Road Infrastructure Safety Management Evaluation Tools (RISMET)

Guidelines for development and application of Evaluation Tools for road infrastructure safety management in the EU

Deliverable Nr 7

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Executive summary

Improving road safety is and has been a priority in most first world countries with the result that road crashes and resultant traffic injuries have thankfully been declining. However, improvements in road safety have also brought about new challenges for managing the remaining problems. One of these challenges is that the declining number of serious injury crashes means a sparser distribution on the network whereby traditional reactive approaches such as blackspot analysis and remedial treatments are less effective. Consequently there is a need to understand the applicability and suitability of other more pro-active tools and methods for managing road safety.

All road safety management tools require some level of data. These data typically include road accident, traffic, road geometry, vehicle, road user and other related data. The level of details also varies depending on the tool that is being applied. The frequency and manner in which such data are collected depend on both the nature of the required analysis and the purpose for which it is intended. In many cases such data are collected incidentally (i.e. for a specific purpose or study) and not applied or used generally whereas others may be collected structurally serving more than one application and purpose.

To this end it is useful to collate knowledge on the available state of the art tools that can be used to assess safety and the effectiveness of countermeasures. The concept of state-of-the-art at RISMET implies the highest level of development (based on a combination of the level of development and application) of a given tool at the time of publication and as recognised by international literature.

Through surveys of road authorities within the European Union, a number of tools were identified as being used within the EU to assess the safety levels of roads sections, including

1. Road safety audits
2. Safety inspections (as per the EU Directive)
3. Network screening (referred to as network safety management in EU Directive)
4. Accident modelling
5. Road protection scoring
6. Identification and analysis of hazardous road locations
7. Impact assessment of investments and road safety measures (referred to as road safety impact assessment in EU Directive)
8. Monitoring of road user behaviour
9. Conflict studies
10. In-depth analyses of crashes
11. Other tools for road safety management

The utilisation of tools appears to be related to the ease in which these tools may be used and in particular the level of data requirements for each tool. To better facilitate the use of such tools this guideline:

1. **Identifies tools that might be useful in terms of proactive network management**

2. **Provides an outline of the data requirements for each tool**
3. **Compares what authorities already collect to that which the tools require**
4. **Make recommendations on what sort of data set authorities should aim to collect so that they can use a variety of these tools.**

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List of Tables

List of Figures

Table of contents

1 Introduction

"ERA-NET ROAD – Coordination and Implementation of Road Research in Europe" was a Coordination Action funded by the 6th Framework Programme of the EC. The partners in the 2009 ERA-NET ROAD (ENR) Safety at the heart of road design initiative were the United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Austria, Slovenia, Belgium, Hungary and Ireland.(www.road-era.net). Within the framework of ENR this joint research project was initiated.

The project aims at developing suitable road safety engineering evaluation tools as anticipated by the ERANET Programme "Safety at the Heart of Road Design" (2009) and furthermore those of the Directive for Road Infrastructure Safety Management (2008). These evaluation tools allow the easy identification of both unsafe (from crashes or related indicators) and potentially unsafe (from design and other criteria) locations in a road network. With such evaluation tools estimates of potential benefits at the local and the network level can be calculated and potential effects on aspects such as driver behaviour can be estimated. Such tools empower road authorities to improve their decision-making and to implement (ameliorative) measures to improve the road safety situation on the roads.

RISMET provides a set of easy to use guidelines and codes of practice for the development and use of comprehensive road safety engineering evaluation tools. These systems based tools consider the relationship between road design, road user behaviour, traffic and road safety. This guideline is the second in the set of two developed in RISMET and covers specifically the development and application of infrastructure focussed evaluation tools that are currently recommended for state of the art road infrastructure safety management.

1.1 *Background*

Road crashes[1] are a persistent concern worldwide, and it is unlikely that road user movement within the road network will ever be completely risk free. However, the quest continues to design a "safe" road that can enable the transport of users from origin to destination with minimal risk of injury. This can entail improving road safety through a "…increased awareness and acceptance of implementing joint road safety solutions throughout Europe, recognising human limitations and tolerances." (Eranet-Road, 2009)

Road safety varies from country to country. While there are some assessment and evaluation tools that can be utilised for this purpose, the details of these are not always available or well documented, making it a challenge to access these as a ready resource. Moreover, some of these tools do not specifically contain predictive capabilities to assess the effect of local measures on overall safety performance within the network.

Simple crash reduction effects no longer appear adequate as a gauge of road safety - countries more advanced in road safety initiatives (such as the United Kingdom, The Netherlands and Sweden) have made considerable progress in mitigating the risk of crashes and injury on road networks. Standard measures historically used to

1 In this document "accident" and "crash" refer to the same undesirable event.

identify problem areas such as Blackspot Programs are considered somewhat unsuitable as a measure in these countries due to the lower incidence of crash clusters. Traditional approaches rely on the occurrence of crashes and consequently are considered reactive approaches. The trend is now leaning toward a pro-active approach aimed at mitigating potential problems before they result in serious injury crashes. Such an approach requires different indicators with which to determine and define safety levels and where historical crash data only supports the identification of potential problems (lessons from the past).

This then necessitates a systematic review of the availability and suitability of tools to improve the safety performance in a network. An EU Directive (European Commission, 2008) on Road Infrastructure Safety Management details expectations of actions to be taken by road stakeholders. In essence it seeks "…the establishment and implementation of procedures relating to road safety impact assessments, road safety audits, the management of road network safety and safety inspections by the Member States" [1]. Some key aspects of the Directive are quoted below:

- Member States shall ensure that a road safety impact assessment is carried out for all infrastructure projects.
- Member States shall ensure that road safety audits are carried out for all infrastructure projects.
- Member States shall ensure that the ranking of high accident concentration sections and the network safety ranking are based on reviews, at least every three years, of the operation of the road network.
- Member States shall ensure that safety inspections are undertaken in respect of the roads in operation in order to identify the road safety related features and prevent crashes.
- Member States shall ensure that guidelines, if they do not already exist, are adopted by 19 December 2011, in order to support the competent entities in the application of this Directive
- Appendix I-III – Road safety impact assessment for infrastructure projects, road safety audits for infrastructure projects and ranking of high accident concentration section and network safety ranking

In order to identify suitable tools that are widely applicable within the various contexts, the challenge is to develop and/or apply the most suited safety assessment tool given the economic and practical limitations for data collection and management. Most road authorities are limited in their capacity for extensive data collection and creating a tool with high data requirements may simply render the tool redundant. This guideline has therefore been prepared with these constraints in mind.

1.2 *Purpose of the guidelines*

Based on the above influences and objectives, RISMET has as general objectives the development of appropriate evaluation tools that allow the easy identification of both unsafe (from crashes or related indicators) and potentially unsafe (from design and other criteria) locations on a road network. RISMET furthers the work started in RIPCORD-ISEREST by bringing together this expertise and providing the platform on which to continue research and development through active co-operation, information sharing and capacity building. This will ultimately provide European road authorities and road safety engineering practitioners with the necessary tools for safely managing their road infrastructure as required by the EU Directive on road safety management (European Commission, 2008). The Directive stipulates a number of requirements without providing a comprehensive set of tools. RISMET aims at facilitating this by providing the road authorities with a tool kit with which road safety on the European (TEN) road network can be better managed and reported. RISMET is aimed at providing evaluation tools for the rural road network and therefore goes further than what the Directive aims at.

This guideline document describes ways for developing and applying evaluation tools in road infrastructure safety management, with a focus on accident prediction models (APM). It is aimed at the European road authorities and represents a state of the art outlining all aspects related to the development, application and future of such tools. Each tool applied in different countries can require different factors to be considered. Many resources are available detailing the use and specific methods of application for each tool and the reader is encouraged to refer to the specific literature relevant to the tool in question. For background information the reader is referred to the underlying reports that were developed in support of this guideline (Azeredo Lopes & Cardoso, 2011; Candappa, Schermers et al., 2011; Elvik, 2011; Stefan, Dietze et al., 2011).

1.3 *Users of the guidelines*

This set of guidelines is likely to be of assistance to the following users:

- Traffic engineers;
- Road safety officers;
- Managerial staff in the position of coordinating and implementing program evaluations;
- Data collection institutes.

Ultimately, the primary end users are the road authorities in the member countries. By improving the management of the road safety problems on their road networks, road authorities will be able to more effectively implement remedial treatments leading to a safer road network for road users. Other potential beneficiaries include researchers, scientists and engineers active in the area of road safety infrastructure management and also traffic and safety engineering. This guideline should be read in conjunction with the Eranet-Road RISMET guideline on data collection and requirements (Candappa et al., 2011).

1.4 *Structure of the guideline*

Chapter 2 of the guideline presents an overview of the theory and fundamentals related to road safety. Chapter 3 provides an introduction to various road safety evaluation tools and their application whereas Chapter 4 provides a summarised review of current state of the art tools. Chapter 5 to 14 give abridged guidelines on the use of specifically:

- Road safety audits (chapter 5);
- Road safety Inspections (Chapter 6):
- Network screening (Chapter 7);
- Accident modelling (chapter 8);
- Road protection scoring (Chapter 9);
- Blackspot safety management (Chapter 10);
- Road safety impact assessments (Chapter 11);
- Monitoring of road user behaviour (Chapter 12);
- Conflict studies (Chapter 13);
- In depth analysis of crashes (Chapter 14).

2 Theory and fundamentals of road safety

Road crashes are the most common descriptor of road safety in road safety evaluations and road safety management. Also in this guideline road crashes are an important input in many of the evaluation tools described. Since the aim of most countries is to reduce traffic related crashes and the severity of these, it is logical that many of the tools used to manage road safety use crash data as a primary input. However, in certain countries the road safety situation is changing and crashes are significantly reduced, in certain cases to the extent that their distribution over the road network is sparse making crash based analyses of problems increasingly difficult. This does not mean that road safety is no longer a problem but rather that new ways to address these remaining issues need to be deployed. Consequently, the guideline also presents approaches that do not necessarily use crashes as input although aim to prevent these from occurring or aim to minimise the severity in the event of them occurring.

This chapter introduces the following aspects:

- Important concepts and definitions relevant for road safety evaluations, a historical perspective of road safety; factors contributing to road safety; the difference between proactive and reactive road safety, what is meant by subjective and objective road safety;
- Road user behaviour affecting road safety;
- Crashes and factors affecting severity.

2.1 Definitions and approaches

2.1.1 Important concepts and definitions

Participation in road traffic is by way of the many conflict situations unsafe and can lead to crashes with varying degrees of severity. Although road users are aware of these dangers they are prepared to accept the risks. Nevertheless road traffic crashes remain socially unacceptable and therefore road authorities must make all efforts to prevent crashes from occurring and should these occur anyway, reduce the damaging consequences.

For the purpose of this guideline we describe road traffic safety as the absence of danger resulting from participation in traffic and as a state of acceptable risk in traffic. Danger can be described as the critical combination of circumstances prevalent in traffic that can result in an accident/crash. By inference, a crash implies damage and in traffic that could be material damage, damage to the environment, fatalities and other injuries and psycho-traumatic damage. It is generally acceptable that a road traffic crash is one involving at least one road vehicle.

The dangers of road traffic are expressed by a series of events given certain prevailing conditions. Generally these events are in balance, namely the road users, vehicles and the road environment react correctly given any set of conditions. When these events are not in balance (i.e. one or more of the components react incorrectly) a series of critical events can occur resulting in a crash with injury and damage to property due to a collision involving at least one road vehicle and an object, another vehicle or another road user. In road safety this chain of events does not stop at the occurrence of the crash, there is the post-crash situation which also has a direct effect on the eventual outcome of the crash. This is often referred to the golden hour, the period during which emergency and other services must correctly respond to the given situation in order to minimise the level of injury and property damage.

Risk is defined in many different ways. The [ISO 31000](ISO 31000) (2009) /ISO Guide 73 defines risk as the 'effect of uncertainty on objectives'. This could also be interpreted as a probability or threat of damage, injury, liability, loss, or other negative occurrence caused by the participation or exposure to a dangerous situation. In road traffic safety, risk is the chance of being involved in a road traffic crash and being killed, injured or suffering material damage. From this it is evident that individual risk is the product of the chance or probability of being involved in a crash and the effect or outcome of that event. The traffic safety risk is often expressed in terms of exposure which is a measure of participation in traffic. Three types of parameters are commonly used to describe the traffic safety risk and with this also to express the degree of safety of the infrastructure, namely crash rate (or accident rate expressed as number of crashes per vehicle-km and sometimes differentiated on the basis of accident severity), injury rate (expressed as the number of injured/veh-km) and crash density (expressed as the number of crashes/km-road length). However, other exposure measures may be relevant for different road safety stakeholders, as explained in detail in a SafetyNet report (Yannis *et al*, 2005).

Generally speaking crashes are the basis on which most safety evaluations are conducted and are considered as one of the most important objective measures of road safety. However, it is not the only indicator and in terms of this guideline road safety can be evaluated objectively and subjectively and consequently the difference between these will be discussed in later sections.

2.1.2 **Perspectives on road safety**

As mentioned in the previous section road safety can be approached from different perspectives and a number of these are described here.

<u>Objective and subjective safety</u>

Objective safety relates to the application of quantitative measures that are independent of an observer, for instance number of crashes or interactions. Subjective safety relates to a perception of road traffic safety and is dependent on the observer (i.e. there is variation between observers). Both, objective and subjective indicators are important in road safety analyses and need to be considered when taking decisions regarding the implementation of ameliorative or other measures.

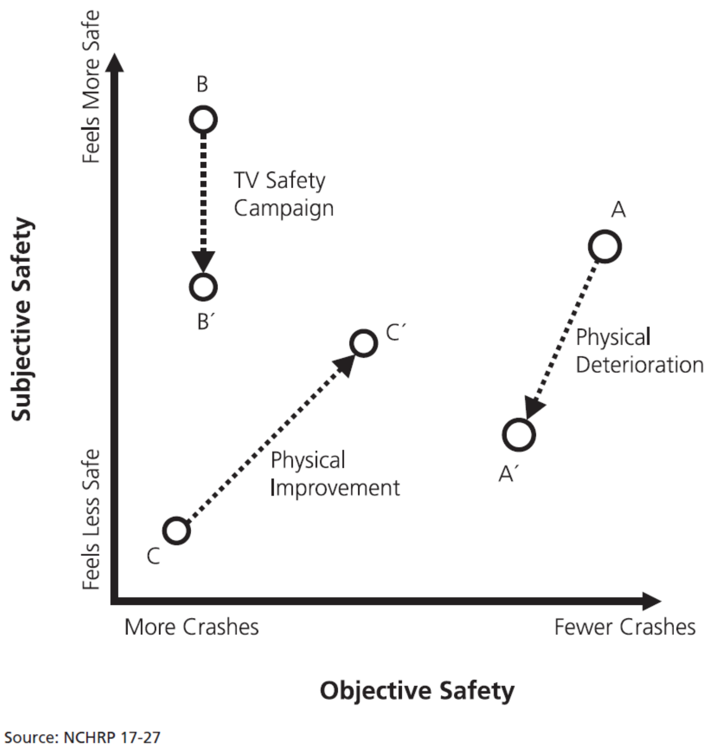
Table 2.1 and Figure 2.1 illustrate the difference between objective and subjective safety.

Table 2.1: Subjective and objective safety (Source: CROW, 2008)

	Objectively safe	Objectively unsafe
Subjectively safe	Desirable situation Well-designed street with well managed (adapted speed) traffic, low conflict potential, self-explaining and self-enforcing	Highly undesirable situation leading to a false sense of safety A wide (urban) road inviting high speeds irrespective of property access etc. or a motor car with many safety features inviting high speed
Subjectively unsafe	Unpleasant situation leading to many complaints A narrow urban street with limited sight distance	Undesirable situation, road safety is an evident problem A quiet residential road used as an alternative route to the main road (rat run)

In Figure 2.1 are examples of both desirable and undesirable relationships between objective and subjective safety. For example a TV campaign against some element of unsafe behaviour may result in road users being more aware of that risk (and therefore feeling less safe) whilst there is minimal or no effect on the actual numbers of crashes, an undesirable condition. The physical replacement of a dangerous intersection with for example a roundabout can lead to improvements to the objective and subjective safety levels, a most desirable condition.

Figure 2.1: Example of changes in subjective and objective safety



It is evident that both subjective and objective safety call for measures which may be fundamentally different. The worst case is a situation which is objectively unsafe but is not perceived as such. Road users will in these cases take essentially unacceptable risks.

Road safety as a random occurrence

Road safety can also be considered from the perspective of being the result of random events. A crash being a random event can be the result of many different factors thereby making the prediction of a single crash difficult. Furthermore, a single crash is seldom sufficient to allow conclusions to be drawn regarding road safety problems. In order to draw conclusions regarding a specific problem more crashes need to be observed before improvements or measures are introduced. The fluctuation in the number of observed crashes resulting from this randomness will decrease as the observation time period increases. In other words by studying the road safety situation (the crashes) over a longer period of time we reduce the relative importance of random fluctuation. However, in many instances this is not socially acceptable and there will be external pressure to introduce improvements before another (serious) crash occurs. In these instances where the number of crashes are inadequate for drawing conclusions or developing solutions, the observation of serious conflicts can be used as an alternative source for describing the safety situations (for this purpose a serious conflict is defined as a situation where two road users on crossing trajectories would collide should they continue with unchanged speed and direction but do not because of some form of evasive action (braking/swerving).

Road safety and accident causes

A road traffic crash/accident is the result of a set of events that culminates in injury and/or damage to at least one road vehicle or pedestrian. These are complex events involving numerous factors that influence the occurrence and the outcome of the crash itself. Generically speaking these factors are the road user; the road environment and the road vehicle; each of which could be further subdivided into causative or contributing factors (e.g. speeding as a human factor; slippery surface as a road factor or brake failure as a vehicle factor). Insight into the causes of crashes can help develop appropriate strategies and solutions. However, since crashes are complex events it is usually not possible to attribute the cause to one single factor, there is always interaction and the focus of the solution lies in the interpretation of that relationship. In the Netherlands it can be said that the human factor (road user) has a role in 64-93% of all crashes, the road environment in 12–34% and the vehicle in 4–13% of all crashes (CROW, 2008). The fact that these proportions do not add up to 100% demonstrates the inter-relationship between these generic categories of contributing factors.

Traffic safety from a systems perspective

The systems approach to road safety was developed once it was realised that crashes are random events caused by a combination of contributing factors and that anyone participating in traffic has the potential to be involved in a crash. Although much is understood about individual factors involved in crashes, the interaction and relationship between them was not well understood. In a systems approach the design of the road transport system influences (road user) behaviour which in turn affects the functioning of that system. Traffic safety is an integral part of that system and crashes are an undesired result of failures in that system. By implication this means that a systems approach strives to find and understand the relationships between the generic factors road user, road infrastructure and vehicle. The result of such a systems approach is that every aspect, consideration, action, etc. that has any influence or bearing on the road traffic system will have consequences on road safety. This realisation brings about a fundamental shift in thinking and ensures that road safety becomes an integral part of the system as a whole.

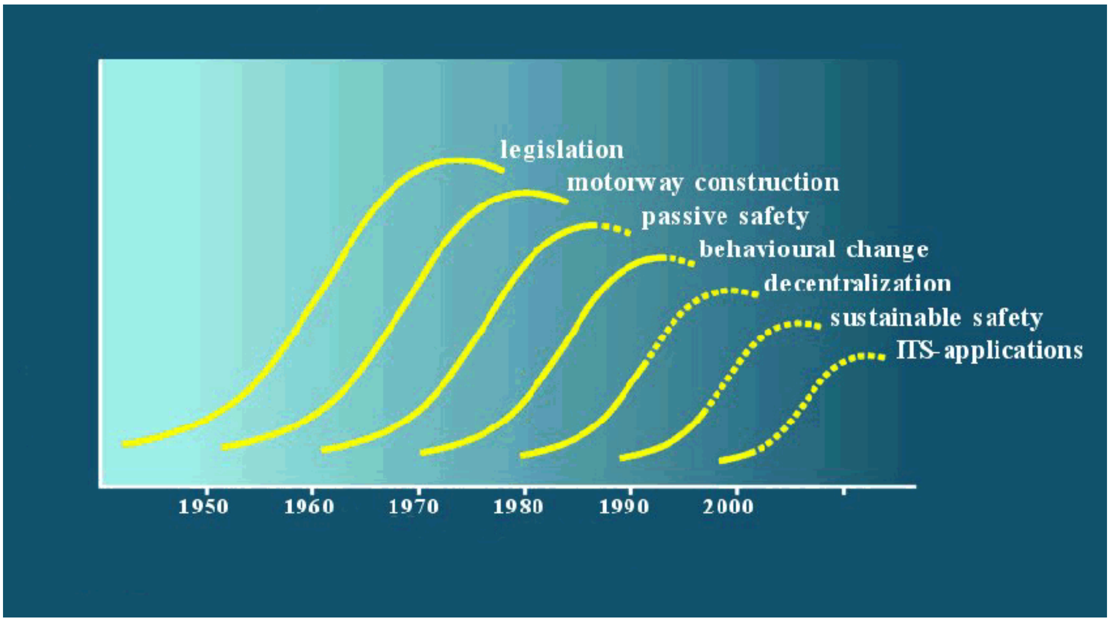
2.1.3 **Historical development**

Over the years, the approach to road safety has undergone quite a radical transformation. In the early part of the 20th century road traffic crashes were regarded as single events, each with unique problems which had to be immediately solved. Each case was independently studied, the cause identified and treated with the belief that the problem would be solved. A drawback of this approach was the fact that it was fairly subjective, treatments of problems often led to new problems and it was not directed at accident clusters/locations whereby measures were not always effective for all crash types. Although this approach no longer is followed in general road safety evaluations, in-depth accident investigations still are applied to gain more detailed insight into specific problems and where evidence regarding the apportionment of blame (in court) must be gathered.

In the period between the end of the first world war to the middle of the twentieth century, the focus of road safety shifted to the road user, particularly those responsible/involved in a number crashes. These persons were targeted for remedial programs or even banned from participating in traffic. The underlying assumption in this approach was that all road users had an equal chance/risk of being involved in an accident so therefore those more involved were automatically "bad" drivers/road users. The degree of exposure and the nature of that exposure were not considered important. In the period 1940 to 1960 the focus shifted again to the causes of crashes and the first real research in this area was initiated (CROW, 2008). This led to causes being sought in driver behaviour and technical aspects (vehicle safety and road design).

In the Netherlands, policy at that time was directed at legislation, very much aimed at regulating the use of the transport and traffic systems Figure 2.2

Figure 2.2: Policy approaches to road safety in the Netherlands



The limitations of the above approaches resulted in the development of a more holistic approach to the road safety problem in the 1960's to 1980's. In the Netherlands this was associated with a period of significant economic growth during which infrastructure development was high on the political agenda. At the same time, policy makers and researchers realised that road crashes were complex events and could only be addressed systematically. Crashes were recognised to be random events with multiple contributing factors. Furthermore everyone participating in traffic had the potential to be involved in a crash. To better understand the complex relationships between the various contributing factors within and between the three system elements (road user, road infrastructure and vehicle), the Haddon matrix was applied to crash analyses. This showed that a crash never has a single cause but is the result of a chain of events (Table 2.2).

Table 2.2: The Haddon Matrix applied to road safety (in CROW, 2008Technical Committee 13 Road Safety PIARC, 2004)

System element	Before the crash (Pre-crash)	During the crash (Crash)	After the crash (post-crash)
Human	Physical condition • *Fatigue,* • *Alcohol- and drug use* • *Handicaps, sight, hearing, etc.* Physiological condition • *Stress,* • *inattention, distraction,* • *attitude* Socio-demographic profile • *Age,* • *Sex, etc.* Experience and skill • *Driving experience,* • *Knowledge of vehicle, traffic regulations etc.* Behaviour • *Speed* • *Manoeuvres before collision* Self-protection • *Seatbelt wearing,* • *helmet*	Physical condition • *Reflex* Error • *Perception of road* • *Perception of distance and speed* • *Inappropriate manoeuvre* Action • *Speed* • *Braking* • *Position on road* • *warning*	Physical condition • *resistance to impact* Physiological condition • *emotional shock* Experience and skill • *safety first* • *protection of crash scene* • *contacting emergency services* Action • manoeuvres after crash
Vehicle	Physical factors • *vehicle type,* • *Colour, weight etc.* Technical factors • *Brakes (ABS)* • *Tyres* • *ESC/LDW* Mechanical condition • *degree of maintenance* • *damage* Running state • *Load and positioning* • *objects*	Passive safety devices • *airbags* • *deformation zones* • *E-call*	Handling of damaged vehicles • *Removal* • *Escape possibilities* • *inspection*
Road infrastructure	Geometry • *alignment* • *cross-section* Surface characteristics • *skid resistance, roughness* • *debris, objects* Surroundings • *land use* • *type of road users* • *traffic volumes* Equipment • *signs and markings*	Recovery area • *shoulders* • *emergency lane* • *central refuge* Roadside conditions • *obstacles, trees* Critical zone • *transition zone* • *road works* • *maintenance* • *obstacles in roadway*	Accident warning • *warning triangles* Clearing up road • *Inspection*

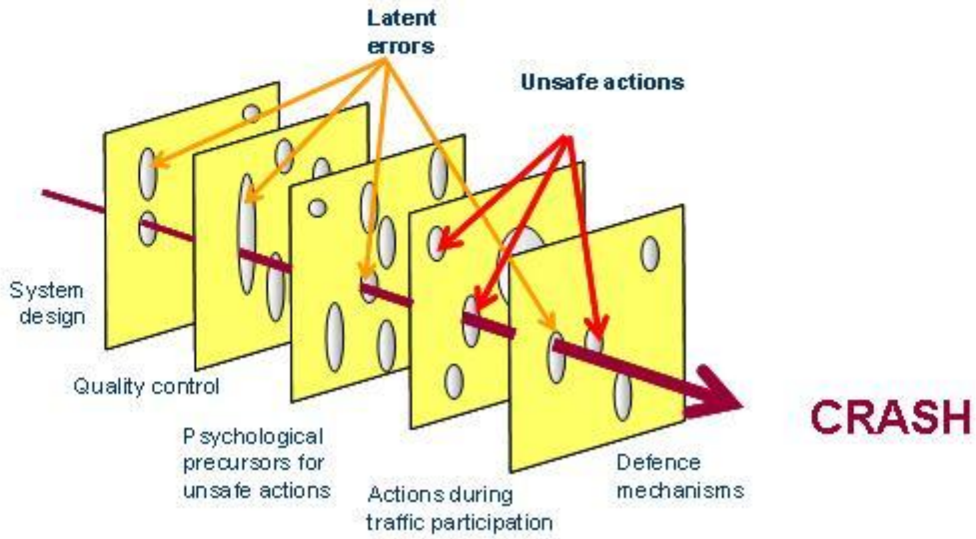
However, this approach is essentially static and does not account for the dynamics of transportation and crash occurrence. Applying the Haddon principles is not a structured process and identifying the critical relationships between the various factors is complex and sometimes not possible. Crashes remain random events with multiple causes, some of which are of a deterministic nature and can be managed whereas others are of a stochastic nature (random) and cannot.

Towards the end of the 1980's the concept of a dynamic systems approach evolved (OECD Scientific Expert Group, 1984). This approach considers a crash as a series of phases, each of which can be influenced and can have an influence on the occurrence and/or the outcome (severity). The phases are:

- The travel need phase (relates to mode and route choice)
- The traffic phase
- The meeting or encounter phase
- The incident phase
- The crash phase
- The damage and injury phase
- The recovery and revalidation phase

The multi causal dynamic systems approach has been well documented (Rasmussen, 1989; Asmussen, 1996). Figure 2.3 illustrates this approach and gives a reasonable representation of how latent errors and unsafe actions can be detected in a system and actions be taken to rectify these before the crash actually occurs.

Figure 2.3: Proactive systems approach – schematic representation of a crash resulting from latent errors and unsafe behaviour (Reason, Manstead et al., 1990; Wegman & Aarts, 2006)



Since 1990 the approach to road safety has been focussed much more on prevention of crashes and where the human (road user) has a dominant position. Although remedial programs (reactive) aimed at redressing recurring crashes and crash types are still applied using both static and dynamic approaches, the emphasis is now more on correcting potential defects in the traffic system before crashes manifest themselves. Examples of such a way of thinking are the Dutch Sustainable Safety approach and the Swedish Vision Zero approach which will be briefly discussed in the following section.

2.1.4 **Integrated or holistic approaches**

Sustainable safety

Following the road safety policies aimed at legislation and infrastructure provision in the 1970's through measures aimed at passive safety and behavioural changes in the 1980's, the Dutch Ministry of Transport set out a spearhead policy in 1988. This was aimed at the reduction of blackspots, speeding, drink driving and crashes involving heavy vehicles, cyclists or mopeds. The spearhead policy set out a target to decrease fatal crashes by 50% and serious injury crashes by 40 % by 2010, using 1986 as the reference year. In the early 90's it was evident that these goals would not be reached and this resulted in the development of Sustainable Safety (Koornstra, Mathijssen et al., 1992). Its underlying philosophy was that the human being is central and that the system should be designed to accommodate for the limitations of humans in a road traffic system. Furthermore, Sustainable Safety advocates a preventative approach rather than a curative one. The original sustainable safety concept was based on three safety principles:

1. Functionality: to prevent unintended use of the infrastructure
2. Homogeneity: to prevent major variations in speed, direction, mass of vehicle at moderate and high driving speeds
3. Predictability: to prevent uncertainty among road users

The above principles were translated into concrete measures aiming at creating:

- A road environment with infrastructure adapted to the limitations of the road user. Three classes of roads are defined: roads with through function for rapid movement of through traffic; roads having a distributor function for distribution and collection of traffic to and from different districts and residential areas; roads with an access function providing access to property whilst simultaneously providing a relatively safe space for different road users to interact and for people to meet. Each of these road classes has to comply with certain functional requirements making each category different and readily recognisable to the road user.
- Vehicles equipped with technology to simplify the driving task and provided with features that protect vulnerable and other users
- Road users who are well informed and adequately educated.

The first phase of Sustainable Safety was implemented in the period 1998-2002 (Schermers, 1999; Schermers & Vliet, 2001; Schermers, Wegman et al., 2010b). Amongst others road authorities were asked to develop new, functional road network categorisation plans, to re-engineer their road networks in accordance with these plans (especially increasing the number of 30km/h zones in urban areas and 60km/h zones in rural areas), to assign priority at all intersections along distributor roads, to provide measures to accommodate mopeds on the roadways and to improve the layout of all roads in such a way that these became recognisable to road users.

The second phase (2003-2010) not only focussed on infrastructure improvements but also on road user education and information dissemination, stricter enforcement, vehicle technologies (alcohol lock, EuroNCAP), spatial planning and specific measures aimed at the commercial road transport sector (safety culture in freight transport) (Wegman & Aarts, 2006).

Although the first phase of the Sustainable Safety programme proved successful, it was felt that the momentum was to an extent lost in the transition between the first and second phases. This resulted in the strategy being reviewed (Wegman & Aarts, 2006) to provide a new stimulus. The original vision was still supported although it was defined more precisely. The human being was given an even more prominent role. Firstly, to prevent fatal and serious injuries, the homogeneity principle was elaborated by defining "safe speeds" for a variety of impact conditions. Secondly it is accepted and recognised that human beings make errors in observation, decision making and implementing decisions (Reason et al., 1990). Based on the "Swiss Cheese model" of Reason (1990, see Figure 2.3), Sustainable Safety strives to create an environment for road users that reduces human error and when these are unavoidable, provide an infrastructure that is forgiving. Consequently two additional safety principles, based on scientific theories and research, were added to the three mentioned above and served to strengthen the philosophy of Sustainable Safety. These principles are:

4. Forgivingness of the road environment. Provide a road environment that minimises the risk of injury and allows for road users to adequately anticipate to given dangerous situations
5. State awareness. Road users must be able to assess their own task capabilities for any given traffic situation.

From a road design perspective, Sustainable Safety has the ultimate goal of realising a road network in which the relationship between function, form and use are in harmony. In effect this strives for mono-functionality of roads where the design of each category accommodates its own traffic demands and allows for the safe and reliable movement of people and goods. An inherent design principle is that each road type actively strives to minimise the consequences of road crashes, that is to say eliminating fatal crashes and reducing the severity of injuries (i.e. the design lends support to the theories of the forgiving roadsides and self-explaining roads).

Swedish Vision zero

The Swedish Vision Zero was approved by the Swedish Parliament in 1997 and has since been the driving force behind road safety in that country. The primary aim of Vision Zero is to realise a road transport system in which no one is killed or seriously injured in traffic crashes. A fundamental concept of Vision Zero is that it recognises and accepts that people make mistakes and consequently crashes cannot always be avoided. Another important dimension is that Vision Zero places human life above all else. Life and health cannot be exchanged for other benefits to society (for instance by applying a cost benefit analysis approach). Vision Zero aims to provide a road transport system designed to ensure that persons involved in crashes are not killed or seriously injured. This implies safer roads, safer vehicles and safer behaviour. In Vision Zero the responsibility of improving traffic safety is shared by all (from policymakers, road engineers to road users).

Initially, Vision Zero set itself a target of a 50 per cent reduction in fatalities by 2007 (using 1996 as the base year). To facilitate this, a short term action plan was launched by the Government in 1999. This plan presented 11 focus areas which encapsulate and stimulate the Vision Zero principles. These strategic focus areas are (Tingvall & Haworth, 1999; Koornstra, Lynam et al., 2002; Wegman & Aarts, 2006)

1. *A focus on the most dangerous roads*;

   These include high priority measures such as eliminating head-on collisions by providing physical separation (cable-barriers, guardrails etc.) between driving directions, removing obstacles next to roads, etc.

2. *Safer traffic in built-up areas*;

   Including a safety analysis of street networks in 102 municipalities resulting in the reconstruction of many streets

3. *Emphasis on the responsibilities of road users*;

   Including programs/initiatives aimed at creating more respect among road users for traffic rules; in particular speed limits, seatbelt use, and drink driving.

4. *Safe bicycle traffic*;

   Including a campaign for using bicycle helmets and introducing a voluntary bicycle safety standard.

5. *Quality assurance in transport work*;

   This initiative is aimed at public agencies with large transportation needs who will receive traffic safety and environmental impact training/instruction to improve the quality of their own transportation services, including those services sourced from outside firms

6. *Winter tyres*;

   Developing and implementing a new law aimed at making use of winter tyres compulsory at certain times (and under certain weather conditions) of the years

7. *Promoting the use of (Swedish) technology*;

   This focus area aims at promoting the introduction of existing or new technology that can be applied in the short term and including seatbelt reminders, in-car speed adaptation systems (ISA), alcohol ignition locks (for preventing drunk driving), and electronic driver licenses

8. *Responsibilities of road transport system designers*;

   It is proposed to establish an independent organisation for road traffic inspection. This follows the recommendations of a commission of inquiry on the responsibilities of the public sector and the business community for safe road traffic.

9. *Public responses to traffic violations*;

   This includes a review of laws and regulations governing traffic violations given the principles of Vision Zero and ensuring due process of law.

10. *The role of voluntary organisations*;

    Including a review of the road safety work of the National Society for Road Safety (NTF or Nationalföreningen för trafiksäkerhetens främjande) and its use of state funds

11. *Alternative forms of financing new roads*.

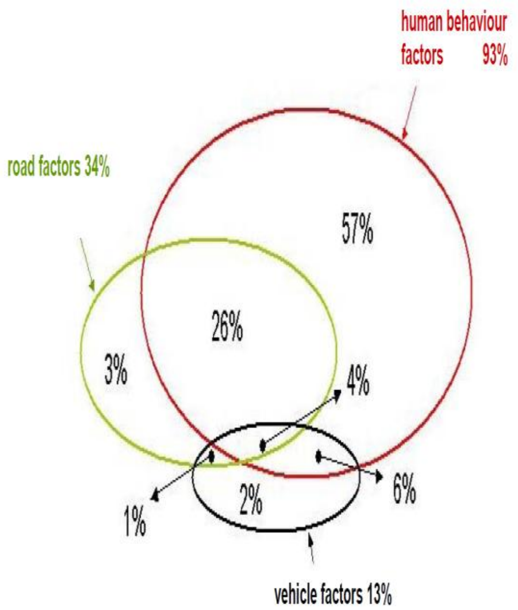
    Including investigating other forms to supplement public financing of major road projects.

Vision Zero has revised its targets and now has set its long term goals at a 50% reduction of fatal crashes by 2020 and 100% reduction by 2050. Since 1997 the programme has booked significant results and the number of fatalities by 2007 had decreased by some 13% (Lie & Tingvall, 2009).

2.2 *Road user behaviour*

As mentioned in earlier sections, the human element plays a role in almost all road traffic crashes. Driver error remains one of the most important causes for road crashes. Road users make errors of judgement, are easily distracted, have (physical and psychological) limitations and even consciously disobey rules, seek and take risks. Several studies have shown that human factors play a predominant role in up to 93% of all serious crashes. Approximately half of these are attributed to solely human factors (Treat, Tumbas et al., 1979) (Figure 2.4)

Figure 2.4: Contributing factors in road crashes (Treat et al., 1979)



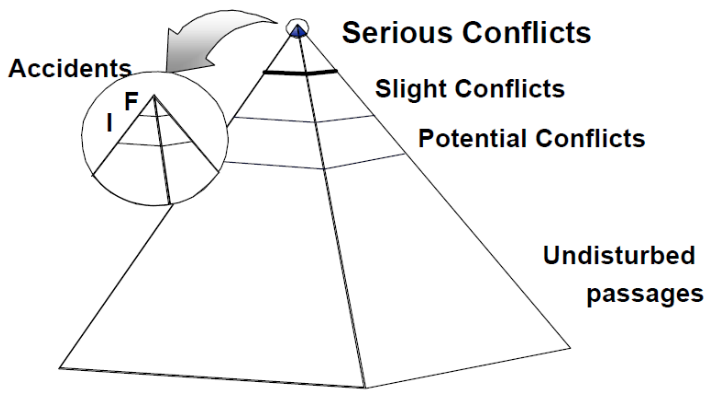
The study by Treat (Treat et al., 1979) further revealed that approximately half of the human behaviour related crashes were related to recognition and decision errors. Factors such as "improper lookout"; “excessive speeds", inattention and improper driving featured strongly as leading causes in crashes. Although this study is rather dated, it remains one of the most cited studies and is to this day relevant. Later studies in for example the Netherlands reveal that incorrect or not yielding (comparable to improper lookout), speeding and improper driving remain prominent as contributing factors in road crashes.

Given this, it is quite logical that concepts such as Sustainable Safety (Koornstra et al., 1992; Schermers & Vliet, 2001; Wegman & Aarts, 2006) have stated that human capabilities and limitations must be at the basis of all road and traffic related designs and decisions. Concentrating related efforts on the weakest link in the system, namely the road user, has the best chance of affecting the desired reduction in casualty related crashes. Obviously road users, vehicles and road environments will continue evolving. To remain relevant, road safety strategies must be dynamic and able to adapt to these changes. However, as history has showed, the behavioural element was a principal issue and will remain one for the foreseeable future.

2.2.1 **Road safety from a user perspective**

Although road users, more specifically factors related to road user behaviour, play a predominant role in road crashes, they are also the main reason that so many incidents do not result in crashes. In an attempt to relate road user behaviour to road safety (crashes) Hyden (1987) studied the relationship between conflicts and crashes. This revealed that most (observed) movements resulted in unobstructed and undisturbed passages whereas only few resulted in conflicts and even fewer in crashes. Consequently this could be represented by a pyramid showing the degrees of (conflict) severity (Figure 2.5).

Figure 2.5: Hyden's Interaction between road users as a continuum of events (Hydén, 1987)



Understanding why different situations lead to different outcomes is quite complex and means that information is required prior to the event (conflict or other) occurring. Normal accident data do not contain this information and obtaining this type of information requires detailed study such as naturalistic driving studies and in-depth accident investigations (including interviews with victims/drivers). Important in this regard is that also data be obtained for the cases where no incident (conflict or crash) happened.

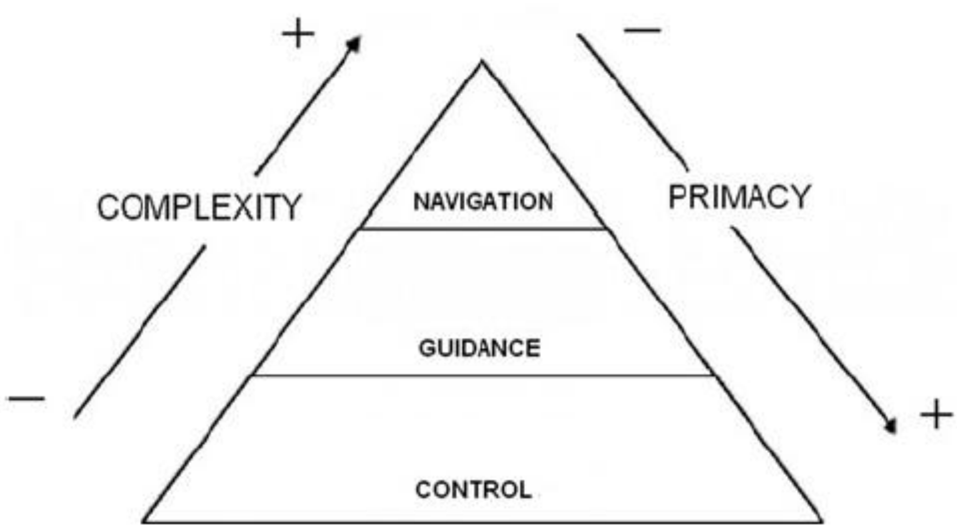
2.2.2 **The driving task**

Driving consists of a combination of tasks which are in part carried out simultaneously and require different skills and knowledge. Driving a vehicle involves a number of sub-tasks such as steering, accelerating and braking, changing gears, indicating etc. Obviously the vehicle is being driven for a reason and therefore a certain route has been planned and is being followed in order to reach a chosen destination, often by a certain time. To follow this safely the driver has to follow road signs, be aware and react to other traffic etc. To complicate the task there are all sorts of distractions such as passengers talking, radio's, advertising along the road etc. All in all the driver is expected to deal with many tasks and activities at the same time. These tasks have been categorised into three primary levels (Michon, 1985; Alexander & Lunenfeld, 1986) as shown in Figure 2.6

At the lowest (control) level the driver controls the vehicle by steering, controlling the throttle, changing gears etc. At this level tasks (and the associated decision making processes) are performed almost continuously and subconsciously (with experience the driver hardly thinks about these matters and automatically performs the required tasks).

At the middle (guidance) level tasks typically involve interaction with other traffic and road users (monitoring following distance, watching traffic from side roads, merging etc.) and the road environment (traffic signals and signs and markings, etc.). At this level tasks are performed both at a conscious and sub-conscious level with tasks (and associated decision making) occurring frequently (depending on the complexity of the traffic situation, from every second to sometimes every minute).

Figure 2.6: The driving task model (Alexander & Lunenfeld, 1986)



The highest (navigation or strategic) level is the most conscious level and involves the planning aspect of making a trip and including the trip purpose (and destination), the transport mode, the route to follow, the time needed to reach the destination etc. Decisions/tasks may be executed with long time periods between them (few minutes to even hours).

As illustrated, the more complex tasks are carried out at the higher levels whereas the most urgent task are carried out at the lowest level (e.g. seeing a ball flying into the roadway requires immediate attention and action and all other tasks related to the strategic choices will be temporarily forgotten).

2.2.3 **Information processing and driving behaviour models**

Humans have to deal with large amounts of information and this is generally dealt with in a cyclical process involving perception/observation, decision making, response selection and response execution. Perception is the process of observing and interpreting that what is being seen. In traffic many things are "seen" but not "observed, either at a conscious or subconscious level" (i.e. we choose to see what's important and the rest not). The decision making process involves taking that what we have observed (really "seen") and comparing it to what we know or have learnt. Once we know what we have seen we must decide what action to take and then we must undertake that action.

In design it is quite normal to base certain design criteria on so called perception-reaction time (AASHTO uses 2.5 seconds, 1.5 seconds for perception, decision making and response selection and 1 second for the reaction itself). However, it is important to note that perception-reaction time is not a fixed value and is influenced by many human factors including driver state (alertness etc.), vision and driver expectations.

Similar to the driving task model Rasmussen (1983) introduced levels of attention needed to perform certain tasks. These were the skill based level, the rule based level and the knowledge based level. The skill based level requires the least attention and tasks are almost automatically carried out. However, as the word "skill" implies, actions/tasks at this level are learnt and develop over time (an experienced driver does not really think about steering a car whereas a novice does). At the rule based level behaviour is typified by the application of knowledge of procedures, rules, regulations etc. to a given situation and taking the necessary actions. These behaviours are governed by rules and in time the reactions to the same situation also become the same (e.g. approaching an amber traffic signal means slow down and stop if safe to do so). At the knowledge based level behaviour is dictated by the high degree of concentration necessary in performing the task. Generally behaviour at this level relates to new situations which the driver has not yet really experienced and therefore the tasks require a great deal of effort and the chances of making mistakes are fairly high.

Hale, Stoop and Hommels (1989)) proposed a combination of the driving task model (Michon, 1985) and the Rasmussen model (1983) resulting in a 9 cell matrix (Table 2.3) and in which the darker cells represent the tasks typical of an experienced driver and the lighter cells those typical of the novice driver. In this model operational tasks quite quickly are operated at a skills based level whereas strategic based tasks require knowledge based behaviour.

Table 2.3: Examples of driving tasks according to combined Michon and Rasmussen models (Houtenbos, 2008) (adapted from Hale, Stoop and Hommels, 1990)

Attention level	Task level		
	Strategic	Tactical	Operational
Knowledge based	Navigating in a strange town	Controlling a skid on a slippery road	Learner driver on first trip
Rule based	Choosing between familiar routes	Passing other cars	Driving an unfamiliar car
Skills based	Travelling to and from home	Negotiating a familiar intersection	Negotiating bends

2.2.4 **Other behavioural factors influencing risks and crashes**

There are many factors such as alcohol and drugs, fatigue, distraction, own estimates of ability, emotion etc. that can negatively affect the performance of road users, in particular drivers of vehicles, in traffic. A decline in the performance leads to an increased risk to be involved in a crash and consequently these issues should also be taken into account as part of the safety management process. A number of these factors are briefly discussed to illustrate the relationship with crash risk. For more details, the reader is urged to consult the most recent and relevant research on these topics.

Perception of own abilities/risk perception

Drivers and road users have a perception regarding their own abilities and this determines what risks they are prepared to take in traffic. This is reflected in aspects such as gap acceptance whereby drivers/road users base a decision to accept or reject a gap in an opposing stream of traffic on their own ability to safely utilise that gap (the latter being variable since the accepted gap size decreases as waiting time increases). Where risks are deemed high, road users may tend to adapt their behaviour (e.g. approaching a poorly sighted bend at high speed in a regular car may led to a reduction of approach speed). However, where risks are deemed low drivers may also adapt their behaviour but in a negative sense (approaching the same bend but driving a sports car with all the technology may result in speeds not being reduced or even increased). Generally speaking drivers tend to perceive themselves as better drivers than the average drivers. Obviously this is an undesired development for road safety and could lead to crashes resulting from errors in judgement. Programmes such as Sustainable Safety have recognised this problem and have introduced the concept of state awareness as one of the principles of the vision (Wegman & Aarts, 2006).

Fatigue

Fatigue leads to decreased alertness, increased reaction times, less efficient information processing etc. and has a negative impact on road safety in general and crashes in particular. Fatigue can be caused by many factors and these include amount of sleep, quality of sleep, time on task (how long a person has been doing a specific task), stress and biorhythms. Although fatigue is difficult to isolate as sole contributing factor in crashes (accident victims are unlikely to report that they were falling asleep behind the wheel or they were exhausted whereas not all police officers are trained to detect fatigue as a cause of crashes), it is known to play a role in crashes involving long distance drivers, drivers with sleeping disorders, professional drivers and shift workers. Often crashes related to fatigue occur late at night or early in the morning and then on higher order roads with long and relatively straight road sections.

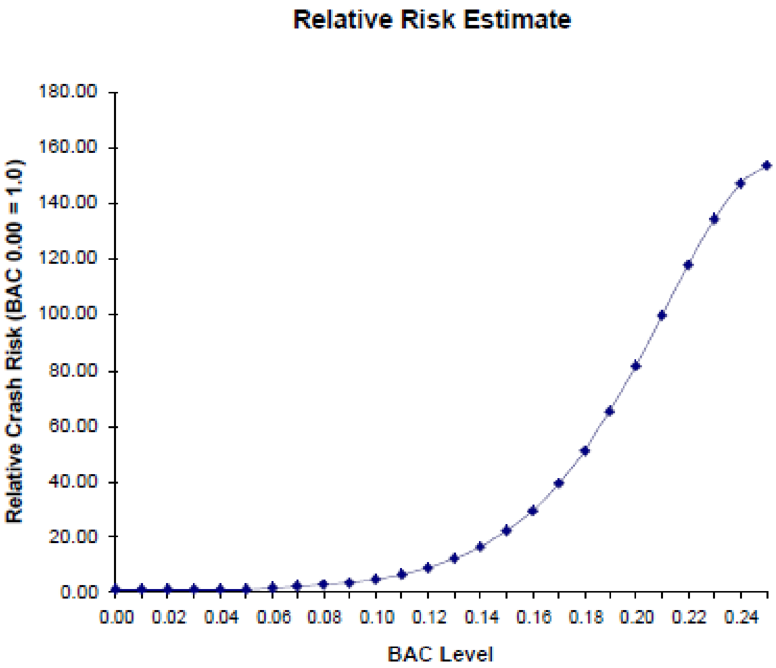
Alcohol, drugs and medication

The use of alcohol and drugs are known to impair driving and its use in traffic accounts for significant numbers of serious and fatal crashes worldwide. Research into the relationship between alcohol use and road safety is extensive. Research into drugs and medication is not as extensive and is currently a topic of research.

In the Netherlands the use of drugs under motorists involved in injury crashes has increased significantly with cannabis being the most commonly used drug (Mathijssen & Houwing, 2005). The results on the effects of cannabis on crash risk are not consistent with some studies revealing an increased risk and others no effect. A Dutch study (Mathijssen & Houwing, 2005) revealed increased crash risk with the use of drugs (excl. heroin) and certain medications with the highest risk increase occurring when drugs are combined with BAC levels above 0,13% (mass of alcohol per volume of blood).

Most countries have introduced limits for drivers' blood alcohol concentration varying from zero to 0,08% and driving under the influence is strictly enforced in most countries. The relative crash risk resulting from driving whilst driving under the influence is shown in **Figure 2.7.**

Figure 2.7: Relative risk of crash as a function of BAC [%] levels (Compton, Blomberg et al., 2002)



Alcohol impairs the driving task in a number of significant ways and these include:

- The ability to maintain a true course;
- Maintaining a constant and safe following distance;
- Reacting to (subtle) speed changes of leading vehicles;
- Increased reaction time;
- Lack of concentration and ability to concentrate on more than one task;
- Tendency for tunnel vision.

2.3 *Crashes*

As discussed earlier, crashes are random events that can seldom be accurately predicted although there are numerous factors which may be related with an increased risk of a crash given a set of circumstances. In Sustainable Safety (Koornstra et al., 1992; Wegman & Aarts, 2006) the principle of homogeneity strives to minimise differences in the mass, direction and speed of road users. In so doing the risk of serious injuries are minimised in the event of a crash. This section summarises the most relevant principles and factors associated with the physics of crashes.

2.3.1 **Energy exchange**

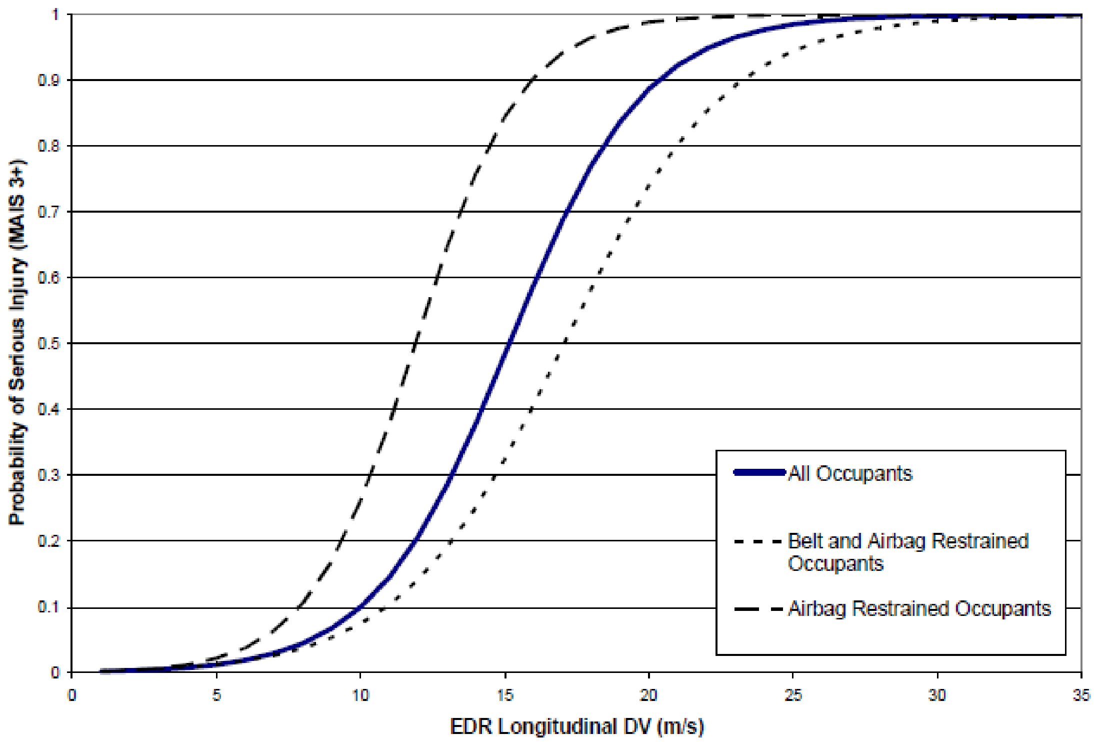
Crashes in traffic are relatively commonplace and when these occur they are governed by the laws of physics, namely the law of conservation of energy and the law of conservation of momentum.

A moving vehicle has kinetic energy (expressed by $E_{KE} = ½ mv^2$), where m is its mass and v its speed; when it comes to a standstill it has no kinetic energy. Under ordinary traffic circumstances (i.e. normal braking and coming to a stop) the law of conservation of energy determines that this kinetic energy is converted into heat through friction (between brake pad/wheel and wheel/road surface), when the brakes are applied, friction between mechanical parts, aerodynamic drag and gravity work (when going uphill). In a case where a moving vehicle comes to rest "unnaturally" (i.e. by hitting a standing object, a moving vehicle, etc.), this kinetic energy can be dissipated via deformation of the vehicle and its occupants or via the terrain surface (in case of vehicle rollover). This transfer of energy is dependent on factors such as the mechanical properties and structure of the vehicles/objects; restraint systems, physical state of the occupants etc.

Momentum is a vector element (which has magnitude and direction, similarly to velocity) equal to the product of vehicle mass and vehicle speed. According to the laws of conservation of momentum, in a collision the total momentum of the colliding vehicles will remain the same whereas the individual momentum of vehicles will change (i.e. a car hitting a truck will lose momentum but the truck will gain momentum). Conservation of momentum laws and conservation of energy laws are generally used in analysis and reconstruction of crashes (e.g. to determine initial vehicle speeds).

In accident analysis and reconstruction the corresponding energy transfer is often approximated by Delta V (in essence the speed change that the vehicle experiences as a result of the impact and measured from start of the impact contact phase to its end, in the separation phase) which is an accepted measure of crash severity and a good predictor of the involved occupants' injury severity (Figure 2.8).

Figure 2.8: Example of using Delta V as a predictor of injury risk by restraint type (Gabauer & Gabler, 2007)

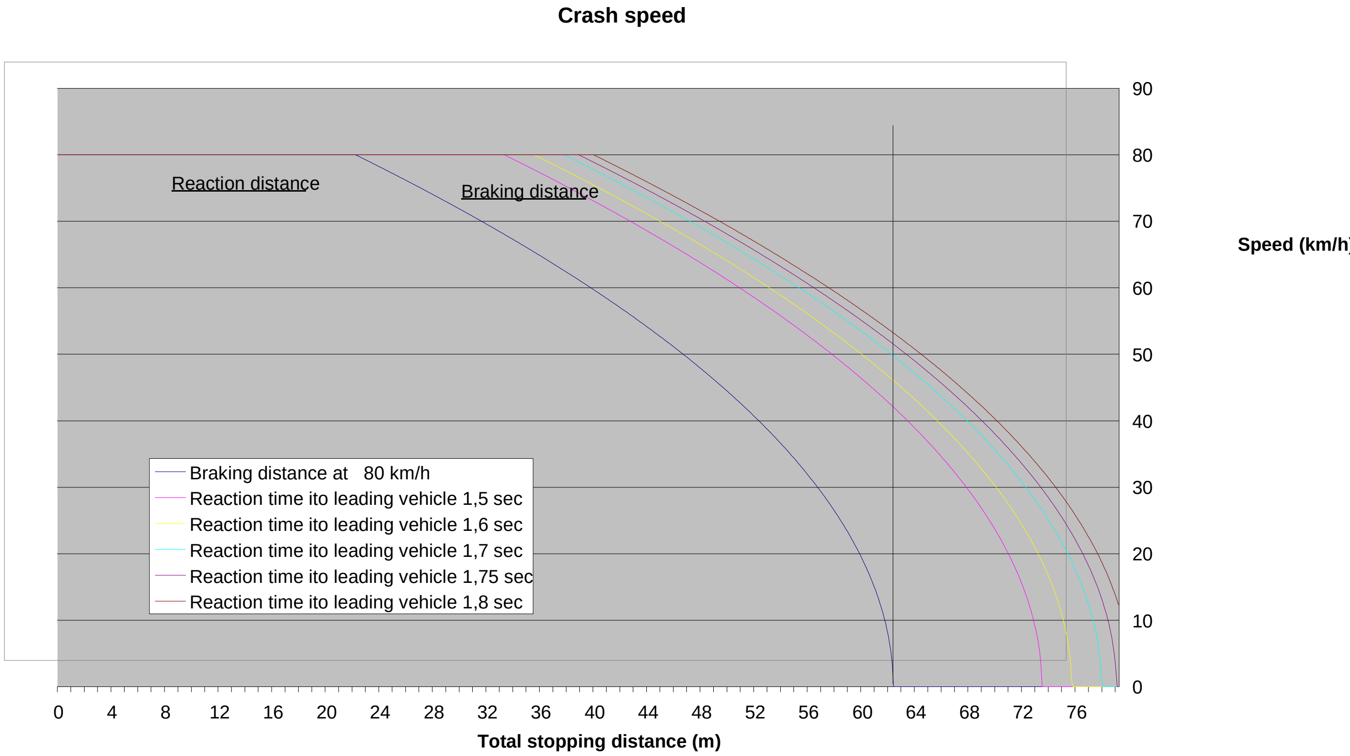


2.3.2 **Differences in speed**

Speed is probably one of the most (if not the- most important) factor in road safety management. Not only does it have a direct relationship with accident severity it also has a relationship with reaction time (given a fixed reaction time, the actual distance covered in that time becomes less as speed increases). Although posted speed limits and speed warning/advisory signs benefit road safety, they cannot prevent crashes and certainly do not imply safe speeds since they are generally intended to be applicable for average conditions and not all conditions. Most speed related crashes are the result of inappropriate driving speeds given certain traffic and other conditions. For instance on higher speed and busy rural roads reaction times and following distance/headway play an important role. Take a situation whereby a leading vehicle suddenly has to stop as illustrated in

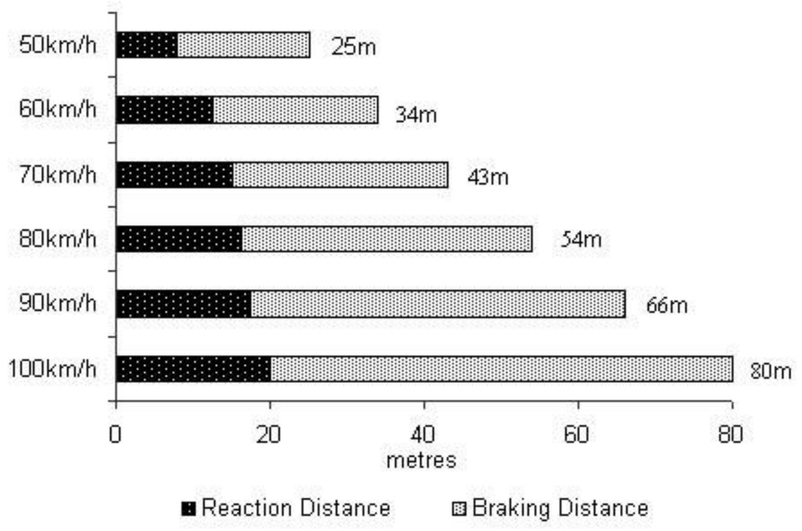
Figure 2.9. Given a speed of 80km/h and a reaction time of 1 second, normal road conditions and at a point where the driver could still bring his vehicle to a safe emergency stop, this vehicle would require a total of 62.5m to stop. If the following vehicle travelling at the same speed has a reaction time of 1.5 seconds he will rear end the stopped leading vehicle (or in the case there is no leading vehicle but an object 62.5m ahead) at 42km/h.

Figure 2.9: Rear end crash speed of car following at 1 second gap with varying driver reaction times (assuming same braking efficiency and road surface in all conditions)



The relationship between reaction time and stopping distance at given speeds (assuming the same reaction times, road conditions etc.) is shown in Figure 2.10.

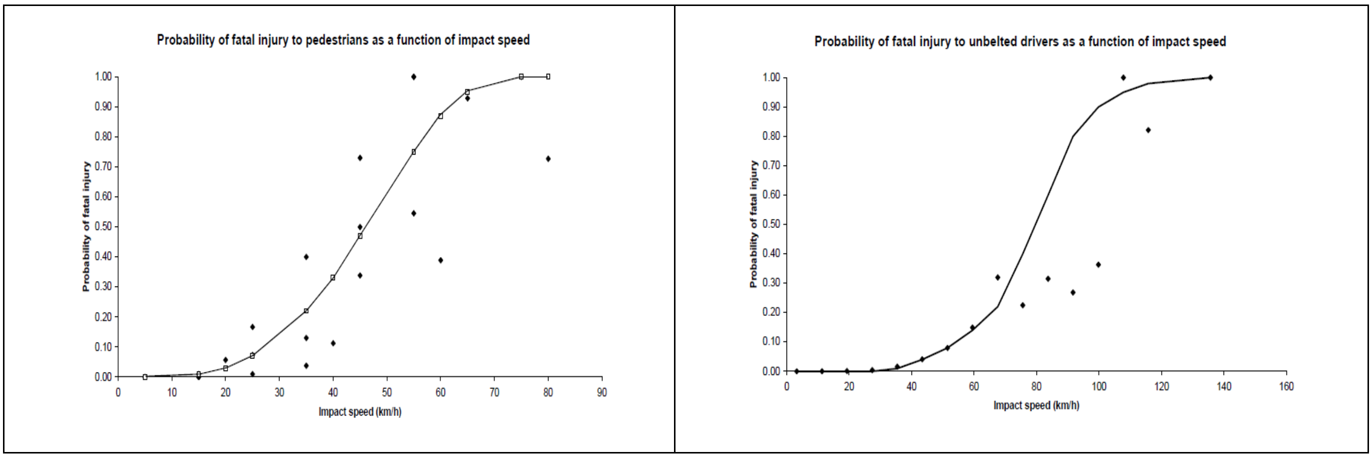
Figure 2.10: Reaction and braking distances, assuming reaction time 0.75s, same road surface and braking efficiency, (from www.goldcoastbrakes.com)



As discussed earlier, Delta V (a measure in the change of velocity of colliding vehicles or also referred to as the 4th power of impact speed) has been used to predict the probability of serious injury resulting from crashes between two vehicles (Figure 2.8).

From these relationships it is evident that the lower the driven speed, the more likely that the outcome of a crash will not be fatal. So for instance, the chance of being killed as a pedestrian rises dramatically once impact speeds increase beyond 25km/h (Figure 2.11) (Elvik, Christensen, & Amundsen, 2004). Similarly the risk of being killed as an unbelted driver of a car in frontal crashes rises rapidly at speeds above 50km/h.

Figure 2.11: Relationship between impact speed and risk of fatal injury (in Elvik, Christensen et al. 2004)



The homogeneity principle in Sustainable Safety (Wegman & Aarts, 2006) calls for minimising differences in speed, mass and direction of traffic participants. Applying this principle and making use of international research on crashes between pedestrians and cars and the Swedish Vision Zero (Tingvall & Haworth, 1999), the

SWOV has developed the concept of safe and credible speed limits (Aarts, Nes et al., 2009). This uses the theory developed in Sustainable Safety for safe speeds given the potential type of conflict (Table 2.4).

Table 2.4: Proposed safe speeds (Wegman & Aarts, 2006)

Road types in combination and permitted road users	Safe speed (km/h)
Roads with possible conflicts between cars and unprotected road users	30
Intersections with possible transverse conflicts between cars	50
Roads with possible frontal conflicts between cars	70
Roads with no possible frontal or transverse conflicts between road users	≥100

2.3.3 Differences in mass

The difference between the masses of two colliding vehicles and the law of conservation of momentum determine which proportion of the released energy is absorbed by the respective parties. Trucks (Heavy Goods Vehicles) may weigh 10 times more than a passenger car whilst the heaviest passenger cars may weigh up to 3 times as much as the lightest passenger cars. The mass difference between pedestrians/vulnerable road users and motorised traffic varies from a factor 10 to as much as 700. Obviously the greater these differences the greater the risk of injury in the event of a crash (SWOV, 2010). A relatively old study of the IIHS (IIHS, 1998) in the United States into the occupant fatality rate (expressed as number of fatalities per million vehicles in that weight class) revealed that occupants of target vehicles are more likely to get killed in collisions with heavier and more rigid vehicles (Pick-ups and SUV's, Table 2.5). The fatality rate of occupants of pickups and SUV's seems to decrease with increased mass whilst the fatality rate of occupants in the target vehicle seems to increase meaning that these heavier and more rigid vehicles are more intrusive. Whilst offering reasonable protection for their occupants in crashes, they can be deadly for persons in the other vehicle.

Table 2.5: Fatality rates in two vehicle crashes (IIHS, 1998 in; Schermers & Derriks, 2005)

Fatality rates among vehicle occupants in 2 vehicle crashes (number/million vehicles/year)						
Weight class (kg) (Car, Pick-up; SUV)	Fatality rate per vehicle type (1990-1995)					
	Car		Pick-up		SUV	
	Car (bullet)	Other vehicle (target)	Pick-up	Other vehicle (target	SUV	Other vehicle (target
<1136	109	35	n.a	n.a	105	58
1136-1363	83	43	89	88	54	75
1364-1590	60	48	56	116	53	75
1591-1817	53	57	52	115	37	92
1818-2045	49	58	44	144	29	91
2045-2272	n.a	n.a	45	169	29	110
>2273	n.a	n.a	38	181	25	112

A more recent study in the Netherlands (Berends, 2009) found that not only are vehicles getting heavier, the spread in the range of vehicle mass is becoming greater. The study revealed an exponential relationship between the relative difference in mass and the fatality rate. For example, the driver of a light passenger car of roughly 800kg who crashes with a passenger car of roughly 1080kg (the average mass of these vehicles in the Netherlands) has double the risk of fatality compared to the driver of passenger car with average mass in the same crash. On the other hand, the risk of the lighter car causing a fatality in the target vehicle is roughly half of that of an average car. If the mass of the bullet vehicle increases to 2100kg, the fatality rate of the driver is a fifth of that of the driver of an average vehicle whereas the fatality rate of the occupant in the target vehicle is five times higher than when struck by a car of average mass.

2.3.4 **Directional differences**

In traffic various conflicting traffic movements are possible and can be the result of the road design and layout but also the result of driver error. Conflicts can result in crashes, the severity of which is determined by a number of factors which have been introduced earlier as was the relationship between conflicts and crashes. Typical conflicts include:

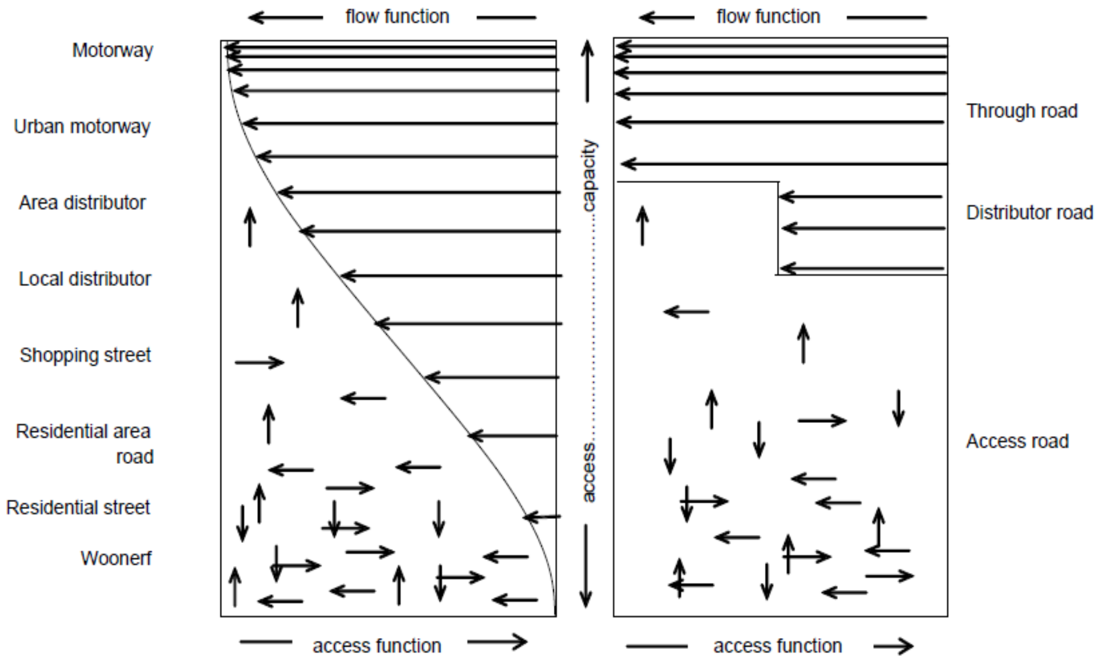
- Conflicts in the direction of travel (e.g. Rear end)
- Conflicts at an angle in the direction of travel (e.g. side swipe when merging/diverging)
- Right angle conflicts (e.g. at intersections or crossings)
- Conflicts in the opposing direction of travel (e.g. head on)
- Object related conflicts (e.g. trees, bridges etc. – single vehicle)

An issue that has a direct bearing on the type of possible conflicts is road network classification and the structure of the road network. This is a subject which is well documented and will not be addressed in too much detail here. However, some important underlying issues will be discussed in order to illustrate the potential of road classification, and linked to that, applying functional and operational requirements in order to reduce the conflict potential.

The importance of road network classification was already demonstrated by Buchanan in the early 1960's (Buchanan, 1963) and later by Goudappel and Perlot (1965). The latter illustrated the relationship between traffic flows on the one hand and traffic access on the other (

Figure 2.12). In this illustration it is evident that the more important the flow function becomes, the fewer disturbances there are. Areas where access plays a predominant role are also prone to many conflicting movements and consequently these areas are serviced by predominantly lower order roads. The Dutch Sustainable Safety approach (Koornstra et al., 1992; Wegman & Aarts, 2006) simplified this relationship and proposed only three primary road classes in a network.

Figure 2.12: Road classification derived from flow versus access



(Goudappel & Perlot, 1965)	Sustainable Safety (Koornstra et al., 1992)

The approach illustrated by Buchanan (Buchanan, 1963) and later Goudappel and Perlot (1965) clearly provides the basis for planners and designers to design road networks that are intended to fulfil these two primary functions and to restrict the highest number of conflicting movements to the lowest order roads, logically at lower speeds.

Since this time, numerous other classification systems have been proposed and discussed and these include the Swedish SCAFT, mesh systems, German guidelines for network structure and American (American Association of State Highway and Transportation Officials, 2001) classification (Dijkstra, 2010). In the Netherlands the introduction of Sustainable Safety resulted in a new classification system that was implemented in the period 1998-2002. This system was based on the concept of mono-functionality, elimination of the most serious conflicts and enhanced recognisability.

Janssen (Janssen, 1997) applied the sustainable safety principles and derived 12 functional requirements essential for road network classification. These requirements have been incorporated in a road classification manual (CROW, 1997) which has since been applied by all road authorities and with the result that virtually the entire Dutch road network has been reclassified (Wegman, Dijkstra et al., 2005; Schermers et al., 2010b). The twelve (safety) requirements are:

1. residential areas must be adjoining and as large as possible;
2. a minimal part of the journey is travelled on relatively unsafe roads;
3. journeys must be as short as possible;
4. shortest and safest route must be the same;
5. searching behaviour must be avoided;
6. road categories must be recognizable;

7. the number of traffic solutions must be limited and uniform;
8. conflicts with oncoming traffic must be prevented;
9. conflicts with intersecting and crossing traffic must be prevented;
10. different road user types must be separated;
11. speed must be reduced at potential conflict locations; and
12. Obstacles alongside the carriageway must be avoided.

Requirements 1 - 4 relate to the road network, 5 - 7 are requirements in relation with routes. Requirements 6 - 12 apply to road sections, 5 - 12 also apply to intersections, and 6 and 7 also apply to transitions between road categories.

A procedure describing the practical process of network classification based on the principles in the guideline has been proposed by Dijkstra (2003) and following applications of the methodology (Arsénio, Cardoso et al., 2008), the method was adapted (Dijkstra, Eenink, & Wegman, 2007)and modified to take into account the other Sustainable safety principles and the new German guideline for network structure and layout of connections (RIN). The result is an adaptation of the safe speed and conflict approach (Table 2.4) in which conflict types are related to speeds and taking into account the sustainable principles of functionality and homogeneity.

Table 2.6 illustrates the principles for urban distributor roads.

Table 2.6: Safe speeds by movement and conflict type on urban distributor roads (Dijkstra et al., 2007)

Traffic movement on distributor road	Conflicts with (on road section, crossing or intersection)	Safe speed (km/h)	Precondition
Motorised longitudinal	Cyclist same direction	30	Mixed/separated by road marking
Motorised longitudinal	Cyclist lateral		
Motorised longitudinal	Pedestrian lateral		
Cyclist longitudinal	Motorised lateral		
Motorised longitudinal	Motorised oncoming		Using the same lane/carriageway (not enough room for centre line marking)
Motorised longitudinal	Motorised lateral	50	
Motorised longitudinal	Cyclist/pedestrian same direction		Physically separated
Motorised longitudinal	Motorised oncoming		Separated by road marking
Motorised longitudinal	Motorised oncoming	70	Physically separated
Motorised longitudinal	Motorised same direction		

From this methodology it is evident that certain conflicts resulting from directional differences are not permitted (e.g. cyclists travelling in the same direction as motorised traffic on 50km/h road have to have an own lane; frontal conflicts/overtaking not possible on 70km/h road due to physical/median separation etc.).

Classifying the road network is in essence an office exercise whereby the type is assigned based on the desired function of the road and taking into account all conflicting interests such as public transport, environment etc. are developed. However, it is at this planning stage when many of the most dangerous conflicts can be prevented, provided the existing roads also comply with the operational requirements. In the Netherlands, roads and intersections are required to have certain features which reduce (and sometimes eliminate) conflicts resulting from directional differences (and aggravated by high speed and/or mass differences). For instance, intersections between the highest order roads (freeways) are always grade separated and non-motorised and slow moving traffic is not allowed on these roads. On rural distributor roads overtaking is generally prohibited/physically made impossible, slow moving (non-motorised) traffic is provided its own separate roadway (often parallel to the distributor road), intersections are generally roundabouts or traffic signals (preventing the most dangerous conflicts in space or time by taking away decisions from the driver), speeds on intersections are reduced (see table 2.4) and relatively large clear zones are provided. Access roads, because of the mixed traffic and many different conflicting movements, have low speed limits and are designed and built in such a manner that speeding is not possible and/or not desired by the motorists.

In essence this approach conforms to a preventative approach and through correct planning, appropriate design and construction methods conflict potential is minimised in order to prevent crashes and should these occur, to minimise their severity.

3 Introduction to evaluation tools for road infrastructure safety management and conditions for application

This chapter introduces relevant road infrastructure safety management tools and their application. It also discusses criteria for assessing the application of evaluation tools for road infrastructure safety management. These tools and their intended functions include:

1. Road safety audits, to help incorporate the best knowledge about how to design a safe road into decisions on the design and construction of new roads, thus making new roads safer than existing roads,
2. Safety inspections, which are ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety,
3. Network screening, to survey road safety on the entire road system and identify those parts of the system that have a higher expected number of crashes, or a higher severity of crashes, than the rest of the system,
4. Accident modelling, to help identify and assess the importance of various factors that contribute to crashes and injuries,
5. Road protection scoring, to help identify roads which offer substandard protection from injury in case of an accident,
6. The identification and analysis of hazardous road locations, i.e. road locations that have an abnormally high number of crashes due to deficiencies of road design and/or traffic control,
7. Road safety impact assessment, which estimates the safety benefits expected from various road safety measures before these measures are introduced,
8. Monitoring of road user behaviour, to help detect unwanted changes in behaviour that may have an important effect on road safety,
9. Traffic conflict studies and naturalistic driving behaviour studies, which is the study of events that nearly lead to crashes or of driver behaviour in a natural setting,
10. In-depth accident studies, in order to learn more about the factors that precipitate crashes, generate injuries, and the opportunities for controlling or removing these factors.

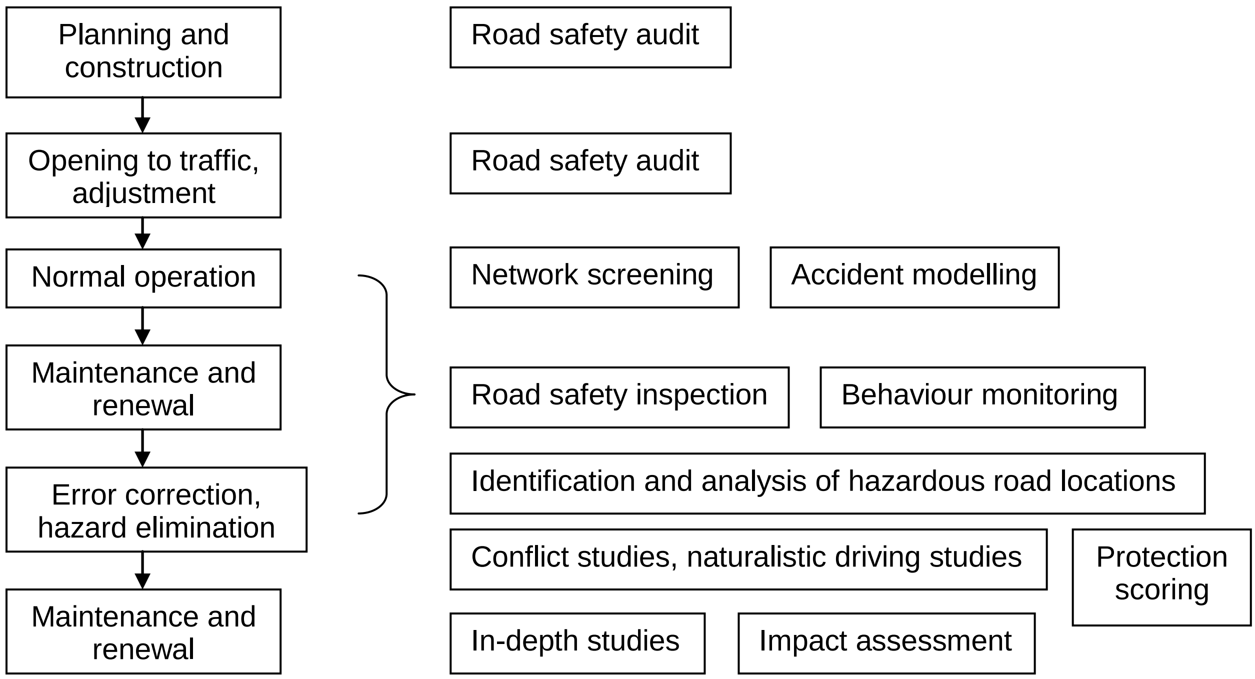
3.1 *When are safety management tools applied?*

The history of a road can be divided into a number of distinct stages:

1. Planning and construction;
2. Opening to traffic and initial adjustment phase;
3. Normal operation;
4. Periodic inspection, maintenance and renewal of equipment;
5. Correction of errors and treatment of hazardous locations;
6. Major upgrading and renewal.

Figure 3.1 presents these stages and indicates at which stage the various tools for evaluating the safety of the road for the purpose of improving it are relevant.

Figure 3.1: Road life cycle stages when safety management tools are applied (Elvik, 2011)



Road safety audits are applied during the planning and construction of a road. Audits can be carried out several times during planning and construction. The final stage of auditing is often a test drive of the road a short time before or after it is opened to traffic, permitting last-minute corrections to be made.

Safety inspections are applied both during the normal operation of a road, i.e. when the road is open to traffic and no major maintenance or upgrading works are in progress and when normal or extraordinary maintenance is planned. Safety inspections may also contribute to error correction and hazard elimination.

Network screening and accident modelling are usually based on the entire road system. No roads are selected for a particular reason, and the objective of both network screening and accident modelling is to describe normal variation in safety on roads that are in normal operation.

The monitoring of road user behaviour also has several purposes. It is both intended to give a representative picture of normal road user behaviour and help identify risky behaviour that may be a target for interventions. It therefore represents both roads in normal operation as well as the identification and correction of errors or departures from normal operation.

The identification and analysis of hazardous road locations, as well as road protection scoring, are intended to identify factors related to road design or traffic control that may lead to crashes or make the crashes more severe. Ideally speaking, there should be no need for these procedures if the road has been properly audited before it was built, and if regular inspections have kept emerging problems under control. However, many roads were built according to other design standards than those that apply today and long before road safety audits or safety inspections were invented. Moreover, changes in traffic patterns that were not foreseen when a road was built can lead to the development of hazardous road locations even if a road complies with design standards. In fact, abiding to road design standards does not ensure a road will be as safe as possible given current constraints. One must therefore expect crashes to occur even on the safest roads and try to detect patterns in crashes as early as possible in order to develop remedial measures.

Conflict studies and naturalistic driving studies also mainly shed light on actual or potential accident problems. These tools are therefore most useful in analysing problems that have not been successfully prevented, in particular problems that are the result of interactions between human factors and infrastructure elements.

In-depth studies of crashes have several applications. Such studies may obviously identify problems of road design or traffic control, but they can also identify problems related to vehicles. The assessment of the impacts of road safety measures is important when choosing the most effective measure to reduce a certain road safety problem. There will usually be more than one measure that can help reduce a given road safety problem. Impact assessments should therefore be based on a broad survey of all potentially effective road safety measures.

3.2 *Data requirements*

As far as data requirements are concerned, a distinction can be made between three levels of data as required by existing evaluation tools (Elvik, 2011):

1. Tools that can be applied by using available data and standard analyses or tabulations of these data (low data requirements),
2. Tools that require a combination of available data and data that are collected specifically for the purpose of using a specific evaluation tool; customised analyses of these data will normally be required (intermediate data requirements),
3. Tools that require the exclusive use of data collected specifically for the use of an evaluation tool and that require analyses tailored to the tool (high data requirements).

Road safety audits have low data requirements, as they rely on predominantly documents, checklists and the extensive experience and knowledge of the auditor. However, one could argue that no audit is complete unless it includes accident studies after a road scheme has been opened. Such follow-up studies are, however, not routinely made.

Safety inspections may require more data, in particular if accident data and field visits are to be included. Network screening is intermediate with respect to data requirements; in general no new data are collected specifically for the purpose of performing a network screening, but several existing sources of data may be combined.

Accident modelling is intermediate or high in data requirements; sometimes new data are collected, but it is more often the case that data from several sources that form a road data bank are combined. Road data banks will usually contain a number of specialised registries, such as the accident record, a traffic volume record, a speed limit record, a road surface record, a record of geometric data, etc. These registries need to be combined when developing accident models. In some cases, new data will be collected by driving along the roads whose safety is to be modelled (Cafiso, A. et al., 2010).

Road protection scoring is intermediate or high in data requirements; it relies on taking careful notes/recording numerous features while driving along roads with an instrumented vehicle. The identification of hazardous road locations as currently practised is low in data requirements, but would require more data if state of the art techniques are adopted. Impact assessment, monitoring of road user behaviour, conflict studies and naturalistic driving studies, and in-depth accident analyses are all high in data requirements. These are tools that rely on extensive data collected specifically to enable the use of the tools.

Besides this general introduction the reader is referred to the extensive RISMET guidelines describing the data requirements for road safety evaluations (Candappa et al., 2011)

3.3 *Availability and use of standard procedures*

Some evaluation tools rely on standardised procedures, some do not. In general, it is more efficient to use a tool when a standardised procedure for using it has been developed.

Most of the evaluation tools employ standardised procedures. In the case of road protection scoring according to EuroRAP, the assessment protocol is not public, but it is standardised and applied uniformly in order to be able to compare roads in terms of their protection score. This is not the case for accident modelling. Accident modelling can be done in many ways, and although researchers working close to the research frontier may discourage some approaches and recommend other approaches, highway agencies cannot always afford the luxury of doing state-of-the-art accident modelling, but may have to settle for cruder approaches. Likewise, impact assessment of road safety programmes can be done in a very detailed and systematic way or in a more informal and judgmental way.

Monitoring of road user behaviour is usually based on protocols specifying how to measure speed, how to observe seat belt wearing, etc. The times and locations of monitoring may be selected to ensure that data are statistically representative of traffic in general, but this is not always the case.

Standard procedures will normally exist for conflict studies and naturalistic driving studies. In-depth studies also tend to be based on detailed protocols specifying how to perform such studies. However, the protocols used may not be the same in all countries. It is therefore not necessarily meaningful to compare, for example, the results of in-depth accident studies made in Sweden to those made in Norway. It has been found that the findings of in-depth accident studies are strongly influenced by the perspective adopted, as reflected in the guidelines serving as the basis of in-depth studies (Lundberg, Rollenhagen, & Hollnagel, 2009).

3.4 *Reporting requirements*

All evaluation tools are based on the assumption that the results of their use are documented. Documenting the use of the tools is essential to enable learning. If, for example, a road safety auditor simply told a planner orally that he had to change a certain design, this knowledge might remain private and the same inappropriate design be proposed again.

Reporting may be more or less systematic. Results of road safety audits and safety inspections are often entered into large databases to permit effective learning. These databases expand as new audits or inspections are reported. This practice is likely to be less common for network screening and identification of hazardous road locations. Ideally speaking, impact assessments should also be entered into a database to enable subsequent evaluation of their accuracy. However, it is still not common practice that the effects of road safety measures are routinely monitored and compared to ex-ante impact assessments.

Annex IV of the EU Directive on road safety management specifies what an accident report should contain. The specification is quite detailed, and it seems clear that current accident reporting does not always fulfil the requirements of the Directive. Article 10 of the Directive calls for an exchange of best practice with respect to the use of the management tools and the experiences gained by using the tools. Such an exchange implies that member countries systematically draft reports regarding their use of the tools comprised by the Directive.

3.5 *Need for training and specialised skills*

All evaluation tools require specialised knowledge and skills. However, there is some variation with respect to the level of training and skill needed to apply these tools. Arguably the most highly specialised is the development of APMs for accident modelling. It is a rapidly evolving field, in which not even leading researchers are able to keep pace with the research frontier. The identification of hazardous road locations, on the other hand, is done by computers applying quite simple criteria.

A rough distinction can be made between tools that require extensive training and highly specialised skills, tools that are at an intermediate level with respect to the expertise needed to use them, and relatively simple tools. Tools that require a high level of expertise include road safety audits, safety inspections, management of hazardous locations, network screening, accident modelling and in-depth analyses of crashes (Vaneerdewegh & Matena, 2007). Expertise at an intermediate level is required for road protection scoring, impact assessment, monitoring road user behaviour and conflict studies.

Article 9 of the EU Directive concerns the appointment and training of safety auditors and instructs member states to develop training curricula for auditors. Training is to be completed by a certification of competence. Periodic retraining is recommended. It is recommended that safety auditors have relevant experience and training in road design, road safety engineering and accident analysis.

3.6 *Objectivity and transparency*

The objectivity of an evaluation tool refers to its between- and within-subject reliability (classically "between subjects" refers to differences between groups and "within subjects" to differences within a group). The "subject" is the analyst, or team of analysts, using a certain evaluation tool. A tool is objective when different analysts or teams of analysts, or the same analyst on different occasions, obtain the same findings when relying on the same data. If findings differ, then something other than the data or the procedure embodied in the tool must have influenced the findings. The tool is then not completely objective.

An evaluation tool is transparent if all steps in its use are explicit. If the progression from one step to the next is made without justification, or is implicit, it is difficult for others to replicate it. This has been a problem in accident modelling. Analysts rarely justify why they included certain explanatory variables. The result is that different accident models include different variables, making their results impossible to compare. The models lack transparency, because no reasons are given for many of the analytical choices that have to be made in developing a model. Indeed, one may suspect that the widespread availability of powerful statistical software has tempted many researchers to simply run a standard model, without reflecting on whether such a model is the best for the data at hand.

Lack of objectivity and transparency is likely to be a problem in accident modelling, analysis of crashes at hazardous road locations, impact assessment and in-depth studies of crashes. It is less likely to be a problem in road safety audits and inspections and road protection scoring, although as already noted the EuroRAP protocol used in road protection scoring is not public and the scores are therefore not easy to replicate.

3.7 *Ease of updating tool and results based on it*

Safety management of roads is a continuous activity. The evaluation tools that support road infrastructure safety management therefore have to be used repeatedly in order to keep track of emerging road safety problems to enable these to be treated effectively. There is, accordingly, a need for updating the tools and the results based on them.

Evaluation tools that rely on data kept in road data banks are likely to be more difficult to update than tools that do not rely on such data. Consider, as an example, network screening. In its most advanced form, network screening relies on the output of accident prediction models. These models, in turn, rely on data in road data banks. These data are not always updated regularly. In Norway, a detailed inventory of access points (driveways) along national roads was made in 1977. It has since not been updated systematically, and now the registry must be regarded as out-dated and too unreliable to be used as a source of data in accident modelling. This is clearly a problem, as several analyses based on the registry, made shortly after it was created found that access point density (number of access roads per kilometre of road) had a major effect on road safety. Thus, not including this variable in an accident prediction model could create a substantial omitted variable bias.

Accident prediction models tend not to be updated systematically. Out-dated models are a problem (Hirst, Mountain, & Maher, 2004).

3.8 *Benefit-cost ratio of evaluation tools*

Use of safety evaluation tools may be influenced not just by their complexity and data requirements, but also by costs and benefits associated with use of the tools. There are few cost-benefit analyses of the safety management evaluation tools included in this report, but Elvik, Høye, Vaa and Sørensen (2009) quote some analyses of road safety audit and road safety inspections. The following is a summary of these analyses.

Cost-benefit analyses of road safety audits have been reported in Denmark, Germany, Norway and Australia. The benefit-cost ratios vary from about 1.34 in Norway to up to 242 in Australia. In Australia the benefit-cost ratio was found be greater than 10 for approximately 75% of all implemented recommendations (Macaulay & Mcinerney, 2002).

In Australia the benefit-cost ratio for road safety inspections has also been estimated. It is between 2.4 and 84. About 47% of all the recommendations had a benefit-cost ratio over five (Macaulay & Mcinerney, 2002).

4 An overview of evaluation tools

The evaluation tools that are described in this chapter are elements of road infrastructure safety management. Their chief purpose is to help highway agencies monitor the safety of roads, identify safety problems and identify promising ways of improving safety. The following evaluation tools will be briefly presented:

1. Road safety audits
2. Safety inspections (as per the EU Directive)
3. Network screening (referred to as network safety management in EU Directive)
4. Accident modelling
5. Road protection scoring
6. Identification and analysis of hazardous road locations
7. Impact assessment of investments and road safety measures (referred to as road safety impact assessment in EU Directive)
8. Monitoring of road user behaviour
9. Conflict studies
10. In-depth analyses of crashes
11. Other tools for road infrastructure safety management

Each of these tools will be briefly described and references given to more extensive descriptions. Key elements of **state-of-the-art** versions of each tool are described. The concept of state-of-the-art implies the highest level of development (based on a combination of the level of development and application) of a given tool at the time of publication and as recognised by international literature. Certain countries may have country specific tools which for that country are state-of-the-art, but these tools are in the context of this guideline, not regarded as state-of-the-art.

4.1 *The European Union Directive on road safety management*

Some of the road safety management tools listed above became mandatory for EU member countries from December 19, 2010. In particular Directive 2008/96/EC of the European Union requires member states of the Union to perform road safety audits, safety inspections, network screening (termed network safety management in the Directive) and road safety impact assessment as a basis for implementing investments on the Trans European Road Network (TERN roads). These are tools 1 to 3 and 7 on the list above.

The Directive defines the tools in the following terms. A road safety audit is defined as an independent detailed systematic and technical safety check relating to design characteristics of a road infrastructure project and covering all stages from planning to early operation. A road infrastructure project is in turn defined as a project for the construction of new road infrastructure or a substantial modification to the existing network which affects the traffic flow.

Safety inspection is defined as an ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety. Management of road network safety is not defined in the Directive, but two activities that constitute network safety management are mentioned. These are network safety ranking and ranking of high accident concentration sections. Network safety ranking is defined as a method for identifying, analysing and classifying parts of the existing road network according to their potential for safety development and accident cost savings. The ranking of high accident concentration sections is defined as a method to identify, analyse and rank sections of the road network that have been in operation for more than three years and upon which a large number of fatal crashes in proportion to the traffic flow have occurred. Finally, a road safety impact assessment is defined as a strategic comparative analysis of the impact of a new road or a substantial modification to the existing road network on the safety performance of the road network.

The Annex to the Directive (European Commission, 2008) provides further details regarding the specific requirement for each tool and how to implement the use of the tool.

4.2 *Road safety audits*

A road safety audit is a systematic assessment in four (sometimes five) stages in the road design process (from planning to realisation) and intended to ensure that new roads have the lowest attainable accident potential for all kinds of road users. The audit process aims to avoid future crashes by removing unsafe features before they are actually constructed. Thus it is a proactive measure. State-of-the-art road safety audits are:

1. Performed by a team of approved (in some countries licensed) auditors who have been formally trained and authorised for the role,
2. Performed in a standardised way according to checklists that are applied consistently and which permit the compilation and comparison of the results of several audits,
3. Organised to ensure that the auditors are independent and have not been involved in the design or planning of the road they are asked to audit,
4. Documented in the form of a report written by auditors, containing specific recommendations indicating changes necessary to ensure a road design will be safe when implemented,
5. Requiring the agency commissioning the audit to give a point-by-point response to auditor recommendations and justify in writing any decision not to comply with the advice of the auditors.

The first road safety audits were performed around 1990 in Great Britain, Australia and Denmark. Road safety audits have now become a standard procedure in road planning in many countries. Detailed guidelines have been developed for road safety audits in many countries. Guidelines for Norway can be found in a handbook issued by the Public Roads Administration (Statens Vegvesen, 2006). Similar guidelines have been issued in many countries.

In principle, the effects of road safety audits on safety can be evaluated by assessing accident occurrence during the first years of operation on roads that have undergone the process prior to their opening compared with similar roads that did not undergo road safety audits. The European Transport Safety Council (1997) refers to a study that evaluated the safety effects of road safety audits by applying such a study design. The study was performed in 1994 by the Surrey County Council in Great Britain and indicated that audited road safety schemes saved about 1 accident per scheme compared to schemes which were not audited. This saving was considerably greater than the cost of the road safety audit and the modifications of the road schemes resulting from the audit. Unfortunately, similarly designed studies have not been replicated. In general, however, the costs of an audit and the resulting modifications to a road scheme tend to be quite small. Thus even accident reductions that are too small to be statistically detectable may provide societal benefits that are greater than the added costs.

4.3 *Safety inspections*

A safety inspection is a systematic periodic assessment of the safety of an existing road. The aim is to identify problem features which are not yet apparent from the accident history, or new problems introduced by engineering changes to the road or by modifications in the way it is used. Safety inspections are have similarities with road safety audits in the sense that no accident data are required to identify the safety problems but procedures are different, as they are applied to operating roads.

Safety inspections can be organised as thematic inspections, for example, an inspection of road restraint systems only. Thematic inspections will often cover a larger proportion of the road system than general inspections will.

The selection of roads for inspection can either be based on the results of network screening or a programme of periodic inspection, in which each section is inspected at fixed intervals. An overview of best practice is given by Cardoso et al. (2008).

4.4 *Network screening (network safety ranking)*

Network screening is a process where the variation in the number of crashes between sections of a road network is analysed statistically. The objective of network screening is to identify road sections that have safety problems – either in the form of an abnormally high number of crashes, a high share of severe crashes or a high share of a particular type of accident. Screening may comprise the entire road system within a jurisdiction or be limited to a particular type of road or traffic environment.

There are several versions of network screening, ranging from simple rankings of road sections according to the recorded number of crashes to statistically advanced techniques based on accident prediction models. The method of network screening implemented in Safety Analyst, which is recommended in the recently published Highway Safety Manual, represents the state-of-the-art (Harwood, Bauer, & Torbic, 2002; Harwood, Potts et al., 2002; Harwood & Rabbani, 2002; Harwood, Torbic et al., 2002).

Scoring roads by risk according to the protocol developed by the European Road Assessment Programme (EuroRAP) can be viewed as a form of network screening (EuroRAP, 2005).

4.5 *Accident modelling*

Accident models are developed by statistically assessing how variation in the number of crashes is explained by a range of measured variables and factors, generally using advanced regression techniques. The purpose of accident modelling is to identify factors which significantly influence the number of crashes and estimate the magnitude of their effects. Accident modelling has been a very active field of research in recent years and important progress in the statistical methodologies has been made. A state-of-the-art approach to accident modelling is characterised by the following elements (Lord & Mannering, 2010; Elvik, 2011):

1. The development of a model is based on a data set that predominantly contains systematic variation in the number of crashes. Models should not be based on small samples with a low mean number of crashes (Lord, 2006; Lord & Miranda-Moreno, 2008).
2. Data are recorded at the lowest available level of aggregation and homogeneous road sections formed on the basis of key explanatory variables to ensure maximum between-section variation and minimum within-section variation (Cafiso et al., 2010).
3. If variables representing safety treatments are included, analysis should be designed to control for a potential endogeneity bias attributable to such variables. Endogeneity refers to a statistical tendency according to which abnormal values on the dependent variable, i.e. crashes, influences the use of safety measures. The problem is analogous to regression-to-the-mean bias in before-and-after studies, but the direction of bias can often go in the other direction, suggesting that a road safety measure is ineffective or has adverse impacts when it is in fact effective. For an instructive example, see Kim and Washington (Kim & Washington, 2006)
4. The functional form used to describe the relationship between an explanatory variable and the dependent variable is explicitly chosen based on an exploratory analysis. Guidelines for choosing functional form are given by Hauer and Bamfo (Hauer & Bamfo, 1997).
5. Potential bias due to co-linearity among explanatory variables is addressed.
6. Potential bias due to omitted variables is addressed.
7. Potential bias due to outlying data points is addressed.
8. The structure of systematic variation in the number of crashes and in residual terms is specified as accurately as possible. Residual terms are described statistically in a way that permits using model output in the empirical Bayes approach to road safety estimation.
9. Crashes at different levels of severity are modelled separately. If possible, different types of crashes should also be modelled separately.
10. The choice of model form is made explicitly. A dual-state model should only be chosen if prior knowledge suggests that it is superior to a single-state model, given the purpose of developing the accident prediction model.
11. The dependent variable should preferably be the number of crashes at a given level of severity.

Accident modelling forms the basis of network screening in some countries. In other countries, network screening is not model-based.

4.6 *Road protection scoring*

Road protection scoring is an assessment of how forgiving a road is. Several road protection scoring systems have been developed. In Europe, the best-known system is the EuroRAP –The European Road Assessment Programme, which was inspired by the success of the European New Car assessment Programme (EuroNCAP). Similar scoring systems have been developed in Australia (AusRAP), New Zealand (KiwiRAP) and the United States (usRAP) and International Road Assessment Programme (iRAP). These are based on the EuroRAp procedure but adapted to account for local conditions in each country.

Road features that are relevant to safety are recorded along a road, and a score is assigned that reflects how well the road environment protect the user from death or disabling injury when a crash occurs. Roads scored according to EuroRAP are assigned a star rating, analogous to the star rating assigned to cars in EuroNCAP. Star Rating results are presented cartographically and are published by motoring organisations, thus informing road users about the safety levels of the road environment of different road sections.

As an example, a road is scored as safe with respect to running-off-the-road crashes if it (Stigson, 2009):

1. Has a speed limit not higher than 50 km/h, or
2. Has a safety zone of at least 4 meters and a speed limit not higher than 70 km/h, or
3. Has a safety zone of at least 10 meters and a speed limit higher than 70 km/h.

A safety zone is a level area beside the running lane which does not contain fixed obstacles that may cause injury in case of an accident. Examples of fixed obstacles include rocks, trees, bridge supports or lakes. Similar criteria for assessing the protection score have been developed for head-on crashes and crashes at junctions. Road protection scoring according to EuroRAP considers the safety of car occupants only. It also assumes that cars have a rating of at least four stars according to EuroNCAP, their drivers obey speed limits and that occupants wear seat belts.

4.7 *Identification and analysis of hazardous road locations (ranking of high accident concentration sections)*

All countries have a system for identifying hazardous road locations (sometimes referred to as black spots, hot spots or sites with promise) and analysing crashes that occur at such locations. However, few, if any, of these systems are close to the state-of-the-art. Key elements of the state-of-the-art are (Elvik, 2008c):

1. Hazardous road locations should be identified from a population of sites whose members can be enumerated. This permits the formulation of precise statistical criteria for the identification of hazardous locations.
2. Hazardous road locations should not be identified by applying a sliding window approach. A sliding window will inflate the number of false positives, i.e. sites that are erroneously identified as hazardous.
3. Hazardous road locations should be identified in terms of the expected number of crashes, not the recorded number of crashes. This is best done by identifying hazardous road locations according to the Empirical Bayes (EB) estimate of safety at each site (Elvik, 2008a).
4. Hazardous road locations should belong to the upper percentiles of a distribution of sites with respect to the expected number of crashes.
5. A suitable period of data for identifying a hazardous road location is 3-5 years. This is a compromise between the need for detecting hazardous road locations quickly and the need for accumulating a sufficient number of crashes to permit analysis.
6. Accident severity can be considered when identifying hazardous road locations, provided the expected number of crashes can be reliably estimated at each level of severity.
7. Specific types of accident can be considered when identifying hazardous road locations, provided reliable estimates of the expected number of crashes by type are available.

As far as analysis of crashes at hazardous road locations is concerned, there are indications that the techniques currently regarded as state-of-the-art fail to discriminate effectively between false positives and correct positives. Ideas for a more rigorous approach have been put forward, but this approach is, as far as is known, not used anywhere (Elvik, 2006a)

4.8 *Impact assessment of investments and road safety measures*

Impact assessment denotes the estimation of the expected effect on crashes and/or injuries of investments or road safety measures, performed as part of the planning process. In many countries, computer software has been developed for performing impact assessment and cost-benefit analyses for road investments. This software is in most cases applied only when major capital investments, like building new roads or major upgrading of an existing road, are planned. Many infrastructure related road safety measures are small scale and low-cost interventions. These are not always subjected to impact assessment although post assessments are undertaken in many cases.

Tools that can make impact assessment of minor projects easier should be developed. The Handbook of Road Safety Measures provides information regarding the effects of many minor road improvements. The Highway Safety Manual (2010) also provides guidance about how to plan and assess the impacts of minor road safety measures. The TARVA tool for road safety impact assessment applied in Finland is virtually identical to the method recommended in the Highway Safety Manual, and should therefore be regarded as a state-of-the-art approach (Peltola & Kulmala, 2006; Peltola, 2007; Peltola, 2009). For an example of a road safety impact assessment at the national level the reader is referred to a study by Elvik (2007a) .

4.9 *Monitoring road user behaviour*

One of the most important factors influencing road safety is road user behaviour. Highway agencies are therefore taking an increasing interest in monitoring road user behaviour in order to assess how it changes over time. Several national road safety programmes contain a number of safety performance indicators that are based on road user behaviour. The most frequently monitored forms of behaviour include:

1. Speed
2. Seat belt wearing
3. Cycle helmet wearing
4. Driving when fatigued (in general based on self-reports)

A potentially very important form of behaviour is drinking and driving or driving under the influence of drugs. These forms of behaviour are rarely monitored systematically, and data available on their prevalence are unreliable and incomplete. Other potentially important types of behaviour that are rarely monitored systematically and reliably include use of mobile phones and driving when fatigued (self-reports should not be treated as reliable). Great Britain has run a sophisticated programme for monitoring the use of mobile phones for many years (Department for Transport, 2010).

Ideally speaking, the choice of which types of behaviour to monitor ought to be based on the risk attributable to the specific form of behaviour. It is, for example, important to monitor speed and speeding, because this behaviour is known to be of major importance for road safety. It may be somewhat less important to monitor cycle helmet wearing, because it makes a smaller contribution to the total number of crashes or injuries than speeding.

It is, however, not possible to base the monitoring of road user behaviour strictly on the risk attributable to it, because this risk is sometimes unknown. As an example, there are few – if any – good estimates of the risk attributable to fatigue. As far as mobile phones are concerned, a few estimates of risk can be found, but these are inconsistent, both with respect to the methods used to estimate risk and the size of the estimated contribution. For some types of behaviour, like internal distractions (i.e. drivers do not concentrate fully on driving, but think about other things), unobtrusive monitoring is difficult although some attempts are being introduced in the form of programs such as Prologue (Christoph, Nes et al., 2010) for monitoring driver behaviour.

4.10 *Conflict studies and naturalistic driving studies*

A traffic conflict is any event that would have resulted in an accident if road users had continued travelling without taking an evasive manoeuvre involving a sudden change in direction or speed. Conflicts can be rated according to the imminence of accident at the moment of the evasive manoeuvre start. A serious conflict is one that nearly results in an accident, in which the road user makes evasive manoeuvres at the last moment.

Recent progress in software for analysing video images has transformed the study of traffic conflicts. It used to be a somewhat subjective technique, which relied on manual coding by human observers. Although these observers were able to make reliable observations when properly trained, a subjective element remained. Modern techniques for processing video images allow for the objective estimation of time to collision by estimating the speed and trajectories of the road users involved (Horst, 1990; Laureshyn, Svensson, & Hydén, 2010). It is then possible to classify conflicts more accurately and consistently than before and thereby study their relationships to accident occurrence more rigorously.

Another technique that permits an objective assessment of the severity of traffic conflicts and their relationship to crashes is naturalistic driving studies. The results of the 100-car naturalistic driving study in the United States have been analysed in order to determine the relationship between serious traffic conflicts and crashes (Klauer, Dingus et al., 2006; Guo, Klauer et al., 2010). The on-going 1000-car naturalistic driving study will permit more analyses.

4.11 *In depth analysis of crashes*

Official road accident statistics are, in most countries, not sufficiently detailed to enable an in-depth analysis of crashes. In-depth studies try to reconstruct in detail the events that lead to an accident and identify the factors that produced injuries. In-depth studies often focus on human factors, as these are normally only recorded in fairly crude terms in official accident statistics.

Important elements of in-depth studies, that are not always part of official accident statistics include the reconstruction of pre-crash dynamics and manoeuvres, the estimation of impact speeds, the identification of technical defects in vehicles and injury producing mechanisms, and a comprehensive assessment of the role of human factors, such as blood alcohol content, traces of illicit drugs, seat belt wearing (which is often incompletely or inaccurately reported in official statistics), the sudden onset of illness immediately before the accident, indications that the driver had fallen asleep before the accident or indications of driver distraction.

The purpose of doing in-depth analyses of crashes is both to understand factors leading to crashes and to identify how best to prevent crashes. In-depth studies of fatal crashes have a long history in Finland and the United Kingdom, but have more recently been introduced in Sweden and Norway. In-depth studies in Finland have in recent years focused on factors that influence injury severity (Toivonen, 2006). Germany and the Netherlands also perform in-depth studies of crashes. Research reports based on in-depth studies include Sagberg and Assum (2000), Stigson (2009) and Assum and Sørensen (2010).

4.12 *Other safety management tools*

The ten tools listed above are all used in more than one country in Europe (Elvik, 2011). Four of them are included in the EU-directive on the safety management of TERN-roads. Assessing the applicability, use and potential effects on road safety of the use of these tools therefore has interest in several countries. However, in addition to these ten analytic tools, other safety management tools that are still not widely used have been developed. One of these tools deserves a brief description, since it deals with a very important aspect of road safety.

A tool for setting safe and credible speed limits has been developed in the Netherlands (Aarts et al., 2009). This is important, since the speed of traffic is one of the most important factors influencing road safety. The Dutch algorithm is based on actual driving speed, but also considers road design and police enforcement. The objective is to set speed limits that are both safe and credible, i.e. accepted by road users as reasonable and therefore eliciting a high level of compliance. The algorithm is fairly complex, and will therefore not be described in detail in this report since it is extensively dealt with in the Eranet Eraser project.

In Australia the ARRB has developed an expert system for the setting of speed limits(Jarvis & Hoban, 1988). The V-Limits programme has been extensively applied in the State of Victoria and is based on the Australian Traffic Engineering Manual. The expert system aims at setting on speed limits that are both consistent and credible. The system takes into account a number of criteria including the road and surrounding environment (incl. road function; number of lanes; access density etc.), development and land use in the vicinity of the road (abutting development; type of development and use etc.), the type and level of road users (schools; vulnerable road users; heavy goods vehicles etc.), crashes, operating speeds, traffic volumes and speed limits on adjacent road sections. The V-Limits expert system is explicitly designed for the setting of speed limits of typical road sections. It is not intended as a tool to address road design deficiencies and aims to provide uniform speed limits with as few speed limit changes as possible. Where design inconsistencies or other local problems necessitate lower speed limits, suitable remedial treatments are introduced.

5 Road safety audits

The new EU Directive on road safety management is applicable to all TEN roads in the EU and member countries are expected to have adopted its requirements by 19 December 2012. Included in these requirements is the application of road safety audit to all new road construction projects.

5.1 *Background, definition and scope*

Road safety audits (RSA) originated from road accident investigations where the road infrastructure and its environment were found to have played a significant part in the occurrence of certain crashes and accident types. This led to countries such as the United Kingdom, New Zealand, Australia, Denmark and the United States of America developing procedures to pro-actively address such problems culminating in what today has been developed and adopted in most countries as the Road Safety Audit. The history and development of road safety audits is well documented and the reader is referred to amongst others Matena et. al. (2008), Proctor and Belcher (1992), Austroads, and Transfund New Zealand (2004).

Road Safety Audits are formally defined as (Jordan, 1994; AUSTROADS, 2009):

"a formal examination of an existing or future road or traffic project, or any project that interacts with road users, in which an independent, qualified examiner reports on the project's accident potential and safety performance."

In Directive 2008/96/EC of the European Union the RSA is defined as:

"an independent detailed systematic and technical safety check relating to the design characteristics of a road infrastructure project and covering all stages from planning to early operation".

The most important characteristics of road safety audits are that they:

- Are carried out by persons not in any way affiliated with the road authority (or client), the designer or the contractor (key word is INDEPENDENT);
- Are carried out by persons with the appropriate knowledge, experience and training (key words are QUALIFIED EXAMINER; TECHNICAL);
- Are formally documented;
- Address only road safety concerns of design projects

Road safety audits are not intended as:

- A design check or peer review;
- A check of compliance to standards;
- Re-design or recommendations on how to re-design;
- Informal check or judgement of a project.

It is of vital importance that RSA is not perceived as a pure check of design standards and guidelines. These are the basis of any good design and are already checked as part of the design process. However, the application of design standards and guidelines is no guarantee for the SAFEST possible design to all road users. A RSA aims at checking whether all different design components will function safely, both as independent parts and as a whole.

The systematic application of RSA has many benefits including reducing the risk for crashes and injuries caused by road (infrastructure) design related mistakes/failures, being a methodical check throughout a project that the risk of design faults slipping through and actually being constructed are minimised. Life-cycle costs are reduced, as it is cheaper to change a design still on paper than amending a constructed situation, once remedial treatments are found necessary. An added benefit is that as more audits are applied, (geometric) designers gather added experience on the procedure and on what constitutes safe design practices.

5.2 *Stages of road safety audit*

Road safety audits are generally carried out during the following stages of a road scheme:

1. <u>Feasibility Stage</u>

   At this stage, the safety implications of route alternatives, design standards and layout options, the relationship of the proposed road and existing roads, numbers and types of intersections etc are examined. They allow an early assessment of the safety performance of the scheme and help in identifying specific road user safety needs.

2. <u>Draft or preliminary design stage</u>

   Based on feasibility or draft designs, the horizontal and vertical alignments, intersection and interchange layouts and associated design standards are assessed.

3. <u>Detail design stage</u>

   Road and intersection layouts, signing and marking, clear road side areas, lighting and other detail design aspects are assessed in terms of the future operation of the scheme.

4. <u>Pre-opening stage</u>

   Once the scheme is completed a site inspection is conducted before the scheme is opened to traffic. The pre-opening audit is conducted during the day and at night and assesses whether the construction has addressed previous concerns and does not contain hazardous conditions or elements.

5. <u>After opening stage</u>

   Once a new or improved road has been opened to traffic for a number of months, it is advisable to assess whether or not it is being used as originally intended. Any design defects can be detected and where necessary adjusted or changed.

5.3 *Involved parties, audit team and skills*

Generally there are a number of parties involved in the road safety audit. These are the client (in essence the organisation responsible for the funding of the project, which normally is a road authority but may also be a developer/consortium etc.); the designer/design team (the design contractor); and the road safety audit team.

The road safety audit team will vary in size and this is dependent on the complexity of the project that is being audited. In all cases it is preferable to have an audit team consisting of at least two people. This has the distinct benefit that different experiences and expertise are deployed and that various issues are debated and discussed before decision/conclusions are drawn. The client appoints the audit team and they should not let the composition of the team be driven by only cost considerations. The team should be drawn up such that the team skills best suit the specific project needs and the design stage. Although it would seem preferable to have the same audit team for all the audit stages, this is not always necessary or possible. The core team should preferably be the same (they will be familiar with the project and therefore can work faster than a new team which must familiarise themselves) and relevant expertise be drawn in depending on the specific expertise required for that stage (for e.g. The preliminary design stage needs a specialist with a broad view whereas the detailed design stage may require somebody with very specific tunnel safety and design experience).

Article 9 of the EU Directive (2008) stipulates that all future road safety auditors will be certified and that all member countries develop suitable training curricula. In accordance with these requirements member countries have developed country specific training curricula and certification procedures (Dienst Verkeer en Scheepvaart, 2011) This article also stipulates that the auditor/s are independent of the client and/or contract/project. The EU has set up the PILOT4SAFETY project specifically for this purpose. The aim of the project is to apply the Directive's approaches related to training and certification of Road Safety Experts for the application of Road Safety Audit and Road Safety Inspection procedures to selected secondary roads.

In accordance with the EU Directive auditors must be suitably qualified and experienced. Although the exact qualifications are not stipulated, countries such as the Netherlands and Germany have stated that auditors must at least have a diploma or degree in civil engineering with majors in traffic and safety engineering and geometric design (FGSV, 2009; Dienst Verkeer en Scheepvaart, 2011). In for example the Netherlands, the auditor must also have at least a number of years (5) of relevant and on-going work experience specifically in traffic engineering, management, road design and safety engineering (incl. crash analysis). In addition he must have proven management and reporting skills and have conducted, and preferably led, a number of RSAs. In the Netherlands a road safety quality institute is being set up and they will be responsible for accreditation of training institutes and auditors. Auditors will be required to be registered with the institute and will have to undergo periodic refresher courses (Dienst Verkeer en Scheepvaart, 2011).

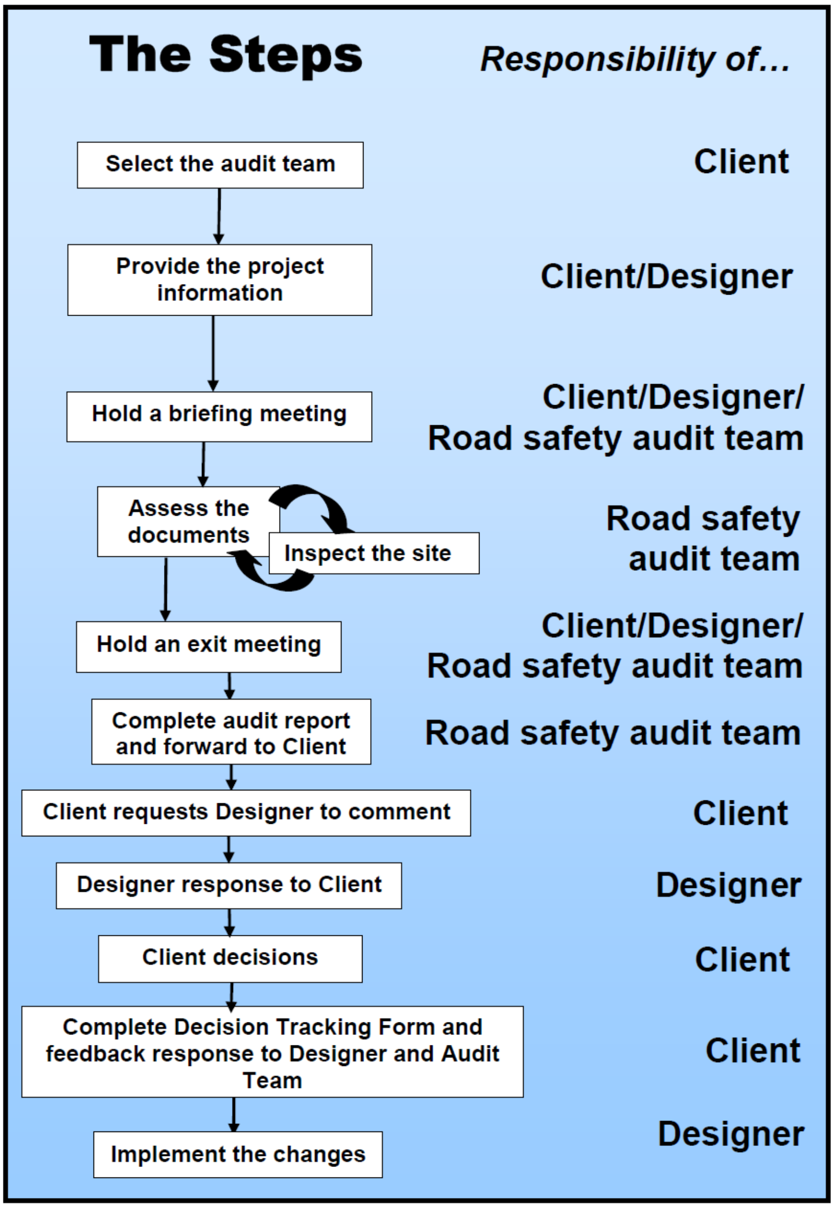
5.4 *The audit process - carrying out a road safety audit*

Many countries conduct and have conducted road safety audits in the past. Most of these also have well documented audit procedures (Sabey, 1996; Transfund New

Zealand, 2004; Belcher, Proctor, & Cook, 2008; Matena, Weber et al., 2008; AUSTROADS, 2009; Dienst Verkeer en Scheepvaart, 2011) and checklists. Since RSA is a well applied road safety tool and the procedures and processes are generally similar (although there may be differences regarding the stages of audit, the certification requirements, etc.), this guideline will not attempt to re-invent the wheel but will make use of the work produced in Ripcord-Iserest (Matena et al., 2008) supplemented by later developments introduced by the EU Directive on Road Safety Management (European Commission, 2008). As far as work processes are concerned, this work still remains extremely relevant to the European situation.

Figure 5.1 shows the typical steps that must be taken when conducting a Road Safety Audit.

Figure 5.1: Typical steps in Road Safety Audit (Transfund New Zealand, 2004)



5.4.1 **Initiating the audit**

The first step in the process is that the client initiates the audit and appoints the audit team and team leader. Since the EU Directive has stipulated that RSA will apply to all TEN roads (roads with an E number), this practically means that all new E-roads and all upgrades or major changes (including adding lanes, adding intersections/interchanges, changed use of shoulders etc.) to existing E-roads, are subject to a RSA. The client will therefore need to initiate audits for all these projects and will need to draw upon the most relevant skills required by each project. It is assumed that all member countries have completed their training and certification requirements and that there is a register of qualified road safety auditors from which a client can draw resources. As mentioned earlier, it is strongly recommended that audits be conducted by teams of at least two auditors. Important is that these auditors are independent of the design team and have the necessary road safety engineering experience and knowledge of RSA. Remember that RSA is NOT merely a road design check!

5.4.2 **Handing over project documents and briefing**

The basis of any audit is the project documentation supplemented by site visits and supported by related data (such as accident data of similar schemes). Once an audit has been initiated and the audit team identified and the roles defined, all project documents are collected by the client and handed over to the audit team. As a guide, the type of documentation relevant to the different audit stages is shown in Table 5.1. The reader is also referred to the data requirement guidelines drawn up for RISMET (Candappa et al., 2011).

Table 5.1: Documents for road safety audits

Relevant documents	Audit stage				
	1	2	3	4	5
Briefing report; inception report, feasibility study	X	X	X	X	X
Audit of previous stages		X	X	X	X
Design drawings (vertical/horizontal alignments; cross-section; structures)	X	X	X	X	X
Intersection design detail	X	X	X	X	X
Maps	X	X	X	X	X
Signing and marking plans			X	X	X
Traffic signal control plans			X	X	X
Accident data (especially the surrounding area and for case control)	X	X	X	X	X
Traffic counts and surveys	X	X	X		
Road safety equipment (details of guardrails, passive safety devices etc.)			X	X	X

Once the audit team has developed a reasonable picture of the project, a briefing meeting can be called. This should be attended by the client, the audit team (or team leader) and (preferably) the design team. During this meeting the client briefs the audit team on the project and potential problems and where relevant discusses briefs that have been given to the design team. It offers the opportunity for the audit team to establish the lines of communication, to discuss potential problems, source or identify lacking documentation etc. Furthermore the planning for the audit is discussed and finalised; as are deadlines and the audit report's general lay-out.

5.4.3 **Document study and site visits (the audit)**

The documents are reviewed in detail. The audit team members systematically examine and review all the project plans, drawings and documents. This is done independently by each auditor and notes of all safety concerns and/or oversights are made. Although not obligatory, checklists can be an important tool in this process. These checklists serve to remind the auditor of the different components and ensure that a systematic process is followed. A checklist is nothing but an aid and cannot cover all possible events/problems/situations that may arise in road safety evaluations and therefore must not be seen as an all-inclusive list. Because different design stages cover diverse levels of detail, checklists have been developed for each audit stage. Seeing that checklists cannot be all inclusive it is recommended that each country develop their own as has been done in Ripcord-Iserest (Matena et al., 2008), in the Netherlands (Dienst Verkeer en Scheepvaart, 2011), the United Kingdom, Australia and New Zealand.

Site visits are held to assess the project and the area affected by it during construction and following opening. These site visits, even at the feasibility stage are valuable to reveal potential shortcomings especially regarding the safety impacts that the project may have on the surrounding area. It is recommended that the site be visited both during the day and at night and that it is viewed from the perspective of all future road users (not just as a road engineer). It is extremely useful to take photographs of potential safety concerns. Visits are intended to provide an answer to the questions **"who may be hurt in the event of a crash, how seriously and why?"** (Matena et al., 2008)

Once the documents have been studied and the site visits are completed, the auditors can compare notes and decide on which issues are real safety concerns. Where possible, these concerns are put into perspective by quoting control data from previous road safety studies/remedial treatments etc. Examples of good sources of such control data are the studies by Elvik et al (Elvik, Høye et al., 2009) and Belcher et al. (2008).

5.4.4 **Exit meeting**

The exit meeting is more common to RSA in New Zealand and Australia but certainly is not unique to those countries and has for instance been applied, albeit in a slightly different context, in the Netherlands (Schermers, Kenjic et al., 2010a). It is an optional meeting, the need for which is determined by the complexity of the project. In complex projects it is advisable to hold these meetings, for preliminary discussion of results. In some cases audit conclusions may already be known to the client and these may already have been discussed and resolved (although not documented). Such meetings are also particularly valuable to resolve misunderstandings and factual errors.

5.4.5 **The audit report**

The primary output from an audit is the audit report. This is a formal report and should include at least the following sections:

- Project title
- Introduction
  - A brief description of the project that was audited;
  - The date/s and time of the site visits, meetings and actual audit:
  - Climatic and other (e.g. traffic) conditions during sits visits:
  - Names, affiliation and responsibilities of the audit team;
  - Description of the project and its objectives.
- Project information
  - A list of documents, drawings etc. used in the audit;
  - Plans showing the scope of the project;
  - List of meetings/discussions;
  - Any other supporting information.
- Audit findings and recommendations
  - A list of potential road safety problems, concerns and recommendations. Where possible the location of these are shown on maps and supported by photographs. Please note that the recommendations do not necessarily provide solutions and are not to be formulated as if the auditor has taken the role of designer; however, in some countries providing a general indication of a feasible improvement to the detected safety issue is encouraged (Cardoso & Bairrão, 2002). Recommendations typically state that a particular road safety problem may occur (where necessary citing control cases) and needs to be addressed and rectified without automatically providing the solution. In the Netherlands a weighting is applied which indicates the severity of the road safety problem. Non-road safety problems are not included in the list but may be included in an appendix.
  - A referencing systems so that the findings can be found back easily.
- A formal statement signed and dated by the auditors to certify that the scheme has been audited by them.
- A report summary
  - A tabled and numbered listing of the audit recommendations (linked to the findings) which is forwarded to the client to record the designers' response and the client's decision.

Once an audit report is completed as a first draft, the team members check and provide comments before finalising it and submitting it to the client. The client DOES NOT get the opportunity to comment on the draft since this would compromise the independent position of the audit team. The audit results are what they are and it is the responsibility of the client to take these into consideration with the design team.

5.4.6 **Documented response to audit reports**

The audit reports are submitted to the client who in turn submits it to the design team for their response. The designers are expected to respond to each audit recommendation, indicating whether or not the recommendations are accepted or adopted and providing motivation to support this decision. An indication of the implications for the project must also be given, including cost implications.

The ultimate decision to accept or reject the audit recommendations rests with the client. Once the responses from the design team are returned the client must make these decisions and motivate the choice. In some cases a third party may be called in to provide an additional independent advice.

The last step in this process is that the client advises the design team which recommendations to address. Copies of these decisions are sent to the audit team and are kept in the clients project file in the event of a follow up stage. Both the responses by the design team and the decisions by the client are added, as annexes, to the final RSA report.

6 Road Safety Inspections (RSI)

Road Safety Inspections (RSI) are mandatory for all EU countries, under the Directive 2008/96/EC (European Commission, 2008) and have to be periodically applied to existing Trans-European Network roads (roads with E-numbers). According to that EU Directive "safety inspection means an ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety;"

In this sense, RSI corresponds to (observing *in situ* and) evaluating the condition of existing roads from a road safety perspective. It aims to find defects with potential negative effects in road safety and resulting from changes in road function or in standard requirements, design and constructions faults, neglected maintenance, damage resulting from vandalism, crashes etc. or combinations of these.

Routine maintenance is an activity traditionally carried out by road administrations that addresses issues arising from the deterioration of road conditions with time and traffic use, and involves tasks such as resealing pavements, substitute damaged safety barriers or crash cushions and worn out signs, cutting overhanging vegetation, and others. Normally, procedures for dealing with these issues and their consequences on road safety exist already and are quite successful at addressing the mentioned issues.

However, the tool included in the Directive is also intended to enable the *in situ* evaluation of existing roads according to current practices. The objective, then, is not just to bring the safety level to its initial status, but also and especially to upgrade it to contemporary safety levels. This is done by identifying hazardous conditions and deficiencies that may contribute to accident occurrence or increase the severity of crashes.

RSI also differ from safety analysis, which is a procedure heavily dependent on the thorough analysis of detailed accident data registered in a road section over a selected time period. In fact, execution of RSI does not require access to local accident data.

This chapter provides guidelines for conducting Road Safety Inspections. The guidelines describe the methodology and tools, the qualifications needed and requirements for human resources in charge of its execution and finally how to use the results of the inspections to define remedial programmes to improve the road safety quality of the road environment.

6.1 *Background, definitions and scope*

6.1.1 Background and definitions

In essence RSI evolved from RSA, which as initially defined in the UK included a stage audit immediately after opening the new road to traffic, that often resulted in comments dealing with design and maintenance related safety issues on the existing road network. The safety inspection of existing roads was perceived to be an appropriate tool to systematically check whether the road safety of the original design had not been compromised, as a result from changed use over time, changed function or purely as a result of inadequate maintenance or obsolete technology being deployed. It is a fact that roads are not static environments and time brings about change; it is the purpose of RSI to monitor this change and to reveal potential road safety dangers for all road users.

Although less widely practised than RSA, RSI are commonly applied throughout the world, even though in several cases just with the strictest objective of maintaining initial conditions. Readers requiring a broader understanding of the development of RSI are encouraged to refer to the wide range of literature on the subject (Elvik, 2006b; Cardoso, Stefan et al., 2007; SETRA, 2009).

Unlike RSA, for which there is a common definition framework, RSI definitions vary considerably at the international level, depending on the emphasis on routine maintenance aspects, overall scope of the activity and the reliance on accident data for both the initiation and the execution stages. According to the World Road Association, a RSI is a systematic, on site review, conducted by road safety expert(s), of an existing road or section of road, to identify hazardous conditions, faults and deficiencies that may lead to serious crashes - PIARC (2008). In France, RSI is intended to detect inconsistencies in a road, its roadside and environment that may have impact on driver behaviour or its passive safety and diminish road safety (SETRA, 2009). Elvik defined RSI as “a systematic assessment of the safety standard of an existing road, in particular with respect to hazards related to traffic signs, roadside features, environmental risk factors and road surface condition" (Elvik, 2006b)

In the RIPCORD-ISEREST research project a common understanding was reached, concerning road safety inspections which were defined as (Cardoso et al, 2007):

a) a preventive tool;
b) consisting of a regular, systematic, on-site inspection of existing roads, covering the whole road network;
c) carried out by trained safety expert teams;
d) resulting in a formal report on detected road hazards and safety issues;
e) requiring a formal response by the relevant road authority and within a specified timescale.

This is the definition adopted in RISMET and in this report.

Derived from this definition it is clear that road safety inspections concentrate on traffic operations aspects and specifically on road accident and injury dangers – potential road risk factors. Key words related to RSI are independent[2], formal, systematic, periodic and accident or injury potential. Road safety inspections strive to identify traffic hazards, propose remedial treatments and monitor the implementation of these. RSI concentrates on those aspects that are known to increase crash risk or are known (from research) to have high crash potential (Elvik, 2011).

RSI do not limit themselves to purely the superficial elements such as road signs and markings, and objects on or along the road; but also provide an assessment of the road design given the current use and function of that road. RSI concentrates on the operational safety of a road and strives to provide the safest possible road environment for the users of that road. RSI are intended to be applied to the entire network of existing roads and not to be used as an incidental check of potentially

[2] In the sense of a “new look” at the safety of a road and its surrounding environment.

dangerous or actually dangerous roads or sections of road.

Road Safety Inspections can generally be integrated with inspections aimed at scheduling and programming road maintenance. However, it must be recognized that according to the definition, RSI are not dealing specifically with routine maintenance – even though issues related to routine maintenance with impact on road safety may be addressed in RSI. Routine maintenance issues are easily picked-up by a local road operator's staff, which is familiar with the "normal" appearance of the road environment. Familiarity with road characteristics, however, hinders the ability to detect inconsistencies with current safety practices; this is the reason why it is desirable that RSI be carried out by independent inspectors – not familiar with the road – in a dedicated inspection procedure. Furthermore, persons conducting routine inspections are often not familiar with current safety practices, another reason for initiating independent road safety inspections.

Road safety inspections are periodic and are conducted irrespective of crash occurrence. In this way RSI is a pro-active tool aimed at redressing potential safety problems on existing roads before they occur. Nevertheless, in some countries accident data are used either as an inspection triggering criteria or as complementary information for setting suitable interventions. This deviance from the common understanding and definition is not expected to seriously affect the application of the RSI concept, an assumption that is valid only provided that the required accident data is readily available and meets quality requirements and that the procedure does not entangle with other safety management tools, such as "Network Safety Management" and "Black Spot Management".

An important aspect is that the RSI is periodic and that remedial (improvement) plans are laid out and executed, subsequent traffic developments monitored, and their effects evaluated.

6.1.2 **Benefits and costs**

RSI involve three types of costs: the ones related to the execution of the inspection and drafting the corresponding report; design and construction costs of the safety interventions; and costs due to monitoring and evaluating results.

Planning the execution and monitoring of RSI can generally be quite easily accommodated within the daily functions of an experienced road administration. The additional cost for carrying out the inspections is relatively low, especially if one considers these are periodic (e.g. once every five years or when changes in traffic or environment have occurred). A Ripcord-Iserest study reveals that the costs in an Austrian pilot with RSI were around €1000/km of dual carriageway highway (including the costs of minor remedial treatment) (Cardoso et al., 2007). On the other hand, estimating design and construction costs of corrective actions is not so easy, as they will depend on both the nature and the number of these safety interventions. There are cases where hazards may be mitigated easily and quickly by means of low cost engineering measures, such as improved signing and marking; however, safety improvements may require considerable investments on several occasions, such as when the layout of a through road has to be upgraded to an urban environment (for example see Figure 6.1). Planning RSI programs ought to match the number of interventions resulting from completed RSI and the amount of corrective actions that may be executed, given the amount of investment allocated for such purposes.

Studies carried out in Australia on over 250 interventions resulting from RSI showed that in most (78%) cases safety interventions had benefit–cost ratios greater than one; furthermore, in 35% of the cases the ratios were above 10 (Macaulay & Mcinerney, 2002).

6.2 *Requirements and principles*

6.2.1 Good practice recommendations

Guidelines for good RSI practice were proposed by (Elvik, 2006b). They consist of seven main recommendations.

a) The elements to be included in RSI should stand as known risk factors for crash occurrence or injury causation.

b) The inspection should be standardised and designed to ensure that all elements included are covered and are assessed in an objective manner. Check lists are not mandatory, but at the initial stages of RSI implementation they may be useful. Furthermore, daylight and night conditions are relevant for RSI.

c) Issues to address in RSI should include the following core of recognised important elements: key aspects of traffic operation, such as matching of traffic speed, local conditions and road function, and need for separation between motorised and vulnerable road users; traffic signs, in particular as regards their compliance with warrants, their quality and whether they are correctly placed and legible (especially in the dark); the quality of road markings, in particular whether they are visible and are consistent with vertical traffic signs; road surface characteristics, in particular with respect to friction (macro and micro-texture) and evenness; sight distance provision and the absence of permanent or temporary obstacles that prevent timely observation of the road or other road users; and the presence of roadside traffic hazards near the carriageway, such as trees, exposed rocks, drainage pipes and culverts, steep high embankment slopes, etc.

d) Each detected hazard in an RSI should be assessed in a standardized way in order to decide if the item: represents a traffic hazard that should be treated immediately (in which case a specific intervention should be broadly proposed); does not require an emergency short term intervention, in spite of not being in a perfectly good condition or although deviating slightly from current standards (in which case follow-up inspections and care are recommended); is in good condition and in accordance with current standards.

e) Results obtained with a RSI should be presented in a standardized written report, with an overall description of the proposed corrective safety interventions.

f) Inspectors should be formally qualified for their job. To be efficient, qualification warrants incorporate basic technical background requirements, initial training and knowledge updating requirements[3].

g) Follow-up procedures should be defined, to check if proposed corrective safety interventions have been implemented and to assess the results obtained.

Previous analysis of European RSI practice showed that six of the above mentioned

[3] Through regular professional meetings to exchange experiences, in order an increasing uniform application of main safety principles is reached in RS.

proposed good practice items were partially fulfilled, as reported by Cardoso *et al* (2008). Nevertheless, the requirement for a standardized formal report was the only item fully observed. On the other hand, the recommendation for RSI follow-up and results assessment was the least fulfilled item. However, ensuring that recommendations have been applied and evaluating their effects are two important tools to ascertain the benefits of RSI; also, there is no evidence that it is impractical to carry-out these activities.

6.2.2 **Types and frequency of RSI**

According to the definition and the Directive 2008/96/EC (European Commission, 2008)requirements, all TEN roads (motorways and other types of interurban) are subject to regular RSI, independently of their average annual daily traffic (AADT) and effective importance in each country's road network hierarchy. Taking in consideration the preventive character of RSI and the recommendations of the Directive 2008/96/EC, ultimately the whole road network should be inspected with some predefined frequency in order to detect road safety hazards. One obstacle to the complete fulfilment of this objective is the fact that road networks usually consist of several thousands of kilometres, of which only a small percentage belongs to the primary road network.

The potential benefits to safety of the application of RSI to non-TEN roads, when weighted against the amount of work necessary to inspect the whole length of potentially interesting road network section, raises questions concerning how to ensure the feasibility of such a task.

In Germany, there are several instruments which can be defined as RSI. One important instrument is the so called "Verkehrsschau" according to the Administrative Prescriptions of Road Traffic Regulations (VwV-StVO). In general, the inspections concentrate on road signs, including road markings and traffic devices, which are important for road safety. Further hazards at the edge of the carriageway and in the roadside environment are inspected, too. The inspectors have to look at the junctions, road sections, and carriageway edge plus roadside environment separately.

The inspection team consists of the representatives of the road traffic authority, road construction authorities and the police. The authority representatives should have the necessary qualification and knowledge of the inspected road section. Further it is recommended to include an expert who is not familiar with the region where the inspected road section is located and thus doesn't know the inspected road section.

The steps are as follows: the invitation to the road safety inspection is sent by the road traffic authority to the inspectors. It should include all necessary documents, such as the inspection schedule, a description of the planned route and a list of problem areas (if there are any). Before the inspection starts a short briefing should take place. The inspected road section has to be driven in both directions. The report must be written by the road traffic authority and contains the type of road safety inspection and the route, start and end time of the inspection, names of the inspectors and their authorities and a detailed description of each point including the precise location of the point, findings, recommendations to solve the problems and the reasons for them, as well as outstanding issues. After three months a progress review should be carried out in order to check whether the recommendations have been implemented or not.

Ad hoc road safety inspections can become necessary in the following cases: changes in or introduction of new traffic rules, opening of new routes, concentration on particular types of road user (e.g. cyclists), safe routes to schools, public transport stops, or installation and alteration of alternative routes for motorway traffic and inconsistencies in existing, long-term diversions including those for particular types of traffic. The intervals at which these inspections are conducted can vary. Depending on the topic at hand, certain experts have to attend the inspection, e.g. representative of transport provider in case of dealing with public transport stops.

To ensure the proper performance of road safety inspections, road safety inspectors must have up-to-date specialist knowledge of issues relevant to road safety. Inspectors must be trained. This can be achieved through short courses and ongoing training.

The inspection team has to be composed of members from the traffic police, traffic and road authorities, and road maintenance staff and there is the option of using external consultants if necessary. For conducting these inspections road traffic authorities are responsible (see also 6.2.3).

Besides some legal binding administrative prescriptions the corresponding German Guidelines ("Merkblatt für die Durchführung von Verkehrsschauen", abbreviated as. M DV) (FGSV, 2006) distinction is made between periodic inspections (performed on all roads at fixed time intervals and covering all issues mentioned in 6.2.1); dedicated inspections (dealing with a set of specific topics and carried out only on selected roads, where those topics are more relevant for safety); and *ad hoc* inspections (no fixed frequency and dealing with a specific issue).

With this approach it is possible to perform regular inspections on trunk roads, at a predefined frequency whilst it is also ensures that important specific safety issues (such as pedestrian crossings, tunnels, etc.) are addressed at regular intervals and in a comprehensive way across the whole country and on all types of road. This approach also makes sense, as different issues need diverse inspecting time intervals. For example, safety related signs and road characteristic issues deserve to be inspected more frequently than destination signs. Furthermore, *ad hoc* inspections contribute to decreasing the time lag between adopting new safety standards and upgrading existing roads to them.

Two other questions are important when setting up the implementation plan for RSI. What is the desirable frequency for RSI and which road sections should be inspected first? In Germany, the administrative prescriptions say that inspections have to be conducted every year on roads with considerable importance and on roads, where crashes often occur, if necessary also at night. All other roads have to be inspected once every two years. Additionally to these legal regulations the guidelines (FGSV, 2006) advise that on minor roads once an interval of four years can be enough; night time, railway crossing, tunnel and destination sign inspections are carried out every four years (FGSV, 2006). The recently issued Portuguese RSI guidelines states that dual carriageway trunk roads are inspected once every four years (still to be confirmed by road authorities), and single carriageway trunk roads inspected once every five years. Roads with low traffic flows and secondary roads may be inspected with less frequency (once every five to seven years).

In selecting priority roads for RSI, several criteria may be adopted. These can be related to traffic (AADT, percentage of heavy goods vehicles, or share of unprotected road users), route function, geographical area and past safety levels. For example, in Norway (Statens Vegvesen, 2006), the safety level of existing roads is assessed in terms of expected density of victims (expected number of victims per kilometre), calculated using the empirical Bayes method (Hauer, Harwood et al., 2002b). Then roads are categorized by colours, depending on their safety level ranking: red routes for the 10% worst routes; yellow routes for the middle 40% routes; and green routes, for the 50% safer routes. RSI are performed firstly in red routes, then on yellow routes and lastly on green routes.

The way RSI are carried out also influences the importance of selection criteria. In some countries RSI are executed by means of a two-step procedure (see 6.4): first, a preliminary on-site inspection is carried out to detect and classify main safety issues; afterwards, a second more detailed ("analytical") inspection is performed, to thoroughly assess the detected hazards and to lay out suitable corrective interventions. With such a two-step procedure, it is possible to quickly obtain a detailed overview of major issues in a large percentage of a road network and to gather an impression of the overall amount of needed corrective actions. This information may be used to support decisions concerning priorities for detailed RSI.

6.2.3 **Administrative competences**

Regulatory and administrative aspects are especially important if RSI are to be applied to the whole road network, in order that legal competences of road operators and ordering entities are clearly set up.

Regulating the RSI of main national road networks will not be especially difficult, as most tasks may be performed by existing national road authorities, most probably using different departments for initiating, executing and responding to planned RSI. In some countries, the increasing use of public private partnerships will dictate the need for a public supervising institution for RSI of this type of roads, which may be assigned to each country's national road administration or to an especially created institution.

Assignment of responsibilities concerning RSI initiation, execution, response and follow-up depend on the administrative organization of each country's road sector. Assuming that the national road administration structure contains a central office and several regional offices, the central office may be assigned the duty to define the list of RSI to perform yearly and to start the execution of the relevant RSI.

Execution of RSI themselves may be carried out by central office's technical staff, by regional offices' technical staff or by outsourcing to inspectors selected from a national pool of qualified road safety inspectors. Regional road administration technical officers should not be in charge of RSI of roads in their own region, to ensure that a new look is effectively taken upon inspected roads. When RSI are carried out through a two-stage procedure, the same options for selecting inspectors apply. Usually, response to RSI reports is a responsibility of regional road administration offices, who take charge of constructing the selected safety interventions, as well.

Monitoring of traffic and safety developments following the implementation of corrective measures may be achieved through routine activity of central road administration offices or the road sector regulator. To evaluate the effect of implemented safety interventions, dedicated evaluation (before and after and using control locations) studies should be carried out to quantify the effects, preferably through cooperation between the central administration and research institutes.

6.2.4 **Requirements for inspecting teams**

Overall, RSI efficiency depends heavily on the inspectors' qualification, whose requirements should include background and experience prerequisites, specific qualification on RSI procedures, regular updating of knowledge and communication skills.

Desirable background requisites include a professional degree in road design and maintenance and a number of years of experience; solid knowledge on traffic engineering, applied human factors and road safety. Inspectors should be familiar with traffic regulations and understanding of road design, signalling, signing and marking guidelines. Experience in day-to-day road operation and maintenance is desirable.

Road safety inspector candidates should attend a short course on the procedures to be executed in a RSI – a requirement that is similar to the one for road safety auditor candidates (see chapter 5). Assuming that candidates already have a strong background in road safety, normally this course lasts for no more than one week and a considerable part of it consists of practical examples.

Currently, knowledge expands rapidity in most domains, road safety not being an exception; accordingly, design, construction and maintenance standards and good practice rosters may change frequently. Therefore, qualification of road safety inspectors should comprise a formal requirement for updating knowledge, which may be obtained through flash one day courses or, preferably, through professional meetings and technical workshops. This last type of events have the advantage of promoting exchange of information between inspectors, with the added advantage of increasing standardization of inspecting criteria and hazard mitigating interventions.

RSI should be carried out by an inspecting team, having at least two qualified inspectors; only in very short or simple roads should there be one single inspector. In this way, diversity of skills within the team is possible and opportunities for a discussion of different opinions on the detected safety issues are available. Qualified inspectors should be independent of the inspected road's operator to ensure a "fresh" look on current maintenance and infrastructure safety procedures. Road administrations with national and regional offices may obtain this independence by outsourcing RSI; alternatively, RSI may be carried out by teams of in-house inspectors from the central office. Road administrations with regional offices only, and not desiring to outsource this activity, may set up RSI teams in such a way that inspectors from one region can only inspect roads from other regions. Under modern road financing schemes, road stretches may be operated by private road concessionaires, in which case RSI should be carried out by public authorities, for instance from the national regulator.

In special cases, experts may be added to an inspecting team, upon recommendation of the team leader.

6.3 *Technical recommendations*

6.3.1 Examples of hazards

RSI addresses issues that have been demonstrated to increase crash risk or are known to increase the severity of crashes; more specifically, RSI concentrates on those aspects of existing roads that do not match current safety good practice, even though they do not necessarily result from lack of routine maintenance themselves.

In this chapter examples of relevant issues for RSI concern are presented. Frequency and severity of hazards on existing roads are expected to vary considerably from country to country, meaning that it is difficult to establish *a priori* a general detailed framework for RSI, their focus depending on each regional area particularities. Nevertheless six important elements were identified in RIPCORD (see ((c) in *6.2.1*), as covering the most important issues likely to be detected in RSI.

Drivers have difficulty in coping with complex and unfamiliar road environments, where reaction times are usually longer and error frequencies higher than in simple or familiar road situations(Matena, Weber et al., 2006). Also it is known that the survival rate of Human beings falls dramatically at impact speeds above 50 km/h. Therefore, matching road function to its geometric and traffic operation characteristics (especially speeds) is an important aspect for increasing road safety. The same applies to providing space for separating motorised traffic from vulnerable road users at high speeds.

Urbanisation in several areas of Europe has transformed some rural road stretches into suburban areas or through roads across small villages. Despite being usually a slow process, frequently this modification in the function of a road is not accompanied by suitable changes to its geometric characteristics and surroundings, with negative consequences for the safety of its users

Figure 6.1 presents an example of divergence between road characteristics and its function (*a*) and how a primary distribution function may be conveyed to drivers and inhabitants through cross-section characteristics and markings (b).

Figure 6.1 – Changes in road environment for improved traffic flow and increased safety

	
a) Divergence between road characteristics and function	b) Improved street environment

Where segregation between motorised traffic and vulnerable road users is required, sufficient space for pedestrians and cyclists (when present) should be provided; also, in these cases, narrower street lane widths may be adopted than in interurban areas, as a way to both gather sidewalk space and encourage lower speed choice by motorised vehicle drivers (Figure 6.2).

Figure 6.2 – Pedestrians need sidewalk space

Geometric consistency may be defined as the agreement between the characteristics of the geometric design of a road and the unfamiliar driver's expectations (Fitzpatrick, Wooldridge et al., 1999). Abrupt changes in road geometric characteristics and unusual combinations of road elements, that do not conform to road user expectations, increase driver workload and diminish the possibility that a situation will be correctly identified, which greatly reduces the time available for executing the manoeuvres needed to successfully deal with it. Major singular points in roads include intersections, railway crossings, horizontal curves and successions of horizontal curves of different radii (Figure 6.3), crest curves, carriageway suppression, cross section reductions at bridges, lane suppressions and lane or shoulder width reductions. These are road elements that increase driver workload and warrant specific treatment, including special warning signs in order to reduce crash risk; also, measures to mitigate accident severity at these sites are recommended.

Figure 6.3 – Road alignment may surprise unfamiliar and novice drivers

Sight distance requirements depend on travelling speed and the type of situation they refer to. In emergency situations drivers need space in order to stop their vehicle or to be able to bypass an unexpected obstacle. In normal driving situations, space is needed for drivers to anticipate difficulties in travelling along a curve, for reading traffic signs, evaluate traffic conditions and geometry of an intersection (Figure 6.4) and passing slower drivers. Sight distance requirements for emergency situations are defined in road design standards; for normal driving situations recommendations are usually described in signing manuals.

Figure 6.4 – Sight distance requirements apply even in low speed streets

Because sight distances depend largely on prevailing traffic speeds, traffic speed distribution characteristics in the inspected road should be available to the inspecting team, or measured specifically for the RSI. The 85th percentile speed is a speed parameter commonly used for sight distance assessments.

Roadside characteristics have a direct and significant influence on the safety of run-off-the-road vehicle occupants. The concept of forgiving roadside (Figure 6.5) was developed to ensure errant vehicle drivers that invade the roadside area have enough space to recover control of their vehicles without sustaining severe injuries.

Figure 6.5 – Forgiving roadsides

It is not always possible to provide such an ideal environment; in these cases, an area (called *clear zone*) bordering the edge of the carriageway is set aside for safe use by errant vehicles. This area is assumed to be free of dangerous obstacles such as trees, hard poles and steep embankments or cut slopes. The width of the clear zone depends on traffic speeds, AADT and roadside geometry. On existing roads, frequently there are obstacles within the space theoretically reserved for the clear zone. A limited number of options are available to deal with these obstacles: to remove the obstacle; to relocate the obstacle to a place with lower probability of being hit; to reduce the severity of impacts by means of breakaway posts (standardized according to EN 12767), make them traversable (Figure 6.6) and recoverable slopes (gradients v:h=1:4 or lower); and, as the least desirable option, to install safety barriers, to protect vehicle occupants. Safety barriers are currently standardized according to CEN-EN1317.

Figure 6.6 – Example of a traversable cross-drainage inlet

Installation of road signs should fulfil a well-defined road user need; the signs should communicate a simple and clear message, be conspicuous for easy perception by drivers, and be positioned in such a way that they have sufficient time to read the message and act accordingly.

Road signing should not be incoherent (Figure 6.7a), nor installed in places where shadows may impede its easy perception and interpretation by drivers (Figure 6.7b). In urban areas, signs should be carefully positioned, in such a way as not to conceal other signs (Figure 6.7c). Optical characteristics of vertical signs and markings are standardized by CEN-EN standards.

Figure 6.7 – Examples of signing issues

a) b) c)

Surface characteristics of pavements are a relevant issue for road safety, having a direct influence on driving dynamics, visibility conditions and driver behaviour. Lateral and longitudinal accelerations depend on available skidding resistance, which on dry pavements is affected by macro[4] and micro-texture surface characteristics, and on wet pavements is also affected by surface drainage. Mega-texture and roughness have an effect on vertical accelerations, which influences tire-road contact conditions and vehicle occupants' comfort. On wet roads, glare varies with macro-texture, especially at night; and splash and spray may reduce the visibility distance, both in daytime and at night.

Mega-texture and roughness defects are easily noticed by drivers, due to the discomfort they generate. When big enough, vertical accelerations generated by roughness degrade the capacity to manoeuvre and decelerate vehicles, negatively affecting road safety. This reduction is especially important when these defects are unexpected (for instance in an otherwise "good" road) or while driving at high speeds in interurban roads. However, usually these deficiencies are corrected under routine maintenance before they start to have a significant effect on safety, which may explain inconsistency in some results of studies on the influence of rut depth and road roughness on crashes (His, Velin, & Wiklund, 2002; Ragnøy & Christensen, 2006). Various studies have shown that crash risk on wet pavement conditions increases abruptly when macro-texture or micro-texture are below critical values (Gothie, 1997; McLean & Foley, 1998; Wallman & Aström, 2001). In key singular sections, such as horizontal curves, intersections and near motorway accesses (entrance and exit areas) micro and macro-texture should be well above those minima.

When sealing pavement cracks, care should be also taken in order it does not create longitudinal low wet skid resistance stripes, which may be dangerous to motorcyclists (

Figure 6.8).

Figure 6.8 – Surface characteristics issues

[4] According to PIARC (1987), surface characteristics of pavements may be described and classified by their singularities' wave length and vertical amplitude: micro-texture (wave length less than 0.5 mm and amplitude below 0.2 mm); macro-texture (wave length between 0.5 and 50mm and vertical amplitude between 0.1 and 20 m); mega-texture (wave length between 50 e 500mm and vertical amplitude from 0.1 to 50 mm; and roughness (wave length longer than 500 mm).

On high speed roads, wide carriageway stretches and super-elevation runoff zones, especially in steep grades and level sections, hydroplaning risk should be assessed and special drainage appurtenances installed, when required.

As mentioned before, the primary objective of RSI is not to detect hazards resulting from lack of routine maintenance, which does not mean that detected problems of this type are not expected to be reported to the relevant road operator, for appropriate remedial action to be undertaken. In fact, RSI procedures should allow that issues of this type are swiftly communicated to the road's operating agency. Detection of situations as exhibited in Figure 6.9a) should be transmitted to the responsible agency even before the RSI report is issued.

Figure 6.9 – Example of a routine maintenance issue and its solution

a) Chevrons concealed by hanging vegetation

b) Visible chevrons delineating a dangerous curve

6.3.2 Classification of hazards

As mentioned in the good practice guidelines, all hazards detected in a RSI should be assessed in a standardized way, in order to decide on the urgency of mandatory corrective measures and to support setting priorities for other interventions.

Road safety inspectors should be equipped with a system to classify hazards according to the probability of associated crashes and the severity of resulting injuries. Basically, the classification should allow for the disaggregation between those hazards that require immediate corrective measures; those that do not require an emergency safety intervention but deserve to be corrected before the next RSI; and those that need only to be reported for close follow-up. The way this is achieved may vary with the country.

The hazard classification system may be substantially intuitive, relying heavily on the inspectors' expert opinion or, at the other end of the scale, consists in the application of an assessment matrix incorporating selected relevant variables such as speed, road user protection, type of collision and others. Systems based on expert judgement are most effective when road safety knowledge is widespread by technical staff and does not vary significantly across a country. They also assume that a successful qualification updating system is available for inspectors. Matrix based systems may contribute to a more uniform danger classification; however, they may be quite unyielding and not suitable for the evaluation of particular existing situations.

According to the Norwegian RSI manual there are three classes of hazards, depending on three consequence severity (minor, seriously and very serious/fatal) and three probability (low, medium and high) categories. Categorization is defined based on judgement by the road inspector. Decisions concerning the application of corrective measures depend also on the class of road: corrective measures are mandatory on red roads; on yellow roads safety interventions are applied if benefit/cost studies are favourable; and on green roads, identified hazards are just monitored for a defined period of time(Statens Vegvesen, 2006).

In Portugal, a four class system was set up, also based on probability and severity of crashes categories, associated to each hazard. Road class (single or dual carriageway) and AADT are used to calculate the probability category (rare, occasional, frequent, and very frequent). Traffic speed and type of accident (rollover, head-on collision, lateral collision, rear end collision, collision with cyclist and hitting a pedestrian) are used to calculate the severity category (minor, slight, serious and fatal). The probability category matrix is binding, and inspectors may not deviate from it; the severity category matrix contains some elements which are binding and others that allow safety inspectors some freedom to use their expert judgement. Four hazard classes are defined and the response by road authorities vary in both need and urgency: the most serious hazards must be corrected with urgency; the second class corresponds to hazards that must be corrected within one year from the RSI; next in class are hazards for which correction should be attempted if costs are not excessive; safety interventions directed to hazards in the less serious class are not mandatory, unless they are low cost measures.

In France there is no formal categorization of hazards. However, a follow-up action must be selected for each detected hazard: low cost maintenance activity; maintenance with high costs and requiring an in-house small study; interventions requiring an in-depth study and specific funding; no action required (SETRA, 2008).

6.3.3 **Relevant normative requirements**

Success in the implementation of RSI depends on the quality of technical standards and recommendations concerning the issues to be analysed by inspectors, as these good practice guides are the yardstick they will rely on.

6.4 ***Methodology / Procedures***

Implementation of RSI requires programming activities at both a strategic and a tactical level. Normally, selecting which road stretches to inspect (see *6.2.2*) and scheduling the corresponding RSI are activities to be carried out at a national level, by central road administration, the road operations regulating agency or any other type of national organization in charge of supervising the national trunk road network operation. The same organization may also take charge of important follow-up activities, such as monitoring responses to RSI and assessing the results obtained with the safety interventions carried out.

The selected inspections are ordered by road operators to an independent inspector selected from the national list of qualified inspectors, who should be free to decide on his team's composition.

Relevant information concerning the road to be inspected must be provided by the ordering entity (usually the national road operator) to the inspecting team, before the initiation meeting: overview maps of road section, including kilometre posts, detailed maps of intersections and other singular sections (at a 1:500 scale), longitudinal profile, AADT (preferably with disaggregation by turning movements at intersections), speed limits and prevailing speeds, pedestrian and other unprotected road users' traffic data. Other related information may also be provided, such as a description of planned interventions and accident data, if easily available.

The inspection starts with the initiation meeting, to present the road stretch to be inspected, to clarify its type, to schedule the onsite inspection activities and to inform on the inspecting process.

Afterwards the inspection is carried out, taking into account the issues described in *6.3.1* and as a result the report is written. This report contains the location and a detailed description of all detected hazards; the report includes also an account of the possible remedial treatment for each hazard, including an overall scheme of works to be carried out, when applicable. RSI should be standardized to facilitate reaction by the road operator.

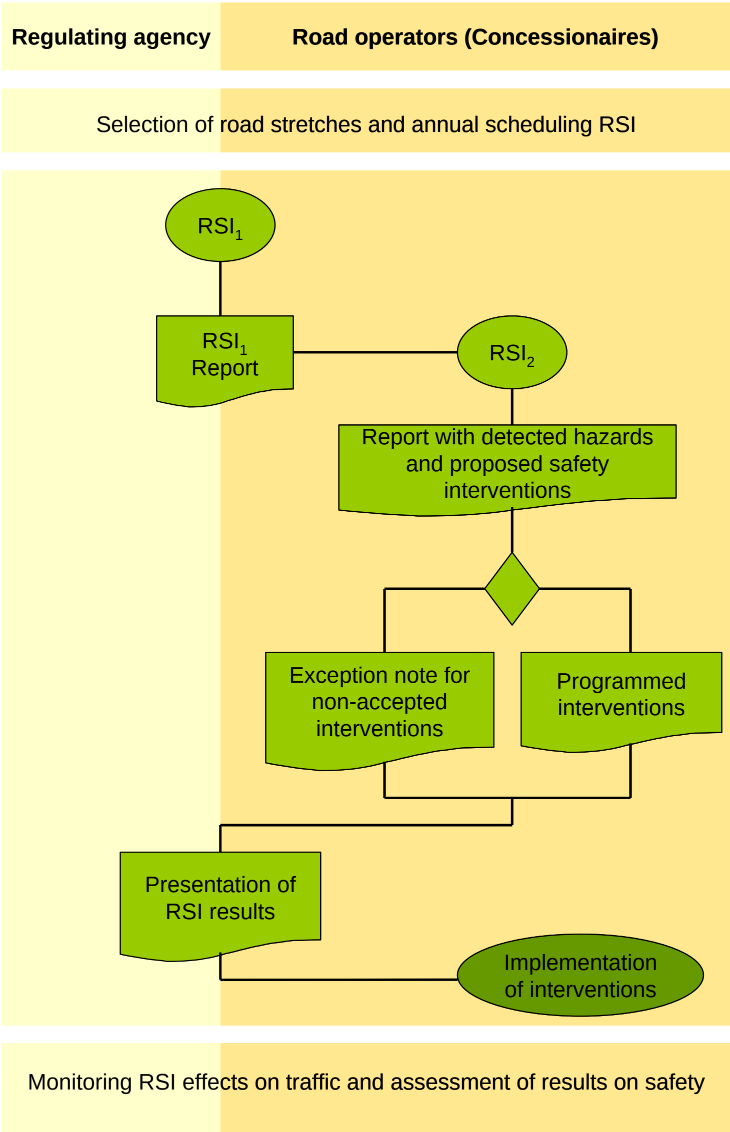
In the final meeting, the results of the RSI are handed to the road operator as a final report, where major issues are highlighted. Clarifications to the report are also provided by the inspecting team in that final meeting.

Following, the road operator has to respond to the report, by outlining an action plan, to be appended to the RSI report. This action plan contains the list of safety interventions to be implemented – including individual detailed design schemes and cost estimates – and exception statements, explaining the reasons for absence of action addressing the other issues mentioned by inspectors. These may be due to technical or to financial reasons. As a general rule, yearly available funding for maintenance activities will determine the number of interventions that will be implemented and the timing of their execution.

The inspection part may be executed using a two-step procedure, as is practice in Norway and Portugal. In the first step a preliminary on-site inspection is completed, with the help of video or photo registry, with the objective of locating the main safety issues, such as area type, curvature and visibility, intersection types, signing and road markings; in the second step a thorough inspection is made on the issues identified in the first step, and safety interventions are selected and detailed. This two-step approach gives the opportunity for inspecting the road at any time of the year (not being influenced by weather nor traffic flow), allows for less exposure of inspectors to traffic dangers, and provides RSI programmers a quick assessment of expected needs, as regards the amount of required investment in safety interventions.

As an example, the overall scheme of RSI in Portugal is presented in Figure 6.10 (see also Annex 1). In Portugal, TEN roads are operated by private concessionaires, which are supervised by a regulating agency (InIR). Roads to inspect each year are selected by InIR, which schedules every RSI in agreement with the relevant road concessionaire. Inspecting teams for each RSI step are selected by InIR: in principle, different teams are selected for the first step (RSI_1) and the second one (RSI_2). The RSI_1 report is presented to both InIR and the relevant concessionaire; and the RSI_2 report is presented to all parties involved – InIR, the concessionaire and the RSI_1 team. Concessionaires take charge of the construction of safety interventions. InIR is responsible for monitoring traffic and safety developments on the whole trunk road network, relying largely on data provided by concessionaires, and for assessing the results achieved with the corrective actions.

Figure 6.10 – Implementation of RSI. Programmed activities in the Portuguese National Road Network



Note: Following implementation of remedial measures and treatments, monitoring and evaluation should be carried out to assess effectiveness.

7 Network screening as part of network safety management

Network screening is a method used to assess the crash reduction potential of locations in a road network and, based on remedial measures, to prioritise these from locations with the highest to the lowest crash reduction potential. The objective is to identify locations with distinct road safety problems manifested by a higher than normal number of crashes (or crash rate); a higher proportion of serious injury crashes and/or a higher proportion of a particular type of crash. Safety Analyst incorporates the current state of the art for network screening (Elvik, 2011) and this has consequently been adopted in the recently published Highway Safety Manual (HSM, AASHTO, 2011).

The European Directive for Road Safety Management (European Commission, 2008) refers to network screening as “Network Safety Ranking” which is defined as:

> a method for identifying, analysing and classifying parts of the existing road network according to their potential for safety development and accident cost savings”.

In Safety Analyst and the HSM network screening is the first step in a cycle, also called the Roadway Safety Management Process (AASHTO, 2010; Harwood, Torbic et al., 2010; AASHTO, 2011). In essence Network Safety Ranking as defined by the Directive (European Commission, 2008) encompasses a similar cyclical procedure whereby locations with safety improvement potential are identified, the nature of the problems diagnosed, countermeasures identified and selected, an economic assessment (BCA) is carried out, the projects are prioritised, the measures implemented and monitored and the cycle starts again. This chapter concentrates on the first step in this procedure, namely network screening and proposes a work procedure based on that developed by Safety Analyst and the HSM.

7.1 *Introduction*

In the past road authorities relied extensively on approaches such as blackspots and high accident locations to manage road crashes at a local and/or network level. Comparing observed crash data to some defined norm or threshold crash value enabled a road authority to identify hazardous locations/high accident locations or blackspots.

In recent years the declining number of crashes in some countries (e.g. Sweden, Netherlands, and UK) has resulted in the definition for a blackspot being adjusted downward. Furthermore, there has been a tendency to increase the area covered by a blackspot (longer road sections etc.). The latter is more commonly referred to today as Network Safety Management (NSM). The major difference between the two approaches is that blackspots typically concentrate on a specific location and considers all crashes within the immediate vicinity of that location (for instance, within 50m of an intersection or a maximum of 250m either side of a chainage marker on road links, if the design and layout are consistent over that length) whereas NSM considers longer road sections (of between 2 and 10km in length).

Both approaches typically rely on a total number of (severe) crashes over a given time period and irrespective of traffic volumes and historical development of crashes at that location. Although the blackspot (and later NSM) approach has certainly had success in that most countries applying the procedure have managed to reduce both the number of crashes and the number of blackspot locations, there remain a number of shortcomings in this procedure (see also Chapter 11). Consequently network screening has become the state of the art process whereby variations in expected crash frequencies between locations in a road network can be analysed statistically (Elvik, 2011).

7.2 *Process*

The network screening process involves the following five steps derived from the procedures described by the new Highway Safety Manual (AASHTO, 2010):

- Establish purpose.

  In this step the purpose or goal of the network screening analysis must be identified. This choice has a direct bearing on the data that will be required, which performance measures are relevant and which screening method is to be followed.

- Define network, type of location and establish reference population.

  In this step the location type (e.g. intersection; road section/link; ramps etc.) within the network (also called reference population) needs to be specified and grouped on the basis of some commonalities.

- Select performance measures.

  In this step the required performance measure must be selected. This will be based on both the purpose of the screening, the data and the tools that are available. Examples of performance measures include crash frequency; crash rate; relative severity index; critical rate; etc.

- Select the screening method.

  This step involves selecting the most suitable screening method given the prevailing situation. Three screening methods may be chosen from, namely the sliding window; peak searching and (simple) ranking.

- Screening and evaluation.

  The last step in the process is actually carrying out the screening analysis and evaluating the results.

7.3 *Establishing the focus of network screening*

The first step in the network screening process is to define the goal or purpose of the screening exercise. Generally network screening is focused on:

1. Identifying and ranking locations where improvements have the potential to reduce the number of crashes;

   and/or

2. Evaluating a road network with the intention of developing and implementing policy aimed at redressing specific problems. By identifying locations with a particular crash type or of a certain severity (e.g. many intersections in a network have high numbers of severe right angled crashes) targeted policies may be devised to structurally reduce these problems.

The first approach is similar to the traditional blackspot approach in that the aim or focus of the exercise is to identify all locations with improvement potential; that is where (infrastructure) measures will bring about the largest reduction in the number of crashes. The improvements will generally be mixed and location specific.

The second approach is more specific and by targeting a crash or severity type, the focus is directed at identifying only those locations which will benefit from a remedial programme directed at this problem. The aim of this type of screening is to introduce policies and/or measures that are of a common nature to all locations.

7.3.1 **Identifying the network and establishing reference populations**

This step entails identifying the elements in the network that are to be screened and these include:

- Intersections
- Road sections or road links
- At grade railway crossings
- On and off ramps
- Facilities (combinations of road sections and nodes)

The above (roadway) elements or screening categories will generally contain locations that fit the general category but show vast differences within that category (e.g. roundabouts are intersections but they are very different from signalised intersections). In this step it is recommended that reference populations are made up which contain locations with as many similar features or characteristics as possible. In this way populations are more homogeneous resulting in a more logical and comparable prioritisation within that population.

Examples of characteristics that can be used to define a reference population are shown in Table 7.1.

Table 7.1: Defining reference populations in different road situations

Characteristics defining reference populations				
Intersections	**Road Sections**	**At-grade railway crossing**	**Facilities (combination sections and nodes)**	**On- and off ramps**
Traffic control	Number of lanes	Number of lanes	Number of lanes	Interchange type
Number of approaches	Classification	Width of crossing	Road width	Number of lanes
Traffic volumes/AADT (intersection; major/minor)	Traffic volumes/AADT	Traffic volumes/AADT	Traffic volumes/AADT	Traffic volumes/AADT
Area type (Urban/rural)	Area type	Access control (booms; signals; etc.)	Location (mid-block/intersection)	Ramp length
Cross-section per approach	Speed limit	Area type	Type	Acceleration/deceleration length
Functional classification	Median type	Approach road speed limit		Speed limit
Surfacing	Density property access	Terrain		
Approach road speed limits	Terrain			
	Road width			

7.3.2 Select the performance measures

This step of network screening is very important and entails selecting the most relevant performance measures to evaluate crash reduction potential. For the selected focus. The performance measures are quantitative measures and can be measured in terms of crash frequency, average crash frequency, crash rate, expected crash frequency, critical rate, etc. The outcome of evaluations may differ depending on the performance measure selected and it is recommended to use more than one measure to improve the level of confidence in the results.

The Highway Safety Manual (AASHTO, 2010) recommends a choice from the following performance measures:

1. **Average crash frequency**

   This measure is in essence the same as for a blackspot. The location with the highest number of crashes of a certain severity within a given time period is awarded the highest ranking.

2. **Crash rate**

   Similar to the above except that the frequency of crashes is normalised by traffic, as a measure of exposure. At intersections exposure is expressed as per million vehicles entering and on road links as million vehicle-kilometres travelled.

3. **Equivalent accident number (Equivalent Property Damage Only (EPDO) average crash frequency)**

   In essence this is the same as 1 with the exception that crashes are weighted by severity (highest weighting for fatal crashes and lowest for damage only). Although this performance measure is not commonly applied in countries such as the Netherlands, countries such as Germany follow this approach by weighting the severity based on costs. These costs reflect both direct (insurance, damage, medical) and indirect (loss of quality of life etc.) costs. The Equivalent Accident Number (E.A.N.) approach is common in blackspot evaluations in countries such as China, Sri Lanka and South Africa where weights are assigned by severity (e.g. 1 fatal crash = 6 Damage only crashes)

4. **Relative severity index**

   This performance measure is based on crash cost. Locations are sorted into reference populations (locations with similar characteristics and operational conditions). Costs per crash type are applied and for each location in the reference population the total and average cost of crashes in a given time period is calculated. The total crash-cost for all locations in the reference population is calculated as is the average per location. By comparing the crash cost of the location/s under consideration to the overall average of the reference population it can be determined which locations have a higher than average cost.

5. **Critical rate**

   This measure compares observed crash rates of each location to a calculated critical rate. The critical rate is calculated from the average crash rate of the reference population, traffic volume and a statistical constant representing a desired level of significance. Locations where the observed crash rate is higher than the critical rate are selected for further study.

6. **Excess predicted average crash frequency using method of moments** (Kononov, J, 2002 - in (AASHTO, 2010, 2011)

   The average crash frequency at the location is adjusted based on the variance in the crash data and the average crash frequency for the reference population. This adjusted value is compared to the average crash frequency of the reference population. The difference between these values reveals the improvement potential and which can be used to prioritise locations.

7. **Level of service of safety (LOSS)** (Allery and Kononov, 2003, in (AASHTO, 2010, 2011)

   This measure compares observed crash counts to a predicted average crash frequency which is calculated from calibrated Safety Performance Functions (SPF) and an over-dispersion function from the HSM. The degree of deviation from the predicted average crash frequency is then assigned to a LOSS category (from I to IV). Locations with poor LOSS are marked for further review.

8. **Excess predicted average crash frequency using safety performance functions**

   Similar to 7 except the difference between the observed and predicted crash frequency is termed the excess predicted average crash frequency. These differences are calculated for all locations in the reference sample and are ranked from highest to lowest with the locations with the highest values meriting more urgent examination.

9. **Probability of specific crash types exceeding threshold proportion**

   This performance measure is also used to identify crash patterns on roadways or at intersections. Crash locations are prioritised based on the probability that the observed proportion of crashes of a particular type or severity is greater than a threshold proportion of crashes. The threshold proportion of crashes is the proportion of crashes of the same type for the reference population. By calculating sample variance and alpha and beta parameters of the beta distribution assumed for the probability of interest, it is possible to calculate the probability for each location and a ranking can be made.

10. **Excess proportions of specific crash types**

    The measure determines the extent to which a specific crash type is overrepresented when compared to other crash types at a location. The locations in the reference population are ranked based on the difference between the observed proportion of crashes and the threshold proportion. The calculation procedure is the same as the Probability of specific crash types except in the final ranking which sets a limiting probability. The ranking is based on the excess (difference between observed and threshold) exceeds a limiting probability.

11. **Expected average crash frequency with empirical Bayes (EB) adjustment**

    The Empirical Bayes (EB) procedure can be used to estimate the expected average number of crashes. To be consistent with the network screening applications in Safety Analyst this method uses annual correction factors. Based on observed data over a sequence of years, a calculated annual correction factor and the (EB) weighted adjustment, the base and final year EB-adjusted expected average crash frequency are estimated, with the variance of the EB-adjusted average crash frequency. Then, ranking may be determined.

12. **Equivalent Property Damage Only (EPDO) average crash frequency with empirical Bayes (EB) adjustment**

    This method is based on a combination of the approach described earlier as the EAN approach (nº 3) using accident cost or some other weight adjustment and method nº 11 above. The calculations results in a ranking of all locations under consideration in the reference population based on an EB-adjusted EPDO score with the highest score representing the location with the highest potential to reduce the number of crashes.

13. **Excess expected average crash frequency with empirical Bayes (EB) adjustment**

    The final method is applied to estimate expected crash frequency. The method is based on the procedure described for approach nº 11 but then the difference between the predicted estimates and EB-adjusted estimates for each location are calculated and the locations are ranked.

Selection of the performance measure is largely determined by data availability; regression to the mean bias and the performance thresholds/limits.

7.3.3 Data availability

Table 7.2 provides an overview of the data and other requirements necessary to apply the specific performance measures.

Table 7.2 Data needs per performance measure (AASHTO, 2010)

Performance measure	Required data and or other input				
	Crash data	**Road data (for homogeneous grouping)**	**Traffic volumes (AADT; Peak hour)**	**Calibrated Safety Performance functions (SPF) and over dispersion parameters**	**Other**
Average crash frequency	X	X			
Crash rate	X	X	X		
EPDO average crash frequency	X	X			EPDO weighting factors
Relative severity index	X	X			Relative severity indices
Critical rate	X	X	X		
Excess predicted average crash frequency using method of moments*	X	X	X		
LOSS	X	X	X	X	
Excess predicted average crash frequency using SPF	X	X	X	X	
Probability of specific crash types exceeding threshold proportion	X	X			
Excess proportion of specific crash types	X	X			
Expected average crash frequency with EB-adjustment	X	X	X	X	
EPDO average crash frequency with EB-adjustment	X	X	X	X	EPDO weighting factors
Excess expected average crash frequency with EB-adjustment	X	X	X	X	

Note * The Method of Moments necessitates an adjustment of observed crash frequency based on the variance in the crash data and average crash counts of reference population. Traffic volumes are required to establish the reference populations based on ranges of traffic volumes as well as site geometric characteristics.

7.3.4 Summary of performance measures, strengths and weaknesses

Table 7.3 summarises whether the performance measures discussed in Section 7.3.2 account for regression to the mean (RTM) and/or a performance threshold. In addition, reported strengths and weaknesses of each measure are indicated (AASHTO, 2010; Harwood et al., 2010).

Table 7.3: Performance measures strengths and weaknesses

Performance measure	Accounts for RTM	Estimates performance threshold	Strengths	Weaknesses
Average crash frequency	No	No	Easy to calculate	Does not account for exposure Does not identify low volume collision locations with high benefit cost potential
Crash rate	No	No	Simple Can be modified to account for severity	Comparisons cannot be made across locations with significantly different traffic volumes
EPDO average crash frequency	No	No	Simple Considers severity	Does not account for traffic volume Depending on weighting factors, may overemphasize locations with low number of severe crashes
Relative severity index	No	Yes	Simple Crash type and severity accounted for	Depending on weighting factors used, may overstate locations with low number of severe crashes Does not account for exposure Low volume, low crash sits may be highly ranked
Critical rate	No, only variance	Yes	Variance in crash data considered Reduces effect of low volume	
Excess predicted average crash frequency using method of moments*	No, only variance	Yes	Variance in crash data considered Sites of all types in one list Method concepts similar to EB	Does not account for exposure Some locations with low frequency non target crash types may be highly ranked Ranking is influenced by reference populations, sites near boundaries may be over emphasized
LOSS	No, only variance	Avg. frequency ± 1,5 standard deviation	Variance in crash data Accounts for exposure	RTM effects still possible
Excess predicted average crash frequency using SPF	No	Avg. crash frequency	Accounts for exposure	RTM bias may still be present
Probability of specific crash types exceeding threshold proportion	Not effected by RTM	Yes	Can be used as diagnostic tool Variance in crash data Not affected by RTM bias	Does not account for exposure Some locations with low frequency non target crash types may be highly ranked
Excess proportion of specific crash types	Not effected by RTM	Yes	Can be used as diagnostic tool Variance in crash data Not affected by RTM bias	Does not account for exposure Some locations with low frequency non target crash types may be highly ranked
Expected average crash frequency with EB-adjustment	Yes	Expected average crash frequency	Accounts for RTM bias	Requires SPF calibrated to local conditions
EPDO average crash frequency with EB-adjustment	Yes	Expected avg. crash frequency	Accounts for RTM bias Considers severity	Depending on weighting factors, may overemphasize locations with low number of severe crashes
Excess expected average crash frequency with EB-adjustment	Yes	Expected average crash frequency per year	Accounts for RTM bias	Requires SPF calibrated to local conditions

7.4 *Selecting the screening method*

The fourth step in the network screening process is the selection of one of the following screening methods:

- Sections (road sections or ramps) are screened on the basis of a sliding window or peak searching method

  Roadway segments are typically 100metres long and the purpose of applying a segment screening method is to identify which portion of that segment affects the critical crash frequency in order to more effectively identify countermeasures. Although in many cases a simple ranking may be applied whereby the performance measure is calculated for the entire length, it is preferable to apply the sliding window or peak searching methods to identify the location within the segment which will benefit the most from remedial measures.

- Nodes (intersections or ramp terminals) are screened using a simple ranking method

  Node based screening focuses on intersections, ramp terminals and at-grade railway crossings. For this reason a simple ranking procedure can be applied whereby the performance measure is calculated for each site and these ranked from highest to lowest. An adapted peak searching method may also be applied

- Facilities (combinations of nodes and segments) are screened using a combination of screening methods.

7.4.1 **Sliding window method**

With this method a road section is divided into shorter subsections (windows) that overlap each other with fixed intervals. For example, a 1 km road section can be split into 5 windows of 200m and with an increment of 100m whereby the first window would cover 0 to 200m, the next 100 – 300m, the next 200-400m, the next 300-500m etc.. The chosen performance measure is then calculated for each window and the window with the highest crash reduction potential would be selected to represent the specific section under consideration.

7.4.2 **Peak searching method**

With this method each road section is subdivided into windows of similar (preferably equal) length (usually 100m) with no overlap between windows. In situations where the road section does not divide exactly by the increment size, the last window will be the length of the increment but will overlap with the previous window (e.g. a road section is 1285m long. Using an increment of 100m means that the last section is only 85m long. To comply with the increment size the last window would therefore be chosen to cover distance 1185m to 1285m). The selected performance measure for each window is then calculated as is the coefficient of variation for that window using

the equations

$$\text{Coefficient of variation (CV)} = \frac{\sqrt{[Var(\text{performance measures})]}}{\text{Performance measures}}$$

and where

$$\text{Variance (Perf. Measures)} = \frac{(x_1 - x_{avg})^2 + (x_2 - x_{avg})^2 + (x_3 - x_{avg})^2 + (x_4 - x_{avg})^2 \text{ etc}}{n-1}$$

where x_1 = *Performance measure for window 1*

etc.

A large CV value suggests a low level of precision in the estimate whereas a low value represents a high level of precision.

The calculated coefficient of variation for each segment is compared to specified limiting CV. If the calculated CV is equal or less than that the limiting CV, it may be used in ranking the segment. If not, then the segment length is incrementally increased and the CV is recalculated for each new window. This continues until such time that the condition is met ($CV_{calc} \leq CV_{limiting}$) or the maximum window length is reached (i.e. window length equals section length). Once a window meets this condition, the process may be stopped. The performance measure for that window then meets the desired precision level and the performance measure may be selected to represent the road section under consideration.

7.4.3 **Simple ranking method**

This method is suited for both nodes (intersections; ramp terminals and at grade railway crossings) and segments and is no more than a ranking based on the calculated performance measure for each location. The location with the highest ranking gets the highest priority for further study and/or remedial treatment.

7.4.4 **Applicability of screening methods**

Table 7.4 summarises the applicability of the three screening methods to the different performance measures. The peak searching method on road sections can only be applied for screening in combination with performance measure calculation where EB adjustments are made. The other road section screening methods can be used in combination with all performance measure calculation. Also important to note that at facilities (length of road/freeway comprising connected roadway sections and intersections) only four performance measures can be applied in combination with the simple ranking method.

Table 7.4: Screening Method Applications (AASHTO, 2010; Harwood et al., 2010)

	Segments			Nodes	Facilities
Performance measure	**Simple Ranking**	**Sliding Window**	**Peak Searching**	**Simple Ranking**	**Simple Ranking**
Average Crash Frequency	Yes	Yes	No	Yes	Yes
Crash Rate	Yes	Yes	No	Yes	Yes
Equivalent Property Damage Only (EPDO) Average Crash Frequency	Yes	Yes	No	Yes	Yes
Relative Severity Index	Yes	Yes	No	Yes	No
Critical Crash Rate	Yes	Yes	No	Yes	Yes
Excess Predicted Average Crash Frequency Using Method of Moments	Yes	Yes	No	Yes	No
Level of Service of Safety	Yes	Yes	No	Yes	No
Excess Predicted Average Crash Frequency Using SPFs	Yes	Yes	No	Yes	No
Probability of Specific Crash Types Exceeding Threshold Proportion	Yes	Yes	No	Yes	No
Excess Proportion of Specific Crash Types	Yes	Yes	No	Yes	No
Expected Average Crash Frequency with EB Adjustment	Yes	Yes	Yes	Yes	No
EPDO Average Crash Frequency with EB Adjustment	Yes	Yes	Yes	Yes	No
Excess Expected Average Crash Frequency with EB Adjustment	Yes	Yes	Yes	Yes	No

7.5 *Screen and evaluate results*

In the foregoing section the method to calculate the performance measures and apply the screening method was discussed. The results of this process are recorded in spread sheets, tabulated or on maps. These outputs and lists reflect locations ranked from those with the highest crash risk (or in other words with the most potential to benefit from remedial treatments) to those with the lowest and showing some cut-off point. As discussed earlier, in many cases the reliability of the generated lists can be substantially improved if more than one performance measure is calculated. In this way the results using the same input data are calculated for a number of performance measures resulting in multiple lists with the same set of locations. By comparing results across different applied methods, locations consistently appearing at the top of the different lists are certain to be those to benefit the most from further analysis and treatment. Similarly, locations appearing at the bottom of all or most lists can be confidently left from further evaluation.

8 Accident modelling (APM)

8.1 *Introduction*

An accident prediction model (APM) is a mathematical relation between the number of crashes and several road (element or intersection) characteristics. They can be used to give an estimate of the expected number of crashes on a road or intersection, based on the characteristics of that road or intersection. APMs are fitted to historical accident data to find this relation. Therefore, the word 'prediction' is somewhat misleading; a better word should be 'explanatory' or 'descriptive'. Nevertheless, prediction is concerned with statements about the likely values of unobserved events, not necessarily those in the future (McCullagh & Nelder, 1989)

APMs have been developed and applied within the scope of the RISMET project, namely in Work Package 4 where these models were successfully applied on accident injury data registered over several years at intersections of the rural road networks of Norway, Austria, Portugal and the Netherlands (Azeredo-Lopes & Cordoso, 2011).

8.2 *Model form*

The general form of an APM is as follows:

$$\mu = \alpha \cdot e^{\sum_{j=1}^{m} \gamma_j \cdot x_j}.$$

Here μ is the expected number of road crashes on a road section or intersection in a certain period, $x_j, j = 1, \dots, m$ are *m* characteristics of that road section of intersection, also called explanatory variables or predictors and α and $\gamma_j, j = 1, \dots, m,$ are the parameters to be estimated. The most important characteristic is the amount of traffic, because more traffic generally leads to more crashes. Hence one of the explanatory variables should describe the amount of traffic. In most APMs this explanatory variable is the annual average daily traffic (AADT). For intersections often the AADT on the minor road and on the major road are distinguished. APMs for road sections should also at least include the length of the road section. Again, the longer the section, the more crashes there will be. This leads to the following two general forms for APMs, one for road sections and one for intersections:

$$\mu = \alpha \cdot AADT^{\beta_1} \cdot L^{\beta_2} \cdot e^{\sum_{j=1}^{m} \gamma_j \cdot x_j},$$

$$\mu = \alpha \cdot AADT_{\text{minor}}^{\beta_1} \cdot AADT_{\text{major}}^{\beta_2} \cdot e^{\sum_{j=1}^{m} \gamma_j \cdot x_j}.$$

Note that the effects of the amount of traffic and the road length are modelled in terms of elasticity, which is the power to which these variables are raised. These elasticities approximate the percentage change of μ when the AADT or road length increases by 1%.

The other explanatory variables $x_j, j = 1, \dots, m$ are not defined yet in the above formulas. It depends on the research question for which APMs are developed and on the available data. In the ideal situation however, the choice of explanatory variables to be included ought to be based on theory and not on data availability. According to Reurings et al. (2007) they should include variables that:

- have been found in previous studies to exert a major influence on the number of crashes;
- can be measured in a valid and reliable way;

- are not very highly correlated with other explanatory variables included.

8.3 *Data requirements*

As mentioned in the previous section, the AADT and, in case of road sections, the length of the sections, are crucial data to develop APMs. Road length is in general available, or rather easy to collect. The AADT of roads and intersections is however not generally available in each country.

Furthermore, information should be available on the explanatory variables that one wants to include in the model. Which variables should be included often depends on the research question.

8.4 *Development*

The development of APMs consists of fitting the models in Section 8.2 to historical accident data. This means that the model parameters are estimated in such a way that the model and the observed data correspond as good as possible, i.e. the model fits the data. The technique that is mostly used in APM development is generalized linear modelling. In this section we will give an overview of this technique, which can also be found in the appendix of Reurings & Janssen (2006).

8.4.1 **General theory**

In this section, the capitals U, X, Y, Z with or without indices, denote stochastic variables. The realisations of these stochastic variables are denoted by u, x, y, z, also possibly with indices. A vector is denoted with a boldface symbol, for example $\boldsymbol{Y} = (Y_1, \ldots, Y_n)^T$, which is a stochastic vector consisting of n components. Finally, an estimate of prediction is indicated with a circumflex, i.e., $\hat{y}$ is the predicted value of y.

Now, let $\boldsymbol{Y}$ be an n-dimensional stochastic vector with independently distributed components $Y_1, \ldots, Y_n$ and let $\boldsymbol{y}$ be the vector with the observed values of $\boldsymbol{Y}$. The mean of $\boldsymbol{Y}$ is given by $\boldsymbol{\mu} = (\mu_1, \ldots, \mu_n)^T$ where $\mu_i = \mathbb{E}(Y_i),\ i = 1, \ldots, n$. The mean $\boldsymbol{\mu}$ can be specified in terms of p variables of which the values are given by $x_1, \ldots, x_p$, i.e., the i-th element of x_j is the value of the j-th variable corresponding to μ_i. In case of ordinary linear regression Y_i is assumed to be normally distributed with mean μ_i and constant variance σ^2. Further, μ_i is supposed to be a linear combination of $x_{i1}, \ldots, x_{ip}$:

$$\mu_i = \beta_0 + \sum_{j=1}^{p} x_{ij}\beta_j, \quad i = 1, \ldots, n,$$

for unknown parameters $\beta_0, \ldots, \beta_p$. By allowing $\boldsymbol{x}_0$ be a vector with each entry equal to 1, this formula can be rewritten as

$$\mu = \sum_{j=0}^{p} \boldsymbol{x}_j\beta_j, \text{ or } \mu_i = \sum_{j=0}^{p} x_{ij}\beta_j \;\; i = 1, \ldots, n.$$

The parameters are estimated by means of the ordinary least squares method. From the formula above it follows that

$$Y_i = \sum_{j=0}^{p} x_{ij}\beta_j + e_{i,}$$

where e_i is a normally distributed stochastic variable with mean 0 and variance σ^2 for $i = 1,\ldots,n$. The e_i's are called the error terms and can be estimated by the residuals, i.e., $\hat{e}_i = y_i - \hat{y}_i$, where $\hat{y}_i$ is the value of Y_i predicted by the model (also called fitted values).

If the components of $\boldsymbol{Y}$ are not normally distributed with constant variance or if the relation between the mean $\boldsymbol{\mu}$ and the explanatory variables is not a linear one, then use can be made of generalized linear modelling. Like the traditional linear models, these models consist of a linear predictor $\boldsymbol{\eta}$:

$$\boldsymbol{\eta} = \sum_{j=0}^{p} \boldsymbol{x}_j\beta_j.$$

However, the relation between the mean $\boldsymbol{\mu}$ of the dependent variable $\boldsymbol{Y}$ and the linear predictor $\boldsymbol{\eta}$ is not necessarily given by the equality $\boldsymbol{\mu} = \boldsymbol{\eta}$, but by $g(\mu_i) = \eta_i$, for $i = 1,\ldots,n,$ where g is a monotone and differentiable map called the link function.

8.4.2 Estimating the model parameters

Once a model is selected, its parameters are estimated and its precision is assessed. In the case of generalized linear models the estimation proceeds by defining a measure of goodness-of-fit between the observed data and the fitted values generated by the model. The parameter estimates are the values that minimize the goodness of fit criterion(McCullagh & Nelder, 1989).

The parameters $\beta_0,\ldots,\beta_p$ of a generalized linear model can be estimated with the maximum likelihood method, which coincides with the ordinary least squares method in case of normally distributed error terms. The maximum likelihood method involves maximizing the log likelihood function $l(\boldsymbol{\mu};\boldsymbol{y})$ over $\beta_0,\ldots,\beta_p$ to get estimates for the parameters $\beta_0,\ldots,\beta_p$. The log likelihood function is given by

$$l(\boldsymbol{\mu};\boldsymbol{y}) = \sum_{i=1}^{n} l_i(y_i;\mu_i) = \sum_{i=1}^{n} \log f_i\,(y_i;\mu_i),$$

where $f_i(y_i;\mu_i)$ is the distribution of Yi given the parameter μ_i.

The Bayesian estimation of model parameters derives from the calculation of an *a priori* probability distribution (i.e. the probability distribution that express the uncertainty about the parameters before the data is collected) and the data observed, Y (given by the likelihood). The prior belief about the parameters is afterwards combined with the data's likelihood function according to the Bayes theorem resulting in the posterior densities of the parameters. In Work Package 4 of the RISMET project these techniques were used to fit APMs for sets of intersection data collected in four European countries(Azeredo-Lopes & Cordoso, 2011).

8.4.3 **The application to road crashes**

Consider a collection of n road segments or n intersections. The number of road crashes on the i-th segment or intersection in a certain fixed period is described by the Poisson distributed stochastic variable Y_i. The relation between μ_i, the expected value of Y_i, and the explanatory variables is

$$\log(\mu_i) = \sum_{j=0}^{p} x_{ij}\beta_j, \quad i = 1, \ldots, n,$$

so the link function is $g(\mu_i) = \log(\mu_i)$. The parameters $\beta_0, \ldots, \beta_p$ are estimated with the maximum likelihood estimates, which are determined by maximizing the following log likelihood function over $\beta_0, \ldots, \beta_p$:

$$l(\boldsymbol{y}; \boldsymbol{\mu}) = \sum_{i=1}^{n} (y_i \cdot \log(\mu_i) - \mu_i).$$

In most cases the resulting model suffers from over dispersion. This means that the variance is larger than expected on the basis of the chosen distribution. One explanation for over dispersion is that the components of $\boldsymbol{Y}$ are indeed Poisson distributed, but that the means $\mu_1, \ldots, \mu_n$ are not constant: they vary between the different road segments and/or intersections in an (imaginary) selection for which $\boldsymbol{x}_0, \ldots, \boldsymbol{x}_p$ have the same values. Hence it can be assumed that the means of the Poisson distributions are stochastic variables themselves, e.g. $\Lambda_1, \ldots, \Lambda_n$.

Generally nothing is known about the distribution of $\Lambda_1, \ldots, \Lambda_n$. However, it is often assumed that they are Gamma distributed. Some theoretical and psychological background for this assumption is provided by Abbess, Jarrett & Wright (1981) and Maycock (Maycock)s.a). Under the assumption that Λ_i is Gamma distributed with $\mathbb{E}(\Lambda_i) = \mu_i$ and $\mathbb{V}\mathrm{ar}(\Lambda_i) = \nu$, the variable Y_i has a negative binomial distribution, so

$$\mathbb{P}(Y_i = y_i) = \frac{\Gamma(\nu + y_i)}{\Gamma(\nu) y_i!} \left(\frac{\nu}{\nu + \mu_i}\right)^{\nu} \left(\frac{\mu_i}{\nu + \mu_i}\right)^{y_i}$$

and

$$\mathbb{E}(Y_i) = \mu_i, \quad \mathbb{V}\mathrm{ar}(Y_i) = \mu_i + \frac{\mu_i^2}{\nu}.$$

The model to be fitted is of the same type as the model based on the Poisson distribution. In other words, the link function for a model based on the negative binomial distribution is $g(\mu_i) = \log(\mu_i)$. The parameters $\beta_0, \ldots, \beta_p$ are estimated with the maximum likelihood method. The log likelihood function corresponding to the negative binomial distribution is

$$l(\boldsymbol{y}; \boldsymbol{\mu}) = \sum_{i=1}^{n} \log\left(\frac{\Gamma(\nu + y_i)}{\Gamma(\nu) y_i!}\right) - (y_i + \nu) \log\left(\frac{\nu + \mu_i}{\nu}\right) + y_i \log\left(\frac{\mu_i}{\nu}\right).$$

In the case of negative binomial distribution, not only the parameters $\beta_0, \ldots, \beta_p$ have to be estimated, but also the parameter ν. In the literature this is done by first developing a model based on the Poisson distribution and then estimating ν using the residuals of this model. The derived value of ν is then used to fit a model based on the negative binomial distribution. Now ν is again estimated, using the residuals of the new model, and again a new model is fitted. This procedure is repeated until the dispersion parameter is close enough to 1.

8.4.4 **Model assessment**

Model assessment involves both choices between competing models in terms of best fit and checks to ensure model adequacy. Therefore, even if one model has superior fit, it still needs to be checked whether predictions from the model reproduce satisfactorily the observed data. The goodness-of-fit of a model can be measured in several ways. One way is by the scaled deviance, $D^*(\boldsymbol{y}, \hat{\boldsymbol{\mu}})$, where $\hat{\boldsymbol{\mu}}$ is the value of $\boldsymbol{\mu}$ predicted by the model. The scaled deviance is equal to twice the difference between the maximum achievable value of the log likelihood function and the achieved value of this function by the model under consideration. So the scaled deviance is

$$D^*(\boldsymbol{y}, \hat{\boldsymbol{\mu}}) = 2\big(l(\hat{\boldsymbol{\mu}}; \boldsymbol{y}) - l(\boldsymbol{y}; \boldsymbol{y})\big).$$

$D^*(\boldsymbol{y}, \hat{\boldsymbol{\mu}})$ is called the scaled deviance because it is equal to the deviance $D(\boldsymbol{y}, \hat{\boldsymbol{\mu}})$, divided by the dispersion parameter. In formula

$$D^*(\boldsymbol{y}, \hat{\boldsymbol{\mu}}) = \frac{D(\boldsymbol{y}, \hat{\boldsymbol{\mu}})}{\varphi}.$$

Another goodness-of-fit measure is Pearson's χ^2, which is defined as follows:

$$\chi^2 = \sum_{i=1}^{n} \frac{(y_i - \hat{\mu}_i)^2}{V(\hat{\mu}_i)}.$$

Analogously to the deviance the scaled Pearson's χ^2 is defined as Pearson's χ^2 divided by φ.

Under the assumption that the fitted model is true, the scaled versions of both the deviance and Pearson's χ^2 are approximately χ^2_{n-p-1} distributed. For this reason the scaled deviance and the scaled Pearson's χ^2 can be used to estimate the dispersion parameter φ in case its value is unknown. Indeed, the mean of D^* is equal to $n-p-1$ because D^* is χ^2 $n-p-1$ distributed. Setting $D^* = n-p-1$ and solving $D^* = D/\varphi$ for φ leads to

$$\hat{\varphi} = \frac{D}{n-p-1}.$$

A similar expression can be deduced for Pearson's χ^2. If many of the predicted expected values of Y are smaller than 1, then it is possible that the scaled deviance is much smaller than the number of degrees of freedom. Hence the scaled deviance cannot be used as a measure for the goodness-of-fit of the model. In this case Pearson's χ^2 can be used.

In ordinary linear regression the residuals can be used to check the assumptions of the model. They should be independent normally distributed variables with constant variance. If these conditions are not satisfied, the conclusions about the statistical significance of the estimated parameters might be too optimistic. If generalized linear modelling is applied to the data, the residuals will not meet the three conditions mentioned above. However, in this case there is another type of residuals which behaves like the residuals in ordinary linear regression and can therefore be used to check the adequacy of the fit of the model. This type of residuals consists of the standardized deviance residuals which are defined as follows:

$$DR_i = \frac{\sqrt{d_i}\left(\operatorname{sign}(y_i - \hat{\mu}_i)\right)}{\sqrt{\hat{\varphi}(1 - h_i)}},$$

where d_i is the contribution of the i-th observation to the deviance and h_i is the i-th diagonal entry of the matrix

$$W^{\frac{1}{2}}X(X^T WX)^{-1}X^T W^{\frac{1}{2}},$$

with $W = \operatorname{diag}(\hat{\mu}_1, \dots, \hat{\mu}_n)$ and X is the design matrix.

8.5 *Applications*

APMs can be used by road authorities in several ways.

APMs are important for measuring safety through accident and injury frequencies, as they may be used to estimate the long term expected number of crashes at a specific road element (for example, a curve or an intersection), through the empirical Bayes method (Hauer & Bamfo, 1997). Then the expected number of crashes may be used to compare the safety performance of a roadway location with the expected safety performance of comparable sites; to identify deviant sites, with extremely high expected number of crashes, for safety intervention; to evaluate the safety effect of safety interventions; and to forecast safety performance developments of alternative planning scenarios and preliminary design schemes.

8.6 *Potential pitfalls*

In an earlier RISMET-report (Elvik, 2011) some potential pitfalls were identified in relation with APMs. First of all, APMs merely show statistical associations instead of causal relationships. Therefore, when a researcher is looking for such a causal relationship, it becomes important to control for confounding factors when developing a model. According to Elvik (2011) the following confounding factors are likely to be present in many APMs:

- Bias due to aggregation, averaging or incompleteness of data. This in particular holds for the AADT, as it is both an average (over a year) and an aggregate (of the various types of vehicles that make up traffic) and it is very often incomplete (pedestrians and cyclists are rarely included). Further, also accident reporting is often incomplete.
- The model form is incorrect and does not correctly show the effects of the explanatory variables. Most models tend to rely on the assumption that all relationships are monotonic. Functional forms ought to be tested in an exploratory analysis.
- Not all relevant variables are always included in an APM.
- Often all crashes are taken into account, not depending on their severity. This mixing of accident severity levels can produce results that are almost impossible to interpret. If separate models cannot be fitted for crashes at each level of severity, then at least accident severity ought to be included as a variable in the model.

For establishing causality it is also necessary to identify the mechanisms that generate the statistical relationships between variables and to check whether or not the shape of the statistical relationships is plausible in view of relevant background knowledge, which includes laws of physics, laws of human perception and information processing, traffic flow theory, and other well-established elements of knowledge gained in engineering and related sciences.

8.7 *Brief results of the APMs obtained in RISMET WP4*

One important task of RISMET's WP4 concerned the attainment of APMs using accident data registered on rural road junctions of four European countries (Norway, Austria, Portugal and the Netherlands). The APMs concerned consisted of generalised linear regression models obtained through Bayesian statistical techniques employing vague (also called non-informative) prior and hyper-prior distributions for the unknown parameters (i.e. the parameters to be estimated). The use of vague distributions was due to the lack of previous information or knowledge about those parameters. The model form adopted was suggested by Eenink et al. (2008) and also Lord (2006) since it is the most favoured by the transportation safety modellers for modelling crash data at intersections (Lord, 2006). The model's assessment and goodness-of-fit was performed according to the recommended Bayesian approaches described in this chapter.

The regression models considered had the injury accident frequencies as the dependent variable and the remaining variables, namely major and minor AADT values, number of legs, approaching speed limit, traffic control and type of junction, as explanatory.

Three models consisting of the Poisson regression model, hierarchical Poisson-Gamma and Poisson Log-Normal hierarchical regression model were fit to each set of data with the aim of finding the one which provided the best fit. The Poisson regression model was found to be not appropriate to model the junction data in any of the data sets due to not being able to capture variations and attributes of the data, namely the over-dispersion. The Poisson-Gamma and the Poisson Log-Normal models obtained similar results and in general performed equally well. It was found that crashes occurring at junctions in all countries depend on the junction's entering traffic volume as well as the other explanatory variables considered.

9 Road protection scoring

These methods involve the collection of road characteristics data which are then used to identify safety deficits or determine, how well the road environment protects the user from death or disabling injury when a crash occurs. Road protection scoring can be considered a ‘proactive’ approach to road safety management.

This type of method is particularly useful where crash data are of poor quality, sparsely distributed or are not geo-referenced and so more traditional reactive approaches (e.g. hotspot analyses and treatments) are not possible.

9.1 *Introduction*

The most common use of this type of methodology is by the Road Assessment Programmes worldwide: EuroRAP (European Road Assessment Programme), usRAP (US Road Assessment Programme), AusRAP (Australian Road Assessment Programme) and iRAP (International Road Assessment Programme) among others.

The Star Rating (or Road Protection Score) EuroRAP protocol began as an assessment of how forgiving the road is, in an analogous manner to the European New Car Assessment Programme (EuroNCAP) which was, in part, inspiration for the development of EuroRAP. The Road Protection Scoring methodology was developed by Swedish Roads Authority (SRA), ADAC (German Automobile Club) and EuroRAP, with technical support and input from TRL.

The method included the collection of road characteristics data that are known to influence the severity of three main crash types (Lynam, Castle et al., 2006):

- Run-off road crashes;
- Head-on crashes;
- Crashes at intersections.

Essentially the methodology allowed the identification of safety deficits in the way that the road user was ‘protected’ in the event of a crash. Different levels of protection were categorised into star rating bands, and so the results could be presented cartographically. These were published by motoring organisations, thus informing road users about the relative protection offered by different road sections.

EuroRAP became inspiration for other Road Assessment Programmes around the world, such as usRAP and AusRAP. The Australian version of the Star Rating protocol started to include the notion of crash likelihood as well as protection. EuroRAP has subsequently moved in the direction of including crash likelihood in its Star Rating methodology.

The iRAP inspection methodology was developed primarily for low and middle income countries; however it has subsequently been used in several countries in Europe and will become the focus for future inspections in the region. The methodology is described in the sections that follow.

9.2 *Goals and Objectives*

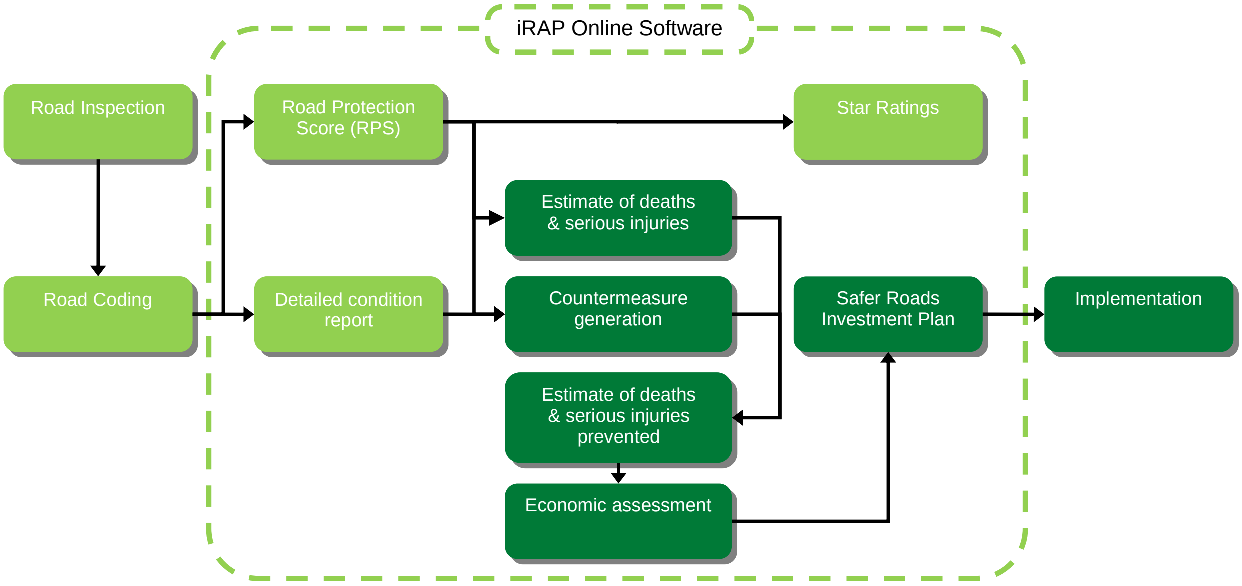
The iRAP method uses road environment characteristics data to identify safety deficits and generate a programme of investment that can be used to reduce casualties. According to iRAP "The approach of Star Rating and subsequent development of Safer Roads Investment Plans represents a systematic approach to road infrastructure design and renewal based on research about where severe crashes are likely and predictable" (iRAP, 2009b)(p. 4).

The output at the end of an iRAP inspection is a Safer Roads Investment Plan that "draws on 70 proven road improvement options to generate affordable and economically sound infrastructure options for saving lives" (iRAP, 2009b, p.4).

9.3 *Data Requirements and Collection Methodology*

The overall iRAP methodology is represented in Figure 9.1. The Star Rating methodology report (iRAP, 2009b) describes the processes shown using light green boxes and the dark green boxes are further described in the Safer Road Investment Plan document (iRAP, 2009a). Both are available in the library section of the iRAP website: http://www.irap.org/library/cat_view/4-research-and-technical-papers.html

Figure 9.1: The iRAP road inspection, Star Rating and Safer Roads Investment Plan process (reproduced with permission from iRAP, 2009a)



Road element data are collected using a video-based method. In video-based inspections, very high quality videos are collected that are geo referenced. These are later coded by a team in an office setting. Several cameras are used in order to get a panoramic view of the road and the main forward view is calibrated in order to allow accurate measurements to be taken later. A coding/rating team then uses specialised software to record details of the road.

Approximately 30 road infrastructure characteristics or elements are recorded throughout the inspected network. These elements are aspects of the road environment known to influence either the likelihood of crashes occurring or the severity of those crashes that do occur. In the iRAP methodology consideration is given to all road user groups including motorcyclists, pedal cyclists and pedestrians, alongside the three main crash types for motorised vehicles (head-on, run-off and intersection). Data on actual driven speeds are also collected.

Traffic volumes, treatment costs, crash data and data to inform crash saving calculations can also be entered.

9.4 *Analysis*

Once the road element data have been collected, these are uploaded into the iRAP analysis tools. These tools are based on algorithms that have been developed to:

- Estimate the number of casualties that would be expected based on the road elements
- Trigger appropriate countermeasures (logic based system) that would treat safety deficits that have been detected
- Re-estimate the number of casualties that would be expected on the basis of the new treatments being in place
- Economically appraise the benefits and costs of the proposed treatments to produce a Safer Roads Investment Plan

The iRAP analysis tool generates a Safer Roads Investment Plan that provides an indication of the cost of different treatment options and the associated casualty savings. The treatment options can be appraised since it is possible to assign an estimated value for the prevention of a fatality or injury; this means that the iRAP Safer Roads Investment Plans can be presented alongside economic appraisal data such as BCRs (Benefit to Cost Ratio).

9.5 *Interpretation of Results and Design of Remedial Programmes*

Results of the analyses are presented in the iRAP on-line analysis system. This system is easy to use for the road safety stakeholders involved in an iRAP inspection. The data are presented cartographically and on interactive maps. The results can be viewed at all levels – from a short road section up to a network wide view.

The following outputs are presented:

- Summary data describing the road elements (by small section, road, or network wide);
- Star ratings;
- Potential treatments for application across the network (includes cartographic presentation – see
- Figure **9.2**);
- Estimates of casualty savings (includes cartographic presentation);
- Economic appraisal of overall Safer Roads Improvement Plans.

Figure 9.2: Locations for countermeasures (reproduced with permission from iRAP, 2009a)

One important stage of the iRAP process is the sense checking of the results of the model by experienced road safety engineers. This is important, since it is necessary to take into account local conditions when considering implementation of the Safer Roads Investment Plans.

10 Identification and analysis of hazardous locations (Blackspot safety management – BSM))

This chapter presents a best practice guideline based on recent state-of-the-art evaluations of blackspot safety management (BSM) in RIPCORD-ISEREST (Sørensen, 2007; Sørensen & Elvik, 2008) and in Eranet Roads RISMET (Elvik, 2011). The guideline discusses the elements of BSM, its purpose, the procedures when applying BSM, and the approach to the prioritisation and selection of remedial treatments. The approach adopted by the guidelines is based on the state-of-the-art defined by Sørensen and Elvik (2007; 2008; 2011) and makes use of Empirical Bayes techniques to control for random fluctuations in the observed number of crashes.

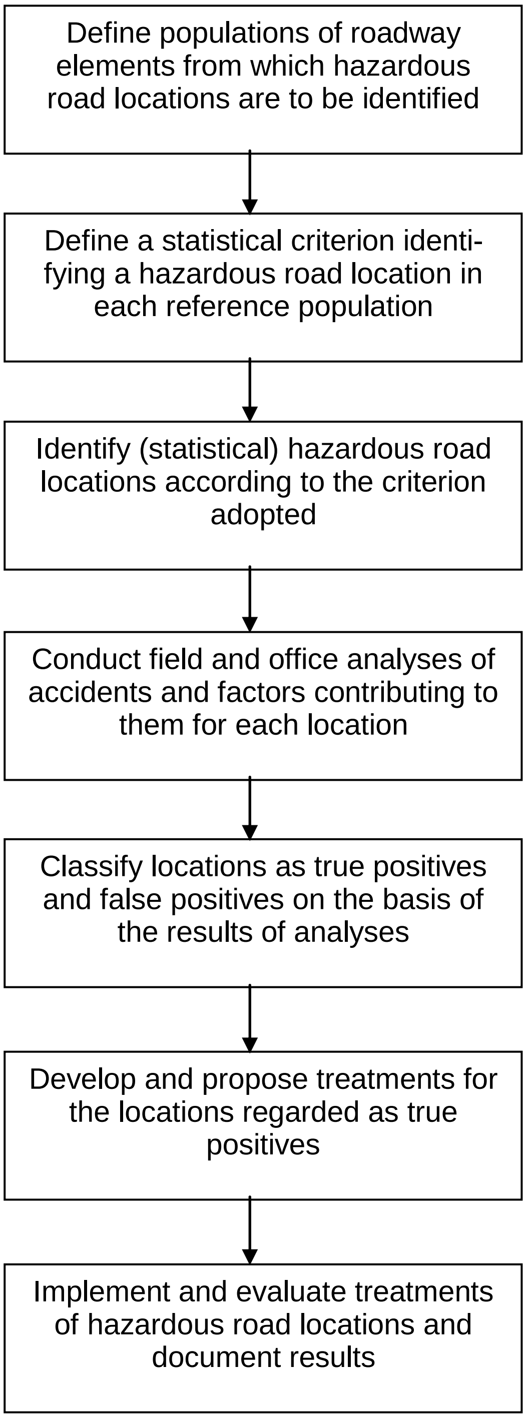
10.1 *Introduction*

Blackspot management has long been used by traffic engineers worldwide to identify and treat locations with higher than average numbers of crashes. Although in many ways similar to Network Safety Management, BSM has always been a purely reactive instrument aimed at finding road safety treatments at a very local level. Historically BSM management has relied on identifying so called blackspots (also called hazardous locations, hot spots, high accident concentrations, sites with promise etc.) based on a some formal definition which takes into account the number of recorded crashes during a given time period (e.g. 4 injury crashes in three years). The blackspot approach has been applied in many countries and is widely regarded as having made an important contribution to reducing the number of crashes (e.g. in Australia the blackspot program yielded benefit-cost ratios of higher than 4:1, Bureau of Transportation Economics, 1995). It is a particularly useful tool in situations where high accident concentrations are evident and where further detailed analysis of accident types can lead to low cost remedial treatments. In its state-of-the-art form, seven main stages of blackspot management can be identified. These stages are listed in Figure 10.1.

The first stage is to define populations of roadway elements from which the hazardous road locations can be identified. Examples of roadway elements that can serve as a sampling frame for identifying hazardous road locations are:

1. Junctions, who may be further grouped according to, for example, the number of legs and the type of traffic control.
2. Access points, which could be classified according to type of use (residential, commercial, industrial, agricultural).
3. Horizontal curves with radius in a certain range.
4. Road sections of a certain length.
5. Bridges
6. Tunnels

Figure 10.1: Stages of blackspot management



The reason why it is important to define populations of roadway elements, is that this permits the amount of systematic variation in the number of crashes to be determined and allows precise statistical criteria of deviance to be formulated. In practice, blackspots are not always identified from a defined population of roadway elements. A fairly common method is to use a sliding window approach (see Section 7.4.1). According to this approach, a window of a given length is moved along the road and the count of crashes within the window is continuously updated. Whenever a local maximum is found, the window will identify a hazardous road location. Thus, as an example, if a window with a length of 100 metres is used and crashes are located at kilometres 1.20, 1.28, 1.33, 1.33, 1.34 and 1.44, the window will start sliding at km 1.20 and contain 2 crashes at this location (since the crashes at km 1.33 are 130 metres away from the one at km 1.20). When the window slides forward to the next accident, it will stop at km 1.33 and now contain all crashes between km 1.23 and km 1.33 (3 crashes). It will then slide to km 1.34 and now contain 4 crashes (between km 1.24 and km 1.34). When it slides further down to km 1.44, it will only contain 2 crashes (those at km 1.34 and km 1.44). The window is fixed at the position that gives the highest number of crashes that pass the critical number for a hazardous road location. If, in the example above, the critical count is 3, the hazardous road location will be fixed between km 1.24 and 1.34 and contain 4 crashes.

Using a sliding window to identify hazardous road locations is discouraged, as this approach will inflate the number of false positives (more about this below).

The second stage of blackspot management is to develop a statistical criterion for deviance, i.e. define a critical number of crashes that must be exceeded for a site to be identified as hazardous. It is essential to identify hazardous road locations in terms of the expected number of crashes, not the recorded number of crashes. The only currently known statistical technique that can identify hazardous road locations in terms of the expected number of crashes is the Empirical Bayes (EB) approach. The Empirical Bayes method should be used to identify hazardous road locations. The basic logic of this method is explained in a subsequent section of this chapter.

The third stage of blackspot management is to identify statistically hazardous road locations according to the criterion of deviance defined in stage two. The stringency of the criterion of deviance will typically depend on pragmatic considerations. One would not want a liberal criterion that identifies thousands of locations, as there will not be capacity to analyse all these locations. Any statistical criterion should be sufficiently restrictive to ensure that the majority of hazardous road locations have a number of crashes that permits a meaningful analysis of common patterns in the crashes and factors contributing to these patterns. Less than, say, five crashes, would not provide a basis for meaningful analyses.

The fourth stage of blackspot management is to conduct analyses, both in the office and in the field by visiting each location. The purpose of these analyses should be to determine whether the location is truly a hazardous locations or a “false positive”, i.e. a site where the number of crashes was mainly the result of random variation. It is important to consider the accident conditions when visiting the blackspot location. If most of the crashes at a blackspot occurred e.g. at night-time, the on-site visit should be also done at night-time. The same is true for crashes at wet weather conditions, in rush-hour etc.

The fifth stage is to classify locations as true and false positives on the basis of the analyses conducted in stage four. For the sites that are classified as false positives, this ends the process. For the sites that are classified as true positives, one proceeds to the next stage of analysis, which is to develop and propose treatments. There will usually be more than one treatment that may be possible. A broad perspective on potential treatments should therefore be adopted. Costs and benefits of alternative treatments should be assessed and potential treatments ranked according to cost-effectiveness. When for sustainable improvements comprehensive constructional measures will be developed it should be taken into account, that often lengthy planning phases are necessary. To prevent further crashes while this time, immediate measures should be implemented.

The final stage of blackspot management is to implement and evaluate treatments. It is important to perform evaluation studies systematically and employ methods that control for important confounding factors such as regression-to-the-mean, long-term trends in the number of crashes and changes in traffic volume.

10.2 *Definition and purpose*

Most countries have adopted their own definition for black spots and these tend to differ for a number of reasons. Elvik (Elvik, 2008c) compared definitions of blackspots in a sample of European countries in terms of six characteristics:

1. Whether hazardous road locations are identified by reference to a population of similar sites, i.e. by means of sampling from a predefined list of sites or identified without referring to any population of sites.

2. Whether a sliding window method is used to identify hazardous road locations.

3. Whether hazardous road locations are identified in terms of deviance from a normal level of safety or without reference to a normal level of safety.

4. Whether hazardous road locations are identified in terms of the recorded or expected number of crashes.

5. Whether accident severity is considered in identifying hazardous road locations or not.

6. The length of the period used to identify hazardous road locations.

The operational definitions of blackspots used were found to vary with respect to all these characteristics.

However, most definitions have a similarity in that black spots are defined as locations having higher crash numbers over a given number of years than other similar locations. Locations are generally defined as an intersection or as a stretch of road of given length (typically 100m).

There appears to be consensus that numerical criteria for defining black spots may be defined in three distinctly different ways (Persaud, Lyon, & Nguyen, 1999; Hauer et al., 2002b; Vistisen, 2002; Elvik, 2008c), namely:

- Numerical definitions such as number of crashes; crash rate and a combination of the two. For example in the Netherlands a location is defined as hazardous when 10 crashes with similar characteristics (e.g. injury crashes or pedestrian-crashes) occur at one location in 3-5 years. According to crash rate definitions a black spot could be any location where the number of injury crashes per million vehicle-kilometres estimated over a given number of years exceeds some threshold value.

- Statistical definitions such as critical values of crash number or crash rate. With statistical definitions black spots are defined as those locations where the recorded number of injury crashes (or rate) over a specific time period is (statistically) significantly higher that the “normal” crash number (or rate) at similar locations.

- Model based definitions such as EB estimates and dispersion values. These definitions are derived from APM (see chapter 8) and the EB method is acknowledged as the current state of the art. A number of model based definitions have been developed and explored (Persaud et al., 1999; Vistisen, 2002; Elvik, 2008a, 2011).

Elvik (Elvik, 2008c) has proposed that the following theoretical definition be adopted :

“A hazardous location (black spot) is any location that has a higher expected number of crashes than other similar locations as a result of local risk factors present at the location”.

The definition comprises three key elements, namely expected crashes, comparison to similar locations and local risk factors. Although not part of this definition, it is advisable to define a time period over which the numbers of crashes are measured. International good practice suggests a minimum of three years but preferably five years. Furthermore, it is advisable to include some description of the severity of these crashes and then it and recognised practice to focus of fatal and serious injury (requiring hospitalisation) crashes.

Regarding the number of crashes it is recommended to identify hazardous locations by the long term expected number of crashes as opposed to using the more traditional actual (observed) number of crashes. Since it is known that observed crashes reflect both random and systematic variation, it is not efficient to treat a location as hazardous simply because it happened to record a high number of crashes in a specific (and relatively) short period of time. The emphasis of safety analysis should be on the systematic variation (which usually can be identified and therefore also treated).

The second element in the definition relates to comparing similar locations (also termed general factors). Black spots should form part of populations of locations with similar characteristics (i.e. be part of the same homogenous group). This population is generally defined by characteristics such as the same speed limit, road width, horizontal curve radius, number of approaches, intersection type etc. In addition, operational features such as traffic volumes can be used in determining these groupings. By grouping into homogenous populations one can control for general explanatory factors. This is important, since it is not efficient to treat a location trying to bring its safety level to a higher rank than its normal safety level.

Since it is not possible (or practical) to disaggregate these populations to account for every single distinguishing variable or factor, a third element, local risk factors, is introduced in the definition to account for crashes which are attributable to local conditions (also termed local factors). These are the target factors to address when defining the safety interventions.

In order to be able to classify hazardous locations by this definition one must be able to identify the contributions of these three elements to the expected number of crashes at a particular location. The EB-method allows for such estimates to be made and the relative contribution of these three elements (random variation, general and local factors) to the observed number of crashes can be determined.

10.3 *Identification and selection*

The steps described for the identification of hazardous locations conform to what was described earlier in Chapter 7 (Network Screening).

10.3.1 **Defining network locations**

The first step in this process (see also Figure 10.1) is to define the characteristics to which locations must comply in order to be grouped in a certain population of locations. For example:

a. Road sections of a given length and given number of lanes;
b. Junctions with a given number of approaches and type of traffic control;
c. Interchanges with a given design and ramp configuration;
d. Horizontal curves with radius in a given range;
e. Bridges of a given design;
f. Tunnels by length and geometry.

Once the locations have been grouped, theoretical probability distributions of crashes can be fitted to the crash data using APM (see chapter 8) and statistical criteria applied to define black spot locations.

Sørensen and Elvik (Sørensen & Elvik, 2008) and Elvik (2011) do not recommend applying the sliding window approach (see section 10.1) for identifying black spots/hazardous locations. According to their state of the art review they concluded that the sliding window approach artificially inflates the number of black spots (i.e. false positives, some road sections are falsely indicated as hazardous). The sliding window approach is more suited to network screening applications where longer road sections are analysed and where the sliding window approach is ideally suited to locate sub-sections within these longer sections that can be used as the section norm (i.e. the sub-section with the most improvement potential represents the entire longer section being screened). In a blackspot approach road sections are by definition already short and dividing these into even shorter subsections has little merit.

The section length defined by the blackspot is quite critical. If it is too short it may occur that crashes essentially belonging to the same problem are spread over two sections and it can occur that neither section is be identified as a blackspot (called a false negative problem). On the other hand, making them too long could have the opposite effect (false positives). Taking into consideration that eligible safety interventions may include small modifications to the road alignment section length may vary with road class. For instance, in Portugal, 250 m sections are used on single carriageway roads and 500 m sections on motorways and other high speed roads (Cardoso, 1998).

The first step in the process is to assign crashes to the defined network locations. It is considered best practice to divide the road network into smaller roadway elements (Sørensen & Elvik, 2008; Elvik, 2011). Although the exact classification may vary from country to country, it is recommended to apply at least the following distinction between types of intersections and road sections:

Intersections	Road sections
Rural or urban	Rural or urban
Type	Type
Roundabout	Straight with specified length (<100m)
Priority control	Horizontal curve with range of radii
Stop control	Vertical curves
On/off ramps	Bridges/tunnels
Number of approaches	Speed limit

In order to be able to categorise a road network into this classification one needs road network data (Candappa et al., 2011). Preferably the road network is digitally available (with GPS co-ordinates, road numbers and kilometre markers) and to which underlying road characteristics and crashes can be linked. Although non accident based indicators have been used in the identification of blackspots, this guideline for blackspot management adopts the recommendations of Sørensen and Elvik (2008) and Elvik, 2011, namely that the identification of these locations is at least to some extent reliant on registered crash data.

10.3.2 Recommended identification methods

Different countries use different methods by which to identify blackspots. Sørensen and Elvik (2008) recommend three methods, all of which are model or category based methods which take into account systematic and random variation.

The preferred and state of the art method is the EB-method which is also recommended in this guideline.

The state of the art approach for identifying hazardous locations based on expected number of crashes estimated by the empirical Bayes method (Sørensen & Elvik, 2008; Elvik, 2011). With this method the expected number of crashes at a location is estimated by applying weights to the observed number of crashes at that location and to the expected number of crashes at similar locations as estimated by an APM using the following equation:

$$E(\lambda|r) = \alpha\times\lambda+(1-\alpha) \times r$$

Where

$E(\lambda|r)$ = expected number of crashes at a specific location where r crashes where registered in the analysis period

$$\alpha = \frac{1}{1+\lambda/k} \quad \text{(weight)}$$

λ = Expected number of crashes at similar locations as estimated by accident model ($E(\lambda) = \alpha_i Q^{\beta i}$ where Q is traffic volume and α_i and β_i are regression coefficients) r = registered crashes at the location

k = the inverse value of the over dispersion parameter (See also chapter 8)

When compared to other methods for selecting blackspots (counts; rates; combined rate and count and EB-dispersion criteria), the EB method was found by Sørensen and Elvik (2008) and Elvik (Elvik, 2008a) to perform best at all three levels of stringency tested. A distinct advantage of the method is that when compared to the more traditional approaches it minimised the number of false positives and false negatives.

Sørensen and Elvik (2008) outline 7 steps that a road authority could adopt should they wish to implement a model based approach for identification purposes in road safety analysis. Typically accident models are used for blackspot/hazardous location identification; before and after studies; design layout evaluation and assessing the effect of road reconstructions. These steps are:

1. Defining objective and application;
2. Identifying and selecting the dependent and independent variables;
3. Data collection;
4. Selecting the method of estimation;
5. Regression analysis;
6. Assessing goodness of fit;
7. Empirical Bayes estimation.

Details of accident modelling are discussed in another chapter (8) of this guideline.

10.4 *Analysis and selection of remedial treatments*

Ideally speaking, analysis of crashes and factors contributing to them at hazardous road locations will provide a good basis for selecting safety treatments. However, as currently practised, analyses are not likely to always be conclusive. Based on a review of research, Elvik (Elvik, 2006a) points to the following problems of the approach commonly used.

1. The frequently used criterion for a true black spot – the presence of a clearly identifiable pattern of crashes characterised by the dominance of a particular type of accident – may not effectively separate true from false black spots.
2. Sites that have been analysed and selected for treatment do not necessarily have a higher long-term expected number of crashes than similar sites that have not been analysed and selected for treatment. Treatments do not appear to always successfully address risk factors contributing to crashes.
3. Analysts may find it difficult to resist the temptation to conclude that a site at which a high number of crashes have been recorded must have some deficiency in design or traffic control, even if no clear accident pattern pointing to such deficiencies can be identified. The idea that an analysis might be inconclusive is unappealing and resisted.

A new approach to the analysis of hazardous locations is proposed that embodies the following features:

1. The use of a binomial probability model to estimate the probability that the observed pattern of crashes at a hazardous road location differs from the normal pattern for comparable sites.
2. A two stage procedure for analysis, in which the first stage consists of an analysis of crashes designed to develop hypotheses about risk factors contributing to the crashes and the second stage is designed to test these hypotheses.
3. The use of a matched pair, single blind method for evaluating risk factors contributing to crashes at hazardous road locations.
4. The development of clear criteria for concluding whether an apparently hazardous road location actually is so or not.

These elements are designed to guard against some of the pitfalls of the traditional approach to accident analysis for hazardous road locations, including confirmation of analyst expectancies, data mining, and non-specific criteria for determining whether a hazardous road location is a true or false positive.

If analysis concludes that a site is truly a blackspot, the next task is to propose remedial treatments. There will usually be more than one treatment that can be applied. A broad perspective should therefore be taken in surveying potentially effective treatments.

10.5 *Implementation, monitoring and evaluation*

It is important to systematically evaluate the effects on safety of blackspot treatments. The history of such evaluations is not very glorious. It is much closer to a disgrace to the profession of civil engineering. Elvik reviewed studies that have evaluated the effects of blackspot treatment. The main findings of the review are reproduced below.

The identification, analysis and treatment of hazardous road location, also referred to as black spots (Elvik, 1997) or sites with promise (Hauer, 1996) has a long tradition in traffic engineering. This approach to crash prevention has been widely applied and has been regarded as a rational and evidence-based approach to crash prevention. Thus, the Institution of Highways and Transportation noted (1990):

“It is well established that considerable safety benefits may accrue from application of appropriate road engineering or traffic management measures at hazardous road locations. Results from such applications at “black spots” demonstrating high returns from relatively low cost measures have been reported worldwide”.

In other words: There have been many studies of the effects of treating hazardous road locations; these studies have been reported in all parts of the world; therefore the results of these studies can be applied to predict the effects of such treatments.

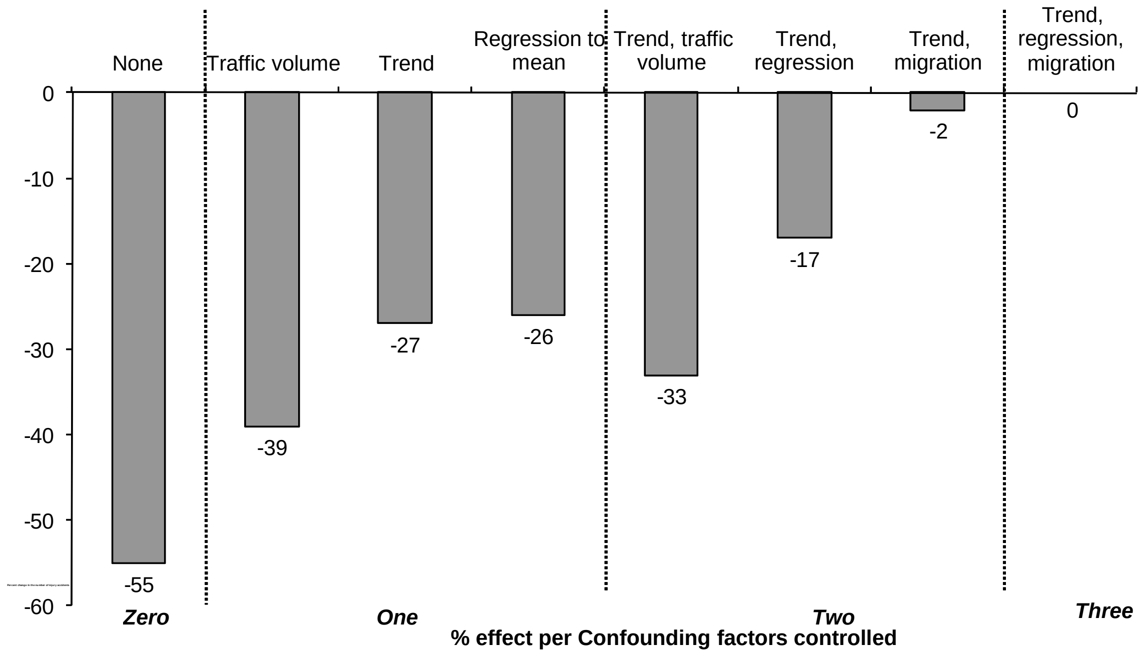
Unfortunately, the claim made by the Institution of Highways and Transportation does not withstand critical scrutiny. Elvik (Elvik, 1997) performed a meta-analysis of 36 evaluation studies reported during 28 years in six countries. In principle, these studies represent a sufficient range of replications for a formal assessment of their external validity to make sense. All the studies were before-and-after studies. Diversity of study designs was therefore not an issue.

When the studies were examined critically with respect to how well they controlled for potentially confounding factors, it was found that studies varied greatly in this respect. Four potentially confounding factors in before-and-after studies of treatment of hazardous road locations were considered:

1. Regression-to-the-mean;
2. Long term trends in the number of crashes;
3. Changes in traffic volume;
4. Crash migration.

It should be noted that these potentially confounding factors will not always actually confound study results. However, the only way to find out whether a potentially confounding factor actually does influence study results, is to control for the factor by means of study design or statistical estimation. Regression-to-the-mean is very likely to be present when a site has been selected for treatment based on a bad crash record. Figure 10.2 shows the effect on injury crashes for studies that controlled for various confounding factors.

Figure 10.2: Effects attributed to black spot treatment in studies controlling for various confounding factors (Based on Elvik, 1997)



It is seen that the effect attributed to treatment varies greatly depending on which confounding factors the studies controlled for. Simple before-and-after studies, not controlling for any confounding factors, reported an impressive 55 per cent crash reduction. Studies controlling for regression-to-the-mean, long term trends and crash migration found no effect of treatment. No study had controlled for all the four potentially confounding factors considered. There were only four studies that had controlled for at least three of the four potentially confounding factors. Three of these studies had been reported in Great Britain, the fourth in the United States. These four studies had not evaluated the same types of treatment. The studies do therefore not provide any meaningful basis for assessing the international transferability of the results of studies that have evaluated the effects of treating hazardous road locations.

10.6 *Steps for improving current practice*

A number of steps can be taken to improve current practice with respect to black spot management. Some important steps include:

1. Develop a classification of roadway elements and make an inventory of each of these. Examples of roadway elements could be intersections, curves with radius in a certain range, sections of a given length, tunnels or bridges. This allows a population of roadway elements to be formed so that the distribution of crashes in each population can be identified. Once this distribution is known, it will be possible to: (a) control for regression-to-the-mean, either by developing EB-estimates of safety based on an accident prediction model, or by applying simpler techniques; (b) identify hazardous road locations as those locations that constitute the upper percentiles of the distribution.

2. Develop accident prediction models for each type of roadway element defined in step 1. This will support the development of EB-estimates of safety, which can identify hazardous road locations more accurately than any of the techniques currently used.

3. Identify hazardous road locations as the upper percentiles of the distribution of EB-estimates of safety for each type of roadway element. Do not identify hazardous road locations as those locations that have a high excessive number of crashes compared to some normal number.

The research reported in this paper did not address reasons why the state-of-the-art approach has not been implemented. It should be noted, however, that it is easy to erroneously believe that the more primitive approaches used in many countries are effective. After all, the number of crashes will in many cases go down following treatment, even if this may partly or fully be the result of regression-to-the-mean. The importance of basing techniques for identifying hazardous road locations on a profound and theoretically founded understanding of accident statistics cannot be overstated.

11 Impact assessment of investments and road safety measures (referred to as road safety impact assessment in EU Directive)

11.1 *Introduction to RIA*

Road safety Impact Assessments (RIA) are mandatory for all EU countries, under the Directive 2008/96/EC (European Commission, 2008) and have to be carried out whenever substantial infrastructure modifications are applied to the Trans-European road Network, either by constructing a new road or by improving existing road stretches. According to that EU Directive a road safety impact assessment is a "strategic comparative analysis of the impact of a new road or a substantial modification to the existing network on the safety performance of the road network".

RIA is essentially a planning tool, that involves assessing the current safety level of the road network (in most cases part of a network) and estimating its safety level as resulting from one or more alternative development scenarios. It aims at comparing the safety effects of each available development scenario, including the do-nothing scenario, in order that road infrastructure investment decisions consider explicitly their estimated safety consequences. RIA is carried out at the initial planning stage before the infrastructure project is approved and indicates the road safety considerations which contribute to the choice of the proposed solution.

According to the Directive, RIA shall provide all relevant information necessary for a cost-benefit analysis of the safety aspects of different options assessed. Besides accident and fatality frequencies, RIA should take into account route choice and traffic patterns, likely effects on the existing networks, seasonal and climatic conditions; impacts on all road user categories are expected to be analysed. The Directive also states that RIA should address seismic activity issues and the presence of a sufficient number of safe parking areas; these issues are not dealt with in this report, as earthquakes do not relate directly to road safety and there is little knowledge on the influence of rest areas density on accident frequency (Elvik et al., 2009).

This chapter provides guidelines for conducting Road Safety Impact Assessments and brings together the state of the art in Europe at present (Elvik, 2011). The guidelines describe the methodology, tools, and requirements for carrying out RIA.

11.2 *Background and definitions*

Decisions concerning developments affecting the road network are regularly assisted by information concerning their expected impact on traffic operations. This information is usually obtained through traffic impact studies, where the effects of traffic caused by a new land use development are assessed and possible improvements are identified, that may be required in order that the road network will operate at an acceptable level of service. Traffic operation impacts of interventions on existing roads are routinely evaluated as well, especially as related to changes in capacity and level of service.

Up until recently, traffic impact studies seldom dealt explicitly with the effects of interventions on road safety. However, safety is also an important aspect of road transport. Furthermore, currently, developments in knowledge on road safety allow for *a priori* comparison of anticipated safety levels of alternative configurations for a road network or resulting from different key characteristics of selected road elements detailed design. The potential therefore exists for a proactive approach, in which roads are evaluated at the planning and preliminary design phases for their potential to operate safely. RIA is in line with the perceived advantage in the explicit consideration of safety aspects on road investment decision making, as early as possible and preferably at the opening stages of the planning phase.

The World Road Association (Technical Committee 13 Road Safety PIARC, 2004) defines road safety impact assessment as a strategic comparative analysis of the impact of a new road, of alternatives or of substantial modifications to the existing network on the safety performance of the road network. The purpose is to demonstrate, at a strategic level, the implications on road safety of different planning alternatives of an infrastructure project. RIA is carried out at the initial planning stage before the infrastructure project is approved.

In the RIPCORD-ISEREST project road safety impact assessment is described as a methodology to assess at the planning phase the impact of road schemes on safety (Eenink et al., 2008). These can be major road works, a new bridge etc. that may or may not be intended to raise the safety level. A RIA can also concern a wider scheme i.e. be intended to make plans for upgrading the safety level of a national or local road network.

This is the definition adopted in RISMET and in this report (Elvik, 2011).

11.3 ***Scope***

As mentioned before, RIA is performed to allow for the explicit consideration of safety in planning decisions concerning the road network configuration or operation. Safety aspects to consider should include the direct effects of the new roadway elements on the affected route and indirect effects on the rest of the road network. As an example, the suppression of left turning at an intersection has a direct impact on its safety level and an indirect effect on the safety of nearby roundabouts – due to increase in their traffic volumes. Two types of planning objects may be subject to RIA:

1. Planning and design of a new roadway connection, redesign of an existing road stretch or road element (for example, an intersection), or the implementation of new traffic control strategies and devices.
2. Planning of infrastructure safety interventions within the framework of national or regional safety strategies (or even at the road administration level), such as the installation of a new signing system for curves in trunk roads.

In the first case, the main objective is to ensure that impacts on safety are considered with the same technical relevance as other important planning issues such as traffic levels of service, aerial emissions and the barrier effect. This may be achieved by comparing suitable safety performance measures associated with each alternative scenario. Elements for alternative scenarios are defined according to the relevant level of decision: roadway category, number of lanes, type of intersection or interchange and type of traffic control are examples of elements considered at the planning and preliminary design phases; lane width and type of traffic channelization at an intersection are cases of differentiating elements appropriate for scenarios for a design phase RIA.

In the second case, the objective consists in measuring the impact of road safety interventions available to the road network administration, in order to support the selection of both the most favourable set to be implemented and the priority and weight allocated to each intervention. This type of RIA helps to support decisions concerning the distribution of annual road safety funds, as regards their assignment to, for example, resurfacing campaigns surface, sign replacing, marking renewal, black spot treatment, and other alternative measures. Network wide scenario impacts are analysed in this type of RIA.

11.4 *Procedures*

Execution of RIA involve the application of techniques for scenario development and assessment, to define relevant scenarios for interventions in the roadways being analysed and estimate and compare the corresponding safety levels, taking into account simply the number of crashes and injuries or including the associated costs, using monetizing techniques, as well.

Overall, a basic RIA requires the following steps:

- Assess the baseline (original) safety level, which describes the current situation (year 0), with respect to traffic volumes and crashes in the analysed roadway (or road network).
- Identify and characterize the “do-nothing” scenario, considering that no intervention will be implemented and assuming that traffic and safety developments will follow previous national or regional trends.
- Define alternative scenarios which result from different design layouts (scope a.) or from diverse sets of interventions (scope b.). In several cases the function of roads may change, for instance by upgrading distributor roads or by introducing 30 km/h zones in residential areas, which may possibly result in re-directing traffic.
- Quantify the safety level of each scenario in the target year.
- Compare safety levels.
- Optimize the selected scenario, fine tuning the chosen interventions and the implementation sequence.

More sophisticated RIA may be carried out if scenarios are assessed in terms of the resulting safety levels and the implementation costs, through either cost-benefit or cost-effectiveness analysis. In all cases, the RIA report should describe the safety arguments supporting the selected interventions in the retained scenario.

11.5 *Methodological issues*

11.5.1 **Safety performance measures**

Assessing the safety impact of interventions on road infrastructure may involve expert opinion, use of reference values from technical handbooks, use of crash risk indexes or the application of accident prediction models (see chapter 8), or exercised by means of cost-effectiveness and cost-benefit analysis.

Expert opinion is a qualitative assessment by experts who may score each relevant safety aspect and intervention using a discrete scale. It is easy to apply; however subjective qualifications are subject to intra-observer variability (the same issue obtaining different classifications by the same expert on different occasions) as well as external variability (the same issue obtaining diverse classifications by different experts at the same time), both affecting negatively their validity and reliability.

Several handbooks exist currently that describe the effects of individual road safety measures. In general the values provided are science based, resulting from national before-after observational studies or from meta-analysis of studies carried out in several countries. In more than a few cases these values have large confidence intervals, reflecting a strong dependency of the expected effects on the specific context of its application. A number of APM's are described in technical and scientific references, too. APM's establish the relations between the accident frequency of a roadway element (during a fixed period of time) and a selection of its characteristics – namely its average annual daily traffic, which corresponds to exposure, and other infrastructure related risk factors. These relations are calibrated for a specific set of roads, and the transferability of APM's to other road networks is a complex and scientifically demanding task, as referred by Persaud et al (2002). Currently, methods exist that may be used to achieve a satisfactory transferability of simple APM from one region to another – see AASHTO (2010) – and even between different countries, as shown by Cardoso et al (2010).

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The RIA potential for supporting safety arguments for decision making is best achieved through safety performance measures that relate directly to accident outcomes:

- the number of crashes and injuries (accident and injury frequencies);
- the costs associated with crashes and injuries (accident costs).

In both cases, usually values are presented for a fixed time period, one year being the most used reference.

The meanings of accident and injury frequencies are straightforward; injuries being classified according to their severity – fatal, serious and slight, see De Meester (2011). Assuming that the same proportion of occurring crashes is reported in official statistics, accident and injury frequencies are a common safety measure for all regions.

Accident cost rates correspond to the average costs to the economy as a whole of accident and injury occurrence, expressed by a monetary value per number of kilometres driven in a selected road. These rates are calculated on the basis of registered accident and injury frequencies, and estimates of both accident costs and AADT. Transferability of accident cost rates from one region (country) to another is not direct, due to spatial variability of accident costs. Furthermore, rates are associated with another methodological issue: the validity of the underlying assumption that accident costs vary linearly with the number of kilometres driven. The validity of this assumption is uncertain, as it has been shown that in some road classes the relations between accident frequencies and AADT are not linear (see for example, Azeredo Lopes & Cardoso, 2007b; Azeredo Lopes & Cardoso, 2007a; 2009). Accident cost rates, however, have the advantages of incorporating an implicit societal weighting of injury severity and of facilitating the application of cost-benefit analysis.

11.5.2 Estimating the number of crashes and injuries per reference time period

By nature, individual crashes are unpredictable; however, on a selected location the long term number of crashes occurring per unitary time period may be described by statistical relations.

The number of crashes registered at a location (for instance a particular road curve) during a reference time period varies with each particular period. Therefore, the number of crashes observed in a particular period is not a good indicator of the true value of the expected number of crashes, which has to be estimated using statistical methods. The observed variation in the number of crashes at a location may be expressed as resulting from the combination of two components, one systematic and another random; the systematic component may be described as including factors shared with other similar locations and factors peculiar to that particular site (Kutz, 2004). Road safety interventions are intended to address the systematic component.

Sophisticated APM are used to represent the influence of exposure (AADT) and several risk factors on accident occurrence; usually, the influence of site specific factors is not captured by APM. Examples of APM may be found in Reurings et al (2007), Eenink et al (Eenink et al., 2008), Azeredo & Cardoso (2011), AASHTO (2010) and Safety Analyst (AASHTO, 2011).

APM may be used to estimate current and future safety levels of a roadway element or network by direct application of their mathematical equations, once the corresponding values of the explanatory variables (AADT and risk factors) are known. In some applications, the accuracy of current safety levels estimates may be improved by combining the number of registered crashes at the analysed sites with the general information (on sites similar to the ones analysed) contained in the APM, which may be achieved through the empirical Bayes method (Hauer & Bamfo, 1997; Hauer, D.W. et al., 2002a).

When no APM are available, accident rates may be used to estimate the safety level of roadway elements, such as stretches of road. Accident rates (Expressed as crashes per unit of travelled distance) are usually obtained by summing up the number of crashes registered during a period of three to five years and dividing that number by the amount of distance travelled in the roadway in the same time period. Multi-year time periods are adopted in an attempt to reduce the impact of random variation in the calculated safety performance measure.

Estimations of the expected number of crashes using the empirical Bayes method are currently considered state-of-the-art (Elvik, 2007b, 2011).

Estimating the number of injuries is subject to additional theoretical and practical issues, as related to estimating accident frequencies. Crashes are mostly independent events; only on rare circumstances is the occurrence of an accident directly related to a previous or future accident. On the other end, the injury severities of crashed vehicle occupants are related to the impacts upon the vehicle, among other factors: therefore, the validity of the assumption that injuries are independent is questionable. Another issue is related to exposure estimates: when available, AADT estimates have a common level of accuracy; however, AADT should be compounded by vehicle occupancy to better reflect occupant injury exposure. Vehicle occupancy is seldom available with the same degree of disaggregation and accuracy as AADT. Due to these aspects only few injury APM are reported. Frequently, the number of injuries is calculated based on estimates of the number of crashes and on injury rates per severity. These correspond to the average number of injuries (of a selected severity) per accident.

11.5.3 **Estimation of accident costs**

Road crashes have several kinds of consequences, including loss of quality of life, damage to resources and the loss of human life itself. Monetizing these consequences is a difficult and delicate task, since it involves the valuation of intangibles, even if only from a statistical perspective. Quantification of road accident costs is, however, important to rationally manage safety intervention investments in the road infrastructure.

Accident costs may be grouped according to personal criteria, using the perspective of victims directly involved and their loved ones (medical costs, rehabilitation, loss of productivity, human and other economic costs) or by looking at the accident itself (value of damaged property, administrative costs and other costs). Other cost classifications are available (Alfaro, Chapuis, & Fabre, 1994), including direct costs (medical costs, rehabilitation, property damage, and administrative costs) and indirect costs (loss attributable to welfare effects on society, such as loss of productive capacity and human costs).

Basically three methods and techniques have been used to estimate accident costs: restitution costs, human capital and willingness to pay. In the first method, costs incurred by society to repair damage caused to the victims, their families and friends are calculated. In some cases, actual values are not directly calculated, being replaced by values obtained from court decisions.

In the method of human capital the cost of death and physical or psychological harm of crashes is calculated as a function of the productive potential of the involved victims, by calculating their loss of gross (or net) production.

According to the willingness to pay method, costs accepted by individuals to reduce the likelihood of getting injured are used to estimate the individual willingness to pay for safety. Assuming that life and safety are goods valued by individuals, the question is to assess the value that each individual and society as a whole attach to them. The value obtained results from the preferences revealed by individuals or by society itself; alternatively willingness to accept a compensation for risk may be used to calculate accident costs. This method is particularly effective to estimate implicit prices (not generated by the market); therefore its application for estimating human costs is advantageous (Hopkin & Simpson, 1995).

11.5.4 **Estimating the safety level of alternative scenarios**

Predicting the effect of alternative scenarios for both types of RIA is possible through the use of APM and reference handbook information.

At the national and site (road stretch) levels, required data for RIA application is frequently available. In fact, at the national level the type of general data needed – on traffic, road length, vehicle park, licensed driver population and socio-economic indicators – is already regularly collected, to support decisions concerning non-road safety related national policies. Data for site specific RIAs is included in the required data set for detailed design of infrastructure interventions. At this micro level, tools exist already that allow the comparative assessment of safety levels associated with several preliminary design aspects, such as the tools tested in RISMET WP 4 (Cardoso, 2011) and the Interactive Highway Safety Design Model (U.S. Department of Transportation DOT, 1998; Federal Highways Administration (FHWA), 2011) developed in the USA, which includes a driver simulation module (ITT Industries, 2004).

At the intermediate levels such as a regional or a municipal road network, however, carrying out a RIA may require that additional data on road network and traffic characteristics are collected and combined. Use of geographical information systems (GIS) may be a valuable tool for the definition of scenarios and the subsequent optimization of the most favoured one. At these intermediate levels, data gathering costs may be considerable, even though probably negligible when compared to the costs of the safety plans and the benefit of applying the method. Additionally, these additional data is relevant for other road network management activities, such as signalling and pavement and marking management. GIS may also be an instrument for roadway equipment inventory and maintenance management.

As an example, in the Netherlands the Regional Road Safety Explorer (RRSE) was used by 19 regions to optimize their safety plans to reach intended targets within the constraints of available budgets (Janssen, 2005). In the RRSE regional road safety levels in the target year are calculated on the basis of the known situation at the reference year (road length, traffic volumes and crash frequencies), the development of the planned sustainably safe road categorizing, the expected growth in road length and traffic until the target year, and the set of road safety measures to be implemented at the national levels and in each region (Janssen, 1997). RRSE was modified and tested in the EU project RIPCORD-ISEREST, as a decision support tool for secondary interurban road networks (Aydin, Iman et al., 2007).

Quality of results depends on the input data and on the assumptions concerning the effect of each possible measure and the combined effect of the selected set of measures. As already stated, existing information on the effects of corrective measures has a non-negligible uncertainty, due in part to context variability. Furthermore, the extent to which the full mitigating potential of a selected measure will be achieved depends on several factors, not all of them already known, or completely controlled by road administrations or road safety authorities.

Also, there remains an important open methodological question, concerning the combined effect of multiple corrective measures. One often used approach assumes that the first order effects are independent and multiplicative (Elvik, 2008b). However, according to this author the effects are not entirely independent, as measures that have large effects are likely to influence other risk factors as well, thus reducing their likely effects. In particular, this is likely to apply to measures that influence speed (like ISA-systems) or survivability (such as seat belts), since speed is a risk factor for all crashes. Elvik (2007a) developed a method for improving the estimates of the combined effects of several road measures, in which the common residuals are raised to the power of the residual of the most effective measure included in the set of measures.

Uncertainties attached to RIA results obtained should be discussed in the assessment report, and adopted assumptions clearly stated

Currently, several tools to assist in RIA execution are available. The Handbook of Road Safety Measures provides information regarding the effects of many minor road improvements (Elvik et al., 2009). The Highway Safety Manual (AASHTO, 2010) also provides guidance about how to plan and assess the impacts of minor road safety measures. An example of a road safety impact assessment at the national level was described in the RIPCORD-ISEREST project (Elvik, 2007b). Examples of the range of effects that road safety interventions may have were also collected and described in the ROSEBUD thematic network, carried out within the 5th EU Framework R&D Program (ROSEBUD, 2006).

12 Monitoring of road user behaviour

12.1 *Background, Definition and Scope*

“One of the most important factors influencing road safety is road user behaviour” (Elvik, 2011).

“Road user behaviour” covers several aspects and must be defined to clarify its meaning. First of all, the term “road user” is obviously not restricted to car drivers but also comprises pedestrians and cyclists. However, the focus in this deliverable is on car drivers. For car drivers, behaviour can be subdivided in driver and driving behaviour. The distinction between driver and driving behaviour is important because monitoring methods differ accordingly.

Weller et al. (Weller, Schlag et al., 2006) define driving behaviour as the outcome of the interaction between the driver and the vehicle in the environment. Driving behaviour is the measurable movement of a human-controlled vehicle within time and space. Two general variables of driving behaviour are distinguished:

- Longitudinal control with the variables speed (and its derivatives over time and space resulting in acceleration) and longitudinal distance to other objects.
- Lateral control with the variables lateral speed and lateral distance to a relevant path.

Driving behaviour can be analysed by solely recording the position of the vehicle within time and space. Alternatively, driver behaviour needs the monitoring of the driver and his actions: where does he look? Which buttons does he press? Driver behaviour is the visible result of top-down and bottom-up processes and driver states and traits (Weller et al., 2006; Weller, 2010). The monitoring of driver behaviour usually is labour intensive as it requires either an observer being at the site (direct observation) or the analysis of videos taken at the site (unobtrusive observation). This is predominantly because the behaviour of interest is shown within the vehicle and thus usually cannot be accurately and reliably detected otherwise.

When deciding to monitor behaviour a decision has to be made which behaviour to monitor. According to Elvik (2011), “ideally speaking, the choice of which types of behaviour to monitor ought to be based on the risk attributable to the specific form of behaviour. [...] It is, for example, important to monitor speed and speeding, because this behaviour is known to be of major importance for road safety. It may be somewhat less important to monitor cycle helmet wearing, because it makes a smaller contribution to the total number of crashes or injuries than speeding” (Elvik, 2011).

“It is, however, not possible to base the monitoring of road user behaviour strictly on the risk attributable to it, because this risk is sometimes unknown. As an example, there are few – if any – good estimates of the risk attributable to fatigue. As far as mobile phones are concerned, a few estimates of risk can be found, but these are inconsistent, both with respect to the methods used to estimate risk and the size of the estimated contribution. For some types of behaviour, like internal distractions (i.e. drivers do not concentrate fully on driving, but think about other things), unobtrusive monitoring is impossible” (Elvik, 2011). However, with available data, Elvik made a list with the most safety critical behaviours.

Once a decision has been made which behaviour to monitor, the study can be planned by following the subsequent practical steps (Eby, 2011).

12.2 *Planning and Preparation of Monitoring*

Before deciding to observe road user behaviour, several questions must be answered. Based on Eby (Eby, 2011) these are :

1. What is the purpose of monitoring the behaviour? Monitoring behaviour is good to determine event frequency or occurrence. Other approaches might be more appropriate to understand behaviour.
2. Can the behaviour of interest be accurately and reliably judged through visual inspection? This is the case for cycle helmet wearing and probably for seat belt wearing. However, other types of behaviour might be more difficult to detect. For example, drivers wearing wireless headsets and not speaking but listening at the time of observation might go unnoticed (Elvik, 2011).
3. What is the population of interest? This question must be asked to determine the extent of the observation.
4. What are the available resources? Monitoring driver behaviour on site is labour and thus cost intensive. Calculating estimated costs in advance avoids being surprised during the study.

After these questions have been answered, the detailed planning can start.

12.2.1 **Select Observation Sites and Times**

Eby (Eby, 2011) states that “perhaps the most common error in naturalistic observational studies is a poor sampling design”. Sampling in this context refers to the selection of sites and times during which the observation is to take place. A good sampling design allows extrapolating the observed behaviour to the population of interest without bias.

The number of sites to be selected must be based on an estimation of the probability of the behaviour under observation. This can be done by referring to earlier studies or by statistically estimating it. Eby and Vivoda estimated seat belt use via regression analysis with available census variables known to influence seat belt use (Eby & Vivoda, 2001). The second variable when determining the number of sites is the accepted sampling design error rate. In Eby (2011) a table is given indicating the number of sites needed depending on these two variables.

After the number of sites has been selected, the location of sites and their scheduling must be determined. Eby (Eby, 2011) suggests randomizing locations and times as far as possible and later weight the observed behaviour by traffic volume or population numbers.

12.2.2 **Definition of behaviour to be recorded**

Categories of the interesting behaviour must be defined as exactly as possible. These definitions must be documented.

12.2.3 Development of a recording device

Depending on the behaviour of interest a proper recording device needs to be developed. This can be paper and pencil (Eby, 2000) or handheld computers (Vivoda & Eby, 2006). A pre-test must be conducted to test both the categories and the instruments. Whereas a final pre-test should be conducted on site, a consultation of experts can help to reduce surprises.

12.2.4 Observer training

“Proper training of observers to conduct naturalistic observational studies is paramount” (Eby, 2011). The training should involve a test of the reliability after two or more observers recorded the same situation. Reliability means “the ability of the measure to produce the same results under the same conditions” (Field, 2009). Depending on the study designs, two forms of reliability can be distinguished, which can both be tested statistically:

- Test-retest reliability: is given when a behaviour is coded in the same way, independent of the time or place it was shown.
- Inter-observer or inter-rater reliability: is given when behaviour is coded in the same way by different observers.

12.2.5 Collecting the data

Probably the most important issue here is to include time for vehicle counts. Eby (2011) suggests using five minutes before and five minutes after a 50 minutes observation interval. As not all vehicles can be observed, this allows later extrapolating the number of observed vehicles to the real number of vehicles showing the behaviour of interest.

12.3 *Estimating the real rate of behaviour*

As has been previously stated, a certain sampling design error rate will be present in every study not observing the entire population. To express this sampling error, the 95% confident interval and the error rate must be calculated (Eby, 2000; Eby, 2011).

12.4 *Conclusion*

This chapter showed that a distinction must be made between the observation of driving and driver behaviour. Whereas driving behaviour can be observed with automatic recording devices, human observers are usually needed to observe driver behaviour. When human observers are involved a thorough observer training is required to ensure reliability of the observations. Independent of whether driving or driver behaviour is observed, a very detailed and carefully designed stratification of samples is needed to ensure the validity of the results.

13 Conflict studies

13.1 *Introduction*

“A traffic conflict is any event that would have resulted in an accident if road users had continued travelling without changing direction or speed. Conflicts can be rated according to their severity. A serious conflict is one that nearly results in an accident, in which the road user makes evasive manoeuvres at the last moment” (Elvik, 2011).

The rationale behind examining traffic conflicts is that conflicts are seen as preceding crashes (Risser, 1985). Following this idea, analysing conflicts would allow inferring information relevant for accident causation and even to predict crashes. This idea is also depicted in the iceberg analogue (see Figure 2.5). The challenge when using conflicts is to correctly estimate accident probability from conflict frequency (Davis, Hourdos et al., 2011).

13.2 *Traditional traffic conflict techniques*

Following the idea of the conflict/accident relationship, the traffic conflict technique (TCT) was developed in 1968 in the USA by Perkins and Harris (Shinar, 1984). The traffic conflict technique “... used to be a somewhat subjective technique, which relied on manual coding by human observers. Although these observers were able to make reliable observations when properly trained, a subjective element remained” (Elvik, 2011). Reliability of the TCT is discussed in more detail in various articles (Shinar, 1984; Chin & Quek, 1997; Archer, 2001). Furthermore, there are numerous articles offering practical advice when conducting a traditional TCT-study (Erke & Gstalter, 1985; Gårder, 1989; Chin & Quek, 1997).

Shinar (1984) distinguished between the traditional TCT approach which he named subjective, and an objective approach. In the past, this so-called objective approach was mainly based on a frame-to-frame analysis of video images with the aim to extract minimum distances or other objective measures. “Recent progress in software for analysing video images has transformed the study of traffic conflicts” (Elvik, 2011, p.15). Laureshyn (2010) developed a method allowing automated processing of video images.

Traditionally, time-to-collision (TTC), time headway or distance are used as the relevant objective measures. However, even when using seemingly objective measures, the relevance of conflicts as accident predictors attracts discussion (Lu, Cheng et al., 2011). This criticism is based on the idea that the number of conflicts and crashes should perfectly correlate. However, as Klebelsberg (1982) already pointed out, a perfect correlation with crashes would not be wished as the gain of studying conflicts instead of crashes would be nil. Furthermore, crashes are rare events from a statistical perspective and some of them happen “by accident” rather than being preceded by a conflict (see Weller et al., 2006 for a summary of the accident criteria). Thus, a medium correlation of conflicts and those kinds of crashes which could result from a specific conflict type would be best.

13.3 *Naturalistic driving studies and Field operational tests*

Traffic conflicts together with driver and driving behaviour can also be analysed in so-called naturalistic driving studies (NDS). Naturalistic driving studies "... includes objectively and unobtrusively observing normal drivers in their normal driving context while driving their own vehicles. Typically, participants get their own vehicles equipped with some sort of data logging device that can record various driving behaviours ..."(Backer-Grøndahl, Phillips et al., 2009).

Naturalistic driving studies are used because they fill a gap in research: experimental research in simulators or in the field either lacks external validity because the drivers are reminded of the research situation or it lacks the numbers of participants or kilometres driven to make reliable statements in relation to the statistically rare crashes (see above). In contrast, data from accident data bases allow inferring broader statistics but lack detailed information regarding causes leading to these crashes. These gaps can be filled with naturalistic driving studies in which a large number of participants drive for a longer period of time in their equipped vehicles. This allows collecting a large number of data from realistic environments.

Because of the vast differences between the three conflict-coding techniques named above (with trained human observers, with manual or automated video processing or by analysing data from naturalistic driving studies), it is not possible to give recommendations for one best method. Which method to apply, depends on the question to be answered and the resources available.

Conflicts are best monitored at a specific location - and not in naturalistic driving studies - when the aim is to assess the risk of a location such as a specific junction. Whether this monitoring is done by trained observers or by automated video analysis depends on the reliability and costs of both methods. With the fast progress the later type of method is making, automated analysis might be the best option.

Naturalistic driving studies are the method of choice to analyse the preceding factors of a specific conflict or accident. Here, the focus is on the driver (driver behaviour such as being distracted, and driving behaviour such as driving too fast) rather than on a specific location. Questions regarding the infrastructure and environment can also be answered but require that different locations with a similar design are grouped together. This is because drivers in a naturalistic driving study can drive freely and are by definition not bounded to a specific location.

Very closely related to NDS are field operational tests (FOT). The only characteristic in which FOT differ from NDS is their aim: in contrast to NDS in FOT a specific (vehicle) function or functions are evaluated. Details regarding FOT can be found in the FESTA project deliverables (FESTA, 2008) (see also http://www.its.leeds.ac.uk/festa/index.php).

According to Klauer et al. (2011) the following four steps are required when planning a naturalistic driving study:

- Study design and data collection
- Data preparation and storage
- Data coding
- Data analysis

Klauer et al. (2011) called this the life cycle of naturalistic driving studies. More details regarding these points are summarized in the following.

13.4 *Procedures*

13.4.1 Study design and data collection:

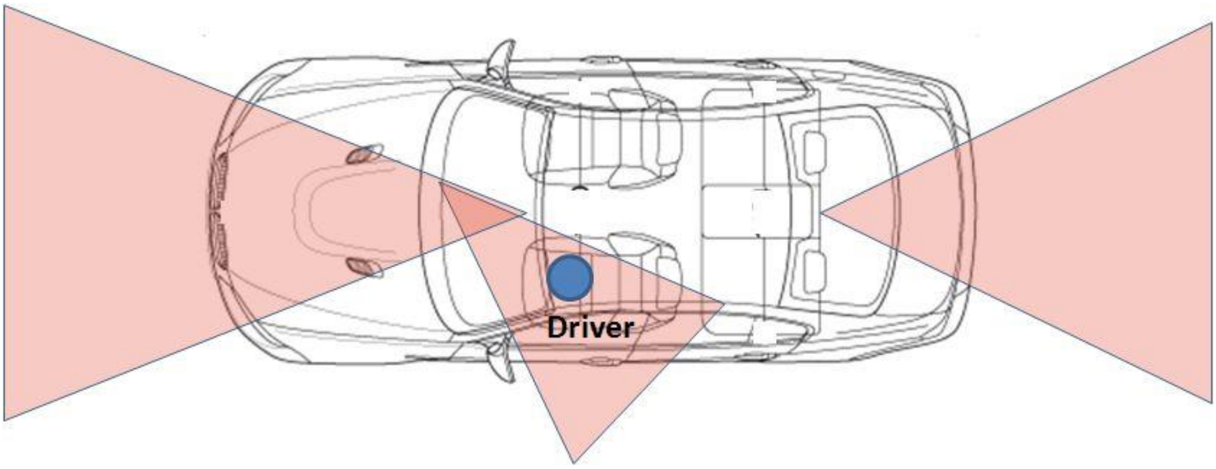
A well-defined research question and a detailed project management plan are critical for NDS because of the vast resources necessary to store, process and analyse data. Table 13.1 gives a generic overview of the different steps involved when planning a field operational test. Except for step 8, the same steps are required for naturalistic driving studies.

Table 13.1: A generic guide to schedule the 22 steps required when conduction a FOT study (FESTA Consortium, 2008).

		Set Up / Design		Preparation			Data Collection		Completion	
1	Convene teams and people									
2	Define aims, objectives, research questions & hypotheses									
3	Develop project management Plan									
4	Implement procedures for stakeholders communication									
5	Design the study									
6	Identify and resolve legal and ethical issues									
7	Select and obtain vehicles									
8	Select and obtain systems and functions to be evaluated									
9	Select and obtain data collection and transfer systems									
10	Select and obtain support systems									
11	Equip vehicles with technologies									
12	Implement driver feedback and reporting systems									
13	Select / implement relational database for storing data									
14	Test all systems to be used according to specifications									
15	Develop recruitment strategy and materials									
16	Develop driver training and briefing materials									
17	Pilot Test equipment, methods and procedures									
18	Run the FOT									
19	Analyse the data									
20	Write minutes and reports									
21	Disseminate the findings									
22	Decommission the study / Completion Set Up / Design Preparation Data									

It depends on the study design which measures are recorded and at what rate or at what events these data are recorded. Data at least comprise video data and CAN-bus data in combination with high precision GPS data. Additional data should comprise driver demographic and psychological variables. A list of variables and data needed is given in Welsh et al. (2010) and in Klauer et al. (2011), minimal video camera positioning is shown in Figure 13.1.

Figure 13.1: Minimum required positions for video cameras in a vehicle equipped for naturalistic driving studies.



Because the data collected can easily amount to terabytes, questions regarding data recording and storage must be given utmost care. Data recording can be continuous or limited to specific periods. Data recording in these periods is triggered by exceeding a target value such as a specific deceleration or TTC (Klauer et al., 2011; Lu et al., 2011). Limiting data recording is done to reduce the amount of data stored and to speed up the analysis process. However, it is recommended to record data continuously. This recommendation is based on the fact that even careful setting of the target values can result in a high number of false positives and false negatives (van Schagen, Welsh et al., 2011).

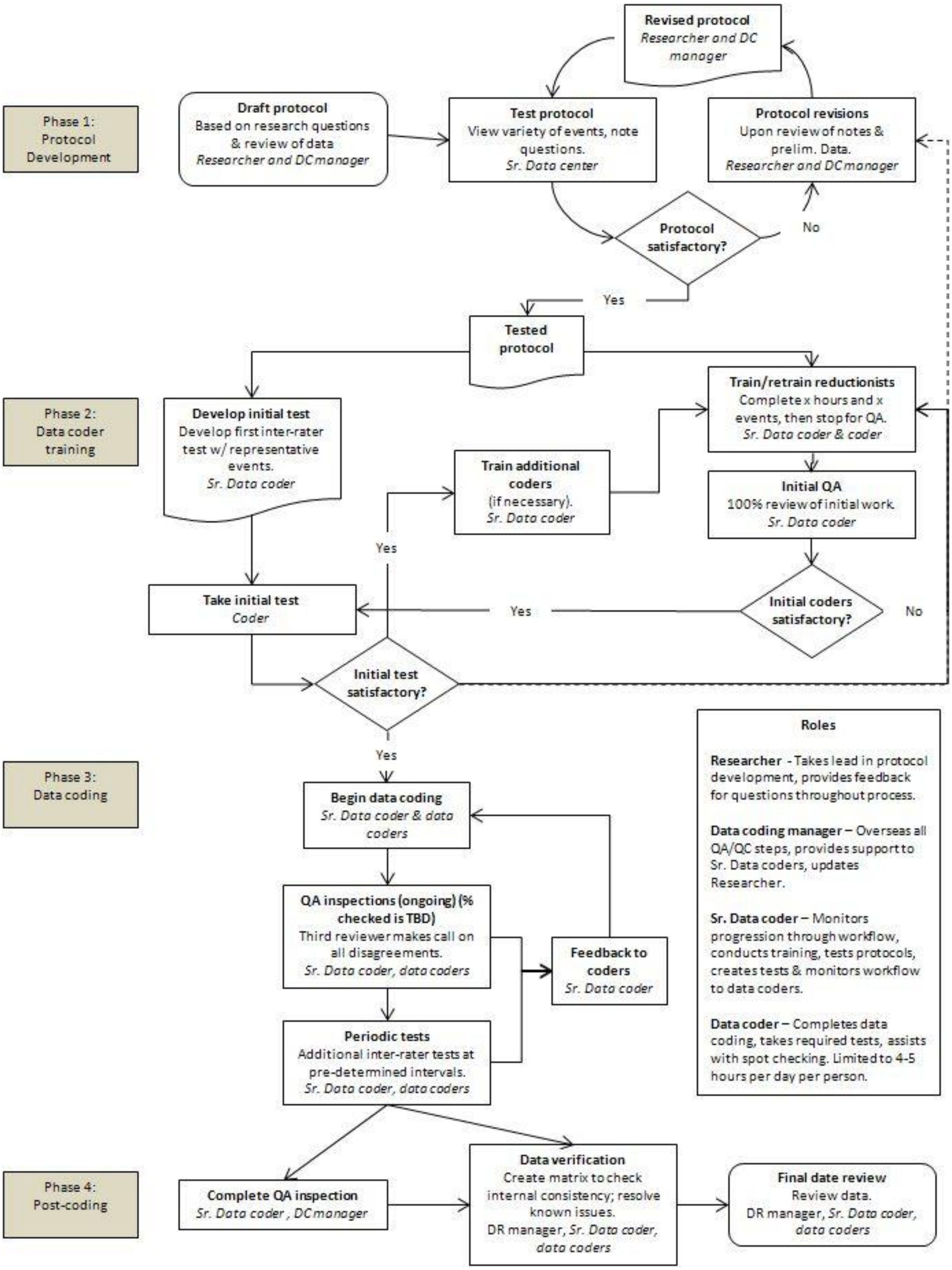
Another issue which needs careful consideration in the planning phase are legal and ethical issues (summaries in Klauer et al., 2011; van Schagen et al., 2011).

13.4.2 Data coding and data analysis

Although data recording in NDS can be based on objective trigger values, a subjective element remains. This is because the video data must be rated regarding the specific behaviour in question. Therefore, the same precautions have to be taken for NDS as for any other traffic conflict study: observer training and testing of observer reliability. Besides manual coding of video data, coding of all other data also requires careful planning and quality assurance. A detailed quality assurance/quality control workflow for data coding is shown in Figure 13.2 (based on Klauer et al., 2011).

Further practical advice how to plan and conduct naturalistic driving studies is given in Dingus et al. (2006), in the PROLOGUE deliverables (van Schagen et al., 2011) and in Klauer et al. (2011).

Figure 13.2: Quality assurance and quality control workflow for data coding (Klauer et al., 2011, p.79).



13.5 *Conclusion*

Analysing traffic conflicts can help to understand and prevent crashes. This statement is based on the idea that crashes can be inferred from conflicts (see the iceberg model). Whereas traditional methods relied on manual coding of conflicts through direct observation, progress in automated video processing and in-car measurement techniques allows collecting larger amounts of data. Naturalistic driving studies are one method applied to collect these data. However, despite the undoubted value of these studies they are extremely cost intensive and require expert knowledge and extensive planning. In addition, their value lies in analysing behavioural and situational antecedents of crashes rather than in analysing a specific location. Thus, for a specific location on a community based level, a traditional traffic conflict studies – whether with observers or advanced video techniques – is the method of choice. The primary reason is that all conflicts between road users at that location can be recorded during the observation period and not only those involving the NDS vehicles and drivers.

14 In-depth analyses of crashes

In most countries road crashes are recorded and reported by the police. The method of recording is based on an accident report form of some sort which is completely filled up by the police based on evidence collected for that purpose or provided by one or more parties involved in the crash. The form is generally a legal document that is intended for statistical purposes and can be used to ascertain who the guilty or offending party is. Most countries use the report form as the basis to record details of crashes in some central database.

A number of problems are evident regarding this method of reporting and recording details of road crashes. These include:

1. Not all crashes are registered. Not all crashes are reported to the police and consequently these are not recorded in the national statistics. The reporting and recording rate declines according to the severity of the crash (crashes with fatalities are almost all recorded whereas damage only crashes are only partly recorded). The registration rates also vary across crash types and involved parties (for example, in the Netherlands crashes involving only cyclists and pedestrians are not as well registered as those involving cars).

2. Police recording forms are based on self-reports and subjective opinions of events recorded mainly for the purpose of establishing guilt. These are not always a true reflection of actual events and details may be omitted or overseen.

3. Details regarding the location where the crash occurred are sometimes incomplete and often not well recorded or accurately collected or registered. Often essential details regarding the exact location are missing/inaccurate,

4. The road user behaviour component is poorly recorded in current crash statistics. The recording forms are reasonably mechanistic and little room is allowed for isolating human factors as an issue in crashes. Where existing, their evaluation is generally subjective and made by officers not thoroughly trained in this domain.

5. Recording details of a crash is generally carried out by an individual and is not the result of an objective multi-disciplinary investigation of events. Detailed investigations of crashes are not carried out as part of the reporting process and when these are carried out they usually are totally independent events.

6. During transcription, data on the report forms may be incorrectly recorded, due to either pure mistakes or incorrect interpretations of written events.

Because of these problems normally general crash data are not sufficiently detailed to enable an in-depth analysis of events. These in-depth analyses attempt to reconstruct the events that led to the crash occurring and to identify the factors which influenced the severity and nature of the injuries sustained.

Consequently many countries including the United States of America, Finland, Denmark, the Netherlands and the United Kingdom, started programmes whereby in-depth studies of crashes are being carried out.

A recent study by Elvik (2011) identified in-depth accident investigation and analysis as one of the essential tools for effective road safety management. Consequently this chapter will provide an overview of in-depth accident investigation and analysis. An outline will be given of the objectives of the tool, the applications for in-depth studies, the methodology, and some examples of the possible analyses of the data and how these can be used to improve the decision making process.

14.1 *Background*

The term "in-depth" in in-depth accident investigation implies that this form of investigation is more detailed or in any event different from "regular" crash investigations. A regular crash investigation can be considered to be that which is needed to complete the (standard) accident reporting form currently used in most countries. In-depth therefore suggests that in addition to this "regular" data, additional information must be collected in order to gain more insight into the events leading to, during and after the crash. Baker *et al* (1986), for instance identified five levels of detail in accident investigation (reporting, at-scene extra data collection, technical follow-up, professional reconstruction and cause analysis); and differentiates investigations made by the police, aiming at solving liability issues, from those of special research programs – namely the National Accident Sampling System – which usually take the form of levels 4 or 5.

A number of countries have been applying some form of in-depth accident investigations and these include the United States of America, Germany, France, Great Britain, the Netherlands, Finland and Denmark (Grayson & Hakkert, 1987; OECD, 1988; Elvik, 2011). Countries such as the USA use accident investigation primarily as an input for accident reconstructions needed by insurance companies and for litigation in court. Other countries, especially in Europe, concentrate on conducting accident investigations as specialised studies aimed at gaining more insight into specific types of crashes which may be relevant to road safety in general or to policy specifically (Davidse, 2007).

Elvik (2011) provides an interesting perspective on the development of in-depth studies and concludes that in-depth investigations have barely evolved and still, as in the past, produce long lists of human factors that have contributed to crashes. However, some progress has been made regarding the process by which these are described and the level of detail has improved. Elvik seriously questions the overall approach, especially the methodology used when conducting in-depth investigations. Due to the subjective nature and margin for interpretational error, in-depths are hardly scientific and there is room for improvement. Nevertheless, Elvik sees in-depths as a tool which can provide valuable supplemental information regarding certain crash types. In-depth crash investigation is one type of inverse problem, in which evidence collected on the crash scene and through follow-up investigation is used estimate key features of the chain of events that produced the crash. The following aspects should be considered when conducting in-depth investigations (Elvik, 2011):

1. A detailed protocol should be developed for in-depth studies. This protocol should describe the approach taken in detail. The theoretical framework for the studies should be made clear, as this will influence significantly the nature of the analysis outcome.

2. In-depth studies should be performed by a multi-disciplinary team, including experts in road design and traffic engineering, psychology, vehicle technology and medicine.

3. Reports from in-depth studies should have a standard format and always be available to the public. Data should be made anonymous to permit such public access.

4. In-depth studies should be performed for the crashes where better data are needed and likely to be made use of in road safety management.

14.2 *Definitions and scope*

ISO has defined in-depth accident investigation as an “accident investigation conducted by an investigator with specialized knowledge” and a multidisciplinary investigation as an “accident investigation conducted by a team of investigators with specialized knowledge encompassing several professional disciplines” (Jähi, Vallet et al., 2008). This definition of in-depth accident investigation would include what was earlier described as regular investigations needed to complete an accident report form and is therefore not supported in the context of this guideline. However, the definition of multidisciplinary investigations holds true and could be incorporated.

The OECD (OECD, 1988) defines accident investigation or in depth studies as a detailed investigation of a crash scene and including a reconstruction of all phases and events having had a role in the crash. Specific attention is paid to the pre-crash, crash and post-crash situations and to factors related to the human, vehicle and road environment.

In the EU SafetyNet project (Jähi et al., 2008) “safety orientated road accident investigation” was defined as:

1. The acquisition of all relevant information and the identification of one or several of the following:

    a. the cause or causes of the accident,

    b. injuries, injury mechanisms and injury outcomes,

    c. how the accident and injuries could have been prevented;

2. Conducted by one or several investigators with specialized knowledge in accident investigation and other fields of knowledge relevant for the purposes of the investigation;

3. Aimed at preventing future crashes and injuries through the development of countermeasures

4. And not contributing to any judicial enquiry or taking a stand on responsibilities.

For the purpose of this Eranet-Roads guideline, in-depth accident investigations will be defined as:

“a detailed investigation of a road traffic crash scene conducted by a team of investigators with specialized knowledge encompassing several professional disciplines”

From this definition it can be deduced that such investigations are complex and necessitate a multi-disciplinary approach involving for example a team of investigators comprising road engineers, traffic psychologists, road user behaviour specialists, medical specialists and legal specialists. This team not only is responsible for collecting all data relevant to the analysis of all different phases of the crash but also for involving their own expertise and knowledge in interpreting events and developing conclusions regarding the factors that played a role in the crash. In depth investigation is therefore not purely a matter of collecting data but more importantly, it is a means to investigate factors that may have influenced the crash in any way.

The obvious advantage of in depth investigations is that details of more variables can be collected than normally is the case when the police record events. In addition the accident investigation team has a direct interest in the accuracy and relevance of the data. By ensuring a high data quality of for instance road geometry data, on-site conditions can be compared with current design guidelines and standards. The data set that is collected will not necessarily be static and will be determined on the basis of the crash type being studied, the road users involved and the traffic situations relevant to these crashes (for example, it is not necessary to collect data on clear zones if one is examining rear-end crashes at intersections).

In-depth crash investigations are carried out by a team of independent specialists. The scope of the investigations is largely determined by the specific objectives for such investigations. For example in America cases are often investigated as isolated events in which information regarding a crash is collected in order to reconstruct an accident for the purpose of establishing the chain of events leading to the crash and ultimately, determining the cause and/or guilty party. In Europe, generally a broader objective is served in which in-depth investigations are used to find common factors within a certain type of crash in order to develop preventative measures to avoid future crashes. The European approach is not so much focused on reconstruction and assigning guilt but rather at finding commonalities within types of crashes. However, that does not take away the need to conduct reconstructions, especially if insight is wanted into the events leading to, during and after the crash. Reconstructions are particularly useful to determine dynamic variables such as approach speeds, collision speeds and angles, deceleration rates and other related parameters needed for biomechanical analysis of injury production.

14.3 *Principles and requirements*

In-depth investigations require a multi-disciplinary team comprising a combination of:

- Traffic and/or safety engineer with experience in geometric road design
- Behavioural scientists/specialist, preferably a traffic psychologist
- Mechanical engineer or technologist with specific experience in road vehicle technology

In complex cases it is advisable to have access to persons experienced in crash trauma (injuries) and traffic legislation (legal requirements regarding road signing and markings etc.).

In-depth investigations need to be carried within the shortest possible time after a crash has occurred. The reasons for this include minimising the risk that data (evidence) is damaged, destroyed or lost, that witnesses or involved persons forget salient facts or that conditions at the crash location are changed. When setting up an in-depth investigation programme it is essential that the road authority (or their appointed party) establish a good working relationship with the police and other involved parties in order to:

- Gain first hand access to police accident reports and other relevant data;
- Be timely notified in the event of a crash occurring;
- Receive assistance in closing off the road/safeguarding a crash scene in order to collect evidence;
- Receive clearance/permission to conduct the required vehicle and road inspections. This also means having access to these for a certain period of time following the crash.

In view of the above it is preferred that the in-depth investigation is carried out simultaneously with the police investigation (i.e. immediately after the crash). In this way the relevant data collected pertains to prevailing conditions at the time of the crash and the risk of missing important data are minimised. Also photo-material of for example skid and scuff marks can be collected for later reference.

In order to conduct an in depth investigation the team needs to have (at least) the following equipment on hand:

- Safety equipment (safety clothes and shoes; safety vests, cones, signs etc.);
- Measuring equipment (tape or laser measure; surveyors' wheel; theodolite; pendulum tester etc.);
- Camera (digital photo camera; video camera; digital recorder);
- GPS;
- Maps;
- Laptop computer and/or drawing equipment (drafting sketches of location etc).

In the event that the crash needs to be reconstructed, use can be made of one of the various commercially available PC-based crash reconstruction tools. It is however advised that users of these tools undergo the necessary training in the use of these tools and techniques.

14.4 ***Data collection and sampling methodology***

To determine which factors played a part in crashes (before, during and after), information is needed regarding the drivers/road users involved, the vehicles involved and the road environment. Since the in-depth investigation is independent of the police investigation or a legal proceeding, it is vital that a high degree of confidentiality is maintained. This is especially the case with details regarding the persons involved in the crash. These must be kept confidential and made anonymous before results are reported.

Regarding the persons involved in the crash (directly involved as drivers of vehicles or pedestrians) the following information is required (this is usually collected by way of interviews):

- Personal data (age; sex; health; education; drivers' license; etc.);
- Trip description (Origin-destination; trip type; trip purpose etc.);
- Mood (general; fatigued; stressed; pressured; angry; sad etc.);
- Interpretation of events;
- Understanding of, and experience with, the local situation (traffic control, speed limits; other road users; signing and marking etc.);
- Behaviour before crash (perception; yielding; visualization; speed etc);
- Role of intoxicating/debilitating substances (alcohol; drugs; medication etc.);
- Driver hours (tachograph etc.);
- Etc.

In addition to the details regarding the directly involved persons, it is advisable to try and get supporting evidence/details from witnesses (including passengers in the involved vehicles). This information is limited to obtaining statements regarding the events leading to the crash and possibly details regarding the outcome.

Also information regarding the road environment (at the scene of the crash and on road sections approaching the crash location) needs to be collected and these include:

- Layout details (cross-sectional elements; intersection type; presence and locations of poles and obstacles etc.);
- Sight distances (stopping; shoulder; passing etc.);
- Signing and marking (type; location; condition etc.);
- Road surface (skid resistance);
- Traffic control (type and strategy);

- Lighting (type and position);
- Visibility (day/night; wet/dry; clear/misty/hazy etc.);
- Traffic volumes and composition (if not available descriptions such as high volumes; few heavy vehicles etc. or extrapolate from short count of say 15 minutes on a different day than the crash day);
- View of the road (ability to interpret and anticipate conditions);
- Skid and scuff marks (length, width; position and description);
- Etc..

It will also be necessary to collect data regarding the vehicles involved and these include:

- General (make and model; year of registration; mass; dimensions; etc.);
- Condition (mechanical; tyres; brakes; windscreen; mirrors; etc.);
- Damage (location; description; impact depth; deformation etc.);
- Safety systems and use/deployment of these (seat belts; airbags; ABS; ESC etc.);
- Position relevant to other parties;
- Tachographs and other on-board recoding data;
- Etc.

Finally data need to be collected relating to the injuries of the crash victims and any other relevant facts. These may be obtained from hospital data, witness reports and other sources to verify and validate the other data sources:

- Nature and scale of injuries (driver and all occupants);
- Role of intoxicating/debilitating substances (alcohol; drugs; medication etc.);
- Driver hours (tachographs etc.);
- Etc.

By using all the relevant data, the entire process describing the crash can be drawn up. Where possible, reference is made to critical moments or events which were decisive in the chain of events leading to the crash. Per investigated crash, relevant data are checked by the inspection team and ultimately digitised for future analysis. As mentioned earlier, it is essential to ensure that personal data are made anonymous and that the data are properly secured. In certain cases it may be necessary to conduct a reconstruction in which case these data are input into a reconstruction simulation model and additional results calculated.

In general (and except where needed explicitly for reconstruction purposes of specific cases) it is best to concentrate the process of in-depth investigations on certain accident types. Instead of conducting in-depth investigations on say all fatal crashes, it would be more efficient concentrating say on all run-off road crashes on high speed rural roads. The type of crashes requiring in-depth investigations will become evident from general road safety analyses (i.e. most prevalent accident types, possibly disaggregated by age or sex of drivers etc.). It is advisable to concentrate on accident types that appear least affected by prevailing road safety policy measures and safety improvements.

In order to conduct a meaningful analysis of the causes underlying a particular crash type means that a sufficient number of crashes need to be investigated. The way in which the crash sample is drawn up depends largely on what the objectives of the in-depth program are. These can vary from determining underlying causes of crashes not affected by governing road safety policies and actions; comparing between crash types; establishing factors common to all crash types etc. Consequently the required sample could be based on random, stratified, clustered or even a multiple stage design (Hakkert, Gitelman, & (Editors), 2007).

Adopting a classical random sampling technique in which each crash has an equal chance of being drawn is not practical for in-depth investigations for a number of reasons including:

- the investigation teams cannot be available at every given moment;
- distances to reach the randomly selected crash location may be too great or take too long; and
- selection criteria can only be applied once a list of crashes has been developed.

By adopting a stratified sampling technique one can restrict oneself to one type of crash and collect sufficient numbers to be representative of national trends (e.g. if we are concentrating on single vehicle crashes then our sample must reflect general national trends regarding this crash type. For instance if 60% of national single vehicle crashes occur at night, our sample should reflect this). By a clustered approach we limit ourselves to investigating crashes in a specific region only. The assumption is that this region is representative of the whole population and hence general crash statistics of the region should be similarly distributed as national crash statistics. Of course a combination of these techniques is also possible (for example, collecting one crash type in one region only).

As a general and pragmatic rule it is sufficient to conduct in-depth investigations of a specific crash type until such time that no new information comes to light following an investigation. In other words, all observations and data are similar/the same as those revealed from previous investigations. Investigating one specific type of crash is a form of stratified sampling and a rule of thumb for the minimum number of sampling units in a stratum is 30 to 50 (Hakkert et al., 2007). Some studies quote a number of 40 to 60 crash investigations of a particular type as being adequate to draw general conclusions regarding possible remedial treatments (Davidse, 2007). However, it is important to note that the data sets must then be complete.

14.5 *Analysis*

For each crash investigated, the data discussed in Section 14.3 are required for all directly involved parties, all involved vehicles and roads where the crash occurred. A clear transcription of events must be developed (who arrived first, what were they doing and what did they see, what were their reactions and how did others react, what actions were undertaken and what were the consequences etc.) Combining these verbal transcriptions with actual evidence, the investigators can establish at which point events went wrong and how this could have been avoided. The analysis of events must include descriptions of factors that may have contributed to the crash and also which factors contributed to the injuries/damage. Distinction is made between driver; vehicle and road environment factors. Examples of such descriptions can be found in the Trace study carried out in 2008 (Molinero, Perandones et al., 2008) and the extensive GIDAS study in Germany (BASt & FAT, 2011).

Once the crash process for each crash has been described, the data for the set of crashes can be analysed to gain insight into commonalities or differences within the group. The purpose of this is to try and isolate factors that played a predominant role in causing the crashes and to attempt to develop remedial measures that may in future prevent these from occurring.

14.6 *In-depth investigation protocol*

At the present time there does not appear to be one standard protocol that describes the approach to be followed when conducting in-depth studies. Unlike procedures such as road safety audit and even though in-depths have been carried out for many years in many different countries, there is no one procedure or protocol which is adhered to by all. This also applies in Europe where generally countries carrying out in-depth investigation follow their own procedures. Although this *Rismet* guideline strives to provide as much uniformity as possible regarding the application of road safety engineering management tools, in-depth investigations will not form part of these. The primary reason for this is that it is arguable whether in-depths are an essential tool for road safety management. In this context in-depths are seen as supplementary tool and its use will be country dependant. For those countries wishing to adopt in-depth investigations, readers are referred to Work Package 2 of the DaCoTA project which aims to develop a standard protocol for in-depth investigations in Europe (Hagström, Fagerlind et al., 2011).

Since the in-depth tool provides a more detailed insight into causative factors in crashes it is advisable to stimulate its application in a uniform way. Therefore it is paramount that a standard protocol for in-depth be developed and implemented. As a guideline such a protocol should include:

- Objectives and definitions.
- Investigating team.
- Minimum apparatus.
- Work procedures:
    - Reporting of incident; response call and time;
    - Conducting inspections (measurement, interviews etc.);
    - Reporting;
    - Data collection ;

- Specification of variables (see **Table 14.1**)
- Details of third parties;
- Address and contact details involved parties;
- Location details;
- Questionnaire or interviews.

- Data processing, storage and quality control.
- Data analysis.

Table 14.1: Example of data to be collected

Personal characteristics	Location	Vehicle
Age	Date and time	Make and model
Sex	Crash type	Type
Driving experience (date of license)	Weather	Mass
Mode of transport	Road surface characteristics	Length, width and height
Knowledge of area/location	Road/intersection type	General condition
Trip purpose	Cross-sectional elements (approach roads)	Occupant Safety features
Origin-destination	Tangent/bend	Functioning of the occupant safety features
Physiological	Traffic volumes	Vehicle systems, condition and functioning
Fatigue	Road signs and markings	Damage (location and description)
Alcohol/drugs	Quality signs and marking	
Illness	Traffic calming measures	
Handicaps	Pedestrian and cyclist facilities	
Distraction	Design consistency	
Position in vehicle		
Restraint use		
Observation/manoeuvres before crash		
Injuries (nature and position)		
Severity of injury		
Type of treatment (hospitalised, first aid)		
Duration in hospital		

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