Rune Elvik
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Institute of Transport Economics
Norwegian Centre for Transport Research

Assessment and applicability of road safety management evaluation tools: Current practice and state-of-the-art in Europe

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Summary:

The report presents an analysis of the current use of ten different formal tools for the safety management of roads in seventeen European countries. The relationship between use of the tools and progress in improving road safety is analysed. No clear relationship between use of the safety management tools and success in improving road safety is found. All tools being amenable to improvement, the report offers some specific suggestions.

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Tittel: Formelle hjelpemidler for sikkerhetsstyring av veger i Europa: dagens praksis og forbedringsmuligheter

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Sammendrag:

Rapporten presenterer en analyse av dagens bruk av ti ulike formelle hjelpemidler for sikkerhetsstyring av veger i 17 europeiske land. Sammenhengen mellom bruk av hjelpemidlene og framgang i bedring av trafikksikkerheten er studert. Det kan ikke påvises noen klare sammenhenger mellom bruk av styringsverktøyene og hvor godt et land lykkes med å bedre trafikksikkerheten. Alle verktøyene kan forbedres, og rapporten peker på en del forbedringsmuligheter.

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Preface

The project RISMET (Road Infrastructure Safety Management Evaluation Tools) is partly a follow-up of the European project RIPCORD-ISEREST, which was funded by the European Commission. RISMET is funded by ERANET, with contributions from the national road administrations of the United Kingdom, Germany, the Netherlands, Norway and Portugal. The project is co-ordinated by the SWOV Institute for Road Safety Research (Netherlands). Partners in the project are the Transport Research Laboratory (TRL, Great Britain), the National Laboratory of Civil Engineering (LNEC, Portugal), the Technical University of Dresden (TU Dresden, Germany), the Kuratorium für Verkehrssicherheit (KfV, Austria) and the Institute of Transport Economics (TØI, Norway).

This report, also published in a nearly identical version as an ERANET report and available in electronic form at the website of RISMET, documents work package 3 of the project: assessment and applicability of road safety management evaluation tools in Europe. The report describes current use of ten road safety management tools in seventeen European countries. It also discusses how use of these management tools can be brought closer to the state-of-the-art (i.e. the best current standard for use of the tools), as some of the tools are still applied in a somewhat primitive form. As an example, the identification of hazardous road locations can best be done by applying the Empirical Bayes method, but all countries apply simpler and less reliable methods to identify hazardous road locations.

A draft of the report has been discussed among the partners of the project. We thank the partners for their helpful comments. The report was written by Rune Elvik. Internal peer review to check the quality of the report was performed by Head of Department Marika Kolbenstvedt. Secretary Trude Rømming prepared the report for printing and electronic publishing.

Oslo, December 2010
Institute of Transport Economics

Lasse Fridstrøm
Managing Director

Marika Kolbenstvedt
Head of Department

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Summary:

Assessment and applicability of road safety management evaluation tools: Current practice and state-of-the-art in Europe

This report surveys current practice and the state-of-the-art in Europe with respect to the use of ten different tools for safety management of road systems. These tools and their intended functions include:

1. Road safety audits, to help incorporating the best knowledge about how to design a safe road into decisions about the design and construction of new roads, thus making new roads safer than existing roads,
2. Road safety inspections, to systematically identify and treat defects in design and traffic control on existing roads, ideally speaking before these defects contribute to accidents,
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 accidents, or a higher severity of accidents, than the rest of the system,
4. Accident modelling, to help identify and assess the importance of various factors that contribute to accidents 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 accidents 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 accidents or of driver behaviour in a natural setting,
10. In-depth accident studies, in order to learn more about the factors that precipitate accidents and the opportunities for controlling or removing these factors.

A questionnaire survey was conducted in order to describe current use of these tools and assess the requirements for using them. The survey found that all countries use several of the tools listed above, but few countries use all of them.

The report can be ordered from:
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A total of 17 countries answered the questionnaire. Between 14 and 16 of these countries were included in statistical analyses designed to uncover the relationship between use of the safety management tools and road safety performance. Use of the management tools was described in terms of an index with a range from 0 to 27 points. Country scores ranged from 9 to 26 points. Four indicators of road safety performance were used:

1. Fatality rate per billion km of travel in 2008.
2. Mean annual percentage reduction of the number of road accident fatalities between 1990 and 2009.
3. Mean annual percentage reduction of fatality rate per billion km of travel from 2000 to 2008.
4. Change in the mean annual percentage reduction of fatality rate from the period 1990-2000 to the period 2000-2008.

Two models of analysis were applied. In the first model, each country had the same statistical weight. In the second model, countries were assigned different statistical weights depending on the number of fatalities in 2008 or on the goodness-of-fit of an exponential trend curve fitted to annual fatality counts from 1990 to 2009. The weighted analyses are regarded as statistically most appropriate.

The findings were mixed and highly uncertain. No clear relationship was found between the use of the safety management tools and safety performance. It is not the case that a more extensive use of these tools automatically ensures a superior road safety performance. It is likely that the findings of the study are primarily related to methodological weaknesses.

The main conclusions of this study highlight the opportunities for further development of the tools for road safety management:

1. Road safety audits, road safety inspections and road protection scoring can be further developed by evaluating their effects on safety and their performance in identifying safe and less safe solutions.
2. Network screening should be based on accident models and should apply the techniques developed in the Safety Analyst approach in the United States.
3. Road accident modelling needs to be developed by testing models empirically and by incorporating in them variables describing road user behaviour.
4. The identification and analysis of hazardous road location should employ the Empirical Bayes (EB) approach for identification of hazardous locations and the matched-pair approach for the analysis of factors that may contribute to accidents at hazardous road locations.
5. The state-of-the-art of road safety impact assessment is described in the Highway Safety Manual recently published in the United States. Changes made in current practice should try to bring it closer to the state-of-the-art.

6. Monitoring of road user behaviour should be targeted at about five types of behaviour that make the largest contributions to road accidents and injuries. In most countries, this would include speeding, not wearing seat belts and drinking and driving.
7. Conflict studies, naturalistic driver behaviour studies and in-depth studies of accidents are tools that road authorities may choose to include in their safety management toolbox; neither of these tools is essential.

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Sammendrag:

Formelle hjelpemidler for kartlegging og forbedring av sikkerheten på veger i Europa: Dagens praksis og forbedringsmuligheter

Denne rapporten dokumenterer dagens bruk av ti formelle hjelpemidler for kartlegging og forbedring av sikkerheten på veger i 17 europeiske land. De ti analyseverktøyene er:

1. Trafikksikkerhetsrevisjoner, som er en systematisk gjennomgang av veger som er planlagt eller under bygging med sikte på å avdekke forhold som kan skape sikkerhetsproblemer på vegen,
2. Trafikksikkerhetsinspeksjoner, som er en trafikksikkerhetsrevisjon av en veg som er åpen for trafikk,
3. Vegnettsanalyser, med sikte på å identifisere veger som har unormalt mange ulykker eller mer alvorlige ulykker enn andre veger,
4. Ulykkesmodellering, som er statistiske analyser av faktorer som medvirker til ulykker med sikte på tallfeste faktorenes betydning for ulykkestallene så presist som mulig,
5. Skadebeskyttelsesklassifisering av veger (Road Protection Scoring), i form av en klassifisering av hvor godt vegens utforming beskytter mot skader ved nærmere angitte ulykkestyper,
6. Utpekning og analyse av spesielt ulykkesbelastede steder,
7. Virkningsberegninger av planer og trafikksikkerhetstiltak,
8. Kartlegging av trafikantatferd (fart, beltebruk, osv),
9. Konfliktstudier og naturalistiske studier av føreratferd,
10. Dybdestudier av ulykker.

Ved hjelp av et spørreskjema distribuert gjennom CEDR (Conference of European Directorates of Roads) ble bruken av disse analyseverktøyene kartlagt. 17 land besvarte spørreskjemaet.

På grunnlag av svarene ble det utviklet en indeks for bruk av analyseverktøyene. Indeksen kunne anta verdier fra 0 til 27. Faktiske verdier på indeksen varierte mellom 9 og 26. Det ble så undersøkt om det er noen sammenheng mellom hvor omfattende bruk et land gjør av analyseverktøyene, angitt ved indeksverdien, og hvor godt landet de siste årene har gjort med hensyn til å forbedre trafikksikkerheten. Nivået på og forbedring over tid av trafikksikkerheten ble angitt ved:

1. Antall drepte per milliard personkilometer i 2008.
2. Gjennomsnittlig årlig prosentvis nedgang i antall drepte mellom 1990 og 2009.
3. Gjennomsnittlig årlig prosentvis nedgang i antall drepte per milliard personkilometer fra 2000 til 2008.

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4. Endring i gjennomsnittlig årlig prosentvis nedgang i antall drepte per milliard personkilometer fra perioden 1990-2000 til perioden 2000-2008.

Det ble kun funnet svake og vanskelig tolkbare sammenhenger mellom bruken av styringsverktøyene og hvor godt et land gjør det ut fra de fire målene på bedring av trafikksikkerheten. Forklaringene på dette er etter all sannsynlighet svakheter ved datagrunnlaget og metoden i undersøkelsen.

Rapporten fokuserer på denne bakgrunn på hvordan de ulike styringsverktøyene kan videreutvikles, slik at de kan bli enda nyttigere redskaper til å forbedre trafikksikkerheten. De viktigste forbedringsmuligheter kan oppsummeres slik:

1. Trafikksikkerhetsrevisjoner og trafikksikkerhetsinspeksjoner kan trolig utvikles ved at man studerer hvilke virkninger disse verktøyene har på trafikksikkerheten. Slike studier er i forbausende liten grad gjort.
2. Vegnettsanalyser bør bygge på ulykkesmodeller og bør følge metoden som er beskrevet i verktøyet SafetyAnalyst som er utviklet i USA.
3. Ulykkesmodeller bør oppdateres jevnlig. Modellutviklingen bør skje slik at det er mulig å teste modellene empirisk. En vanlig føyningstest kan i denne sammenheng ikke betraktes som en empirisk test av en modell, slik begrepet empirisk testing av teori vanligvis brukes i vitenskapsteori.
4. Utpekning og analyse av ulykkesbelastede steder bør bygge på Empirisk Bayes metode. Ulykkesanalyser bør bygge på en sammenligning av et ulykkesbelastet sted med et ellers så likt som mulig kontrollsted som ikke er ulykkesbelastet.
5. Virkningsberegninger av trafikksikkerhetstiltak bør gjøres etter den metoden som er beskrevet i Highway Safety Manual, som ble utgitt i USA i 2010.
6. Kartlegging av trafikantatferd bør fokusere på inntil fem typer atferd som man vet har stor betydning for trafikksikkerheten. I ethvert land vil dette omfatte fart, bruk av personlig verneutstyr og kjøring under påvirkning av alkohol eller andre rusmidler.
7. Konfliktstudier, naturalistiske studier av føreratferd og dybdestudier av ulykker betraktes som mindre viktige styringsverktøy som et land kan velge å benytte dersom man finner det nyttig.

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 ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research project are United Kingdom, Germany, the Netherlands, Norway and Portugal.

This report gives a description of current practice and an assessment of the state-of-the-art with respect to tools for the safety management of roads. The elements and objectives of safety management are outlined. A set of tools for road safety management are described. Current use of these tools in European countries is surveyed. State-of-the-art techniques are described for each of the tools. State-of-the-art refers to the best current procedure or standard for use of a tool. Actual use of a tool may rely on simpler and less reliable techniques than those representing the state-of-the-art. The project may in some respects be viewed as a follow-up of RIPCORD-ISEREST. However, it goes further than that project with regard both to the set of management tools covered and with respect to the assessment of the state-of-the-art. The project is aimed primarily at rural main roads.

Safety management denotes all activities undertaken for the purpose of monitoring the safety of a specific system, such as a road system; detecting unfavourable trends in safety as quickly as possible; gaining an overview of variation in the level of safety between elements of the system; identifying locations that are particularly hazardous, and systematically planning and assessing the impacts of road safety measures. Figure 1 presents an analytical model of road safety policy making, in which the activities that constitute the formulation and implementation of road safety policy are laid out in a logical sequence (Elvik and Veisten 2005).

1.1 Safety management as a part of safety policy

Monitoring safety and assessing the contribution of various factors to accidents and injuries is a management activity that forms part of stage 1 of the model in Figure 1. Analysis of potentially effective road safety measures is an important part of road safety management and contributes to stage 3 of the process of policy development. Activities such as network screening and monitoring of road user behaviour (see chapter 2) can be viewed as contributions to stage 4 of policy development, as these tools enable a description of systems and an assessment of the opportunities for intervention. Road safety impact assessment refers to the systematic estimation of the contributions that different road safety measures may give in improving road safety and is a key element in any road safety programme. Impact assessment is placed at stage 6 of the process of policy development.

Safety management is an analytic and politically neutral activity. It is, ideally speaking, based on knowledge and research exclusively and should not be influenced by political considerations. The more politically oriented stages of policy development, such as the setting of safety targets (stage 2) or the determination of the size of safety budgets, are therefore not treated as part of safety management and will not be further discussed in this report. Moreover, determining the priorities between different road safety measures tends to be influenced by multiple factors, some of them analytical, others more political (stage 8). This report will not discuss how to determine priorities between road safety measures, nor will it discuss the constraints that policy makers often take as given when deciding on road safety policy.

Stage 1	Describe current road safety problems and assess their relative importance in contributing to fatalities and injuries
Stage 2	Develop road safety targets and decide on quantification of these as well as other policy objectives
Stage 3	Survey potentially effective road safety measures and decide which measures still have a potential for improving safety
Stage 4	Describe the current road transport system and establish a framework for analysis of alternative policy options
Stage 5	Develop alternative road safety policy options, showing the main directions for road safety policy
Stage 6	Estimate the effects of each policy option on the number of killed or injured road users, as well as effects with respect to other policy objectives
Stage 7	Assess sources of uncertainty in estimated effects and discuss the treatment of uncertainty in road safety policy making
Stage 8	Determine considerations relevant to the choice of road safety policy and choose preferred policy
Stage 9	Implement preferred road safety policy and evaluate effects of that policy

Source: TØI report 785/2005

Figure 1: An analytical model of road safety policy making

1.2 Research problems

The following questions are the main focus of interest in this report:

1. What are the principal analytic tools that can be applied in order to assess the safety of a road?
2. How easy is it to apply these analytic tools?
3. To what extent are the various analytic tools currently used in Europe?

4. Is road safety performance associated with the use of the safety management tools included in this report?
5. How can the tools for assessing the safety of roads be developed in order to further improve the efficiency of road safety management?

Short descriptions of the principal road safety management tools are given in Chapter 2. Criteria for assessing their applicability are discussed in Chapter 3. Current use of the tools is surveyed in Chapter 4. This chapter also reports the results of a study intended to evaluate the effects on safety performance of the use of the various management tools. The state-of-the-art and possibilities for improving the tools are discussed in Chapter 5.

1.3 Objective of this report

The first objective of this report is to assess the applicability of existing analytic tools for evaluating the safety of roads as part of road safety management. For this purpose, current use of the tools has been surveyed and potential barriers to the use of the tools have been identified.

The second objective of the report is to outline steps that can be taken in order to improve the efficiency of the safety management tools, i.e. bring current practice closer to the state-of-the-art.

1.4 Context of the report

This report is part of a recent growth in research regarding road safety policy and tools for safety management that can inform road safety policy and make it more successful. Increasing ambitions for improving road safety, as manifested in the quantified target adopted by the European Union, and concepts of Vision Zero and Sustainable Safety, has stimulated interest in research designed to assess how countries can enhance their road safety performance, i.e. realise important gains in road safety more quickly, preferably without having to spend very much more resources on road safety measures than before.

A collection of 16 scientific papers dealing with road safety management, plus an editorial, was recently published as a Special Issue of Safety Science (Wegman and Hagenzieker 2010). Most of the papers were presented at a conference held in Haarlem in November 2009. The papers discuss various aspects of road safety management, including:

1. How to compare the safety performance of different countries (Wegman and Oppe 2010).
2. The need for adopting a systems theory perspective and a broad view of factors influencing road safety when developing a targeted road safety programme (Larsson, Dekker and Tingvall 2010, Johnston 2010).
3. How to predict future developments in road safety (Hauer 2010A, Wesemann, van Norden and Stipdonk 2010).
4. How to establish a rational framework for deciding on numerical targets for improving road safety, in particular determining the “right” level of ambition for such targets (Broughton and Knowles 2010).

5. Whether the effects on road safety performance of a quantified road safety are sustained in the long run (Wong and Sze 21010).
6. How to set efficient priorities for road safety measures, and how to strengthen incentives for efficient priority setting (Elvik 2010A).

Recently, a large study was reported in the United States concerning what the country may learn from other countries with respect to improving road safety. A fairly detailed discussion of lessons to be learnt from France, Norway, Sweden, the Netherlands and the United Kingdom was presented by Ezra Hauer (2010B).

Neither of these topics is discussed in this report. This report focuses more on the details of continuous road safety management, i.e. on the analytic tools that help government detect emerging safety problems early, that help in locating the most hazardous parts of the road system, that identify the most important factors contributing to road accidents and injuries and that help to estimate the likely effects of specific road safety measures or a road safety programme consisting of several measures.

2 An overview of safety management tools

The evaluation tools that are described in this chapter are elements of road 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. Road safety inspections
3. Network screening (also referred to as network safety management)
4. Accident modelling
5. Road protection scoring
6. Identification and analysis of hazardous road locations
7. Impact assessment of investments and road safety measures
8. Monitoring of road user behaviour
9. Conflict studies
10. In-depth analyses of accidents
11. Other tools for road 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.

Some of the road safety management tools listed above are mandatory. In particular Directive 2008/96/EC of the European Union requires member states of the Union to perform road safety audits, road 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).

2.1 Road safety audits

A road safety audit is a systematic assessment of plans for new road schemes, 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 formally 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. Require 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, Håndbok 222, 2005). 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.

2.2 Road safety inspections

A road safety inspection is a systematic assessment of the safety of an existing road. Road safety inspections are, so to speak, road safety audits applied to a road that has already been constructed and open to traffic for some time. 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. Road safety inspections are therefore performed according to the same procedures as road safety audits.

Road safety inspections can be organised as thematic inspections, for example, an inspection of guard rails 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)

2.3 Network screening

Network screening is a process where variation in the number of accidents 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 accidents, a high share of severe accidents 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 accidents to statistically advanced techniques based on accident prediction models. The method of network screening implemented in SafetyAnalyst, which is recommended in the recently published Highway Safety Manual, represents the state-of-the-art (Harwood et al. 2002A, 2002B, 2002C, 2002D).

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 is, however, not an official body and the risk rating does not have any official status (EuroRAP 2005).

2.4 Accident modelling

Accident models are developed by statistically assessing how variation in the number of accidents 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 accidents 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 and 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 accidents. Models should not be based on small samples with a low mean number of accidents (Lord 2006, Lord and 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. accidents, 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 (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 (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 accidents 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. Accidents at different levels of severity are modelled separately. If possible, different types of accidents 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 accidents 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.

2.5 Road protection scoring

Road protection scoring is an assessment 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).

Road features that are relevant to safety are recorded along a road, and a score is assigned that reflects risk. 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 relative safety levels of different road sections.

As an example, a road is scored as safe with respect to running-off-the-road accidents 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 accidents 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 and that occupants wear seat belts.

2.6 Identification and analysis of hazardous road locations

All countries have a system for identifying hazardous road locations (sometimes referred to as black spots, hot spots or sites with promise) and analysing accidents 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 2008A):

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 accidents, not the recorded number of accidents. This is best done by identifying hazardous road locations according to the Empirical Bayes (EB) estimate of safety at each site (Elvik 2008B).
4. Hazardous road locations should belong to the upper percentiles of a distribution of sites with respect to the expected number of accidents.
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 accidents to permit analysis.
6. Accident severity can be considered when identifying hazardous road locations, provided the expected number of accidents 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 accidents by type are available.

As far as analysis of accidents 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).

2.7 Impact assessment of investments and road safety measures

Impact assessment denotes the estimation of the expected effect on accidents 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.

Tools that can make impact assessment of minor projects easier are now 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. For an example of a road safety impact assessment at the national level, see Elvik (2007A).

2.8 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 (including speeding)
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. 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 accidents 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 impossible.

2.9 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 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.

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 (Laureshyn 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 accidents 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 accidents (Klauer et al. 2006, Guo et al. 2010). The ongoing 1000-car naturalistic driving study will permit more analyses.

2.10 In depth analysis of accidents

Official road accident statistics are, in most countries, not sufficiently detailed to enable an in-depth analysis of accidents. 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 speed, the estimation of impact speed, the identification of technical defects in vehicles 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 accidents is both to better understand factors leading to accidents and to better identify how best to prevent accidents. In-depth studies of fatal accidents have a long history in Finland and the United Kingdom, but have more recently been introduced in Sweden and Norway. The Netherlands also performs in-depth studies of accidents. Research reports based on in-depth studies include Sagberg and Assum (2000), Stigson (2009) and Assum and Sørensen (2010A).

2.11 Other safety management tools

The ten tools listed above are all used in more than one country in Europe. 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.

2.12 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

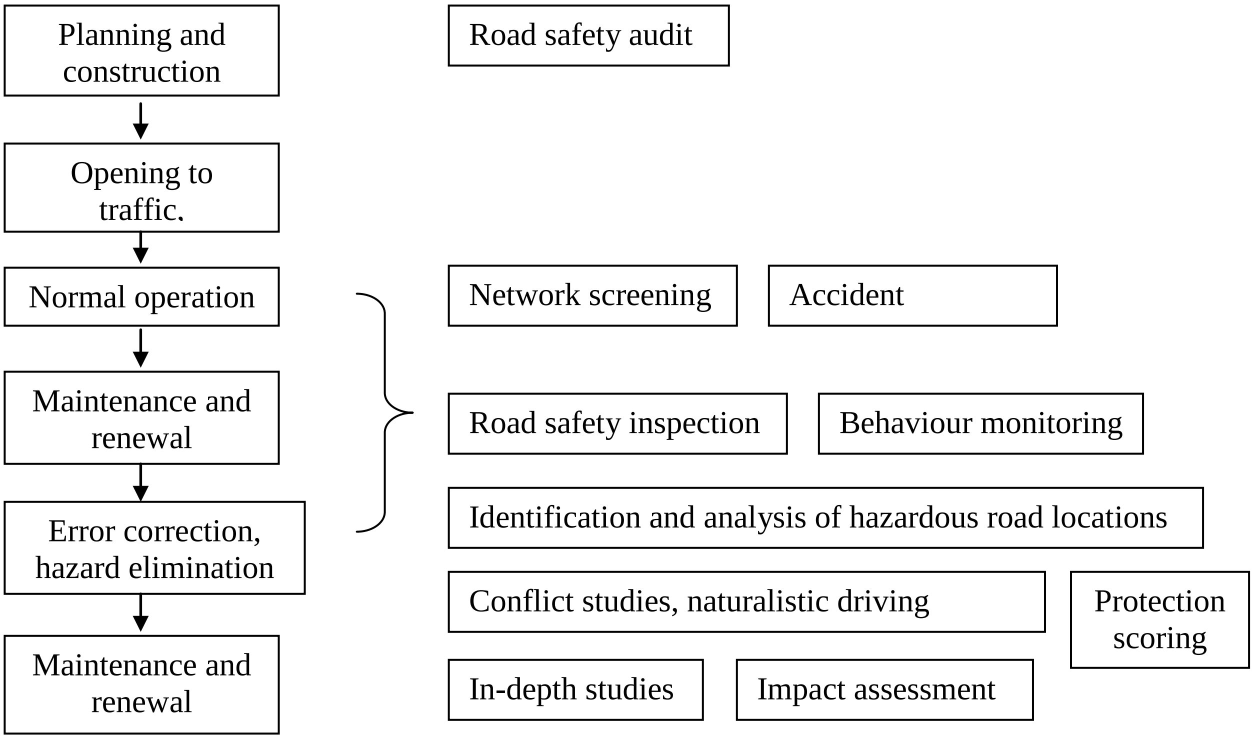
Figure 2 presents these stages and indicates at which stage the various tools for evaluating the safety of the road for the purpose of improving it are relevant.

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 it is opened to traffic, permitting last-minute corrections to be made.

Road 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. Road 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.



Source: TØI report 1113/2010

Figure 2: Stages when tools for safety management are applied

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 accidents or make the accidents 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 road 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. One must therefore expect accidents to occur even on the safest roads and try to detect patterns in accidents 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 accidents 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 Criteria for assessing the applicability of management tools

The tools for road safety management that were presented in Chapter 2 differ in terms of their complexity. Not all of them may be readily applicable. This chapter proposes criteria for assessing the application of the tools for road safety management.

3.1 Data requirements

As far as data requirements are concerned, a distinction can be made between three levels of data requirements for using the evaluation tools presented in Chapter 2:

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).

The evaluation tools presented in Chapter 2 differ with respect to data requirements. Road safety audits have low data requirements, as they are based on documents and checklists only, although 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. Road 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 (see e.g. Cafiso et al. 2010).

Road protection scoring is intermediate or high in data requirements; it relies on taking careful notes 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 more sophisticated 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.

3.2 Availability and use of standard procedures

Some evaluation tools rely on standardised procedures, some do not. In general, it is easier to use a tool when a standardised procedure for using it has been developed than when the user has to invent his or her own procedure.

Most of the evaluation tools presented in Chapter 2 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 and Hollnagel 2009).

3.3 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 road 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 that the effects of road safety measures are routinely monitored and compared to ex-ante impact assessments.

3.4 Need for training and specialised skills

All evaluation tools require specialised knowledge and skills. However, there is some variation with respect to the needs for training and specialised skills. Arguably the most highly specialised tool is 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, road safety inspections, network screening, accident modelling and in-depth analyses of accidents (Vaneerdewegh and Matena 2007). Expertise at an intermediate level is required for identification and analysis of hazardous road locations, road protection scoring, impact assessment, monitoring road user behaviour and conflict studies.

3.5 Objectivity and transparency

The objectivity of an evaluation tool refers to its between- and within-subject reliability. 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 one hundred percent 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 accidents at hazardous road locations, impact assessment and in-depth studies of accidents. 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.

3.6 Ease of updating tool and results based on it

Safety management of roads is a continuous activity. The evaluation tools that support road 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. The reason for this is that data in road data banks are not always routinely updated. 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 outdated 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. Outdated models are a problem (Hirst, Mountain and Maher 2004).

4 Current use of evaluation tools in Europe

This chapter presents a survey of the current use of evaluation tools for safety management of roads in Europe. The survey was conducted by means of questionnaire. The questionnaire is first presented and briefly discussed. Then the answers to the questionnaire are presented.

The questionnaire is reproduced in Appendix 1, including the codes assigned to answers.

4.1 The questionnaire

The questionnaire consisted of two main parts. The first part was intended to collect information regarding current use of the ten safety evaluation tools presented in Chapter 2. The second part was intended to help assess the applicability of evaluation tools in terms of six criteria that influence the ease of their use. These six criteria were discussed in Chapter 3.

In part 1, each country provided information about whether it currently uses any of the ten evaluation tools described in Chapter 2 (the Dutch algorithm for determining speed limits was not listed explicitly). Additional questions were asked to provide more details regarding the use of accident modelling, road protection scoring, road safety impact assessment and monitoring of road user behaviour.

In part 2, each country rated the demands for using each of the evaluation tools in terms of need for original data, need for standard procedure, reporting requirements, need for training and specialised skills, objectivity and transparency and ease of updating.

4.2 Coding answers to the questionnaire

Answers, generally given by the national road authorities, were received from seventeen countries:

Austria, Cyprus, Denmark, Estonia, France, Germany, Great Britain, Hungary, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Slovenia, Spain and Sweden.

These countries can be considered as a representative cross section of Europe, including both small and large countries, countries in the north and south of Europe, as well as central and eastern European countries. The sample, although small, does permit exploratory analyses of the relationship between the use of the safety management tools and safety performance.

For the purpose of these analyses, the answers to the questionnaire were coded. With respect to the use of the ten listed evaluation tools, a code of 1 was assigned if a country reported that a tool was used; if the tool was not reported to be used, the answer was coded as zero. Based on this coding, a simple count variable was developed for the use of the safety management tools, ranging from 0 (no tools used) to 10 (all tools used).

Answers to the supplementary questions regarding the use of four of the tools were coded as follows. If accidents models were updated regularly, a code of 1 was assigned; if models were not updated regularly, a code of 0 was assigned. Models including multiple independent variables were coded as 2; models including only traffic volume as an explanatory variable were coded 1. Thus, countries could earn 3 points if they used comprehensive accident models that were updated regularly. Countries not using accident models scored 0 on the supplementary question regarding the use of accident models. A score of 1 was assigned if road protection scoring was reported to influence the use of safety measures; otherwise a score of 0 was assigned. Finally, with respect to road safety impact assessment, a score of 2 was assigned if these assessments comprised both large investments and minor treatments; if impact assessments were made only of major projects, a score of 1 was assigned. A score of 1 was assigned if road safety impact assessments were updated regularly; if not a score of 0 was assigned. A score of 1 was assigned if the validity of road safety impact assessments was evaluated; otherwise a score of 0 was assigned. Thus countries could earn 8 points in total depending on their use of accident modeling, road protection scoring and road safety impact assessment: 3 for accident modeling, 1 for road protection scoring and 4 for road safety impact assessment.

The monitoring of road user behaviour was coded as follows: 2 if speed was monitored, 1 if the use of crash helmets was monitored, 2 if the use of seat belts was monitored, 1 if the use of mobile phones was monitored, 1 if the following distances were monitored and 2 if drinking and driving was monitored. Drinking and driving was not listed in the questionnaire, but countries had the option of reporting whether they monitored other types of behaviour than those listed. Some countries answered that drinking and driving was monitored. In total, countries could earn 9 points with respect to the monitoring of road user behaviour.

An index for the use of safety management tools was thus developed with a maximum score of 27. The components of the index were:

1. Use of the ten listed safety management evaluation tools (maximum 10 points).
2. Use of accident modelling, road protection scoring and road safety impact assessment (maximum 8 points).
3. Monitoring of road user behaviour (maximum 9 points).

Table 1 reports the scores each country obtained with respect to the components of the index.

Table 1: Use of road safety management evaluation tools in a sample of European countries

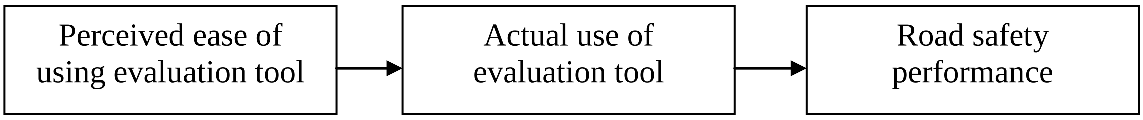
Country	Use of ten tools for road safety management	Accident modelling, road protection scoring, road safety impact assessment	Monitoring of road user behaviour	Total score for use of road safety management tools
Austria	9	3	7	19
Cyprus	5	1	6	12
Denmark	9	4	5	18
Estonia	5	0	7	12
France	9	5	7	21
Germany	6	4	3	13
Great Britain	9	6	5	20
Hungary	7	0	8	15
Iceland	8	3	5	16
Ireland	7	4	5	16
Luxembourg	4	0	5	9
Netherlands	10	7	9	26
Norway	9	8	4	21
Portugal	7	6	5	18
Slovenia	9	0	8	17
Spain	10	6	5	21
Sweden	7	7	4	18

Source: TØI report 1113/2010

The total score obtained ranges from 9 (Luxembourg) to 26 (Netherlands). Some of the scores are as expected, like the high score of the Netherlands. Other findings are somewhat more surprising, like the comparatively low score of Sweden, which is among the safest countries in Europe. Germany scored rather low – 13 – while France scored 21. Both these countries have accomplished substantial improvements in road safety in recent years, although the progress made in France has attracted a greater international interest than the progress made in Germany.

4.3 Framework for statistical analysis

Statistical analysis of the answers was based on a simple causal model, shown in Figure 3.



Source: TØI report 1113/2010

Figure 3: Causal model underlying statistical analysis

It was assumed that the likelihood of a country using a specific road safety management evaluation tool depended on the perceived ease of using the tool. If a tool was rated high with respect to data requirements, high with respect to the need for specialised skills and training, etc., it was judged to be less likely to be used. Part 2 of the questionnaire was intended to elicit the perceived level of difficulty of using the various evaluation tools.

Unfortunately, most countries have not interpreted the questionnaire as intended. Most countries not using a certain evaluation tool have not answered part 2 of the questionnaire, and have thus not provided any information regarding their perception of how easy it is to use a certain tool. Besides, for the countries that did answer this part of the questionnaire, the answers display very limited variation. It was therefore not possible to meaningfully analyse the first part of the causal model shown in Figure 3.

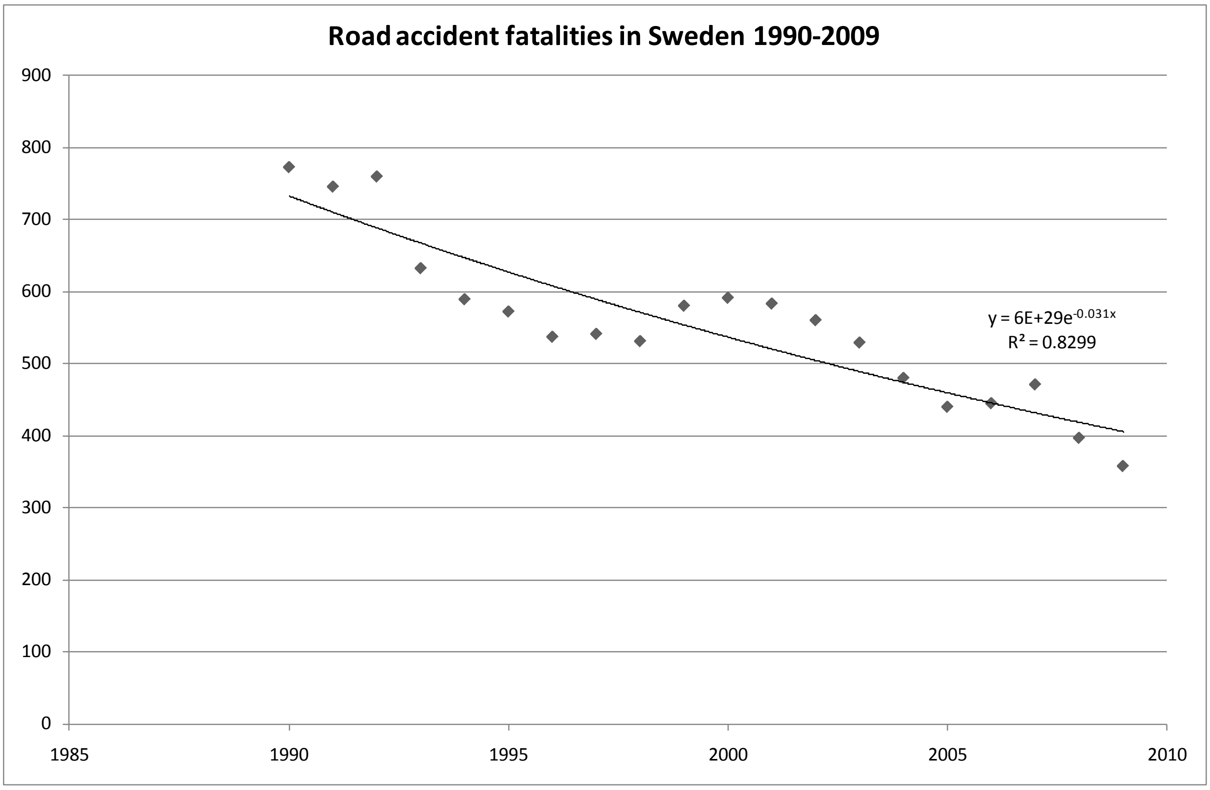
Analysis therefore focussed on the second part of the model – the relationship between use of the road safety management tools and road safety performance. The basic hypothesis is that the more extensive use a country makes of the road safety management tools, the better will be its road safety performance. The extent of use of the tools is measured by the index values given in Table 1. Road safety performance can be measured in a number of ways. The following four indicators of road safety performance were used in the analysis:

1. Fatality rate in 2008. This was measured as the number of road accident fatalities per billion km of travel performed by means of cars and buses. Data were taken from Eurostat.
2. Trend in fatalities between 1990 and 2009. For each country, the count of road accident fatalities each year from 1990 to 2009 was plotted and an exponential curve, showing the mean annual percentage change in the number of fatalities, was fitted to the data. Figure 4 shows an example of such a curve.
3. Trend in fatality rate from 2000 to 2008. Fatality rate was defined as the number of fatalities per billion km of travel performed by means of cars and buses. The trend in fatality rate was indicated by the mean annual percentage decline in fatality rate between 2000 and 2008.

4. Change in trend in fatality rate from 1990-2000 to 2000-2008. The annual decline in fatality rate during 2000-2008 was compared to the annual decline in fatality rate between 1990-2000 to determine if the rate of progress in improving road safety has slowed down or speeded up.

With respect to the first indicator, it was expected that an extensive use of safety management tools is associated with a low fatality rate. This indicator is rather weak, however, as fatality rates are influenced by very many factors and there are historical differences between countries that have not been fully eliminated, although the differences in fatality rate between countries have tended to become smaller over time.

All countries, except Iceland, have experienced a decline in the number of road accident fatalities between 1990 and 2009. For Iceland, the annual number of fatalities, varying roughly between 10 and 30, was too small to reliably determine any trend. Figure 4 shows a typical example of the trend between 1990 and 2009.



Source: TØI report 1113/2010

Figure 4: Road accident fatalities in Sweden 1990-2009

All long term trends were summarised in terms of an exponential function showing the mean annual percentage reduction of the number of fatalities. Although it is clear that other functions, such as polynomials, would often fit the data points better than an exponential function, the exponential function was preferred because it is simple and can be interpreted as a learning curve, with the annual percentage change indicating how fast learning takes place. Progress in reducing accident rates can often be adequately modelled in terms of an exponential function (Duffey and Saull 2003, Evans 2003).

It was assumed that an extensive use of road safety management tools is associated with a larger annual percentage reduction of the number of fatalities than a less extensive use of road safety management tools.

In nearly all countries, traffic is growing. The faster the growth in traffic, the more difficult it is to reduce the number of fatalities. In Figure 4, for example, it is seen that the decline in the number of fatalities in Sweden stopped in 1998. It was not until 2003 that a lower number of fatalities was recorded. Similar periods of stagnation are seen in many countries. To describe the long term trend in fatality rate, the fitted values according to the exponential function were used, rather than the recorded number in a particular year. Thus, for Sweden the recorded number in 1990 was above the fitted value. The same applied to the year 2000, whereas in 2008, the recorded number of fatalities was below the fitted value according to the exponential function. Most of the differences between the annual recorded numbers and the fitted numbers are the result of random variation. To minimise the influence of random variation on the statistical analysis, change in fatality rate was calculated on the basis of the fitted number of fatalities in the years 1990, 2000 and 2008, rather than the recorded numbers for those years. There was a tendency in all countries for fatality rate to be reduced. This trend was summarised in terms of the annual percentage reduction of fatality rate.

It was expected that the more extensive use a country makes of the safety management tools, the larger will be its annual reduction of the fatality rate.

However, not all the safety management tools have come into use at the same time. Thus, the identification and treatment of hazardous road locations – traditionally referred to as black spot treatment – started to be done systematically in Norway around 1970. Road safety audits started to be performed in the 1990s and road safety inspections were only performed to any significant extent after 2000. Accident modelling was also adopted as an element of road safety management in Norway after 2000. Similar stories could be told for many of the other countries included in this study.

If the use of the safety management tools has expanded over time, one might also expect that the rate of decline in fatality rate has increased over time. To test whether this is in fact the case, the annual decline in fatality rate between 2000 and 2008 was compared to the annual decline in fatality rate between 1990 and 2000. It was expected that the more extensive use a country currently makes of the safety evaluation tools, the more likely it is to have improved its performance over time, by accomplishing a higher annual decline in fatality rate after the year 2000 than before the year 2000.

To summarise, if using road safety management evaluation tools helps improve road safety performance, it is expected that:

1. The more extensive the use of the management tools, the lower the current road accident fatality rate (a negative relationship).
2. The more extensive the use of the management tools, the larger the annual reduction of the number of fatalities (a positive relationship).

3. The more extensive the use of the management tools, the larger the annual reduction of fatality rate after the year 2000 (a positive relationship).
4. The more extensive the use of the management tools, the more the rate of decline in fatality rate has increased from before the year 2000 to after the year 2000 (a positive relationship).

Annual reductions of fatalities and fatality rate are stated as positive numbers – the larger the number, the larger the rate of decline. Hence, a positive relationship is expected between use of the safety management tools and these rates. Similarly, if a country had a 3.5 percent annual decline in fatality rate between 1990 and 2000 and improved this rate to 3.9 percent per year after 2000, the ratio between these numbers, i.e. 3.9/3.5 shows the rate of improvement. If the ratio is greater than 1, progress is now faster than it was before the year 2000. If the ratio is less than 1, progress is now slower than it was before the year 2000.

Statistical analysis has been performed both for un-weighted data and weighted data. In the analysis not weighting data, each data point is treated as equally reliable. In other words, the 2008 fatality rate in a small country is treated as being equally reliably estimated as the fatality rate in a larger country. This is clearly not correct, as a fatality rate based on, say, 200 fatalities has a considerably larger uncertainty than a fatality rate based on, for example, 4000 fatalities. Fatality rates for 2008 have, accordingly, been weighted in proportion to the number of fatalities used when estimating them. Countries recording less than 100 fatalities in 2008, i.e. Cyprus, Iceland and Luxembourg were omitted from the analysis.

For the analyses relying on trend data, the same set of statistical weights was applied to all analyses. These weights were defined as follows:

Statistical weight = $1/(1 - R^2)$

R-squared is the squared correlation coefficient showing the goodness-of-fit of the exponential trend line to the actual fatality counts between 1990 and 2009. In figure 4 above, this was 0.8299 for Sweden. The statistical weight for Sweden thus becomes 1/0.1701 = 5.88. The reason for defining the statistical weights this way is that the better the fit of the exponential trend line, the more precise is the description it gives of long term trends. In general, data points should be weighted in proportion to their precision.

4.4 Results of analysis

The results of the analysis are reported in Table 2. All analyses were performed using SPSS version 18. The following functional forms were tested in all analyses:

1. Linear ($Y = A + B_1 \cdot X$)
2. Logarithmic ($Y = A + B_1 \cdot \ln(X)$)
3. Inverse ($Y = A + B_1/X$)
4. Quadratic ($Y = A + B_1 \cdot X + B_2 \cdot X^2$)
5. Power ($Y = A + X^{B1}$)
6. Exponential ($Y = A \cdot e^{B1 \cdot X}$)

Table 2: Results of analysis of relationship between use of road safety management tools and road safety performance

Dependent variable (Y)	Type of model	Best fitting function	P-value of function	Constant term (coefficient A)	Coefficient B1	Coefficient B2
Fatality rate	Not weighted	Exponential	0.108	17.053	-0.055	
	Weighted	Quadratic	0.007	-7.527	1.738	-0.052
Fatality trend	Not weighted	Linear	0.896	4.235	-0.012	
	Weighted	Linear	0.062	5.812	-0.063	
Rate trend	Not weighted	Linear	0.282	7.819	-0.138	
	Weighted	Exponential	0.081	7.135	-0.014	
Trend change	Not weighted	Linear	0.207	0.652	0.014	
	Weighted	Quadratic	0.000	1.199	-0.049	0.002

Source: TØI report 1113/2010

Fourteen countries were included in the analysis using fatality rate in 2008 as dependent variable. None of the functions tested were statistically significant at conventional levels in the analysis applying equal weight to all countries. An exponential function fitted the data best, suggesting that as the score for use of road safety management tools increases, fatality rate declines. This is in line with prior expectations. In the analysis where cases were weighted in proportion to the number of fatalities used in estimating fatality rate, a quadratic function best fitted the data. The function is rather implausible. It suggests that fatality rate increases as the score for use of road safety management tools increases from 12 to 16, and declines if the score increases beyond the value of 16.

Sixteen countries were included in the analysis using trend in the number of fatalities as dependent variable. No model approached statistical significance in the analysis giving all countries the same weight. When countries were weighted in proportion to the precision of the exponential trend line fitted to the data for each country, a linear function best fitted the data. This function indicates that when more road safety management tools are used, the annual percentage reduction of the number of fatalities becomes smaller. This is the opposite of what was expected.

In the analysis using annual percentage change in fatality rate as dependent variable, a linear function fitted best in the non-weighted analysis. The function indicates that as more tools for road safety management are used, the annual percentage decline in fatality rate becomes smaller. This is the opposite of what was expected. In the weighted analysis, an exponential function best fitted the data. Again, the function indicates that a more extensive use of road safety management tools is associated with a lower annual percentage decline in fatality rate. In other words, there is no support for the hypothesis that a more extensive use of road safety management tools helps improve road safety performance.

Finally, in the analysis using change in the annual percentage decline in fatality rate from the period before the year 2000 to the period after the year 2000, the best fitting function in the analysis giving all countries the same weight was a linear function. This function suggests that a more extensive use of road safety management tools is associated with an improvement in road safety performance after the year 2000, compared to the performance before that year. This is in line with prior expectation. The analysis in which countries were weighted in proportion to the precision of the exponential trend in fatality counts found that a quadratic function best fits the data. This functional form is somewhat implausible, but for most of the range of the observations, it shows that a more extensive use of the tools for road safety management is associated with an accelerated decline in fatality rate in recent years.

4.5 Discussion of findings

The main impression from the analysis made is that only a weak and noisy relationship can be found between the use of road safety management evaluation tools and road safety performance. Some of the findings were contrary to prior expectations, apparently suggesting that the more road safety management tools a country uses the worse it performs in terms of road safety. On the other hand, other findings did suggest that road safety performance – or more specifically an improvement in road safety performance after the year 2000 – was positively related to the use of the management tools. Still other findings indicated implausible functional forms relating road safety performance to the use of the management tools.

It is difficult to interpret these findings. There is no strong support for the general hypothesis that the more extensive use a country makes of formal road safety management tools, the better it will perform in improving road safety. However, the results of analysis do not amount to a clear refutation of this hypothesis. It is a mixed picture: some results support the hypothesis, others go against it.

In general, there are two main interpretations of research results: methodological and substantive. A methodological interpretation usually points to weaknesses in data and method and often concludes that findings must be rejected for these or other methodological reasons. By contrast, a substantive interpretation often argues that findings represent true causal relationships.

It is difficult to see how a substantive interpretation of the findings can be defended. The relationships are weak and noisy and point in different directions for the different indicators of road safety performance. This hardly suggests that the analysis has uncovered any meaningful causal relationships.

As for methodological interpretations, the three most obvious weaknesses of the study are:

1. The variable indicating the use of the safety management tools may be too crude. It merely counts the number of tools used and does not address whether the tools are used in a rudimentary form or in a version closer to the state-of-the-art. It is reasonable to assume that applying the tools in a form that is close to the state-of-the-art could have a greater influence on road safety performance than using simpler versions of the tools.
2. The sample of countries is small. The analyses were based on data referring to between 14 and 16 countries. Clearly, any statistical

relationship would have to be very strong to attain statistical significance in such a small sample. Moreover, the possibility of self-selection bias cannot be ruled out. This means that the use of the safety management tools is related to prior interest in and performance in improving road safety. In other words: The tools tends to be used by those countries that took a strong interest in improving road safety even before all the tools had been developed to their current state-of-the-art. These countries would probably have continued to perform well in improving road safety even if they did not apply all the safety management tools included in this study.

3. The study did not control for any confounding variables. Road safety performance is likely to be related to very many influencing factors. Important factors include the political commitment to improving safety, the adoption of ambitious long term targets for improving safety, how well co-ordination between various governmental levels and agencies functions, how well funded road safety measures are, and so on. The use of a formal tool entails the risk of becoming a purely ritual act. A road safety audit is performed because it is mandatory, but it may be purely a formality.

Obviously, there could be other reasons why the study did not produce clear findings. In principle, it cannot be ruled out that even a conscientious use of all the safety management tools failed to improve road safety performance – because the mechanisms needed to bring about such an association did not function. As an example, road safety inspections may be carried out to high standards, but have no impact because funds to implement recommended safety measures may be lacking. Likewise, you can do the most beautiful analyses of hazardous road locations, but the document may end in the file drawer if money is lacking to implement the measures proposed. In other words, the road safety management tools need to be embedded in a well-functioning political system in order to produce the safety improvements they are intended to help produce.

5 The state-of-the-art and steps to improve road safety management evaluation tools in Europe

This chapter briefly surveys the state-of-the-art for the different road safety management evaluation tools and outlines steps that can be taken to bring current practice in Europe closer to the state of the art.

5.1 Improving road safety audits

Road safety audits are applied in many countries, but not all. Interestingly, Sweden – which is generally regarded as a leading country in road safety – does not carry out road safety audits for national roads. Such audits are used for municipal roads, but they are voluntary and their use depends on local discretion.

Ideally speaking, if design standards for roads are based on current knowledge regarding factors that influence safety, and if these standards are adhered to when new road schemes are developed, there should be no need for road safety audits. The case for them rests on a presumption of neglect on the part of road planners – either in the form of deficient design standards or in the form of disregard of these standards. Just as an accounting auditor will normally not find anything to criticise in the accounts of a business, a road safety auditor should approve of all projects that are based on the most recent and well-established knowledge about the relationship between design elements and road safety. Checklists used in road safety audits are, however, usually not based strictly on formal design standards for roads, but refer to a broader consideration of safety issues. Moreover, it is not necessarily correct to presume that current design standards for roads are to a major extent based on recent knowledge. These standards have evolved gradually during a very long period and may be based more on tradition and engineering conventions than on state-of-the-art road safety research.

As an example, the Norwegian guidelines for road safety audits calls on auditors to check if the width of driving lanes and shoulders is "sufficient" (Statens vegvesen, Håndbok 222, 2005). The answer is that the official design standards for roads define adequate lane width. If these design standards are applied when designing the road, the answer to question is therefore self-evident. Similar remarks could be made with respect to a host of other items that are listed on the checklist for road safety audits.

In principle, it could of course be the case that design standard lane widths are insufficient to accommodate large vehicles. However, that is not an auditing issue. It requires modification of the design standards, not just the specific project being audited. Knowledge about the actual effects on safety of road safety audits is almost non-existent. The few estimates that can be found tend to be hypothetical, meaning that the studies do not compare road schemes that were audited to similar road schemes that were not audited in terms of the accident experience after the schemes were opened to traffic. Rather, the studies (see e.g. Schelling 1995, Brownfield and Faber 1995) apply engineering judgement to assess what the safety of a road might have been had it not been audited.

There is a need for more rigorous evaluation studies to validate road safety audits. If it is not possible to perform controlled studies employing the design outlined above, a second best solution might be to conduct before-and-after studies of road safety inspections. These are in many respects analogous to road safety audits, but apply to an existing road which has an accident history that can be used as a source of data in an evaluation study. Care should of course be taken to control for important potentially confounding factors like regression-to-the-mean, long-term trends in accident and local changes in traffic volume.

The following steps are proposed to improve the quality of road safety audits:

1. Conduct systematic evaluation studies designed to assess the impacts of road safety audits on accidents. Such studies should ideally speaking be designed as controlled trials, in which pairs of similar road schemes are formed – one member in each pair is audited, the other is not. Following opening to traffic, accident experience is compared. A second best design might be to perform before-and-after studies of road safety inspections, to obtain estimates of the effects on accidents of minor measures that are identical to, or closely resemble, those proposed in road safety audits of road schemes similar to the roads that have been inspected.
2. An archive of all road safety audits should be kept and periodically analysed. This will inform highway agencies about learning associated with road safety audits. If road planners are learning, recent audit reports should contain fewer remarks than older audit reports. Particular attention should be paid to whether certain items or remarks are repeated often in audit reports. This indicates that learning does not take place, or that the audit remarks are very difficult for road planners to implement. The latter suggests that the form and content of audits should be changed.

Countries that are not using road safety audits today might consider introducing them once the steps outlined above have been taken.

5.2 Improving road safety inspections

The remarks made above with respect to road safety audits apply to a large extent to road safety inspections as well. An attempt to assess the likely effects on safety of road safety inspections was made in RIPCORD-ISEREST (Elvik 2006B), but it was to a large extent based on studies that did not evaluate road safety inspections as such.

The review made for RIPCORD-ISEREST also proposed best practice guidelines for road safety inspections. These guidelines are repeated here:

1. The elements to be included in road safety inspections should be known to be risk factors for accidents or injuries.

2. Inspections should be standardised and designed to ensure that all elements included are covered and are assessed in an objective manner. For this purpose, developing check lists may be of help.
3. The list of elements to be included in road safety inspections (check lists) should include those that are recognised as important. The following elements should be included in all road safety inspections:
    a. The quality of traffic signs, with respect to the need for them, whether they are correctly placed and whether they are legible in the dark.
    b. The quality of road markings, in particular whether the road markings are visible and are consistent with traffic signs.
    c. The quality of the road surface, in particular with respect to friction and evenness.
    d. Sight distances and the presence of permanent or temporary obstacles that prevent timely observation of the road or other road users.
    e. The presence of traffic hazards in the near surroundings of the road, such as trees, exposed rocks, drainage pipes, etc.
    f. Aspects of traffic operation, in particular if road users adapt their speed sufficiently to local conditions.
4. For each item included in an inspection, a standardised assessment should be made by applying the following categories:
    a. The item represents a traffic hazard that should be treated immediately. A specific treatment should then be proposed.
    b. The item is not in a perfectly good condition, but no short term action is needed to correct it. Further observation is recommended.
    c. The item is in good condition.
5. Inspections should report their findings and propose safety measures by means of standardised reports.
6. Inspectors should be formally qualified for their job. They should meet regularly to exchange experiences and to ensure a uniform application of safety standards in inspections.
7. There should be a follow-up of inspections after some time to check if the proposed measures have been implemented or not.

To this list can be added the need for evaluating the effects on safety of road safety inspections and the measures taken as a result of them. Before-and-after studies employing the Empirical Bayes design are well suited for this purpose.

5.3 Improving network screening

Various approaches that can be taken to network screening were examined extensively in RIPCORD-ISEREST (Elvik 2007B). The review found that current approaches differ between countries. Steps that can be taken to bring current practice closer to the state-of-the-art include:

1. Develop accident prediction models that can be used as an element of network screening.
2. Develop an exhaustive list of roadway elements (sections, junctions, curves, bridges, tunnels, etc) to which screening is applied. This is to prevent screening from, for example, identifying a large number of junctions as abnormal, simply because there tends to be more accidents in junctions than on road sections of similar length (say 100 metres).
3. Estimate the expected number of accidents for each roadway element by means of the empirical Bayes method.
4. Apply the peaks-and-profiles algorithm in order to identify longer road sections that have a higher than normal expected number of accidents.
5. Survey a broad set of potentially effective road safety measures that can improve safety for elements that have substandard safety.

In addition to these points, it is important to conduct network screening regularly in order to update results.

5.4 Improving accident modelling

There is no doubt that the field of accident modelling has made impressive progress in recent years. Some of the recent models are statistically very advanced and make a very efficient use of available data. The understanding of potentially confounding factors in accident modelling has also increased. It seems clear that many of the accident models published the last 10-15 years have increased our understanding of factors that are associated with accidents.

It is nevertheless not possible to applaud these impressive contributions without pointing out some common shortcomings of accident models that need to be corrected in order to make these models more valuable in increasing knowledge. More specifically, the following steps should be taken:

Researchers need to be explicit about whether they want the model to show causal relationships between variables or merely statistical associations. If causal relationships are sought, it becomes important to control for confounding factors when developing a model.

The most important potentially confounding factors in multivariate accident models include (Elvik 2011):

1. Small sample and/or low mean value bias
2. Bias due to aggregation, averaging or incompleteness in data
3. Presence of outlying data points
4. Inappropriate choice of dependent variable
5. Endogeneity of safety treatment

6. Wrong functional form for effects of independent variables
7. Co-linearity among explanatory variables
8. Omitted variable bias
9. Misspecification of the structure of systematic variation in accidents and residual terms
10. Mixing levels of accident severity
11. Inappropriate model form

Confounding factors that are likely to be present in many accident models include:

1. Bias due to aggregation, averaging or incompleteness of data. In particular AADT as a measure of traffic volume may be biased both because it is an average, it is an aggregate (of the various types of vehicles that make up traffic) and it is very often incomplete (pedestrians and cyclists are rarely included). Accident reporting is always incomplete; however this is not a problem that can be solved by statistical estimation only.
2. Wrong functional form for effects of independent variables. Most models tend to rely on the assumption that all relationships are monotonic. Functional forms ought to be tested in an exploratory analysis.
3. Omitted variable bias. Pedestrian and cyclist volumes are very often omitted. Variables describing road user behaviour are also very rarely included in accident models.
4. Mixing levels of accident severity. As shown in the discussion above, mixing levels of accident severity can produce results that are almost impossible to interpret. If separate models cannot be fitted for accidents at each level of severity, then at least accident severity ought to be included as a variable in the model.
5. Inappropriate model form. A dual state model should not be used merely because it happens to be the case that it fits the data better than a single state model. A reason should always be given for choosing a dual state model. Models implying a zero-state, i.e. a state in which the expected number of accidents is zero or very close to it, have no substantive meaning and should never be used.

In addition to controlling for confounding factors, establishing causality requires that:

1. One or more mechanisms that generate the statistical relationships between variables be identified, and
2. 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.

The value of replication and accumulation of knowledge needs to be recognised. It is only by fitting a set of identical or comparable models that the results can be compared and possibly synthesised by means of meta-analysis.

At present, it has to be concluded that few accident models have dealt adequately with these issues. Therefore, these models do not contribute as much to knowledge as they could do by addressing the points listed above.

5.5 Improving road protection scoring

The most widely applied tool for road protection scoring appears to be the EuroRAP scoring system. This system takes into consideration a number of factors that are known to influence the severity of accidents, but the scoring system has not been validated. By validation is meant an empirical study that shows actual accident severity for road sections that are assigned different star ratings in EuroRAP.

In a recent study Pardillo-Mayora et al. (2010) validated a roadside safety index for Spain based on the following variables:

1. Slope of roadside, with five values ranging from 1:6 (safest) to 1:2 (most dangerous),
2. Clear zone along roadside, with four values ranging from no obstacles within 10 metres from the road (safest) to obstacles within 3 metres from the road (most dangerous)
3. Presence of safety barrier, with three values with no barrier as safest and a non-approved barrier as most hazardous,
4. Alignment, with straight as safest and curve as most hazardous.

Based on combinations of values for these variables, five categories of road were formed. For each category, accident severity was stated in terms of the percentage of all reported accidents that were fatal. Figure 5 shows the results.

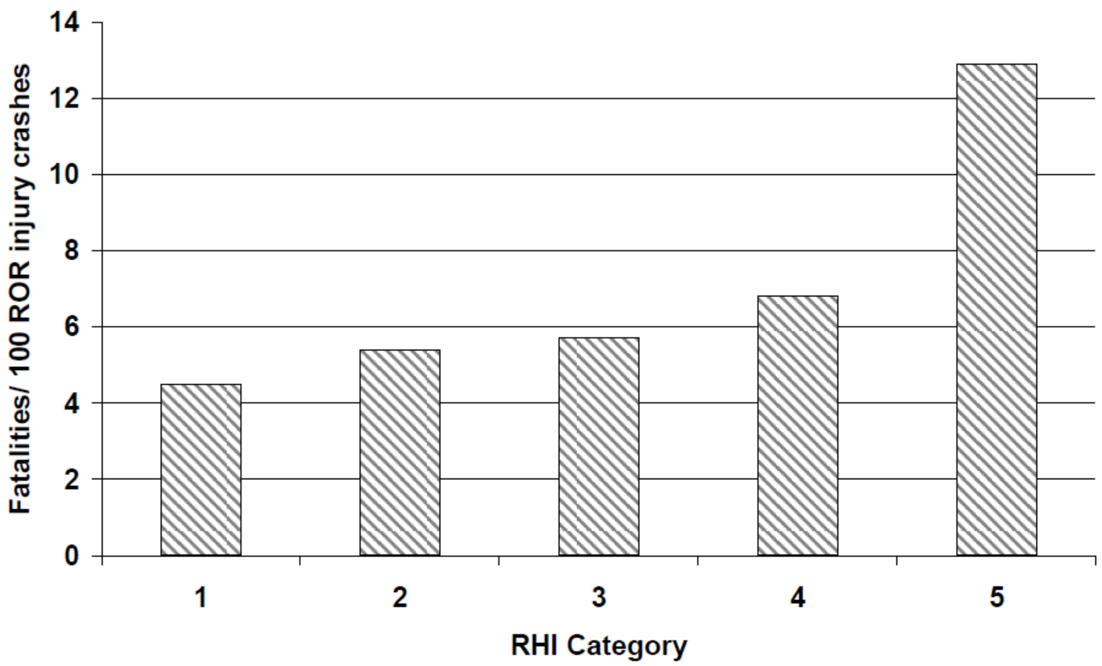


Figure 5: Accident severity for five groups of roads in Spain formed by combining values for roadside slope, size of clear zone, presence of safety barrier and road alignment. Source: Pardillo-Mayora et al. 2010

It can be seen that group 5, which is characterised by sideslopes steeper than 1:3, fixed obstacles closer than 5 metres from the edge of the road, no safety barrier and the presence of horizontal curves, differs markedly from the other four groups. While the increase in accident severity as one proceeds from group 1 to group 4 is fairly constant, there is a jump in group 5.

If one imagines the categories 1 to 5 converted to a star rating, the scale would be somewhat difficult to interpret, as the steps between adjacent stars are not equally large. It would be interesting to perform a similar validation of the EuroRAP road protection scoring system.

5.6 Improving identification and analysis of hazardous road locations

How best to identify and analyse hazardous road locations was analysed in depth in RIPCORD-ISEREST, and the main findings remain valid (Elvik 2007B). Briefly, to improve current techniques, road administrations ought to:

1. Develop a classification of roadway elements. A list of elements might include:
    a. Road sections of a given length and given number of lanes
    b. Junctions with a given number of legs 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
2. For each element, form a population of sites, all members of which can be enumerated.
3. For each element, identify hazardous locations by means of the Empirical Bayes (EB) method. Hazardous locations should be defined as those forming the top 10%, 5% or 2.5% of the distribution of sites according to the EB-estimate of the expected number of accidents.
4. Analyse the presence of risk factors contributing to accidents for each identified site by adopted a case-control approach, in which a safe site which is similar to the hazardous site forms the control group.

Most countries need to make major changes in their current systems for identifying and analysing hazardous road locations in order to approach the state-of-the-art.

5.7 Improving impact assessment

Impact assessment is a key activity in road safety policy making. It consists of estimating the safety impacts expected by implementing specific road safety measures and the total impacts on safety of introducing a set of road safety measures. As shown by the questionnaire survey, impact assessment is not always performed for minor road safety measures. It is, however, often minor measures that can make the largest contribution to improving road safety.

Table 4 shows an estimate of the potential for reducing the number of fatalities in Norway by means of a number of road-related safety measures (Elvik 2009). For each measure, two alternatives for the extent of its use are given:

1. The measure is used only when benefits exceed costs (in monetary terms).

2. The measure is used to the maximum conceivable extent, no matter what the benefit-cost ratio is.

The concept of "maximum conceivable extent" is of course somewhat imprecise. It has, however, been clearly defined for all the measures included in Table 3.

Table 3: Potential reduction of the annual number of road accident fatalities in Norway by means of road-related safety measures. Source: Elvik 2009

	Potential reduction of the annual number of fatalities or serious injuries					
	Measures applied if benefits exceed costs			Measures applied to maximum conceivable extent		
Measure	Number of locations	Fatalities	Serious injuries	Number of locations	Fatalities	Serious injuries
New motorways (freeways)	30	1.8	4.7	350	13.2	33.9
Bypass roads	35	0.2	1.3	190	0.6	3.4
Median guard rail	130	4.7	7.2	500	9.5	14.7
Median rumble strips	155	0.7	1.2	500	1.1	2.0
Guardrail along roadside	610	1.0	3.9	1670	1.3	5.2
Roadside safety treatment	190	0.3	1.1	1670	0.7	2.6
Curve treatments	1750	1.3	3.5	2200	1.4	3.7
Follow-up of inspections	345	3.1	5.3	500	3.5	6.1
New road lighting	3150	7.7	11.0	15840	13.7	19.7
Improving road lighting	380	0.7	1.7	660	0.8	1.9
Roundabouts – three legs	460	1.7	5.3	8735	7.2	23.1
Roundabouts – four legs	325	3.0	12.0	825	4.4	17.5
Upgrading pedestrian crossings	1643	5.4	12.8	2210	5.8	13.6
Pedestrian bridge/tunnel	442	3.3	10.6	1155	4.6	14.6

The number of locations is the length of treated roads in kilometres for the measures that refer to road sections. For measures in junctions or at pedestrian crossings, the number of locations refers to the number of junctions or the number of pedestrian crossings.

It can be seen that major road projects, like building new motorways or bypass roads will only make a comparatively small contribution to reducing the number of fatalities or serious injuries. Upgrading existing roads by means of, for example, road lighting or upgraded pedestrian crossing facilities can make a larger contribution. It is therefore important that road safety impact assessment tries to include all road safety measures, even minor improvements to existing roads.

There are many sources of uncertainty in road safety impact assessments. Elvik (2010B) identifies and discusses ten sources of uncertainty. These are:

1. Random variation in the number of accidents or injuries in the target group of a road safety measure. The target group is the type of accident or injury the measure is intended to influence (e.g. accidents in darkness for road lighting),
2. Incomplete or inaccurate reporting of accidents or injuries in official road accident statistics,
3. Uncertainty about the definition of the target group of accidents or injuries influenced by a road safety measure (e.g. road lighting may influence accidents in daylight as well, not just darkness),
4. Random variation in the effect of a road safety measure on accidents or injuries,
5. Unknown sources of systematic variation in the effect of a road safety measure on accidents or injuries,
6. Unknown duration or stability over time in the effects of a road safety measure,
7. Uncertainty with respect to a potential modification of the effect of a road safety measure when it is combined with other road safety measures in a programme (e.g. are pedestrian reflective devices equally effective on lit roads as on unlit roads?),
8. Uncertainty about the effects of exogenous factors influencing road safety,
9. Uncertainty about the degree to which a road safety measure or set of measures will be implemented to the extent planned,
10. Uncertain monetary valuation of the benefits of reducing accidents or injuries.

The latter source of uncertainty is only relevant if a cost-benefit analysis of road safety measures is performed and the results of the analysis are intended to influence policy making.

It is at the current state of knowledge impossible to quantify all these sources of uncertainty. It is nevertheless important that those sources that can be quantified are quantified, to allow an assessment of which of these sources of uncertainty makes the greatest contribution to overall uncertainty. To improve the quality of road safety impact assessments, the following steps should be taken:

1. Conduct a broad survey of potentially effective road safety measures and include as many of them in an impact assessment as possible.
2. Try to assess as many sources of uncertainty in an impact assessment as available data allow for.
3. Monitor the implementation of road safety measures as well as changes in exogenous factors (i.e. everything other than a road safety programme) that influence road safety.
4. Periodically update road safety impact assessments and check the accuracy of previous assessments.

5.8 Improving the monitoring of road user behaviour

All countries monitor road user behaviour. However, the types of behaviour that are monitored, and the use of the results varies between countries. The two main reasons for monitoring road user behaviour are to explain changes in the number and severity of accidents and to give an early detection of emerging road safety problems. In principle, very many types of behaviour could be monitored. For the purpose of influencing road safety, it is particularly important to monitor violations that contribute to fatalities and injuries. According to estimates made by Elvik (2010C), the following violations make the largest contribution to fatalities and should therefore be monitored:

1. Speeding
2. Drinking and driving
3. Not wearing seat belts
4. Driving under the influence of drugs
5. Violating hours of service and rest regulations for commercial transport

Unfortunately, monitoring all these types of behaviour is difficult. Monitoring speed and seat belt wearing is comparatively easy. It can be done by means of reliable technology or low-cost roadside observations. Monitoring drinking and driving, on the other hand, is very costly and difficult. The best method for obtaining representative data on drinking and driving is to conduct a roadside survey. However, such a survey would normally have to include several thousand drivers, as the incidence of drinking and driving is quite low in many countries. A statistically reliable estimate of the incidence of drinking and driving would therefore require the collection a large amounts of data and fairly sophisticated statistical analysis of these data. Similar difficulties are encountered when trying to monitor driving under the influence of drugs.

Existing data on drinking and driving are very poor and unreliable (Assum and Sørensen 2010B). This is remarkable in view of the fact that drinking and driving is likely to be a major risk factor for accidents and injuries. To improve the monitoring of road user behaviour, the following steps can be taken:

1. Select up to five different types of road user behaviour for regular monitoring. Make the selection on the basis of how much the various types of behaviour are believed to contribute to accidents, fatalities and injuries.
2. Develop a sampling plan for monitoring road user behaviour, ensuring that results are representative for road user behaviour at large.
3. Monitor road user behaviour by means of the same methods for a number of years in order to establish a basis for investigating the relationship between changes in behaviour and changes in the number of accidents, fatalities or injuries.
4. Allow police to make routine checks for alcohol whenever a road user is stopped and checked. Perform such checks as a routine. Use police statistics as an indicator of the incidence of drinking and driving.

5.9 Improving conflict studies

Historically, conflict studies were introduced as a substitute for accidents, to enable road safety evaluation studies to be performed in cases where a low count of accidents made an evaluation based on accidents highly uncertain. To use conflicts as a substitute for accidents, there should ideally speaking be a strong and fairly constant statistical relationship between the number of conflicts and the number of accidents. One would then be able to convert a recorded number of conflicts to an expected number of accidents.

Research has shown that such conversion factors are difficult to establish (Hauer and Gårder 1986). Both the number of conflicts and the number of accidents are greatly influenced by random variation. Besides, in the early days of conflict studies, observation of traffic conflicts depended on human observers and their classification of conflicts by type and severity. Although observers were trained to make the observations as reliable as possible, there was bound to be an element of subjectivity both in the count and classification of conflicts.

This has changed in recent years. In the first place, a connection can be made between specific traffic events and potential conflicts (Elvik, Erke and Christensen 2009). The idea of defining exposure as events that generate the potential for a traffic conflict is not new (Hauer 1982). Events, such as simultaneous arrivals at junctions or pedestrian crossing facilities, can meaningfully be counted and regarded as homogeneous, as opposed to summary measures of exposure, like vehicle kilometres of driving. Defining exposure in terms of countable and reasonably homogeneous events, re-establishes the connection between the concepts of exposure and risk and the concepts of trials and probability in probability theory, from which the statistical analysis of accidents emerged historically. Once exposure can be measured as the potential number of conflicts, a meaningful denominator for estimating a conflict rate exists. This can in turn be related to the accident rate, again using the count of events as the measure of exposure.

In the second place, techniques for observing and analysing data on traffic conflicts have improved substantially in recent years (Svensson and Hydén 2006, Laureshyn, Svensson and Hydén 2010). Conflicts are now registered objectively by means of video cameras, and the analysis of videos has been greatly improved by means of modern techniques for video image analysis. This does not mean that data collection and analysis can be fully automated, nor does it mean that all problems of classification and interpretation have been solved. It has, however, made the study of traffic conflicts more objective than it was before.

Studying traffic conflicts is therefore probably more useful and informative today than it was just a few years ago – provided state-of-the-art techniques are used. It can be a valuable supplement to accident analyses at hazardous road locations and shed light on why these locations become hazardous.

To make a fruitful use of conflict studies in road safety management, it is recommended to:

1. Select a set of sites at which the rate of conflicts is monitored continuously. This is intended to establish a baseline rate of conflicts for a number of common traffic situations. Use video to record conflicts and modern image processing techniques to analyse the data.
2. Perform conflict studies at hazardous road locations to supplement accident analyses at these sites, in particular if accident analyses are inconclusive and no clear contributing factors are identified.
3. Determine conversion factors in order to convert a recorded number of conflicts to an estimate of the expected number of accidents.

5.10 Improving in-depth accident studies

In-depth studies of accidents have become more popular in recent years. Finland has had a programme of in-depth studies of fatal accidents since the 1970s. In the 1990s, Sweden started in-depth studies of fatal accidents, in part to help promote Vision Zero by identifying factors contributing to fatal accidents (or a fatal outcome of an accident), thereby hoping to prevent these accidents more effectively. In 2005, Norway started a similar programme of in-depth studies of fatal accidents. In-depth studies of accidents are also carried out in Great Britain, Germany and the Netherlands.

The popularity of in-depth studies of accidents has varied in cycles of about 30 years in the period after the Second World War. The first wave of such studies took place in the 1950s. It was initiated as a reaction to the breakdown of accident proneness theory. It was felt that the statistical approach taken in many studies of accident proneness did not reveal the underlying causes of accidents and was therefore not very fruitful from the point of view of accident prevention. The hope was that the “real” causes of accidents could be found by studying each accident in great detail and reconstructing the events that lead to the accident.

It soon became apparent that various human factors contributed importantly to most accidents. Many accidents happened simply because road users were not paying full attention to traffic. The first in-depth studies of accidents therefore often lead to recommendations to improve the education of road users, or to conduct information campaigns exhorting road users to pay attention to traffic, to always be fully alert, to always be on the lookout for hazards, etc, etc. It soon became apparent that these campaigns were ineffective. In-depth studies lost their popularity and a new approach to the study of factors contributing to accidents, systems theory, gained widespread acceptance. The central tenet of systems theory is that accidents are produced by a failure in the interaction between the elements of a complex system – hence it does not make sense to blame a single of these elements, like the human factor, for accidents. Road users make errors, for sure, but there is always a reason why these errors are made. That reason could be that the system was poorly designed and not sufficiently adapted to human capacities.

Systems theory was a stunning success as far as preventing accidents and making them less severe was concerned. Despite this, important elements were felt to be missing in systems theory, and a new wave of in-depth studies arose in the latter half of the 1970s, leading to thick reports in Great Britain the United States and Sweden. Rumar (1985) gives an interesting comparison of these studies. The findings were remarkably similar and it was once more concluded that human factors precipitated most accidents.

The third wave of in-depth studies is the one that is still going on. This wave has partly been brought on by the heightened ambitions for improving road safety, as expressed in concepts like Vision Zero. Another reason for the renewed interest in in-depth studies, is that methods for studying factors contributing to accidents have developed and it is therefore believed that methodologically better studies can be made today than in the past.

Yet, a cursory examination of the findings of in-depth studies in Sweden (Sagberg and Assum 2000) and Norway (Haldorsen et al. 2009) reveals that there is little news in the results. The typical result of an in-depth study is still a long list of human factors that may have contributed to the accident. The classification of these factors, and the level of detail with which they are described, may have changed somewhat over time. On the whole, however, results are remarkably stable over time.

The enduring use of in-depth studies is remarkable from a methodological point of view. The method is perhaps best viewed as a structured way of developing hypotheses (Shinar 2007). It does usually not test these hypotheses, by exposing them to the risk of falsification. Nor do in-depth studies develop general law-like statements about accident causation, akin to the laws of nature that are at the heart of the so called "covering law" model of scientific explanation in the natural sciences (Hempel 1965). In-depth studies are often based on small samples, selected for study precisely because they are not typical of accidents in general. However, the routine in-depth studies performed in recent years in, for example, Norway and Sweden, include all fatal accidents.

Despite this criticism, it is wrong to dismiss in-depth studies as entirely worthless. In some cases, fairly well-supported statements about factors contributing to accidents can be made. Official accident statistics are known to be incomplete and biased; if one wants better data, in particular about the most serious accidents, it is necessary to perform in-depth studies. The use of in-depth studies should remain selective, as it is today, at least in Norway and Sweden. It is not an indispensable element of road safety management. Road safety management can be successful without relying on in-depth studies. If, however, road authorities want to make use of in-depth studies as a tool of road safety management, the following points are worth bearing in mind:

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.
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 accidents where better data are needed and likely to be made use of in road safety management.

6 Discussion and conclusions

Road safety has been greatly improved in many highly motorised countries during the past 40 years. While a rigorous analysis of the factors that have contributed to this development is difficult to perform, it seems clear that a systematic use of many road safety measures has contributed importantly to improving road safety. To use road safety measures in a way that brings about maximum benefits, a systematic approach to the planning and implementation of such measures is needed. To help support such planning, a number of road safety management tools have been developed. This report has reviewed ten of these instruments, including:

1. Road safety audits, to help incorporating the best knowledge about how to design a safe road into decisions about the design and construction of new roads, thus making new roads safer than existing roads,
2. Road safety inspections, to systematically identify and treat defects in design and traffic control on existing roads, ideally speaking before these defects contribute to accidents,
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 accidents, or a higher severity of accidents, than the rest of the system,
4. Accident modelling, to help identify and assess the importance of various factors that contribute to accidents 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 accidents due to deficiencies of road design and/or traffic control,
7. Road safety impact assessment, which is estimates of the safety benefits expected from various road safety measures, made 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 accidents or of driver behaviour in a natural setting,
10. In-depth accident studies, in order to learn more about the factors that precipitate accidents and the opportunities for controlling or removing these factors.

These tools for road safety management have developed during a long period. The identification and analysis of hazardous road locations, traditionally referred to as black spot management, has a long history in many motorised countries. This tool has been applied at least since about 1970 in countries like Denmark, Great Britain, the Netherlands and Norway. In some countries, notably the Netherlands and Norway, this tool has become less important and less useful in recent years, because very many road accident black spots have been treated and few remain. There are, to be sure, a number of locations that have a high number of accidents, but in many cases this is simply because these locations serve very high traffic volumes.

The statistical techniques for identifying and analysing hazardous road locations have developed considerably in recent years. Current practice in most countries does not reflect these developments. A case can therefore be made for bringing the techniques for identifying and analysing hazardous road locations closer to the-state-of-the-art. This could make this tool more useful, in particular in countries where the traditional approach to the identification and analysis of hazardous road locations has lost some of its efficiency recently.

Another tool that has existed for a long time is in-depth accident studies. The use of such studies has always been very selective. Only a few accidents – often the most serious accidents – have been subjected to in-depth study. The techniques for performing in-depth studies have developed, and it is worthwhile to observe that recent studies in Norway and Sweden have broadened the scope of factors studied compared to older in-depth studies. More attention is now given to the potential contributions of factors related to infrastructure and vehicles, not just factors related to road users. Thus, in the most recent Norwegian in-depth study (Haldorsen et al. 2009), the following main categories of factors were listed as contributing to fatal accidents:

1. Factors related to road users: 576 (2.43 factors per fatal accident)
2. Factors related to vehicles: 47 (0.20 factors per fatal accident)
3. Factors related to the road: 89 (0.38 per fatal accident)
4. Factors related to environment: 49 (0.21 per fatal accident)

Factors related to the road users are seen to dominate, but factors related to other elements of the system are also mentioned in quite a few cases. Human factors, however, is the only main category that was regarded as having contributed to all fatal accidents investigated in 2008.

The fact that factors that are the responsibility of road authorities are gaining more attention reflects a change in the way road authorities define their responsibility for road safety. In the past, road authorities adopted a strictly legal point of view and assigned the entire responsibility for road safety to road users. The view was, so to speak, that road authorities are infallible and cannot in any way be held responsible for safety. The emergence of new ideals for road safety, like Vision Zero and Sustainable Safety, and a more mature interpretation of the systems perspective on road safety, has changed this. This change in philosophy is part of the reason why tools like road safety audits, road safety inspections and road protection scoring have been developed. These tools are all based on the notion that there exist safer and less safe road designs, and that it is the responsibility of road authorities to choose the safer designs. While it may be because a driver fell asleep that he went off the road, it is not the driver's fault if there are large and unprotected trees close to the road.

To help develop road safety audits, road safety inspections and road protection scoring, it is important to evaluate these tools. A few evaluations have been reported, but too few to quantify the safety benefits of these tools. New roads tend to be safer than existing roads (Elvik et al. 2009), but little is known about which elements of road design that have contributed to this.

Accident modelling is a recent innovation in the set of tools available for road safety management. Accident modelling has been a very active field of research in recent years, but many of the recent contributions appear to be motivated primarily by a purely academic interest in modelling, less by a concern about how to improve the application of accident models in road safety management. Some of the recent innovations in accident modelling are probably of limited usefulness for practitioners.

It is worthwhile to point out that almost all accident models identify traffic volume as the clearly most important factor explaining systematic variation in the number of accidents. Variation in traffic volume typically explains 60-80% of the systematic variation in the number of accidents. However, traffic volume is rarely the primary target for road safety interventions. Most road safety measures seek to reduce the number of accidents at a given traffic volume, not to reduce traffic volume itself. Some of the measures taken by road authorities, in particular building new roads or expanding the capacity of existing roads, may induce more traffic.

In general, road authorities see their mandate as serving prevailing travel demand efficiently, not trying to influence this demand. This means that no attempt is made to influence the most important factor associated with accidents. In that sense, the results of accident models are interesting by making it clear that road authorities do not control the most important factor generating accidents.

The recent flurry of statistical wizardry in the field of accident modelling is, for the most part, likely to be irrelevant for any practical use of accident models. This statistical wizardry has not produced any important new insights regarding factors that generate accidents. It has, for example, not made any difference to the fact that traffic volume remains the single most important explanatory variable. Road authorities are not likely to commit a large error by applying a standard negative binomial accident model, and not try to keep up with all the statistical innovations in the field of accident modelling.

Many road authorities monitor road user behaviour. Road user behaviour is obviously very important for road safety; in fact probably the greatest weakness of nearly all current accident prediction models is that they do not include any variables describing road user behaviour. Yet, the usefulness of monitoring road user behaviour is limited by at least two factors.

In the first place, year-to-year changes in road user behaviour may often be too small to establish any meaningful relationship between these changes and changes in road safety. Behaviour tends to change slowly and gradually; major changes are only found when legislation is changed, for example when wearing seat belts became compulsory. On the other hand, cross section variation in behaviour could be greater.

In the second place, it is very often outside the power of road authorities to influence road user behaviour. Law enforcement is the task of the police, whose priorities may include very many tasks in addition to maintaining or improving road safety by influencing road user behaviour.

Despite these limitations, monitoring of road user behaviour is a necessary element of any road safety management system. Ideally speaking, the monitoring of road user behaviour ought to be developed to the point of making the results easy to include in accident prediction models. This would both improve these models and provide a basis for improving knowledge regarding the size of the influence of changes in road user behaviour on road safety.

Surprising as it may sound, road safety impact assessment is also a comparatively recent addition to the toolbox for road safety management. As noted in Chapter 4, it is still the case in many countries that an assessment of safety impacts is made only for major road projects. Few countries have extensive experience in making road safety impact assessments and still fewer have created a system for updating and validating road safety impact assessments.

This is clearly a shortcoming of the current system for road safety management. While learning by trial-and-error, or learning-by-doing, may succeed in improving road safety to some extent, a more systematic approach is needed to fully exploit knowledge about opportunities for improving road safety. Road safety impact assessment is a field in rapid development. The recently published Highway Safety Manual in the United States represents the state-of-the-art with respect to road safety impact assessment.

It should be pointed out that the management evaluation tools discussed in this report are mainly tools for collecting and analysing data. A successful road safety policy requires additional management tools, for example cost-benefit analysis or cost-effectiveness analysis to help identify the most cost-effective road safety measures.

The main conclusions of this study highlight the opportunities for further development of the tools for road safety management:

1. Road safety audits, road safety inspections and road protection scoring can be further developed by evaluating their effects on safety and their performance in identifying safe and less safe solutions.
2. Network screening should be based on accident models and should apply the techniques developed in the Safety Analyst approach in the United States.
3. Road accident modelling needs to be developed by testing models empirically and by incorporating in them variables describing road user behaviour.
4. The identification and analysis of hazardous road location should employ the Empirical Bayes approach for identification of hazardous locations and the matched-pair approach for the analysis of factors that may contribute to accidents at hazardous road locations.

5. The state-of-the-art of road safety impact assessment is described in the Highway Safety Manual recently published in the United States. Changes made in current practice should try to bring it closer to the state-of-the-art.
6. Monitoring of road user behaviour should be targeted at about five types of behaviour that make the largest contributions to road accidents and injuries. In most countries, this would include speeding, not wearing seat belts and drinking and driving.
7. Conflict studies, naturalistic driver behaviour studies and in-depth studies of accidents are tools that road authorities may choose to include in their safety management toolbox; neither of these tools are essential.

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Appendix 1: Questionnaire

The aim of this questionnaire is to survey the use in European countries of ten evaluation tools for road safety management. The ten evaluation tools, with a very short description of each tool, are listed below:

Evaluation tool	Short description
Road safety audit	Systematic assessment of designed elements relevant for safety for new/planned roads.
Road safety inspection	Systematic assessment of safety for an existing road (sometimes known as road safety assessment). Similar to road safety audits but for existing roads.
Network screening	Screening of accident data to identify road sections/links with a high number of accidents or high accident rates.
Accident modelling	Multivariate statistical analyses designed to estimate effects of factors influencing the number of accidents.
Road protection scoring	Assessment of how well a road protects from injury in case of accident.
Identification and analysis of hazardous road locations	Cluster and density analysis to formally identify sites that have a high number of accidents (sometimes known as blackspot analysis).
Road safety impact assessment	Estimation of the number of accidents or injured road users expected to be prevented by specific road safety measures. (Extended to economic appraisal when benefit to cost returns considered).
Conflict studies	Systematic collection of observational data concerning events almost resulting in accidents.
Monitoring road user behaviour	Observation of road user behaviour and compilation of statistics on behaviour (e.g. seatbelt wearing rates etc.).
In-depth accident studies	More detailed investigations of circumstances of individual accidents than normally done in routine reporting.
Other tools	Any other tool used in safety management.

The questionnaire has two parts. The first part is intended to collect information regarding current use of the evaluation tools. The second part offers an opportunity to assess the evaluation tools in terms of six criteria that influence the ease of their use. All questions can be answered by ticking boxes.

Are any of the following tools used in the safety management of roads? Please answer yes (by road authority or other organisation) or no for each of the tools listed:

	Yes		**No**
	By road authority	By other organi-sation	
Road safety audits	1A	1O	0
Road safety inspections	1A	1O	0
Network screening	1A	1O	0
Accident modelling	1A	1O	0
Road protection scoring	1A	1O	0
Identification and analysis of hazardous road locations	1A	1O	0
Impact assessment of road safety measures	1A	1O	0
Conflict studies/naturalistic driving studies	1A	1O	0
Monitoring of road user behaviour	1A	1O	0
In-depth analysis of accidents	1A	1O	0
Other tools	1A	1O	0

Please specify if any other tool is used:

Supplementary questions are asked with respect to some of the evaluation tools. These questions are listed below.

Supplementary questions regarding *accident modelling* *(please answer if the tool is used by road authority or another organisation)*

Who developed the accident model or models?

Research institute	1R	Highway agency	1A	Don't know	0

Is the model updated regularly?

Yes	1	No	0	Don't know	0

What relationships do the models include?

Traffic volume only	1	Multiple explanatory variables	2	Don't know	0

Supplementary questions regarding *road protection scoring* *(please answer if the tool is used by road authority or another organisation)*

Who scores roads?

Highway agency	1A	Other organisation	1O	Don't know	0

Does road protection score influence priorities for safety treatment?

Yes	1	No	0	Don't know	0

Supplementary questions regarding *impact assessment* *(please answer if the tool is used by road authority or another organisation)*

What is the scope of road safety impact assessment?

Major projects	1	All safety measures	2	Don't know	0

Is the basis for impact assessments updated regularly?

Yes	1	No	0	Don't know	0

Is the accuracy of impact assessments evaluated?

Yes	1	No	0	Don't know	0

Supplementary questions regarding *monitoring of road user behaviour* *(please answer if the tool is used by road authority or another organisation)*

Please specify which types of behaviour are monitored regularly?

Speed	S
Mobile phone use	M
Seatbelt use	B
Motorcycle helmet use	H
Close following	F

Other (please specify):

This part of the questionnaire asks you to assess the applicability (ease of use) of these tools with respect to six criteria: need for collecting new data, use of standardised procedures, reporting requirements, need for training and specialised skills, objectivity and transparency, and ease of updating. A short explanation of each of these criteria is given below. You are asked to rate each of the tools with respect to each of the criteria using the scale provided in the questionnaire.

Criterion for assessment	**Short description**
Need for data collection	If use of a tool requires the collection of new data or if routinely collected data can be used
Standard procedure	Whether a standard procedure for using a tool has been developed or not
Reporting requirements	If a written report presenting results is required each time a tool is used
Training and special skills	If training, formal authorisation and specialised skills are needed to use a tool
Objectivity and transparency	Objectivity: different people using the same tool based on the same data should get identical results. Transparency: reasons are given for all choices made when applying a tool
Ease of updating	Whether updating requires collection of new data or can be done without new data

		Assessment of each criterion			
Tool	**Criterion**	**High**	**Medium**	**Low**	**Don't know**
Road safety audits	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0

		Assessment of each criterion			
Tool	**Criterion**	**High**	**Medium**	**Low**	**Don't know**
Road safety inspections	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0
Network screening	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0
Accident modelling	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0

		Assessment of each criterion			
Tool	**Criterion**	**High**	**Medium**	**Low**	**Don't know**
Road protection scoring	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0
Identific-ation and analysis of hazardous locations	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0
Road safety impact assessment	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0

		Assessment of each criterion			
Tool	**Criterion**	**High**	**Medium**	**Low**	**Don't know**
Conflict studies	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0
Monitoring road user behaviour	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0
In-depth accident studies	Need for original data	3	2	1	0
	Need for standard procedure	3	2	1	0
	Reporting requirements	3	2	1	0
	Need for training and specialised skills	3	2	1	0
	Objectivity and transparency	3	2	1	0
	Ease of updating	3	2	1	0

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