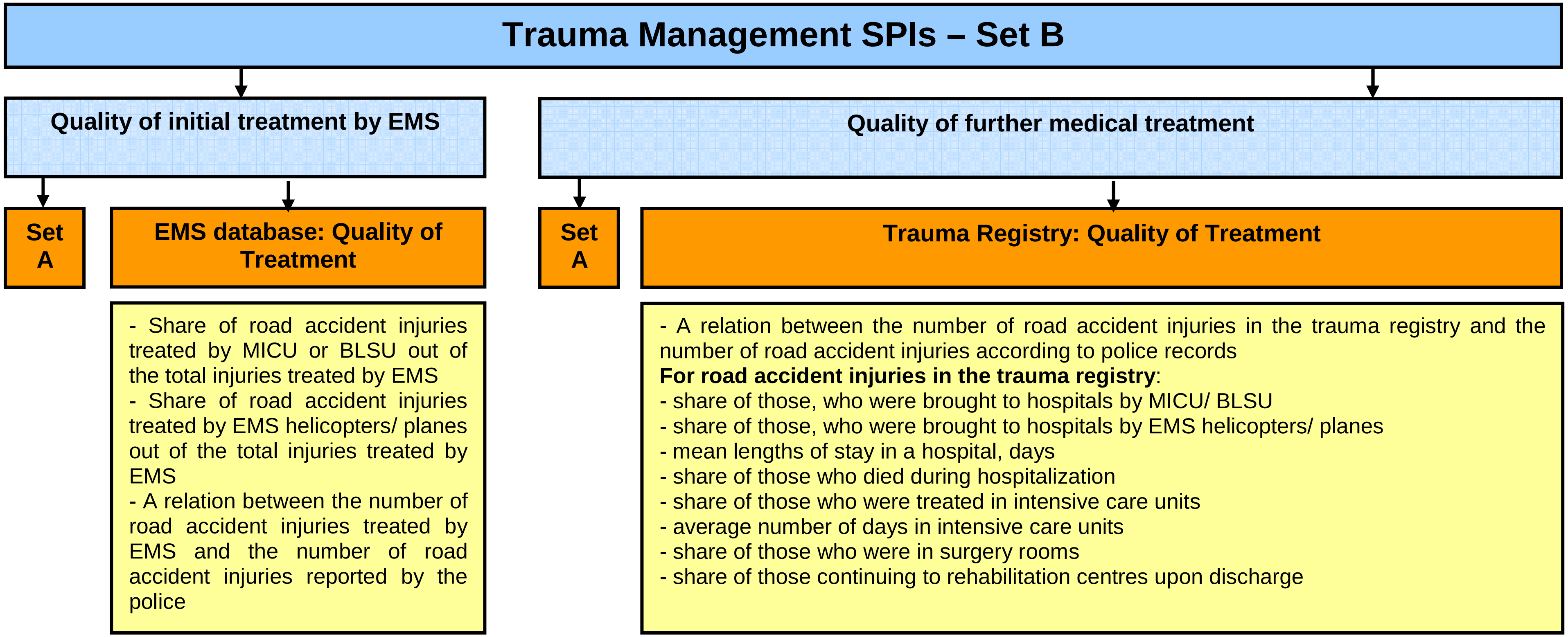

Figure 9.3 Trauma Management SPIs – original set (cont.)

Comments to the original version of TM SPIs:

Indicators, which were suggested by the general concept of TM SPIs (sec. 9.3.1) but not included in the above set, are:

- "The distribution of medical level of EMS teams" (total figures and shares of different types) – these figures differ significantly among the countries; no international standard is available to serve as a basis for the classification;
- "Values of notification time" - unavailable in the countries.
- "Average time for treating a case at the scene", "average time for arriving to hospital" - the values are generally unavailable in the countries as well as no demands exist. Besides, the policies for treating injuries at the scene differ among the countries: some countries state "scoop and carry/load and go", others - "stay and play".

Final set

Finally, assuming that the data are not easily available in the majority of countries, it was suggested to introduce a ***Minimum set of Trauma Management SPIs*** that are necessary for an initial characteristic of the system's performance. The minimum set is derived from *Set A only*.

Based on the analysis of data available in the countries, a minimum set of the data items to be provided by the countries, was defined. This minimum set covers seven data items as follows:

- Total number of EMS stations,
- Number of EMS staff in service (according to categories),
- Number of EMS transportation units in service (according to categories),
- The demand for a response time (min),
- Percentage of EMS responses which meet the demands for response time,
- Average response time of EMS (min),
- Total number of beds in permanent medical facilities (according to categories).

The minimum set of the TM SPIs, which can be estimated using the minimum data set, includes fourteen items as follows:

1. EMS stations per 10,000 citizens (No 3a[9])
2. EMS stations per 100 km length of rural public roads (No 3b)
3. Percentage of physicians out of the total EMS medical staff (No 5a)
4. Percentage of physicians and paramedics out of the total EMS medical staff (No 5*)
5. EMS medical staff per 10,000 citizens (No 6)
6. Percentage of MICU out of the total EMS units (No 8b)
7. Percentage of BLSU, MICU and helicopters/ planes out of the total EMS units (No 8*)
8. EMS transportation units per 10,000 citizens (No 9)
9. EMS vehicles per 100 km road length of total public roads (No 11)

[9] The number of a data item in Set A – see Fig.9.3.

10.-11. Percentage of EMS responses which meet the demand for response time (No 20); should be accompanied by a data item "The demand for a response time, min".

12. Average response time of EMS, min (No 21)

13. Percentage of beds in certified trauma centres and trauma departments of hospitals out of the total (No 24a*)

14. Number of the total trauma care beds per 10,000 citizens (No 25)

Remark: * means a new SPI in comparison with the original Set A (as presented on Figure 9.3).

The above minimum set of TM SPIs enables to characterize both the scope and the quality of the post-crash care in the country, in terms of the EMS treatment potential (the availability and quality of resources), EMS response time and the treatment potential of permanent medical facilities (the availability and quality of resources).

In comparison with the original Set A, three new SPIs were introduced - No 5, 8, 24a, which replaced other more detailed SPIs - groups 5a-5b, 8a-8b-8c and 23-24 accordingly, in the original Set A (see Figure 9.3). The change was made mostly aiming to create a consistent SPI set for a further development of combined estimates.

Combined indicator

According to our results, the TM system in a country can be characterized and the countries can be compared using a set of SPIs. However, comparing the countries it is frequently desirable to have a combined indicator which could provide an overall characteristic of the system.

Developing such a combined indicator we should emphasize that it is ***limited*** to the following considerations:

- We search for a qualitative indicator which would combine the TM SPIs' values, which are available for a country;
- A comparison by means of the combined indicator should be based on available data and then, provide an indication of "higher"/ "lower" level of the system's performance *relatively* to other countries in the sample;
- According to the meanings of separate SPIs, the combined indicator will tell us something about the level of the EMS treatment potential, EMS response time and the treatment potential of permanent medical facilities, i.e. the message is limited mostly to the availability of these services and, to a lesser extent, to the shares of higher-quality resources.

The combined indicator should not be considered as an overall estimate of the trauma care system in a country. As we discussed in Sec. 9.2.1, the trauma care system is a matter of strategic approach with necessary guidelines, standards and regulations; distribution of emergency care; education and training of trauma teams; definition of clinical capabilities of hospitals, etc, where the system's performance is followed up in a long-term and is estimated in terms of actual treatments applied and their outcomes (changes in mortality and the quality of life). Besides, our consideration of the TM system (in the context of SPIs) is limited to the system's characteristics which are associated with the treatment of road crash victims.

The combined indicator was developed by means of ranking the values of separate TM SPIs and weighting the results together. The following rules were applied:

1. The combined indicator is estimated using the minimum set of trauma SPIs - 14 indicators.
2. The values of each SPI should be consistent, i.e. higher values of SPIs should correspond to a better system's performance.
3. To avoid the dependency of the results on the estimation method and to check the sensitivity of results, three ways of ranking are applied: "ranks A", "ranks A-1" and "ranks B".

Ranking methods

The ranking techniques were as follows.

Ranks A: according to the values of each SPI, a direct ranking of countries is performed, e.g. rank "1" corresponds to the best SPI value, rank "2" to the next value after the best, etc. Using the ranks for all the SPIs, for each country, an average rank is estimated. The average ranks are considered as a final population which is subdivided into five groups. The groups indicate the levels of the system's performance: (1) H - high; (2) RL - relatively high; (3) M - medium; (4) RL - relatively low; (5) L - low, where level H includes the values (ranks) which are lower than the population mean minus standard deviation; level M – the values (ranks) between the percentiles 40% and 60%; level L – the values (ranks) over the population mean plus standard deviation; level RH comprises all the values between H and M, and level RL – all the values between M and L.

In mathematical terms, the procedure is as follows.

Let x_{ij} designates a rank of country i for SPI j, $i \in$ [1,N], $j \in$ [1,14], N – the number of countries compared.

Then $X_i = \sum_j x_{ij}/n_i$ presents an average rank, where n_i – the number of SPI values available for country i (excluding missing values).

For the sample $\{X_i\}$ the statistical values are estimated: a mean MN(X), a standard deviation SD(X), a 40% percentile P40(X), a 60% percentile P60(X).

Then, belonging of country i (Y_i) to one of the five groups of the TM system's performance is defined as follows:

$Y_i \in$ H if $X_i \leq$ MN(X) – SD(X)

$Y_i \in$ RH if MN(X) – SD(X) < $X_i \leq$ P40(X)

$Y_i \in$ M if P40(X) < $X_i \leq$ P60(X)

$Y_i \in$ RL if P60(X) < $X_i \leq$ MN(X) + SD(X)

$Y_i \in$ L if MN(X) + SD(X) < X_i

Ranks A-1: similar to "ranks A", a direct ranking of countries is performed. However, before the average ranks of countries are estimated, the initial ranks are weighted, accounting for the two categories of SPIs: basic ones for which weight "1" is given, and supplementary ones for which weight "2" is assigned; the second category includes SPIs No 5a, 8b, 19. (Prior to the application the weights are normalized using their total sum.) Further steps are similar to "ranks A".

Ranks B: according to the values of each SPI, the countries are ranked using five groups of performance level, where rank "1" (high level) includes the SPI values which are higher than the population mean plus standard deviation; rank "3" (medium level) –

the SPI values between the percentiles 40% and 60%; level "5" (low level) – the SPI values which are lower than the population mean minus standard deviation; rank "2" (relatively high level) comprises the SPI values between "1" and "3", and rank "4" (relatively low level) – the SPI values between "3" and "5". Then, based on the ranks for all available SPIs, for each country, an average rank is estimated. The average ranks are considered as a final population which is subdivided into 5 groups using the aforementioned levels of the system's performance (H, M, L, RH, RL as introduced for "ranks A").

Additional comments to the ranking procedures are:

- Ranking the countries according to the values of SPIs, exceptional rules were applied for the SPIs No 19, 20, 21 (characteristics of the response time), No 8 (percentage of specially-equipped EMS vehicles) and No 24 (percentage of beds in higher level medical facilities). The rules are empirical. For example, for SPI No 20 (percentage of EMS responses meeting the demand) three ranks were defined: "1" for values 95%-100%; "2" for 80%-95%; "3" for values lower than 80%.
- Many countries did not provide the whole set of data; therefore, there are missing values for SPIs. Missing values are ignored by all rankings.
- A country should not be considered when the number of missing SPIs is high; for this context, a threshold of "over 7 missing values" was applied.

By each ranking procedure, the country is attributed to one of five levels of the TM system's performance, which are "high", "relatively high", "medium", "relatively low" or "low". Consistency of the results of different rankings increases the reliability of findings.

9.3.4 TM SPIs: conclusions

Main findings from developing the TM SPIs are as follows.

The quality of the post-crash trauma care has a direct implication on the condition and the number of crash injuries. To reduce the severity and the number of road crash victims, the TM system should provide rapid and adequate initial care of injury, combined with sufficient further treatment at a hospital or trauma centre. Thus, TM SPIs should qualify and quantify the performance of the post-crash care system in the country. In order to do this, the speed and the quality of the post-crash care, both initial and further, should be estimated.

In many countries, much data on the performance of post-crash trauma care in the country is lacking, i.e. not in use in the current decision-making practice. Available trauma registry and other medical databases are generally not linked to the road safety research and management activities. Mapping the trauma data and integrating them with the road safety data would lead to significantly improved decision-making in emergency medical treatment of road crash casualties.

The state and forms of the post crash trauma care differ among the countries. These differences need to be accounted for in estimating SPIs.

No complete systematic information on the performance of the trauma care system and on outcomes of road crash survivors is routinely available in the majority of countries. Hence, special efforts will need to be undertaken to collect the data for estimating the TM SPIs.

Only some countries are able to provide detailed data on the performance of different steps of the post crash chain of care. The majority of countries may provide only general figures on the availability of services but not on the characteristics of their functioning. Thus, in general, two sets of TM SPIs were considered: an initial (reduced) set, which can be filled in by the majority of countries today (Set A), and an extended set, which should be available in the future, with the perspective to provide a comprehensive picture of the performance of the TM system in the country (Set B).

Assuming that the data are not easily available in the majority of countries, it was suggested to introduce a Minimum set of TM SPIs that are necessary for an initial characteristic of the system's performance. The minimum set is a reduced version of Set A.

For comparisons among the countries a combined indicator was developed which is based on the suggested Minimum set of TM SPIs and the data provided by the countries. The estimate is obtained by means of several rankings, which attribute the countries to one of five levels of the TM system's performance: "high", "relatively high", "medium", "relatively low" or "low".

Both the TM SPIs suggested and the combined Indicator are applicable for the comparison of TM systems in different countries, where the evaluation and the comparison is performed in terms of characteristics which are associated with the treatment of road crash victims. However, one should realize that the TM SPIs developed provide a limited message, which mostly concerns the availability and the treatment potential of the EMS and permanent medical facilities, for road crash victims, and that they do not pretend to supply an overall estimate of the trauma care system in the country.

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9.5 Glossary

Notification time: The time interval between the crash occurrence and the emergency call is made.

Response time: The time interval between emergency call and the response of the EMS (thus the time of arrival of the EMS at the scene of crash).

Arrival time: The time interval between the crash occurrence and the response of the EMS (thus the time of arrival of the EMS at the scene of crash).

Medical terms:

Emergency Medical Services (EMS) System includes the emergency dispatch system and the emergency units. The dispatch system takes incoming calls for emergency care.

A dispatching centre is an office which is informed in case of emergencies (mostly by telephone calls) to ask for medical assistance. The dispatching centre then alarms and coordinates the EMS units.

An EMS station is the location/base station where at least one EMS vehicle or helicopter/plane (and in most cases its crew) are positioned.

The EMS units are mostly ambulances but also helicopters/planes/boats, which arrive at the scene of crash and provide initial medical assistance to injured patients. There are different forms of EMS units, which depend on the type of a transport means (helicopter, ambulance); EMS vehicle equipment (mobile intensive care unit; basic life support unit); medical staff arriving with the vehicle.

The medical staff may include a physician, a paramedic, a “critical care” nurse, and an emergency medical technician.

Advanced life support (ALS): medical care given by medical doctors and nurses trained in critical care medicine with the use of specialized technical equipment, infusion of fluids and drugs aimed to stabilize or restore vital functions.

Basic life support (BLS): consists of emergency medical care to restore or sustain vital functions (airway, respiration, circulation) without specialized medical equipment and to limit further damage in the period preceding advanced medical care.

Mobile intensive care unit (MICU): a unit with a medical doctor and a nurse transported to the scene of the crash with the knowledge, skills and equipment necessary for performing advanced life support.

Basic Life Support Unit (BLSU): a transportation unit with personnel and equipment necessary for performing basic life support.

Emergency medical technician: a person who received training in emergency medical care for sick or injured patients in need of transportation to a hospital. This training includes BLS and the ability to assist doctors and nurses in the delivery of ALS.

Paramedic: an emergency medical technician who received further training for the delivery of some aspects of ALS care.

The term „*emergency call*" includes all calls which are answered by EMS dispatching centre and which lead to an emergency response by the EMS. The term includes false and abusive alarms, but excludes calls due to patient transportation requests.

EMS rides are rides of the EMS in consequence of emergency calls, including false and abuse alarms**.**

EMS vehicles according to European Norms 1789

According to the European norm EN 1789 (+A1:2003) there are three types of EMS vehicles:

Type A_1/A_2*:* A vehicle that is appropriate to transportation of one or more patients - transportation ambulances.

Type B: A vehicle that is equipped for transportation, basic life support and medical monitoring of patients (similar to *BLSU*).

Type C: A vehicle that is equipped for transportation, advanced life support and medical monitoring of patients (similar to *MICU*).

Meanwhile, there is no European norm for helicopters, planes, and boats. Thus any helicopters, planes, and boats that are in use by EMS can be mentioned.

Definitions of crash injury severity used by the police and national crash databases:

Killed (fatality): a person who died as a result of the crash, or died of his injuries within 30 days of the crash.

Seriously injured: a person who was hospitalized as a result of the crash for a period of 24 hours or more.

Slightly injured: a person who was injured as a result of the crash and was not hospitalized, or was hospitalized for a short period (up to 24 hours).

Hospitalized[10]*:* non-fatal victims who are admitted to hospital as in-patients.

Definitions of crash injury severity using medical scales:

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[10] In use by IRTAD – International Road Traffic and Accident Database

Abbreviated Injury Scale (AIS): a score from 1-6, for anatomically different injuries, indicating the chance that such injuries lead to death. AIS 6 injuries are usually considered to lead to inevitable death, AIS 5 to probable death, AIS 4 to possible death; other grades rarely lead to death. AIS 0 means "no injury". ***AIS 3-6*** correspond to patients which are ***hospitalized***.

Injury Severity Score (ISS): a score based on the AIS, which accounts for multiple injuries in one patient; calculated as a sum of the squares of the highest AIS grades in each of the three most severely injured body regions (out of 6 body regions). Groups of ISS values, which are usually applied for a qualification of injury's severity, are: ISS 1-8 for slight injuries, ISS 9-14 for medium injuries, ISS 16-25 for serious injuries, ISS 25+ for very serious injuries. ***ISS 16+*** indicates ***severe*** injuries.

Glasgow-Coma Scale (GCS): a score that focuses on the neurological situation of the patient by the item „eyes open" and on the verbal and motoric reactions of the patient. Maximum value: 15 (no neurological disorders), minimum value: 3 (severe neurological disorder). Groups of values, which can be applied for a quantification of injury's severity, are: GCS 13-15 - slight craniocerebral injury, GCS 9-12 - „medium severe" craniocerebral injury, GCS < 9 - severe craniocerebral injury, possibility of long-term/lasting disorders. ***GCS < 9*** indicates ***severe*** injuries.

10 Summary and conclusions

HAKKERT[A], S.

[A]TECHNION

This document provides details about the theory behind the development of Safety Performance Indicators (SPIs) in seven major areas which are central to the fields of activity in road safety in Europe. The fields of activity were selected as a result of reviews of national road safety plans in many of the EU countries and around the world and are considered the central themes of activity in road safety, necessary to bring about a significant improvement in road safety in the EU countries.

Within each field SPIs were developed which are directly related to that field of activity, can be quantitatively measured, can provide the basis for the assessment of the level of road safety in each country and can serve as an indicator to describe the level of activity in that field and country and can provide a yardstick for comparison. Comparisons can be before and after certain actions are taken or can be comparisons between countries.

As stated above, this document deals with the theory behind the development of each of the seven SPIs. It provides the rationale behind their development, the proofs for their relevance in the specific fields and the existing limitations that led to the adoption of the specific SPIs. The document provides also some recommendations for the possible improvements required to obtain better SPIs. Two companion documents are also being prepared. One is a manual which provides details on the procedures necessary to collects the required data for the development of each SPI in each country. The second document provides results on the data collected so far for each of the 25 EU countries and the SPIs developed so far, based on the data submitted by each of the countries. It can be seen that a lot of work still has to be done, both in collecting the necessary data and in improving the SPIs, once better and more detailed data becomes available.

10.1 Alcohol and drugs

Due to the limitations in the current state of accident data collection and data from surveys on the levels of alcohol and drugs in the driving population, three SPIs are proposed:

4. The number and percentage of severe and fatal injuries resulting from road accidents involving at least one active road user impaired by psychoactive substance (concentration above a predetermined impairment threshold);
5. The percentage of fatalities resulting from accidents involving at least one ***driver*** impaired by alcohol;
6. The percentage of fatalities resulting form accidents involving at least one ***driver*** impaired by drugs other than alcohol.

The first one is not yet possible to realise. Consequently the two latter ones are proposed as realisable for some countries at present.

10.2 Speeds

The speeds that are most relevant for safety purposes are spot speeds measured at various locations on the road network during periods when traffic can be considered free flowing, i.e not during periods of congestion when speeds are severely restricted. The SPIs developed are the mean speed, the standard deviation, the 85th percentile speed and the percentage of drivers exceeding the speed limit. These indicators should be segregated by road type, vehicle type, period of day and period of the week, i.e week-days and weekends. For road types it is suggested to adopt the classification developed in the roads task. In the manual document procedures are developed and described to obtain statistically valid results on a national basis, calculated from the sample of sites at which speeds are measured.

10.3 Protective systems

The major protective systems in vehicles that are relevant for the development of SPIs are seat belts for adults and for children, in various types of vehicles and the use of safety helmets by cyclists, moped riders and motorcyclists.

The SPIs developed are:

Set I: Daytime wearing rates of seat belts

SPI A – Front seats – passenger cars + vans /under 3.5 tons/

SPI B – Rear seats – passenger cars + vans /under 3.5 tons/

SPI C – Children under 12 years old - restraint systems use in passenger cars

SPI D – Front seats – HGV + coaches /above 3.5 tons/

Set II: Daytime usage rates of safety helmets

SPI F – Cyclists

SPI G – Moped riders

SPI H – Motorcyclists

All the indicators should come from independent observational surveys carried out on an annual basis, according to sampling procedures described in the Manual and in-time stationary conditions. The values should be aggregated from the values for major road types in the country considered for each one indicator and weighted on the basis of traffic volume on each of these road types. Measurements should be classified according to motorways, other rural roads and urban roads.

SPIs for airbags have not been included at this stage because at present there is no Nationally available data on the number of airbags installed in vehicles.

10.4 Daytime running lights

DRL SPIs are usually considered in the form of the percentage of vehicles using daytime running lights.

The general indicator can be estimated for the whole sample of vehicles, which were observed in the country. Similar values can be calculated for different road categories and for different vehicle types.

The road categories to be considered are: motorways, rural roads, urban roads, and DRL-roads, where the term “DRL roads” implies the road categories where the usage of DRL is obligatory.

The vehicle types to be considered are: cars, heavy good vehicles (including vans), motorcycles and mopeds.

In countries, where the automatic DRL was introduced long time ago (e.g. Sweden, Norway), according to expert estimates, the DRL usage rate is close to 100%, thus the DRL usage rate as a behavioural safety performance indicator does not have practical implications any more. In general, once the option of automatic DRL is introduced Europe-wide the DRL indicators will lose their importance.

Following the general concept of the DRL SPIs and accounting for current practices on the DRL use measurements in different countries possible DRL SPIs can be considered.

In total, 9 DRL SPIs are recommended for application, which are: the total usage rate and the percentages of vehicles using DRL according to four road types and according to four vehicle categories.

To estimate the above SPIs, each country should perform an annual survey of the DRL use. The details of survey will be discussed in the “Manual” document.

10.5 Passive vehicle safety

EuroNCAP is widely used as an indicator of passive safety for individual vehicles to give consumers a guide to the crashworthiness of specific makes and models. However there is no current recognised measure of an entire vehicle fleet.

For passive vehicle safety the correspondents were asked to send data containing the entire vehicle fleet database according to vehicle type, make, model and year of first registration, as it stood in 2003.

EuroNCAP scores are only currently available for passenger cars, so the present analysis concentrates on those vehicles within the national fleet. For this study it was decided that a EuroNCAP score, although describing a specific model variant, would be applied to any vehicle of the same model, to ensure a larger sample size.

For each country a EuroNCAP score was attributed to eligible vehicles. An average figure was then calculated for each year and weighted by the number of vehicles present in the 2003 fleet from that year. An overall average EuroNCAP score was then awarded for each country and together, with the median age of passenger cars in the fleet, these two figures make up the SPI for each country.

In order to validate the SPI with real-world data, car occupant fatality rates in each of the countries were considered. The number of car occupant fatalities in 2003 for each country was divided by the number of passenger cars present in each 2003 fleet, to give a figure for the number of car occupant fatalities per million cars. The average EuroNCAP score for each country was weighted by the percentage of passenger cars in a country’s 2003 fleet, which were less than 10 years old. This figure for each country was then plotted against the car occupant fatality per million cars figure for each country.

10.6 Roads

There are no direct or indirect SPIs for road networks in use in Europe at the moment. The Dutch study on quality aspects of a sustainably safe road infrastructure presented a method to assess network and design quality aspects of a safe road infrastructure at the regional level. This method could be used to formulate road network SPIs. However, the method is not commonly used yet and needs more development for use in Europe.

Even for the assessment of detailed road design there are no direct SPIs in use at the moment. Two methods could be used to formulate indirect SPIs: The Road Protection Score (RPS) of EuroRAP and the Dutch Sustainably Safe Indicator (SSI). These methods score specific road design elements. This score can be used to formulate SPIs for road design. There is some overlap in the road elements that are considered in the two methods, however the way these elements are scaled differs a lot. Both methods pay attention to *homogeneity* of the road traffic and *forgiving* road environments. The SSI has strong roots in the Dutch Sustainable Safety vision, and therefore paying more attention to the *predictability* of the road environment and the *function* in the network of the distinguished sustainably safe road categories.

The RPS turned out to be more useful in the SafetyNet context because of two main reasons:

- all road design elements used are broadly accepted as relevant for road safety, and
- the method itself is worked out in detail and already in use in a lot of European countries.

At this stage it was considered more practical to adopt the RPS scores developed in EuroRAP as the basis for Road SPIs Europe-wide, this in view of the large amount of work already invested in the practical data collection for these RPS scores.

The assessment and weighting methods, to determine the RPS-score of EuroRAP are far more elaborately been worked out than the proposed SPI-method in the State-of-the-Art document [SafetNet 2005a]. EuroRAP has even designed a method to determine an aggregate RPS for a road. The scores for the four design elements are combined in proportion to the frequency with which the accident types matched to these design elements occurred, averaged across Sweden, Denmark, France, Hungary, Switzerland and Britain. Besides that, the potential data availability proved to be higher for EuroRAP than gathered from the questionnaire.

Therefore we propose to adopt the RPS protocol in the future so as to use and possibly share the same data as much as possible.

Nevertheless, there are three main obstacles to overcome:

- Details of the scoring and weighting methodology;
- Vulnerable road users are not included yet;
- A network approach is missing (i.e. no functional road categorization).

EuroRAP designed a method to calculate a final score for a road, expressed with one to four 'stars'. The scores on the several SPIs are weighted to calculate this final score. The magnitudes of these weights are based on accident statistics of a small and arbitrary group of European countries. Possibly these weights should depend on the distribution of accidents types in the country or region, or on the road type, where the RPS is applied. This weighting method should be as transparent as possible. Details of the scoring and weighing methodology are expected to be published soon.

Despite the fact that accidents with vulnerable road user are a main crash type, this item is not yet included in the RPS assessments currently being conducted in Europe..

The 'SafetyNet Road Network SPI' enables a road authority to assess the extent to which a connection complies with the demands. EuroRAP assesses whether a road complies to design criteria. However, the EuroRAP RPS-score by itself does not indicate to which extent a road (or connection) complies with the requirements for that connection, arising from the function of the connection in the network. Therefore we propose to combine the RPS with a functional road categorization.

This will result in two aggregated network SPIs:

- Network SPI: percentage of appropriate road category (AAA-C) length per connection type (I-V);
- Road design SPI: distribution of stars (1-4) per road category (AAA-C).

10.7 Trauma management

The mechanism of post-crash trauma care (or Trauma Management – TM) comprises two types of medical treatment: that provided by emergency medical services (EMS) and that provided by permanent medical facilities.

EMS are those, which normally answer the emergency calls and deal with the next steps, like sending an ambulance to the scene of crash. EMS staff provides basic medical assistance to injured patients on the scene and during the transportation to a hospital. There are different forms of EMS, which depend on:

- the type of transport means (ambulance, helicopter);
- EMS vehicle equipment (mobile intensive care unit; basic life support unit; regular ambulance);
- medical staff arriving with the vehicle, which may include a physician, a paramedic, a “critical care” nurse, an emergency medical technician.

Further medical treatment can be provided at a regular hospital or at a specially equipped trauma centre/ the trauma department of a hospital, whereas minor injuries are usually treated by doctors/ other medical staff outside a hospital. The focus of the TM system is on patients who are hospitalized.

Based on the analysis of data available in the countries, a minimum set of the data items to be provided by the countries, was defined. These data enable the calculation of a ***Minimum set of Trauma Management SPIs*** that are necessary for an initial characteristic of the system's performance.

The minimum dataset covers seven data items as follows:

- Total number of EMS stations;
- Number of EMS staff in service (according to categories);
- Number of EMS transportation units in service (according to categories);
- The demand for a response time (min);
- Percentage of EMS responses which meet the demands for response time;
- Average response time of EMS (min);
- Total number of beds in permanent medical facilities (according to categories).

The minimum set of the TM SPIs, which can be estimated using this minimum data set, includes fourteen items as follows:

1. EMS stations per 10,000 citizens
2. EMS stations per 100 km length of rural public roads
3. Percentage of physicians out of the total EMS medical staff
4. Percentage of physicians and paramedics out of the total EMS medical staff
5. EMS medical staff per 10,000 citizens
6. Percentage of MICU out of the total EMS units
7. Percentage of BLSU, MICU and helicopters/ planes out of the total EMS units
8. EMS transportation units per 10,000 citizens
9. EMS vehicles per 100 km road length of total public roads

10.-11. Percentage of EMS responses which meet the demand for response time; to be accompanied by a data item "The demand for a response time, min".

12. Average response time of EMS, min

13. Percentage of beds in certified trauma centres and trauma departments of hospitals out of the total

14. Number of the total trauma care beds per 10,000 citizens

The above minimum set of TM SPIs enables to characterize both the scope and the quality of the post-crash care in the country, in terms of the EMS treatment potential (the availability and quality of resources), EMS response time and the treatment potential of permanent medical facilities (the availability and quality of resources).

According to our results, the TM system in a country can be characterized and the countries can be compared using the above described set of SPIs. However, comparing the countries it is frequently desirable to have a ***combined indicator*** which could provide an overall characteristic of the system.

Developing such a combined indicator we should emphasize that it is *limited* to the following considerations:

- We search for a qualitative indicator which would combine the TM SPIs' values, which are available for a country;
- A comparison by means of the combined indicator should be based on available data and then, provide an indication of "higher"/ "lower" level of the system's performance *relatively* to other countries in the sample;
- According to the meanings of separate SPIs, the combined indicator will tell us something about the level of the EMS treatment potential, EMS response time and the treatment potential of permanent medical facilities, i.e. the message is limited mostly to the availability of these services and, to a lesser extent, to the shares of higher-quality resources.

The combined indicator was developed by means of ranking the values of separate TM SPIs and weighting the results together. The following rules were applied:

- The combined indicator is estimated using the minimum set of trauma SPIs - 14 indicators.
- The values of each SPI should be consistent, i.e. higher values of SPIs should correspond to a better system's performance.
- To avoid the dependency of the results on the estimation method and to check the sensitivity of results, three ways of ranking were applied and compared.

Acknowledgement

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Appendix A Protective systems

A.1 Step-sheet

0	**Level 0**	Describe:
	Key information: Exact definition of the problem; which operational conditions of road traffic are unsafe and leading to crashes or fatalities as the "worst case"?	The human body is vulnerable and is exposed to the immense forces leading to injury or death during crashes. The availability, road users awareness and enforcement resulting to the use of protective systems, which might reduce the severity of the injury occurring during the crash is crucial for lowering system's outcomes (injury severity).

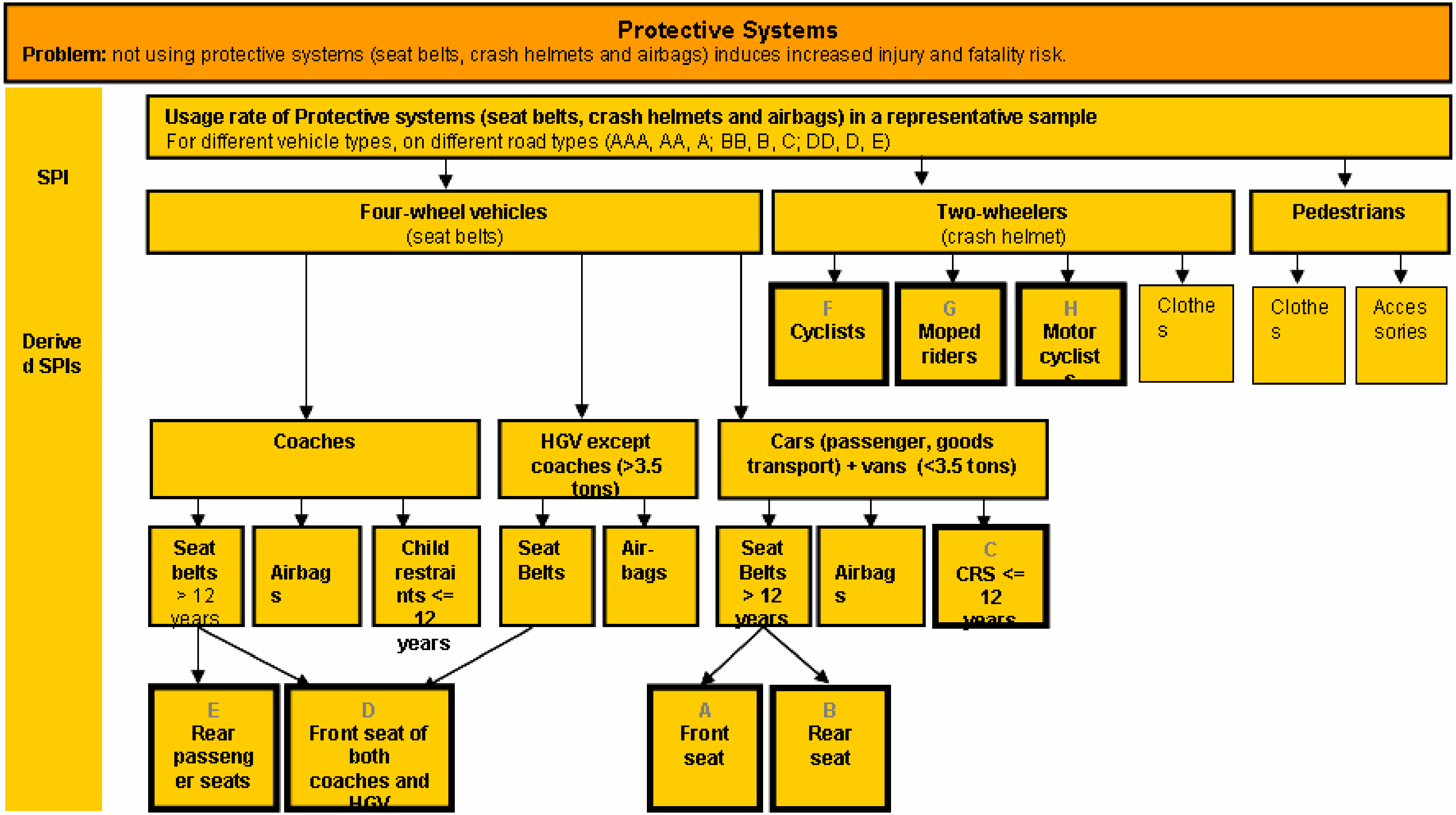
1	**Level 1**	
a	Direct measurement possible?	Yes
b	How can the identified problem - the unsafe operational conditions - be measured?	1. Use / wearing rates of protective systems from observational surveys
		a) Need for common methodology b) Accuracy demands

2	**Level 2**	
a	Are there suitable indirect indicators to describe the latent variable?	Yes
b	Which indirect indicators are suitable to describe the latent variable and how?	*2.* The use of protective systems recorded in accidents for fatalities by Police. (1) 3. The presence of the systems, or their availability in general. (2)
		???

3	**Level 3**	**not applicable**

4	**Level 4**	**not applicable**

A.2 Diagram


Protective Systems
Problem: not using protective systems (seat belts, crash helmets and airbags) induces increased injury and fatality risk.
SPI
Derived SPIs
Usage rate of Protective systems (seat belts, crash helmets and airbags) in a representative sample
For different vehicle types, on different road types (AAA, AA, A; BB, B, C; DD, D, E)
Four-wheel vehicles (seat belts)
Two-wheelers (crash helmet)
Pedestrians
F Cyclists
G Moped riders
H Motor cyclists
Clothes
Clothes
Accessories
Coaches
HGV except coaches (>3.5 tons)
Cars (passenger, goods transport) + vans (<3.5 tons)
Seat belts > 12 years
Airbags
Child restraints <= 12 years
Seat Belts
Air-bags
Seat Belts > 12 years
Airbags
C CRS <= 12 years
E Rear passenger seats
D Front seat of both coaches and HGV
A Front seat
B Rear seat

Formula	**X** Either A, A, B, C, D, E, F, G or H **i** road type **N** Total number of road types assessed ***WR_i*** Wearing rate of the protective system under consideration for road type *i* ***TS_i*** On road type *i*, the share in traffic, i.e., the percentage of kilometres travelled on road type *i* by the vehicle type under consideration	For each SPI indicated (A through H), the value is calculated by taking the weighted sum of the wearing rate of the protective system under consideration, for all road types studied, in a representative sample: $SPI\_X = \sum_{i=1}^{N} WR_i \times TS_i$ where: $\sum_{i=1}^{N} TS_i = 1$ WR_i is the 'wearing rate', the number of persons using the protective system divided by the total amount of users of the particular vehicle type, observed in a representative sample during an independent roadside survey And TS_i is the 'traffic share' for road type *i*, i.e., the amount of kilometres travelled on road type *i* by the vehicle type under consideration, divided by the total amount of kilometres travelled by the vehicle type under consideration for all road types assessed	**A** Seat belt; front seats; over 12 years old; passenger cars and vans **B** Seat belt; rear seats; over 12 years old; passenger cars and vans **C** Child restraint, front and rear seat; under 12 years old; passenger cars and vans **D** Seat belt; front seat; over 12 years old; coaches and heavy goods vehicles **D** Seat belt; rear seat; over 12 years old; coaches **E** Crash helmet; cyclists **F** Crash helmet; moped riders **G** Crash helmet; motorcyclists
Primary Data		Number of persons wearing the particular protective system studied, for each road type studied, for each vehicle type under consideration Total number of persons that were in the position to wear the particular protective system studied, for each road type studied, for each vehicle type under consideration	
General Data	➢Number of kilometres travelled by coaches, heavy goods vehicles, cars, vans, bicycle, moped and motorcycle for each road type assessed		

Appendix B Derivation of a measure for collision severity related to vehicle characteristics

B.1 Energy absorbed

When two vehicles collide, energy is absorbed by the vehicles' structures and by the occupants. The amount of energy absorbed by the occupants determines the severity of their injuries. Since there is conservation of energy, the amount of energy absorbed by the occupants mainly depends on:

- The (kinetic) energy stored in the vehicles before the collision, and
- The amount of energy absorbed by the vehicles during the collision.

The kinetic energy stored in the vehicles before the collision can be calculated from the vehicles' masses and velocities. The amount of energy absorbed by the vehicles during the collision, however, very much depends on the characteristics of both vehicles, like the crumple zone. It is therefore impossible to say a priori how much energy is absorbed by the occupants.

B.2 Occupant acceleration

An alternative way to assess the energy that the vehicles' occupants are subject to, is to look at the acceleration of the vehicles during a collision. The acceleration of the vehicles during a collision is the acceleration that occupants are subject to. The acceleration of the occupants is proportional to the forces on the occupants, and thus strongly related to the severity of possible injury.

It is possible to estimate the velocities of the collided vehicles, using the vehicle masses and velocities before the collision. From these velocities, calculations can be made involving the accelerations during the collision. This will now be derived more formally.

For simplicity we consider an purely inelastic crash in one dimension. Purely inelastic means that the vehicles do not bounce off each other after the crash, but 'stick' and assume the same speed.

Let

m_i and m_j indicate the masses of two vehicles of *i* and *j*, respectively.

v_i and v_j indicate the velocities of these two vehicles, respectively.

The velocity of the two vehicles after the crash, v_{after}, follows from the conservation of momentum:

(A1) $$v_{after} = \frac{m_i v_i + m_j v_j}{m_i + m_j}$$

Now, let Δt denote the time span in which the change in velocities takes place. The average acceleration of vehicles *i* and *j*, respectively, a_i and a_j can then be calculated from:

(A2) $$a_i = \frac{v_{after} - v_i}{\Delta t}$$

(A3) $$a_j = \frac{v_{after} - v_j}{\Delta t}$$

The largest acceleration of the two determines the most severe injury. Nevertheless, Δt is unknown a priori. If it is assumed, though, that Δt is the same for all crashes, the velocity differences can be used as a surrogate for the accelerations. Therefore, a good measure for the severity of a crash is the maximum occurring absolute velocity difference in a crash, ΔV_{max}

(A4) $$\Delta V_{i,j,\max} = \max(\left|v_{after} - v_i\right|, \left|v_{after} - v_j\right|)$$

Note that the velocity difference can be rewritten as:

(A5) $$v_{after} - v_i = \frac{m_j}{m_i + m_j}(v_j - v_i)$$

(A6) $$v_{after} - v_j = \frac{m_i}{m_i + m_j}(v_i - v_j)$$

As a side note, from this it can easily be seen that the ratio of the velocity differences of the two vehicles equals the negative reciprocal ratio of their respective masses:

(A7) $$\frac{v_{after} - v_i}{v_{after} - v_j} = -\frac{m_j}{m_i}$$

The relative severity $g_{i,j}$ of a crash between two vehicles of vehicle types *i* and *j* (*i, j* 0 {PC, HGV, MC}) is then calculated by dividing the maximal velocity differences for crashes between any two vehicle types by the maximal velocity difference in a crash between two passenger cars (PC1 and PC2):

(A8) $$g_{i,j} = \frac{\Delta V_{i,j,\max}}{\Delta V_{PC1,PC2,\max}}$$

To be able to compare the severities related to different collision cases, the velocity differences between the two colliding vehicles, v_i - v_j, should be taken the same for all cases. It can be shown that Equation (A8) can then be simplified:

(A9) $$g_{i,j} = \frac{\Delta V_{i,j,\max}}{\Delta V_{PC1,PC2,\max}} = \max(\frac{2m_i}{m_i + m_j}, \frac{2m_j}{m_i + m_j})$$

Note that the relative severity is independent of the velocity difference. And only depends on the colliding vehicles' masses. It also follows from this equation that 1 # $g_{i,j}$ < 2. The relative severity equals 1 if the vehicle masses are equal.

As an example, the following table shows the calculated velocity after a crash between two vehicles of type *i* and *j*, where the average mass of HGVs is taken to be 8000 kg, the average mass of passenger cars 1500 kg, and that of motorcycles 100 kg. The vehicles are assumed to collide while driving 20 m/s towards each other. The velocity after the crash, v_{after}, was calculated with equation (A1).

i - j	m_i (kg)	v_i (m/s)	m_j (kg)	v_j (m/s)	v_{after} (m/s)
HGV-HGV	8000	20	8000	-20	0,00
PC-PC	1500	20	1500	-20	0,00
MC-MC	100	20	100	-20	0,00
PC-HGV	1500	20	8000	-20	-13,68
MC-HGV	100	20	8000	-20	-19,51
MC-PC	100	20	1500	-20	-17,50

Table 10.1 Calculated values of the velocity after a crash, v_{after}, between two vehicles of the same or different vehicle type, for given vehicle mass and velocity.

From the values in this example, the absolute and relative severities were calculated. The following table shows the results.

	Absolute severity (m/s)			Relative severity		
	HGV	**PC**	**MC**	**HGV**	**PC**	**MC**
HGV	20,00	33,68	39,51	1,00	1,68	1,98
PC		20,00	37,50		1	1,88
MC			20,00			1,00

Table 10.2 Absolute and relative severity of crashes between two vehicles of the same or different vehicle type.

The table shows that a crash between a heavy good vehicle and a motorcycle is assumed to cause the most severe injuries. This is due to the large mass difference between the two vehicle types.