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PRACT
Predicting Road ACcidents - a Transferable methodology across Europe

Overview of existing Accident Prediction Models and Data Sources

Deliverable D1
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Glossary of Terms

- **Road Safety Measures / Treatments / Countermeasures / Interventions**: any modifications in road design, maintenance and equipment, traffic control, vehicle design, inspection and protective devices, driver training, public education, enforcement and post-accident care, that aim at reducing accident frequency or severity;
- **Accident Prediction Model (APM)** or Safety Performance Function (SPF): an equation used to estimate or predict the expected average accident frequency at a location, as a function of traffic volume and road infrastructure characteristics (e.g. number of lanes, type of median, traffic control);
- **Crash Modification Factor (CMF)** or Function, or Accident Modification Factor: the relative change in accident frequency due to a change in one specific condition (when all other conditions and site characteristics remain constant). CMF is the ratio of the expected accident frequency after a modification or measure is implemented to the estimated accident frequency if the change does not take place;
- **Crash Reduction Factor (CRF)**: the percentage accident reduction that might be expected due to a change in one specific condition (when all other conditions and site characteristics remain constant). The CRF is equal to (1 - CMF);
- **Road safety measures assessment / evaluation**: the procedure applied by a road safety authority or stakeholder, in order to compare alternative measures or interventions, in terms of road safety, taking into account effectiveness, implementation cost and acceptability;
- **Cost-Benefit Analysis (CBA)**: a method to evaluate economic justification of a measure implementation project, based on the estimation of the ratio of the present-value benefits of a project to the implementation costs (Benefit-Cost Ratio - BCR = Benefits/Costs);
- **Cost-Effectiveness Analysis (CEA)**: a method to estimate the ratio of the present value cost to the total estimated crash reduction, i.e. in contrast to cost-benefit analysis (CBA) the change in the estimated accident frequency is not converted to a monetary value;
- **Net Present Value (NPV)**: a method to evaluate the economic justification of a measure implementation project, by expressing the difference between discounted costs and discounted benefits of the project. A greater than zero NPV indicates that the project is economically justified.

Executive summary

Evaluation of road safety measures appears to be the weakest component of road safety management systems in Europe. Only in few countries the evaluation of road safety measures is part of the culture and a routine activity within the road safety programme, with a dedicated budget. Where this is in place the evaluation is usually limited to infrastructure and enforcement measures while the evaluation of entire road safety programmes is even more rare.

To improve Road Infrastructures Safety Management the road authorities and the road designers need prediction tools allowing them to analyze the potential safety issues, to identify safety improvements and to estimate the potential effect of these improvements in terms of crash reduction.

The PRACT Project (Predicting Road ACcidents - a Transferable methodology across Europe) aims at developing a European accident prediction model structure that could be applied to different European road networks with proper calibration. PRACT is funded by the National Road Authorities of Germany, Ireland, UK and Netherlands within the Conference of European Directors of Roads (CEDR) 2013 Transnational Research Programme - Safety.

The research partners of the PRACT project are:
- Università degli Studi di Firenze (Italy) - Project Leader,
- National Technical University of Athens (Greece),
- Technische Universität Berlin (Germany), and
- Imperial College London (UK).

The **core principles** behind the PRACT project structure are that:
- the idea that a unique Accident Prediction Model (APM) and unique set of Crash Modification Factors (CMFs) can actually be developed, valid for all Europe and for all the different type of networks of motorways and higher ranked rural roads, is unrealistic;
- the development of a specific APM model and a set of CMFs based on local data is extremely time consuming and expensive and requires data and experience that most road administrations do not have;
- the development of “local” CMFs only based on historical local data prevents the possibility of evaluating the effectiveness of new technologies.

The basic assumption on which the PRACT project is therefore built is that APMs and CMFs can be transferred to conditions different from the ones for which they have been developed if selected based on scientifically valid criteria and adapted to local condition based on historical crash data.

The PRACT project is aimed at addressing these issues by developing a **practical guideline and a user friendly tool** that will allow the different road administrations to:
- adapt the basic APM function to local conditions based on historical data;
- identify the CMFs that could be relevant for the specific application;
- verify if the selected CMFs are transferable to the specific condition;
- apply the calibrated model to the specific location to be analysed.

As far as different countries, as well as different road authorities within a country, have different level of expertise and different data availability, the system will be structured with different possible calibration levels ranging from a total lack of historical data (in this case the user will be presented with the most suitable set of calibration parameters among the ones that will obtained within the PRACT project with the available datasets) to situations where crash data, traffic data and geometric data are all available when the system could allow also for the calibration of key CMFs.

An important outcome of the PRACT Project will also be the establishment of a European APM and CMF web repository with an open access database and hints for their application and transferability on the European road networks.

Work Package 1 of the PRACT Project aims at presenting a complete **overview of currently used APMs** by different National Road Administrations (NRAs) in Europe and worldwide, as well as the **currently used data sources** for the development and application of APMs.

Specifically, the WP1 aims at reviewing and assessing existing APMs, in terms of theoretical approaches, characteristics of models in use, implementation conditions, data requirements and available results, with focus on motorways and higher ranked rural roads. A questionnaire was designed and dispatched to several NRAs in Europe and worldwide, in order to collect detailed information on APMs developed and used by them. Furthermore, a review of relevant international literature was carried out, with focus in particular on identifying those modelling approaches and specific models that may be applicable or transferable in the European context. On the basis of the questionnaire data and of the literature review results, a synthesis of current practices regarding APMs has been developed, that will assist in the identification of the most usable models as well as in the repository development procedure that will take place in Work Package 4 of the project.

Additionally, since the development of APMs relies upon the availability and quality of diverse data (concerning road infrastructure design, traffic volumes, road accidents and other, e.g. weather conditions), a section of Work Package 1 is devoted to data availability, quality and definitions among European countries and worldwide. The aforementioned questionnaire includes information on microscopic data used for the development and implementation of APMs (crash data, traffic data, Road design data and other related data), and, on the basis of the questionnaire responses, complemented with additional information from the literature, a description and discussion of available data sources for the development of APMs, including an assessment of the quality of data, is presented.

Within the above context, this Deliverable presents the results of the Work Package 1 of the project, that include: a critical review of existing literature regarding Accident Prediction Models (APMs) and Crash Modification Factors (CMFs) in Chapter 2, a presentation of the national contributions regarding development and use of APMs as well as existing data sources (Chapter 3), a synthesis of current practices in APMs, based on both the questionnaire data and the literature review (Chapter 4) and a description and discussion on available relevant data sources (Chapter 5). Chapter 6 is devoted to concluding remarks, summarization and presentation of the next steps of the PRACT project.

In Annex A, individual reviews of the examined relevant literature are presented, and in Annex B a copy of the aforementioned questionnaire dispatched to NRAs regarding APMs and data sources.

1 Introduction

The PRACT Project (Predicting Road ACcidents - a Transferable methodology across Europe) aims at developing a European accident prediction model (APM) structure that could be applied to different European road networks with proper calibration.

One of the key issues in developing a transferrable methodology for accident prediction is defining the current state of the art, the current practices for road safety assessment within National Road Authorities (NRAs) and in research organizations as well as identify the data availability for developing and calibrating reliable accident prediction models.

For this aim an extensive literature review and a survey among NRAs and researchers worldwide has been conducted in Work Package 1 of the PRACT project as documented in this report. As far as the final aim of the development and use of APMs is the evaluation of the safety effectiveness of different possible treatments a specific section of the report is devoted to the core references for the assessment of the effectiveness of road safety treatments.

APMs can be developed as a single regressive equation (Safety Performance Function, SPF) or as a combination of a base SPF developed for a standard road configuration and a set of CMFs that allow to adjust the prediction to account for specific local features.

Even though the latter is the most suitable approach to develop a transferable model most countries in Europe use purely SPF based APMs and therefore in the literature review both the studies aimed at developing full APM and the ones aimed at developing CMFs have been considered.

2 Literature review

Several researchers, in Europe and worldwide, have examined the safety effects of various road safety measures in an attempt to quantitatively assess road safety measures and interventions, in terms of accident frequency (number of accidents per year) and accident severity (level of injury due to accidents). As a result of this research, a large amount of relevant knowledge has been developed, as well as various methodologies and techniques to estimate future accident frequency and severity and to identify and evaluate options to reduce them.

In the following pages of the report, a critical overview of existing literature regarding road safety measures assessment and accident prediction modelling is presented. A large number of relevant studies, research projects, handbooks, guidelines and manuals was collected and reviewed to provide the background for effectively transferring selected accident prediction models to a given road network, as well as for the web-based repository, that will be developed within PRACT Work Packages 3 and 4 respectively.

In order to improve the comprehensibility of the present report, relevant literature has been organized in the following basic categories:

- **Highway Safety Manual and related references**: The release of the Highway Safety Manual (AASHTO, 2010) which includes a very comprehensive set of models for predicting road accidents, was a milestone in accident prediction research, and several studies have been published since then, to examine the transferability of the HSM models in other conditions, to expand the HSM models in other types of roads, etc.;
- **development of Accident Prediction Models**, according to pertinent literature;
- **web-based CMF databases and toolkits**: In this category, web-based road safety toolkits and repositories are included, that present in a comprehensive and user-friendly way quantitative information about the safety effect of various road safety measures and interventions;
- **road safety measures assessment in general**: In this category, research projects, handbooks and studies that deal with the assessment of road safety measures are included, based on previously developed Accident Prediction Models (APMs) and Crash Modification Factors (CMFs);
- literature related to **methodological issues**: Some of the examined references deal with methodological issues of accident prediction modelling, before-and-after studies, protocols for CMF development, etc. and are presented in this category;
- **other related research and literature**, not included in any of the above categories.

In Table 2.1 that follows, the examined studies, handbooks, manuals and guides are presented, along with basic facts regarding the topic, field of measures examined, user types, geographic area, existence of CMFs, methodology etc. of each reference. Also, in Annex A, reviews of the examined literature are presented, that include a description of each reference's scope, methodology, data used and results obtained.

Table 2.1: *Examined studies, handbooks, manuals and guides*

No	Title	Issue Date	Author / Publisher	Topic	Field of Measures	User Types	Geographic Area Covered	Area	Road Elements	Years Covered by Data	Number of Cases Examined	Including CMFs	Methods Used
AASHTO Highway Safety Manual and related literature													
2	The Highway Safety Manual	2010	American Association of State Highway and Transportation Officials (AASHTO)	Accident Prediction Models CMF of measures	Road	all	USA	Rural / Urban	all	1960 - 2008	162 measures	YES	Meta-analysis of existing studies
2	The Highway Safety Manual - 2014 supplement	2014	American Association of State Highway and Transportation Officials (AASHTO)	Accident Prediction Models	Road	all	USA	Rural / Urban	motorway segments & interchanges	n/a	n/a	YES	SPF and CMFs application
17	Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges	2012	National Cooperative Highway Research Program (NCHRP) - Transportation Research Board (TRB)	Accident Prediction Models CMF of measures	Road	all	USA	Rural / Urban	Freeway segments - Interchanges	-	-	YES	SPF and CMFs application
34	A Guide to Developing Quality Crash Modification Factors	2010	Frank Gross, Bhagwant Persaud, and Craig Lyon Federal Highway Administration, Report No.FHWA-SA-10-032	CMF development	Road	all	n/a	Rural / Urban	all	-	-	YES	CMFs
46	How to Develop and Use CMFs		Federal Highway Administration (FHWA)	CMF development and use	Road	all	USA	n/a	n/a	n/a	n/a	NO	n/a
47	How to Develop and Use SPFs		Federal Highway Administration (FHWA)	Accident Prediction Models Accident Modification Factors	Road	all	USA	n/a	n/a	n/a	n/a	NO	n/a
50	Transferability of the Highway Safety Manual Freeway Model to the Italian Motorway Network	2014	Francesca La Torre, Lorenzo Domenichini, Francesco Corsi, Francesco Fanfani	Accident Prediction Models	Road	all	Italy	Rural	motorways	2005-2009	56 freeway sections	NO	HSM model calibration
51	Calibration of the Highway Safety Manual's Accident Prediction Model for Italian Secondary Road Network	2009	Filippo Martinelli, Francesca La Torre, Paolo Vadi	Accident Prediction Models	Road	all	Italy	Rural	secondary road segments	2001-2005	n/a	NO	AMF
Development of Accident Prediction Models (including CMFs)													
22	Accident Prediction Models and Road safety Impact Assessment: Results of the pilot studies	2007	RIPCORD - ISEREST Consortium	Accident Prediction Models Transferability	Road	all	Europe	Rural	all	-	Meta-analysis of 6 existing studies	YES	Meta-analysis of 6 existing studies
23	Accident Prediction Models and Road safety Impact Assessment: a state-of-the-art	2008	RIPCORD - ISEREST Consortium	Accidents Prediction Models Methodology, Rural Roads	Road	all	Europe	Rural	all	-	Meta-analysis of 18 existing studies	YES	Meta-analysis of 18 existing studies
24	Safety Performance Function	2007	RIPCORD - ISEREST Consortium	Safety Performance Function	n/a	all	Germany	Rural	road segments	2003-2005	6 design parameters	YES	Safety Performance Function based on accident paramters
26	A comprehensive methodology for the fitting of predictive accident models	1996	Maher/Summersgill in Accident Analysis & Prevention	APMs Modelling, Goodness-of-fit	n/a	n/a	UK	Rural / Urban	Intersections	4-7 Years	Only simulation statistic tests are conducted	NO	extending or modifying the basic GLM methodology.
28	The next generation of rural road crash prediction models: final report	2012	NZ Transport Agency research report 509	APMs, CMFs for rural roads	Road	all	New Zealand	Rural / Urban	road segments	2002-2006	17087 curved elements and 13940 straight elements	YES	CPM
29	Analyse von Zusammenhängen zwischen Verkehrssicherheit und Straßenentwurf auf Außerortsstraßen - "Analysis of relations between traffic safety and road design on rural roads"	1999	Lamm/Beck/Zumkeller	CMFs	Road	all	Germany	Rural	motorway segments	1970-1974; 1978-1985; 1993-1995; 1989-1995	8 design parameters	YES	CMFs deduced from accident parameters

No	Title	Issue Date	Author / Publisher	Topic	Field of Measures	User Types	Geographic Area Covered	Area	Road Elements	Years Covered by Data	Number of Cases Examined	Including CMFs	Methods Used
30	Zusammenhang zwischen der Verkehrssicherheit und den Elementen des Straßenentwurfs - "Relationship between traffic safety and road design elements"	1989	Leutzbach/Zoellmer	CMFs	Road	all	Germany	Rural	road segments	1978 - 1985	9 design parameters	YES	CMFs deduced from accident parameters
35	Using multivariate adaptive regression splines (MARS) to develop crash modification factors for urban freeway interchange influence areas	2013	Kirolos Haleem, Albert Gan, Jinyan Lu / Accident Analysis and Prevention 55 (2013) pp12–21	CMFs	Road	all	State of Florida, USA	Urban	Interchanges	2007-2010	391 observations	YES	Multivariate Adaptive Regression Splines (MARS)
36	Accidentt prediction models for road networks	2008	Gianluca Dell'Acqua, Francesca Russo	Accident Prediction Models	Road	all	Italy	Rural	two-lane road segments	2003-2005	2897 accidents on 3343 km	NO	AMF
37	A crash-prediction model for multilane roads	2007	Ciro Caliendo, Maurizio Guida, Alessandra Paris	Accident Prediction Models	Road	all	Italy	Rural	motorways	1999-2003	594 accidents on 46.6 km	NO	AMF
38	Crash Prediction Models for Rural Motorways	2008	Alfonso Montella, Lucio Colantuoni, and Renato Lamberti	CMFs	Road	all	Italy	Rural	motorways	2001-2004	2245 accidents on 646 homogeneous segments	NO	AMF
40	A crash-prediction model for road tunnels	2013	Ciro Caliendo, Maria Luisa De Guglielmo, Maurizio Guida	Accident Prediction Models	Road	all	Italy	Rural / Urban	Tunnels in motorways	2006-2009	232 tunnels	NO	AMF
43	Safety Performance Function for motorways using Generalized Estimation Equations	2012	Salvatore Cafiso, Carmelo D'Agostino	Accident Prediction Models	Road	all	Italy	Rural	motorways	2003-2009	451 accidents on 127.5 km	NO	exploratory analyses of APM
44	Investigating the influence on safety of retrofitting Italian motorways with barriers meeting a new EU standard	2014	Cafiso, D'Agostino, Persaud	Accident Prediction Models	Road	all	Italy	Rural	motorways	2006-2009	327 severe accidents on 76 km	NO	exploratory analyses of APM
45	Development of comprehensive accident models for two-lane rural highways using exposure, geometry, consistency and context variables	2010	Salvatore Cafiso, Alessandro Di Graziano, Giacomo Di Silvestro, Grazia La Cava, Bhagwant Persaud	Accident Prediction Models	Road	all	Italy	Rural	motorways	5-year period	279 accidents on 107 homogeneous sections	NO	exploratory analyses of APM
52	RISMET research project - "Road Infrastructure Safety Management Evaluation Tools"	2011	RISMET Consortium	Accident Prediction Models	Road	all	Germany, Portugal, Austria, Norway, The Netherlands	Rural	rural roads / intersections	2005-2007	18,870 accidents on 4,912Km of roads	NO	exploratory analyses of APM
Web-based CMF databases and Road Safety Toolkits													
10	FHWA Clearinghouse CMFs		Federal Highway Administration (FHWA)	CMF of measures (web-based database)	Road / User (limited)	all	USA	Rural / Urban	all	-	-	YES	CMFs
11	AustRoads Road Safety Engineering Toolkit		AustRoads	Web-based database	Road (other measures mentioned but not analyzed)	all	Australia	Rural / Urban	all	Not Specified	67 measures	YES	Review of existing studies & submission of case studies by users
12	International Road Assessment Programme (iRAP) Road Safety Toolkit		Collaboration of International Road Assessment Programme (iRAP), Global Transport Knowledge Partnership (gTKP) andWorld Bank Global Road Safety Facility	Web-based database	Road / Vehicle / User	all	International	Rural / Urban	all	Not Specified	58 measures	NO	Review of existing studies
Road safety measures assessment in general													
1	The Handbook of Road Safety Measures (2nd Edition)	2009	Elvik, R., Hoye, A., Vaa, T. & Sorensen, M. / Emerald Group Publishing Ltd	Assessment of measures	Road / Vehicle / User	all	Europe	Rural / Urban	all	1939 - 2009	128 measures	YES	Meta-analysis of existing studies

No	Title	Issue Date	Author / Publisher	Topic	Field of Measures	User Types	Geographic Area Covered	Area	Road Elements	Years Covered by Data	Number of Cases Examined	Including CMFs	Methods Used
3	ROSEBUD research project - "Examples of assessed road safety measures - a short handbook"	2006	ROSEBUD Consortium	CEA/CBA of measures	Road / Vehicle / User	all	Europe	Rural / Urban	all	1967 - 2006	54 measures	NO	Meta-analysis of existing studies, based on B/C ratio
4	CEDR Report - "Best Practice on Cost Effective Road Safety Infrastructure Investments"	2008	Conference of European Directors of Roads (CEDR)	CEA/CBA of measures	Road	all	Europe	Rural / Urban	all	1980 - 2007	55 measures - 5 in-depth analyses	YES	Meta-analysis of existing studies, based on B/C ratio and experts' judgement
6	PROMISING research project - "Cost-benefit analysis of measures for vulnerable road users"	2001	PROMISING Consortium	CBA of measures	Road / Vehicle / User	vulnerable / inexperienced	Europe	Rural / Urban	all	Not Specified	20 measures	NO	Cost - Benefit Analysis
7	SUPREME research project - "Handbook for measures at the Country level" and "Handbook for measures at the European level"	2007	SUPREME Consortium	Assessment of measures	Road / Vehicle / User	all	Europe	Rural / Urban	all	Not Specified	55 measures (Country Level) 31 measures (European Level)	YES	Review of existing literature by experts & Questionnaires
9	Countermeasures that work: A Highway Safety Countermeasure Guide For State Highway Safety Offices - 7th Edition	2013	National Highway Traffic Safety Administration (NHTSA)	Assessment of measures	User	all / vulnerable	USA	Rural / Urban	all	1984 - 2013	116 measures	NO	Systematic Reviews of existing studies
13	2BESAFE research project - "2-wheeler Behaviour and Safety"	2011	2BESAFE Consortium	Qualitative assessment of measures	Road / Vehicle / User	Powered Two-Wheelers	Europe & Australia	Rural / Urban	all	Not Specified	143 measures	NO	Experts' opinion
15	Road Safety Design Synthesis	2005	Federal Highway Administration (FHWA)	Accident Prediction Models Accident Modification Factors	Road	all	USA	Rural / Urban	all	-	-	NO	AMF
16	Safer Brain Research Project - "Innovative Guidelines and Tools for Vulnerable Road Users Safety in India and Brazil"	2011	SaferBraIn Consortium	Assessment of measures	Road	vulnerable	European Experience transferred to Brazil & India	Urban	Pedestrian / Bicycle related	Not Specified	16 measures	NO	European Best Practice applied in pilot projects in India & Brazil
49	Procedure for Ranking Unsignalized Rural Intersections for Safety Improvement	2012	Alfonso Montella and Filomena Mauriello	cost/benefit analisis	Road	all	Italy	Rural	Unsignalized Intersections	2001-2009	22 rural three-leg intersections	NO	n/a
Literature about methodological issues													
14	Sharing Road Safety: Developing an International Framework for Crash Modification Functions	2012	OECD / ITF	Transferability of Crash Modification Factors	n/a	all	International	n/a	n/a	-	-	NO	-
18	ESN - Empfehlungen für die Sicherheitsanalyse in Straßennetzen - "Recommendations for safety analysis in road networks"	2003	German Road and Transportation Research Association (FGSV)	Safety evaluation on roads	Road	all	Germany	Rural / Urban	-	-	-	NO	accident parameters, safety potential
19	MUko - Merkblatt zur örtlichen Unfalluntersuchung in Unfallkommissionen - "Guidelines for local accident surveys within accident commissions"	2012	German Road and Transportation Research Association (FGSV)	Safety evaluation on roads	Road	all	Germany	Rural / Urban	-	-	-	NO	accident parameters, safety potential
20	Bewertungsmodell für die Verkehrssicherheit von Landstraßen - "Evaluation model for traffic safety on rural roads"	2013	Federal Highway Research Institute (BASt)	Accident Prediction Models	Road	all	Germany	Rural	all	2005-2009	80 variables tested, 32 are significant at different section types	YES	APM

No	Title	Issue Date	Author / Publisher	Topic	Field of Measures	User Types	Geographic Area Covered	Area	Road Elements	Years Covered by Data	Number of Cases Examined	Including CMFs	Methods Used
21	Quantifizierung der Sicherheitswirkungen verschiedener Bau-, Gestaltungs- und Betriebsformen auf Landstraßen - "Quantification of safety effects through different construction, design and operation measures on rural roads"	2010	Federal Highway Research Institute (BASt)	Assessment of measures	Road	all	Germany	Rural	all	2002-2006	10 different road widths; 7 interesection types	YES	accident parameters, safety potential
27	Goodness-of-fit testing for accident models with low means	2011	Ye/Zhang/Lord	APMs Modelling, Goodness-of-fit	n/a	n/a	Canada	n/a	3-legged intersections	1985-1995	13 measures in an earlier report	YES	goodness-of-fit (GOF) test for Poisson or NB models
32	Calibration and Transferability of Accident Prediction Models for Urban Intersections	2002	Persaud B., Lord D. and Palmisano J./ Transportation Research Record 1784, Paper No. 02-3293, pp. 57 -64	Accident Prediction Models	Road	all	Canada/USA	Urban	Signalized/Unsignalized 3/4-legged Intersections	1990-1995	4 Types of intersections are examined	NO	exploratory analyses of APM
33	Two tools for finding what function links the dependent variable to the explanatory variables.	1997	Ezra Hauer and Joseph Bamfo / Proc., Conference of the International Co-operation on Theories and Concepts in Traffic Safety, Lund, Sweden.	APMs Modelling, Goodness-of-fit	n/a	all	USA	Rural	two-lane noncontiguous road sections	3 years	NA	Select One	analysis of appropriate functional form for APM
39	Crash Modification Factors Foundational Issues	2012	Ezra Hauer, James A. Bonneson, Forrest Council, Raghavan Srinivasan and Charles Zegeer	CMF develop	n/a	n/a	USA/Canada	n/a	n/a	1992-1995 for Arizona; 2001-2006 for British Columbia	illumination	YES	Meta-analysis of existing studies
42	Observational Before-After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety	1997	Ezra Hauer	APMs Modelling, Goodness-of-fit	n/a	n/a	n/a	n/a	n/a	n/a	n/a	NO	n/a
48	Improving Transferability of Safety Performance Functions by Bayesian Model Averaging	2012	Yongsheng Chen, Bhagwant Persaud, and Emanuele Sacchi	APMs Modelling, Goodness-of-fit	n/a	n/a	Canada - Italy	Urban	Intersections	6 years	n/a	NO	n/a
Other related research and literature													
5	The Cochrane Injuries Group Reviews - "Prevention of road traffic injuries"	2014	The Cochrane Collaboration	Assessment of measures Injury oriented - not restricted to road accidents	Road / Vehicle / User	all	International	Rural / Urban	all	Not Specified	26 measures	NO	Systematic Reviews of existing studies
8	IRTAD Annual report - 2013	2013	Organisation for Economic Co-operation and Development/International Transport Forum (OECD/ITF)	Assessment of measures	Road / Vehicle / User	all	International	Rural / Urban	all	2010 - 2012	n/a	Select One	Overview of measures (country reports)
25	Black Spot Management and Safety Analysis of Road Networks - Best Practice Guidelines and Implementation Steps	2007	RIPCORD - ISEREST Consortium	Black Spot Management	Road	all	Europe	Rural	n/a	n/a	n/a	NO	n/a
31	Interactive Highway Safety Design Model (IHSDM): Making Safety a Priority in Roadway Design	2014	Feferal Highway Administration (FHWA)	software analysis tools to evaluate the safety	Road	all	USA	Rural / Urban	road segments - Intersections	-	-	YES	SPF and CMFs application
41	A tool for safety evaluations of road improvements	2013	Harri Peltola, Riikka Rajamäki, Juha Luoma	software analysis tools to evaluate the safety	Road	all	Finland	Rural / Urban	All	2007-2011	92 measures	YES	EB based methods for estimating safety measures effects

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2.1 AASHTO Highway Safety Manual and related literature

2.1.1 HSM predictive method

The release of the Highway Safety Manual (AASHTO, 2010) was an important milestone in accident prediction research. Besides providing key information for integrating safety analysis to highway planning, design, and operation and suggesting steps to monitor and reduce crash frequency and severity, the HSM provides a **predictive method** for estimating the expected average crash frequency (by total crashes, crash severity or collision type) of a network, facility or individual site. In the predictive method, the roadway is divided into individual sites that are either homogenous roadway segments or intersections. A facility consists of a contiguous set of individual intersections and roadway segments, each referred to as "site". A roadway network consists of a number of contiguous facilities.

The predictive method is used to estimate the expected average crash frequency of an individual site. The sum of all sites is used as the estimate for an entire facility or network. The estimate is applied to a given time period (in years), traffic volume and constant geometric design characteristics of the roadway and can refer to the existing conditions, alternative conditions or proposed new roadways.

The estimate relies upon regression models developed from observed crash data for a number of individual sites. Different regression models, called base **Safety Performance Functions** (SPFs) have been developed for specific facility types (e.g. undivided segments of rural two-lane two-way roads, divided segments of urban and suburban arterials, 3-leg intersections with "STOP" control in rural multilane highways etc.) and "base conditions", that are the specific geometric design and traffic control features of a "base" site. SPFs are typically a function of only a few variables, primarily average annual daily traffic (AADT) volumes and segment length. An example of a SPF (for rural two-lane two-way roadway segments) is shown in the following equation:

$$N_{spf} = (AADT) \times (L) \times (365) \times (10^{-6}) \times e^{(-0.312)}$$

where:

N_{spf} = predicted average crash frequency determined for base conditions using a statistical regression model;

$AADT$ = average annual daily traffic volume (vehicles/day) on examined roadway segment;

L = length of roadway segment (miles).

For freeway segments the base SPF function has the form:

$$N_{spf} = (0.001 \times AADT)^{b} \times (L) \times e^{(a)}$$

where a and b are a function of the type of crash (single vehicle or multi vehicle) and the crash severity (fatal+injury of property damage only crashes).

SPFs in the HSM have been developed through statistical multiple regression techniques using historic crash data collected over a number of years at sites with similar characteristics and covering a wide range of AADTs. In the different models the effect of AADT can be considered as linear (as in the two-lane two-way rural roads) or non linear (as in the freeway model).

Adjustment to the prediction made by an SPF is required to account for geometric design or traffic control features differences between the base conditions of the model and local conditions of the site under consideration. For this, **Crash Modification Factors** (CMFs) are used - see also paragraph 2.1.4 of the present report. Finally, a **Calibration Factor** (C) is used to account for differences between the road network for which the models were developed and the one for which the predictive method is applied.

The **general form of the predictive models in HSM**, for a given type of site, is shown in the following equation:

$$N_{predicted} = N_{spf} \times (CMF_1 \times CMF_2 \times \ldots \times CMF_y) \times C$$

where:

$N_{predicted}$ = predicted average crash frequency for a specific year;

N_{spf} = predicted average crash frequency determined for the base conditions of the Safety Performance Function (SPF);

CMF_1 .... CMF_y = crash modification factors (that could be also derived from crash modification functions) accounting for specific site conditions (geometric design, traffic control features etc);

C = calibration factor to adjust the SPF for local conditions related to the network where the model is to be applied. This accounts for all the factors that lead to safety differences and that are not considered by the safety prediction methodology itself, such as differences in climate; differences in animal populations that lead to higher frequencies of collision with animals; differences in driver populations and trip purposes; complexity of the geometric layout; driver attitude and behaviour (e.g. rate of compliance with road code rules); vehicle fleet characteristics; crash reporting practices; differences in road standards etc.

Using the above equation, the predicted average crash frequency of an individual site, $N_{predicted}$, can be estimated, based on geometric design, traffic control features and traffic volumes of that site. To improve the statistical reliability of the estimate for an existing site or facility, the observed crash frequency $N_{observed}$*, can be combined with* $N_{predicted}$, to obtain the expected average crash frequency, $N_{expected}$. This is an estimate of the long-term average crash frequency that would be expected, given sufficient time to make a controlled observation. Since the observed crash frequency in a site, roadway or network varies randomly over any period, using averages based on short-term periods (e.g. 1 to 3 years) may give misleading estimated due to regression-to-the-mean bias. Thus, using the estimate of long-term average crash frequency allows for more sound decisions about improvement programs.

The HSM predictive method consists of 18 steps, presented graphically in Figure 2.1.

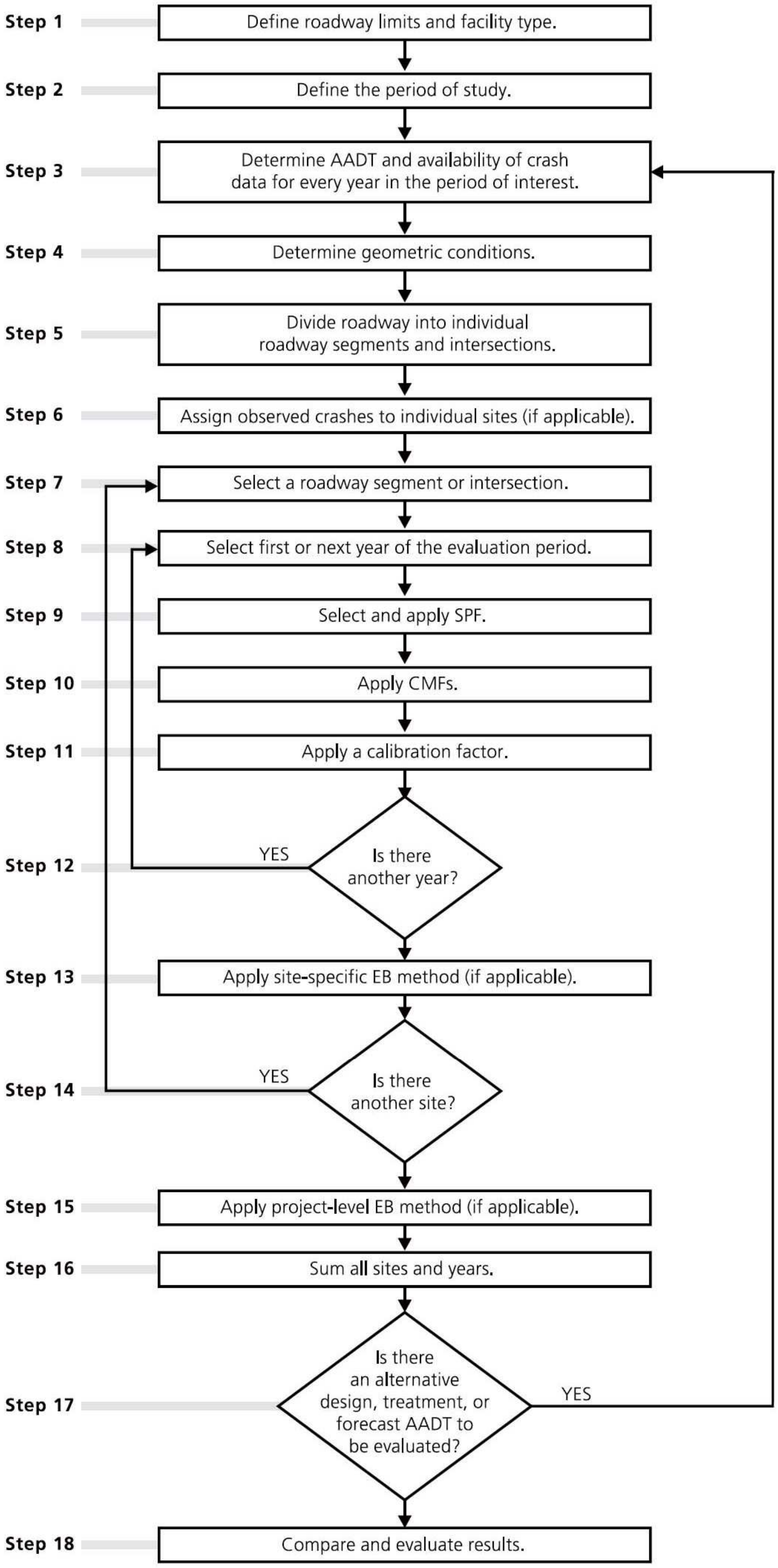


Figure 2.1: *Diagram of the HSM Predictive Method (AASHTO 2010).*

2.1.2 HSM complementary literature

The Highway Safety Manual is complemented by reports and guides that provide guidance on the implementation of the methods and procedures included in the Manual. The "Safety Performance Function Decision Guide: SPF Calibration vs. SPF Development" (FHWA, 2013a), aims at providing guidance on whether an agency should calibrate the safety performance functions from the Highway Safety Manual or develop jurisdiction-specific SPFs. The guidebook includes a brief discussion on SPFs and how they are used for different applications, i.e., network screening, project level analysis, and determining the safety effect of improvements. Furthermore, the two options for obtaining SPFs for a jurisdiction (calibration of existing SPFs versus development of jurisdiction specific SPFs) are discussed along with a brief overview of the steps involved in the calibration and development of jurisdiction specific SPFs. Finally, the step by step process that an agency could use to obtain SPFs is presented.

Another guidebook, entitled "Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs" (FHWA, 2013b), provides guidance on developing SPFs from the Highway Safety Manual. The guidebook includes a discussion of the statistical issues associated with the development of jurisdiction specific SPFs, such as: overdispersion, selection of explanatory variables, functional form of the model and the explanatory variables, overfitting of SPFs, correlation among explanatory variables, homogenous segments and aggregation, presence of outliers, endogenous explanatory variables, estimation of SPFs for different crash types and severities, and goodness of fit. This is followed by a step by step approach to develop jurisdiction specific SPFs. Finally, recent developments in SPF development are discussed, such as: variance of crash estimates obtained from SPFs, temporal and spatial correlation, other model forms, Generalized Additive Models, Random Parameters models, Bayesian Estimation methods, and a brief overview of available software tools is provided.

Additionally, a guide entitled "User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors" (NCHRP, 2014), provides guidance on the calibration of HSM's Safety Performance Functions and the replacement of crash severity and collision type distribution tables and adjustment factors to local and current conditions.

Finally, further information and guidance regarding the use and development of Crash Modification Factors, is provided by a series of guides concerning CMFs in the HSM (see paragraph 2.1.4 of the present report), as well as the web-based FHWA CMF Clearinghouse (paragraph 2.3.1).

All of the above complementary guides enhance the practical applicability of the predictive methodology of the Highway Safety Manual, thus making it a very valuable tool for the road safety practitioners.

2.1.3 Recent additions to HSM

In the original version of the Highway Safety Manual (AASHTO, 2010) safety prediction procedures have been developed for rural two-lane highways, rural multilane highways, and urban and suburban arterials (for roadway segments and at-grade intersections). However, the HSM does not include a safety prediction methodology for freeways and interchanges.

To address this need and develop safety prediction methodologies regarding freeway segments and speed-change lanes in freeways, suitable for inclusion in the HSM, a relevant research was undertaken (NCHRP, 2012b) during which data were assembled that included a wide range of geometric design features, traffic control features, traffic characteristics, and crash records for freeway segments, ramp segments, and crossroad ramp terminals. The freeways and interchanges model has recently been published as an HSM supplement (AASHTO, 2014).

The assembled data were used to calibrate predictive models, each of which included a Safety Performance Function (SPF) and several Crash Modification Factors (CMFs).

Four different sets of models were developed for the following combinations:

- Single vehicle–fatal and injury crashes
- Single vehicle–property damage only crashes
- Multi vehicle–fatal and injury crashes
- Multi vehicle–property damage only crashes

Severity distribution functions were also developed using these data. These functions allow the user to estimate the expected crash frequency for each of the four severity levels of the K, A, B, C scale for total and injury crashes (i.e., fatal, incapacitating injury, non-incapacitating injury, and possible injury).

The procedure for freeways is divided in two different models distinguishing between freeway segments and freeway speed-change lanes. As in the HSM approach each model consists of a safety performance function (SPF) and a set of crash modification factors (CMFs). The SPF is used to estimate the crash frequency for segments and speed-change lanes with "base conditions" in terms of design elements and operating conditions. The CMFs are used to adjust the SPF estimate whenever one or more elements or conditions deviate from the base ones.

The HSM prediction models for freeway segments address the following area types and lane combinations:

- rural freeway with four/six/eight through lanes
- urban freeway with four/six/eight/ten through lanes

The speed-change lane models address ramp entrances and ramp exits for each of the area type and lane combination listed above. The prediction models used to determine the predicted average crash frequency have the same general form as in the aforementioned HSM models.

An issue that still is not addressed by HSM related research is the development of a safety prediction method for access roads, which are considered sufficiently unique in their design and operation that a separate safety prediction method should be developed to specifically address them (NCHRP, 2012b).

2.1.4 Crash Modification Factors in the HSM predictive method

According to the Highway Safety Manual (AASHTO, 2010), Crash Modification Factors (CMF) are defined as the ratio of the crash frequency of a site under two different conditions and they represent the relative change in crash frequency due to a change in one specific condition (when all other conditions and site characteristics remain constant) as shown below:

$$CMF = N_{\exp}(specific\ condition) / N_{\exp}(base\ condition)$$

They can therefore provide an estimate of the effect of a particular geometric design or traffic control feature or of the effectiveness of a particular treatment or condition.

Crash Modification Factors are an important element of the predictive method in the HSM and the existence of a reliable set of CMFs regarding various geometric and operational modifications at a site are a prerequisite for the implementation of the method.

In Part D of the HSM, the effects of various road safety treatments are summarized and over 200 Crash Modification Factors (CMFs) are provided, in order to quantify the change in expected average crash frequency as a result of these modifications. The presented CMFs concern roadway segments, intersections, interchanges, special facilities and road networks and are readily applicable to any design or evaluation process where optional treatments are being considered.

Regarding the inclusion of CMFs in the Highway Safety Manual, the following procedure was applied to document available knowledge using a consistent predetermined approach (Bahar, 2010):

- Step 1. Determine estimate of safety effect of treatment as documented in respective evaluation study publication. This step involved determining the CMF based on the information provided in the study, whether the authors explicitly presented the CMF or whether the CMF could be derived based on information provided in the study.
- Step 2. Adjust estimate of safety effect to account for potential bias from regression-to-the-mean and changes in traffic volume. If the study appeared to have been affected by a significant bias, the reviewers would adjust the CMF value to account for the bias effect.
- Step 3. Determine ideal standard error of safety effect. The reviewers would calculate the ideal standard error if not presented in the study. The standard error gives an indication of the relative reliability of the CMF estimate, taking into account factors such as sample size and variance inherent in the data.
- Step 4. Apply method correction factor (MCF) to ideal standard error, based on evaluation study characteristics. An MCF would be determined by the reviewers based on the reliability of the study, with consideration of factors such as study methodology, treatment of possible biases, treatment of potential confounding factors, and selection of appropriate functional form for regression models. Higher MCF values indicated a less reliable quality of study. It should be noted that the highest MCF values were assigned to those CMFs that had a severe lack of information published regarding study data and findings.
- Step 5. Adjust corrected standard error to account for bias from regression-to-the-mean and changes in traffic volume. Once the MCF was applied to the standard error, the reviewers would adjust it to account for any significant biases.
- Step 6. Combine CMFs when specific criteria are met. In situations where multiple studies evaluated the same treatment, the reviewers would, where appropriate, combine the CMFs to produce the single, best value for that treatment.

After the literature review process was completed, the HSM reviewers filtered the list of CMFs to include only those CMFs with an adjusted standard error of 0.1 or less. In addition, CMFs with an adjusted standard error between 0.1 and 0.3 that were produced from a study that also produced CMFs with an adjusted standard error less than or equal to 0.1 were also included.

Additional guidance regarding development and application of CMFs within the HSM predictive methods is provided in several publications that are available through the part "How to Develop and Use CMFs" of the FHWA CMF Clearinghouse (http://www.cmfclearinghouse.org/resources_develop.cfm).

Specifically, a report entitled "Recommended Protocols for Developing CMFs" (NCHRP, 2012a), aims at providing guidance for the development and documentation of research studies that develop CMFs, that would attain high marks of quality during the review process to be included in the Highway Safety Manual or the FHWA CMF Clearinghouse. The major goal of these protocols is to describe what pieces of the research study should be documented by the study authors and how various potential biases should be addressed.

Another guide by FHWA, "A Guide to Developing quality CMFs" (FHWA, 2010) provides directions to agencies interested in developing CMFs, discusses the process for selecting an appropriate evaluation methodology and the many issues and data considerations related to various methodologies. The guide includes a background of CMFs (definition of CMFs and related terms, purpose and application, and general issues related to CMFs), and an outline of various methods for developing CMFs, such as Before-After with Comparison Group Studies, Empirical Bayes Before-After Studies, Full Bayes Studies, Cross-Sectional Studies, Case-Control Studies, Cohort Studies, and Alternative Approaches for Developing CMFs. Finally, a resources section is provided to help users identify an appropriate method for developing CMFs based on the available data and characteristics of the treatment in question. The resources section also includes sample problems as well as a discussion of considerations for improving the completeness and consistency in CMF reporting.

Finally, a technical report entitled "Investigation of Existing and Alternative Methods for Combining Multiple CMFs" (Gross & Hamidi, 2011) discusses issues associated with the application of multiple CMFs and provides guidance on how to estimate the combined treatment effect when multiple treatments are installed at a given location. In the report, several existing methods for combining multiple CMFs are presented, and issues related to the application of multiple CMFs are discussed, such as the assumption of independence, the logic of added benefit versus fallacy of additive effects, the lack of consistency (judgment), the applicability of CMFs, the lack of detailed CMF information and issues in computing a confidence interval. Several ideas and methods are explored for overcoming the identified issues, and, finally, the methods are applied and compared to existing CMFs for multiple treatments in an attempt to validate the new procedures.

All the above guides, along with Part D of the Highway Safety Manual and the web-based FHWA CMF Clearinghouse, constitute a very comprehensive set of resources regarding CMFs, that can be applied not only in the United States (where they were developed), but also in Europe, with the required modifications and calibrations, as described in the following paragraphs.

2.1.5 Transferability of the HSM predictive method

Several researchers have examined and discussed the issue of effectively implementing the HSM predictive method to conditions different from the ones it was developed, and properly adjusting and calibrating the various parameters and functions. As mentioned in paragraph 2.1.2 of the present report, a relevant guide regarding SPF calibration (FHWA, 2013a) has been published by FHWA, in which the steps involved in the calibration of jurisdiction specific SPFs are described.

Martinelli et al (2009) applied the HSM two-lane two-way rural roads segment model calibration procedure to the Arezzo province road network in Italy, in order to evaluate the effective transferability of the HSM model. By analyzing actual versus predicted accidents and residual plots, they came to the conclusion that the best approach is the base model with CMF calculation, applied to the stratified classes defined by the HSM procedure but with the calibration coefficient calculated not as a simple mean of each class coefficient but using a weighted average based on the total length of the sections in each class.

La Torre et al (2014) also examined the transferability of the HSM freeway model to the Italian motorway network, in order to evaluate the potential issues that occur applying this methodology to a network characterized by different environmental conditions, road characteristics, driver behaviour and crash reporting systems, as compared to the ones where the HSM models have originally been developed. By applying the HSM calibration procedure and using four indicators (mean absolute deviation, calibrated overdispersion parameter, root means square error, and residual plots) to assess the performance of the calibrated models, the researchers came into the conclusion that the models show a good transferability to the Italian network and especially the freeway models for fatal and injury crashes. Some improvements could be made considering variable calibration factors within the datasets or crash modification factors local calibrations. The need for an improved localization of the crash data on the Italian road network has also been highlighted, mainly for speed-change lanes.

2.2 Development of Accident Prediction Models

Besides the AASHTO Highway Safety Manual, several references exist in pertinent literature dealing with the development of Accident Prediction Models, based on available data (concerning road infrastructure design, traffic volumes, road accidents and other, e.g. weather conditions). A brief overview of the most important ones is presented in the following paragraphs.

An important initiative regarding the development of Accident Prediction Models and Safety Performance Functions in Europe took place within the **RIPCORD-iSEREST research project**, which aimed at developing best practice guidelines for several road safety tools, including Accident Prediction Models for two-lane two-way rural roads.

Within the project, a state-of the-art report (RIPCORD 2005) was developed, in which already existing APMs were discussed, regarding the choice of explanatory variables, the choice of model form and modelling process, residuals, explained variation, interpretation, predictive performance and sources of error. The general form of APM proposed according to the state-of-the-art study was the Generalised Linear Model (GLM) using a Poisson or a Negative Binomial Distribution. Furthermore, in the report, a set of criteria for assessing the quality of accident prediction models is proposed, that could be further developed into a quality scoring system.

As a next step, pilot studies on developing Accident Prediction Models for Austria, Portugal and the Netherlands were undertaken (RIPCORD 2007a). The models were developed according to the Generalised Linear Model (GLM) using a Negative Binomial Distribution, as proposed in the state-of-the-art study. From the pilot studies it became clear that the availability of detailed and good quality data is an important issue to be considered when developing APMs. If such data are not available, only a few explanatory variables can be incorporated in the models which is expected to reduce the accuracy of the prediction.

Furthermore, within the RIPCORD project, a Safety Performance Function was developed for the analysis of two-lane two-ways rural roads (RIPCORD 2008), considering both the impacts of road infrastructure parameters as well as the behaviour of drivers. This was achieved by defining section types which classify the existing horizontal alignment of roads based on driving behaviour models. The development of the SPFs was based on the investigation and evaluation of selected accident types which are connected to the alignment of roads. The models were based on a three-year period (2003-2005) of accidents on the rural road network of Saxony, Germany, with a total length of 500 km. The correlation between accident parameters and infrastructure was used to establish separate models for the defined road sections. The geometric parameters included in the model are curvature change rate for sections with similar alignment and curve radii as well as speed difference for transitions. Furthermore the road width, traffic volume and both differentiated accident types were taken into account. The SPF allows for the identification of possible safety improvements potential based on accident predictions. If the difference between the predicted accident parameters and the representative average of accident occurrence in the investigation area is above zero, there is potential for improvement.

Expanding the knowledge gained by RiPCORD-iSEREST project, the **RISMET research project** aimed at developing suitable road safety engineering evaluation tools which will allow the easy identification of both unsafe and potentially unsafe locations in a road network. One of the activity performed within the project was accident modelling, and in this context several accident prediction models were developed and discussed.

In Deliverable 6.1 of the project (RISMET 2011a), several accident prediction models in rural junctions were developed based on data from four European countries: Norway, Austria, Portugal and the Netherlands. Six combinations of the available data were analyzed and for each combination, three different statistical methods were applied for the model development (Poisson regression model, Poisson-Gamma hierarchical regression model and Poisson Log-Normal regression model). The developed models were assessed with methodologies such as Gelman-Rubin diagnostics (for convergence assessment), and deviance information criterion, effective model dimension, and posterior predictive checking (for model assessment). The most appropriate models for each data set are presented in the following list:

1. junctions - Norway: Poisson-Gamma Regression model;
2. junctions - Austria: Poisson Log-Normal Regression model (however it possibly overestimates accidents on roundabouts);
3. junctions - Portugal: Poisson-Gamma Regression model ;
4. junctions - Austria, Norway, Portugal (combined): Poisson-Gamma Regression model;
5. non-roundabout Junctions - Austria, Norway, Portugal (combined): Poisson-Gamma Regression model;
6. roundabout Junctions - Austria, Norway, Portugal, The Netherlands (combined): Poisson-Gamma Regression model.

In Deliverable 6.2 of the project (RISMET 2011b), an accident prediction model for rural road segments was developed based on data from the road network of the German federal state Brandenburg, including Federal highways B “Bundesstraßen” (not autobahns) and State roads L “Landesstraßen”, with a total length of 4,912 km. A total of 18,870 accidents with injuries of the years 2005, 2006, and 2007 were taken into account. Regarding prediction of the number of accidents, Poisson regression approaches were utilised to develop the following models for single curves, curved sequences and straight sections, also exploring the selection of explanatory variables:

<u>APMs for Single Curves:</u>

- curve radius, AADT and curve length;
- curve radius, AADT, curve length and length of prior sequence;
- speed reduction, curve length and AADT;
- speed reduction, curve length, AADT and length of prior sequence.

<u>APMs for Curved Sequences:</u>

- curvature change rate, AADT and length of curved sequence.

<u>APMs for Straight Sections:</u>

- curvature change rate, AADT and length of straight section.

Further prediction models were developed regarding the accident cost rate (thus taking also into account accident severity).

The developed models were later evaluated on a 42 km long stretch of the Portuguese road IP 04 and from this evaluation several interesting observations were made:

- what has to be predicted is important in APM development. In order to focus on the statistical potential of geometric configurations that cause accidents, the models dealing with the number of injury accidents seem to be more appropriate. If the consequences of accidents are in the focus of the research, a weighted value such as the accident cost rate should be applied.
- significant differences were found between the number of accidents predicted by the models and the real accident occurrence (predicted accidents being too low). This was attributed to numerous reasons, such as "*the entire road stretch is disproportionally*

unsafe, the longitudinal profile of this hilly road affects speed choice (a condition which is not frequent in normal roads and also not considered by the speed prediction model) and, the prediction is based on German data". Thus, a model calibration in order to take into account local (national) conditions in terms of accident structure, driving behaviour and standard of design, is considered essential.

In **New Zealand**, an initiative was undertaken to develop updated crash prediction models for two-lane rural roads (Turner et al 2012). The objectives were to update crash prediction modelling methods to align with recent developments overseas (for example the use of homogenous rural road sections rather than sections of a fixed length), develop a relational database containing all the key variables for rural roads, and create a database that could be used by university students and New Zealand researchers for further analysis. Generalised Linear Models (GLM) were developed for key crash types including head-on, loss-of-control and driveway related crashes. In addition, the models quantify the safety impact of key road features, many of which can be influenced or changed by highway safety engineers, including: traffic flow (AADT), segment length, minimum radius of curvature, average gradient, seal width, SCRIM coefficient, mean texture depth, region, KiwiRAP roadside hazard rating, approaching vehicle speed, traffic on driveways.

Using data from interchange influence areas on urban freeways in the **state of Florida, US**, Haleem et al (2013) applied an interesting SPF development procedure in developing Crash Modification Factors (CMFs) regarding the effect of changes in median width and inside and outside shoulder widths. In this study the "total" number of crashes, the number of "fatal and injury" crashes, as well as two most frequent crash types (rear-end and sideswipe) have been considered. The study applied a promising data mining method known as Multivariate Adaptive Regression Splines (MARS). To fit a MARS model, three main steps are applied. In the first step, i.e., the “constructive phase”, base functions are added to the model using a forward stepwise procedure. The predictor and the knot location that contribute significantly to the model are selected. In this stage, interactions are also introduced to examine if they could improve the model’s fit. In the second step, or the “pruning phase”, the base functions with the least contribution are eliminated using backward deletion. To overcome overfitting, a generalized cross-validation statistic is usually used, where a penalty for model complexity is accounted for. The last step is the “selection phase”, which selects the optimum MARS model from a group of recommended models based on the fitting and predictive capability of each.

Furthermore, several references in pertinent literature can be found regarding APM development in the road network of **Italy**. Caliendo et al (2007) developed a prediction model for Italian four-lane median-divided motorways, based on accident and road geometry data from a 46.6 km long section, which was monitored from 1999 to 2003. The model, estimating crash frequency as a function of traffic flow, infrastructure characteristics, pavement surface conditions (including whether wet or dry) and sight distance, was developed using a stepwise forward procedure based on the Generalized Likelihood Ratio Test (GLRT).

Montella et al (2008) developed separate crash prediction models for total crashes and severe (fatal plus all injury) crashes in Italian rural motorways, using Generalized Linear Modelling techniques and assuming a negative binomial distribution error structure. The study used a sample of 2,245 crashes (728 severe crashes) that occurred from 2001 to 2005 on Motorway A16 between Naples and Canosa in Italy. The developed model for total crashes included as variables: curvature, operating speed reduction, length of the tangent preceding the curve, and traffic effect, all with a positive sign; difference between the friction demand and supply, deflection, and upgrade, all with a negative sign.

Cafiso et al (2010) attempted to define accident prediction models for two-lane rural road sections based on a combination of exposure, geometry, consistency and context variables directly related to the safety performance. The study was based on a sample of 168.20 km of two-lane local rural roads, with a 5-year accident analysis period to compensate for the low traffic flow and accident frequencies anticipated on local roads. The models proposed are also based on the Generalized Linear Modelling approach (GLM), assuming a negative binomial distribution error structure. Three of the examined models were considered appropriate, based on practical considerations, statistical significance, and goodness of fit indicators.

APMs for tunnels should be developed as a separate tool as compared to general road segment models. The most commonly used tunnel APM has been developed in Switzerland by Salvisberg et al. (2004) accounting for the effect of tunnel length (which is not linear), AADT, percentage of heavy vehicles, number of tunnel bores, right shoulder width. This model has been calibrated for the Italian Motorway network by Domenichini et al. (2012) showing a very good prediction capability of the model if this is calibrated to local data with only few outliers (3 out of 52 tunnels) for which the estimation was deemed inadequate.

Caliendo et al (2013) also developed an accident prediction model for Italian motorway tunnels, based on a database of 260 tunnels with a 4-year monitoring period extending from 2006 to 2009. For the development of the model, a procedure based on the Generalized Likelihood Ratio Test (GLRT) was used, taking into account two different regression models: the Negative Multinomial (NM) regression model and the Random Effects Negative Binomial (RENB) regression model.

2.3 Web-based CMF databases and Road Safety Toolkits

In the recent years, web-based databases of effective road safety measures, usually including Crash Modification Factors (CMFs) have been developed, to help transportation engineers in identifying the most appropriate countermeasure for their safety needs. Such databases are the FHWA CMF Clearinghouse (http://www.cmfclearinghouse.org), the AustRoads Road Safety Engineering Toolkit (http://www.engtoolkit.com.au/), and the iRAP Road Safety Toolkit (http://toolkit.irap.org/). All of the above incorporate a web-based searchable database that provides useful information, usually including Crash Modification Factors, for several common road safety measures.

2.3.1 FHWA CMF Clearinghouse

The FHWA CMF Clearinghouse (www.cmfclearinghouse.org) offers transportation professionals a central, web-based searchable repository of Crash Modification Factors (CMFs), as well as additional information and resources related to SPFs and CMFs, that have been summarised in paragraphs 2.1.2 (regarding SPF calibration or development) and 2.1.4 (regarding CMFs) of the present report.

The FHWA Clearinghouse is directly related and provides support to the predictive methodologies included in the Highway Safety Manual (AASHTO, 2010). As far as the CMF repository is concerned, while the HSM provides only a selection of the available research-based CMFs, the CMF Clearinghouse is a comprehensive listing of all available CMFs, including the ones listed in the HSM.

Both the HSM and the CMF Clearinghouse conducted a review process of CMFs and assigned a "confidence" in the CMF based on the quality of the study that produced it. The HSM review process applies an adjustment factor to the study's CMF (to correct for regression-to-the-mean and traffic volume bias) and a method correction factor to the study's standard error (to correct for the study design and method selected, sample size, confounding factors, and other study characteristic documented during the critical review of each study documentation).

The CMF Clearinghouse review process rates the CMF according to five categories - study design, sample size, standard error, potential biases, and data source - and judges the CMF according to its performance in each category. It assigns a star rating (one through five) based on the cumulative performance in the five categories. It differs from the HSM process in that it does not attempt to adjust the standard error, but similarly to the HSM it explicitly considers criteria such as data source, which examines whether a study used data from just one locality or from multiple locations across the state or nation, among others.

An important aspect of the FHWA CMF Clearinghouse is that for each CMF value included in the database, detailed background information is generally available, regarding the exact study from which the CMF was retrieved (citation, abstract and in many cases full text), the CMF development procedure (including date range of data used, geographic origin of the research, statistical methodology used, "before" sample size, "after" sample size etc.) and the aforementioned star quality rating.

A drawback of the FHWA CMF Clearinghouse is that the search function of the database is less user friendly, since it is generally limited to keyword search (on the treatment's name, study's abstract, study's citation or CMF ID). More advanced search capabilities are available only by performing a two-stage search, i.e. searching with a blank field on the treatment's name and subsequently filtering the results according to crash type, crash severity, road type, intervention category etc. This procedure can be more complicated and time consuming and furthermore, some useful search functions existing in Austroads or iRAP toolkits (eg. searching for measures addressing a specific road safety issue, or affecting specific road user groups), are not available.

2.3.2 Austroads Road Safety Engineering Toolkit

The Austroads Road Safety Engineering Toolkit (www.engtoolkit.com.au) brings together existing road safety engineering knowledge for easy access by practitioners, based on research into the effectiveness of road safety countermeasures, retrieved from relevant studies in Australia and New Zealand. In addition to the originally included data, road safety practitioners are allowed to submit case studies which will be evaluated and possibly included in the knowledge framework of the Toolkit.

A total of 67 treatments, all concerning road infrastructure, are included in the Toolkit, which incorporates more user-friendly search functions as compared to the FHWA Clearinghouse. Users can search the existing database in four different ways:

- according to the specific treatment type/name (as in the FHWA Clearinghouse);
- according to the dominant crash types;
- according to the related safety issues;
- according to the affected road user groups.

For each treatment, the following information has been gathered and presented in the Toolkit:

- description of the treatment;
- key benefits associated with the treatment;
- issues concerning implementation of the treatment;
- crash reduction effectiveness;
- qualitative cost rating (using a 5 scale system);
- qualitative treatment life estimation (using a 4 scale system);
- reference to technical papers, studies and guides concerning the treatment.

Quantitative values for the expected crash reduction effectiveness of each measure are included in the Toolkit, however detailed information regarding the development of each expected crash reduction percentage is not available (such as the exact reference for each CMF, the statistical method that was used, the geographic area, conditions that the value refers to, the data that were used, etc.).

The knowledge included in the Toolkit is constantly updated with recent experience from local and state government agencies, and with the results of comprehensive road safety research reviews and case studies that can be submitted by road safety practitioners.

2.3.3 iRAP Road Safety Toolkit

The iRAP Road Safety Toolkit is very similar in design and operation with the Austroads Road Safety Engineering Toolkit, incorporating however less information and capabilities. A total of 58 treatments are included in the Toolkit: 42 related to road infrastructure, 5 related to vehicles and 11 related to users. Search within the web-based toolkit can be performed according to the specific treatment name, the dominant crash types or the road user groups, while the search according to the road safety deficiency to be addressed (as in the Austroads Toolkit) is not possible. For each treatment, the following information is available in the Toolkit:

- description of the problem and the treatment;
- benefits associated with the treatment;
- issues concerning implementation of the treatment;
- crash reduction effectiveness (qualitative);
- qualitative cost rating;
- qualitative treatment life rating;
- reference to technical papers, studies and guides concerning the treatment;
- reference to related case studies (if available).

It should be noted that specific CMF values are not included in the iRAP Toolkit, only an assessment of each treatment's effectiveness using a four scale system (0-10%, 10-25%, 25-40%, 60% or more).

2.4 Road safety measures assessment in general

Further information regarding assessment of the efficiency of road safety measures can be found in pertinent literature, in various handbooks, guides and relevant research projects. An overview of the most important initiatives is presented in the following paragraphs. A brief review of each reference can be found in Appendix 1.

2.4.1 Handbooks and Guides

<u>The Handbook of Road Safety Measures (Elvik et al, 2009)</u>

The handbook aims at providing a systematic overview of current knowledge regarding the effects of road safety measures, by presenting state-of-the-art summaries of current knowledge regarding the effects of 128 road safety measures on road safety.

The handbook seeks to develop objective knowledge about the effects of road safety measures by relying on an extensive and systematic search of literature and by summarising this literature by means of formal techniques of meta-analysis that minimise the contribution of subjective factors that are endemic in traditional, narrative literature surveys. A systematic meta-analysis framework has been used to assess the validity of the studies that are quoted.

Moreover, the need to develop crash modification functions (CMF) in order to describe systematic variation in the effects of road safety measures is stressed.

The data used for the meta-analysis of road safety infrastructure investments were gathered through a systematic literature search. An important criterion for study inclusion is to have quantified, or at least have tried to quantify, the effect of one or more road safety measures on the number of accidents, accident rate and the number of injuries or risk of injuries.

The road safety evaluation studies examined within the handbook were assessed in terms of four types of validity:

- statistical conclusion validity: sampling technique, sample size, reporting of statistical uncertainty in results, measurement errors, specification of crash or injury severity;
- theoretical validity: identification of relevant concepts and variables, hypotheses describing the relationships between variables, knowledge of causal mechanisms;
- external validity: possible generalisation of the results of a study;
- internal validity: basis for inferring a causal relationship between treatment and effect, statistical association between treatment and effect, clear direction of causality, dose-response pattern, specificity of effect, control of confounding factors.

The handbook results in a detailed presentation of existing knowledge classified, according to each road safety measure, including descriptions and analysis of the problem and objective, of the measure, of the effect on accidents (including CMFs), of the effects on mobility and on the environment, and of available information regarding the measure's cost and cost - benefit analysis. In the handbook it is also demonstrated that the safety effect of a measure may vary from place to place, depending on the design of the measure, the number of accidents at the spot, any other measures that have been implemented, etc. An attempt has been made to identify sources of variation in the findings of different studies and to try to form groups as homogeneous as possible when presenting estimates of the effects of measures on road safety.

<u>"Countermeasures That Work" Guide (NHTSA, 2013)</u>

The guide, published by National Highway Traffic Safety Administration of the US Department of Transportation, is intended to assist US State Highway Safety Offices (SHSOs) in selecting effective, evidence-based traffic safety countermeasures for major road safety problem areas. The guide describes strategies and countermeasures that are relevant to SHSOs, summarizes their use, effectiveness, costs, and implementation conditions and includes references to the most important publications (research summaries and individual studies) in the field. The data for the development of the guide were collected from published and reported material from the US, dating from 1984 to 2013.

A total of 116 countermeasures are presented in the guide, referring mainly to legislation, enforcement, training and communication measures and infrastructure treatments. Quantitative CMFs are generally not included in the guide, and the effectiveness (reductions in crashes or injuries) of the examined countermeasures is demonstrated by means of a qualitative star rating (1-star for limited or no high-quality evaluation evidence, 5-stars for effective measures according to several high-quality evaluations with consistent results). The use of countermeasures, implementation costs and time to implementation are also assessed in the guide.

<u>The ROSEBUD Handbook (ROSEBUD, 2006)</u>

A handbook titled “Examples of assessed road safety measures - a short handbook”, was issued in July 2006 as the main outcome of the ROSEBUD research project. ROSEBUD was based on internationally available knowledge and experience gathered in the application of monetary evaluation techniques by scientists, politicians and practitioners, and the handbook includes information about various assessed road safety measures.

The examined measures were classified as user related, vehicle related and infrastructure related measures, and were assessed by application of Cost-Effectiveness Analysis (CEA) or Cost-Benefit Analysis (CBA). For each assessed measure, a short description is provided along with an example of additional information. The assessment method (CBA or CEA) and the assessment result (poor, acceptable, excellent), as well as their sources, are highlighted in a table. Crash Modification Factors (CMFs) were not explicitly analysed within the ROSEBUD project.

The CEDR Reports (CEDR, 2008 & CEDR, 2012)

A report entitled "Best Practice for Cost-Effective Road Safety Infrastructure" was developed within a project issued by the Conference of European Directors of Roads (CEDR) aimed at quantifying and subsequently classifying several infrastructure related road safety measures, based on the international experience attained through extensive and selected literature review and additionally on a full consultation process including questionnaire surveys addressed to experts and relevant workshops. The aforementioned process resulted in the identification of **five most promising investments** that were further examined within an in-depth analysis procedure. These investments concern the following measures:

- roadside treatments;
- speed limits;
- junction layout;
- traffic control at junctions;
- traffic calming schemes.

The results suggested that the overall cost-effectiveness of a road safety infrastructure investment is not always in direct correlation with the safety effect and it was recommended that cost-benefit ratios and safety effects are always examined in conjunction with each other in order to identify the optimum solution for a specific road safety problem. Crash Modification Factors (CMFs) were not explicitly analysed within the CEDR Report.

In 2012 the Forgiving Roadside Design Guide (CEDR, 2012) was published based on the outcome of the ERANET Funded Project IRDES (Improving Roadside Design to Forgive Human Errors).

In this report for safety features are studied in details:

- barrier terminals;
- shoulder rumble strips;
- forgiving support structures for road equipment;
- shoulder width.

For each road safety feature design guidelines and CMF values are given in the report.

Roadway Safety Design Synthesis (FHWA, 2005)

Prior to the publication of the Highway Safety Manual, an important initiative was undertaken by FHWA to develop safety design guidelines and evaluation tools for incorporation in the planning and design stages of the project development process, that resulted in the handbook entitled "Roadway Safety Design Synthesis" (FHWA, 2005). In the Design Synthesis, available quantitative information for various roadway facilities (freeways, rural highways, urban streets, interchange ramps, rural intersections and urban intersections) has been collected and analyzed. For each facility type, safety prediction models are described, compared and discussed, providing a roadway designer useful insight into the model types and design-related factors that correlated with crash frequency. Additionally, crash modification factors (CMFs) for various design-related factors that have been found to be correlated with crash frequency are presented. However, the practical use of the FHWA Roadway Safety Design Synthesis is nowadays limited, since most of the data and information included have been incorporated in the more recent and updated Highway Safety Manual (AASHTO, 2010 & AASHTO, 2014).

2.4.2 Research projects

Efficiency assessment of road safety measures and treatments has also been examined and analysed by various research projects.

PROMISING project (PROMISING, 2001)

The PROMISING research project aimed at the identification of the potential for reduction in casualties of vulnerable road users like pedestrians, cyclists, motorised two wheelers and young drivers, by technical non restrictive-measures. Within the project, four groups of vulnerable road-users were distinguished (pedestrians, cyclists, riders of motorised two-wheelers, and young car drivers), and for each group safety problems were analysed, an inventory of measures was developed and the restrictiveness and the cost and benefits of the measures were evaluated.

SUPREME project

The main objectives of the SUPREME research project were the sound identification and publication of Best Practice from the vast amount of available measures, and the development of a strategic approach and a framework for dissemination activities of the key findings in the target countries (EU members as well as Switzerland and Norway). Amongst other issues, the project involved an in-depth-analysis of road safety measures in order to identify Best Practice measures. The project resulted in the development of two handbooks: the "Handbook for measures at the Country level" (SUPREME, 2007) and the "Handbook for Measures at the European Level" (SUPREME, 2007a).

In the "Handbook for measures at the Country level" 55 measures are identified as best, good or promising practices, in the following areas: Institutional Organisation of Road Safety, Road infrastructure, Vehicles and Safety Devices, Education and Campaigns, Driver Training, Traffic Law Enforcement, Rehabilitation and Diagnostics, Post Crash Care, and Road Safety and Data collection.

In the "Handbook for measures at the European level" 31 measures are identified as best, good or promising practices, in the following areas: Policy Framework for Efficient Road Safety, Vehicle Safety, Road Infrastructure Safety, Enforcement of Traffic Law, Tackling Novice Drivers' Higher Risks, Campaigns, Post-Accident Care, Data Collection and Analysis, and Practices from Related Policy Areas - e.g. Environmental Protection and Advocating Health.

The Handbooks provide a brief description of each measure, a presentation of involved stakeholders and an analytic outline on effects and costs, including Benefit/Cost ratio, if available. In addition, useful links for more information are presented.

2BESAFE project (2BESAFE, 2011)

Within 2BESAFE research project, issues related to two-wheeler behaviour and safety are investigated in order to define the parameters of their behaviour resulting in their high risk. First, the possible causes for two-wheeler road accidents were investigated obtaining data from accident databases to define specific scenarios that contain high risk for two-wheelers.

Next, two-wheeler behaviour, conspicuity and risk perception were investigated using a set of tools part of which was designed/customised within the framework of the project. Such tools were instrumented two-wheelers for naturalistic riding studies, questionnaires, riding simulators and video tools. The synthesis of the project results led to the assessment and presentation of measures for the improvement of two-wheeler road safety, based mainly on experts' opinions. In Part C of the Deliverable "Guidelines, Recommendations and Research Priorities" of the 2BESAFE project, a total of 143 measures has been assessed and presented. For each measure, a short description is provided, along with an example of the measures implementation and an attempt to determine possible beneficiaries of the measure. Short comments are included regarding the relevant safety problem, its size and scientific background, issues on the measure's implementation, the expected impact and the riders' perspective. Finally, the experts' assessment of the measure is summarized in a table, providing a five star qualitative assessment of the measure overall as well as of eight important aspects: size, total impact, safety impact, efficiency, transferability, implementation, acceptance and sustainability.

SaferBraIn project (SaferBraIn, 2011)

SaferBraIn research project aimed at increasing the level of safety Pedestrians and Cyclists in India and Brazil. In the Deliverable "Innovative Guidelines and Tools for Vulnerable Road Users Safety in India and Brazil", a total of 16 relevant road safety measures has been assessed and presented, along with information such as advantages and disadvantages of each measure, comments regarding the transferability of the measure to the local conditions in India and Brazil and general guidance for use.

2.5 Literature related to methodological issues

Several publications can be found in pertinent literature that address methodological issues on accident prediction models and Crash Modification Factors. The most important ones are briefly presented in the following paragraphs.

A research report entitled "Sharing Road Safety: Developing an International Framework for Crash Modification Functions" (OECD-ITF, 2012) was published in 2012, with the objective of analyzing the issue of Crash Modification Functions transferability, focusing on the Range of Replications technique and how it can give an indication of the stability of research results across countries and years. The report provides also preconditions that should be fulfilled before applying the Range of Replications technique. The technique can be fruitfully applied to assess external validity when a large number of studies have been reported during a long period of time

The report highlights the growing demand for reliable crash modification factors (CMFs) that relate safety effectiveness to interventions, and suggests that transferable CMFs from one situation to another are a valuable tool in spreading effective safety policies. The report has documented ways to address the issue of CMF transferability, by analysing the extent to which a CMF is dependent on the circumstances in which it was developed, and provides a framework that illustrates how studies can control for the most important confounding factors related to the countermeasure analysed and thus provides guidance for uniform screening and control procedures. In this regard, the report serves as a useful guide for transferring road safety measures and aids in supporting countries in their efforts to collaborate on essential road safety research.

A useful publication to road safety practitioners, aimed at assisting them in understanding, planning, analysing and interpreting observational before - after studies, is the book "Observational Before-After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety" (Hauer, 1997). It includes essential background information regarding road safety as well as planning and analysis of an observational Before-After Study, attempts to adapt conventional approaches to the realities of observational studies and explores new approaches to the interpretation of observational Before - After Studies, such as the Empirical Bayes approach, and a suggestion of a more coherent approach to the conduct of an observational Before-After Study, based on a multivariate model. The book offers a valuable insight on the scientific background required to develop Accident Prediction Models and Crash Modification Factors and can assist in the identification of bias and errors in Before-After Studies. Thus, it provides the background information to assess the validity and reliability of existing APMs and CMFs.

A paper by Hauer et al (2012) aims at providing guidance for research about CMFs, by discussing CMF foundational issues. The main idea is that a CMF is not a universal constant that has the same value always and everywhere, but instead it should be viewed as a random variable, the value of which depends on a host of factors (circumstances of implementation). Therefore, it has a probability distribution with a mean and a variance. Thinking of CMFs as random variables allows the question of transferability to be correctly framed. In order to increase the effectiveness of CMF research, the variance must be reduced. Two approaches are discussed: conducting more studies, and making the CMF a function of the circumstances of implementation. In the paper it is stressed that every CMF research should contain information about the relevant circumstances of the implementation, that might affect the CMF value, because only this will allow subsequent researchers to make the CMF a function of circumstances.

2.6 Other related research and literature

An approach to road safety measures from a health care point of view is performed by the Cochrane Reviews (Cochrane Collaboration, 2014). Cochrane Reviews are systematic reviews of primary research in human health care and health policy. They investigate the effects of interventions for prevention, treatment and rehabilitation, and they also assess the accuracy of a diagnostic test for a given condition in a specific patient group and setting. The Cochrane Injuries Group has been preparing Cochrane Reviews on the effectiveness of interventions for road safety, including slowing traffic speed, wearing helmets, and driver education. The findings of these Cochrane Reviews provide guidance on the effectiveness of interventions for road safety.

Information regarding the efficiency of road safety measures can also be retrieved from the reports published annually by IRTAD, the most recent published in 2013 (IRTAD, 2013). These reports include road safety data from several member countries and summarize the recent road safety measures as well as the national road safety strategies and targets. In many cases, data regarding the effectiveness of implemented measures are included in the reports.

Finally, a couple of interesting software tools provide safety evaluations of road infrastructure, based on accident prediction models. Probably the most important one is the Interactive Highway Safety Design Module (IHSDM), developed by FHWA, which includes a Crash Prediction Module (CPM), that is claimed to be a faithful software implementation of the HSM Predictive Method. Thus, it can provide accident frequency estimates of a roadway segment or intersection, based on the parameters provided by the user, and can be used to evaluate either existing or proposed road designs.

Another interesting software tool identified in the review is the TARVA software (Peltola et al, 2013), which uses EB safety predictions as the basis for selecting locations for implementing road-safety improvements and provides estimates of safety benefits of selected improvements. The tool provides a method to predict the expected number of road accidents if no measures are implemented for selecting locations for safety treatments and to estimate the safety effects of road safety improvements in order to evaluate the cost-effectiveness of combinations of safety measures. The underlying logic of TARVA is combining general safety (accident model) with information from local safety factors (accident record) using the EB method.

3 National contributions

3.1 Procedure

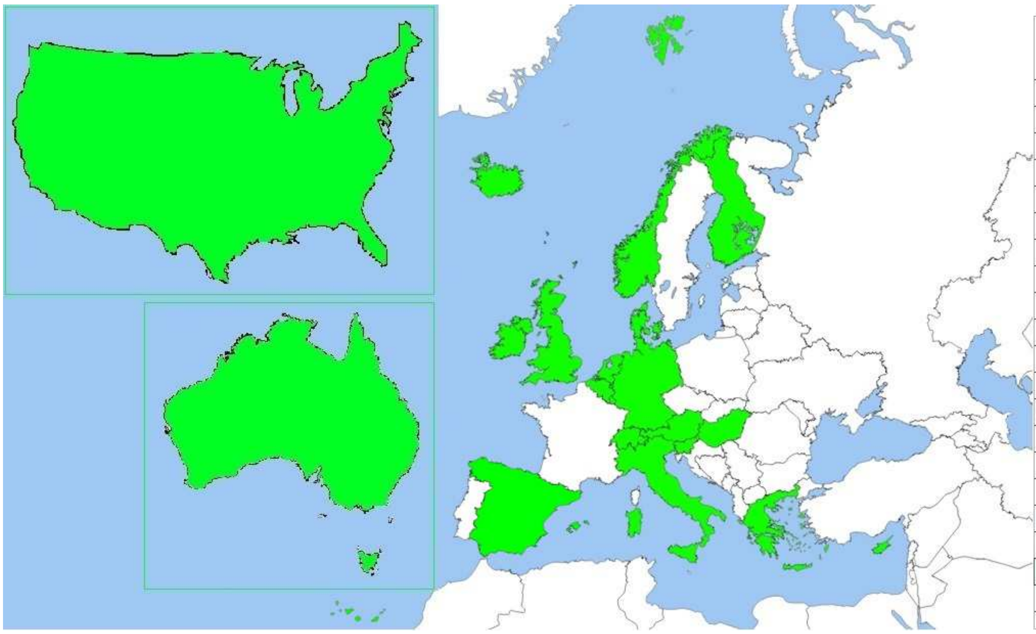
In order to collect information about currently used APMs and data sources by different National Road Administrations (NRAs) in Europe and worldwide, a questionnaire was designed and dispatched to several NRAs in Europe and worldwide, with a two-fold objective: (1) to collect detailed information on APMs developed and used by the NRAs, and (2) to collect information regarding data availability, quality and definitions among European countries and worldwide. A copy of the questionnaire regarding APMs and data sources is included in Annex A of the present report.

The **questionnaire** comprises of the following parts:

- A brief introductory part, that presents the principles, objectives and partners of the PRACT project, a list of definitions of terms found in the questionnaire and a list of references.
- Part A regarding the Decision Making Process: This part of the questionnaire refers to information on procedures followed by NRAs, their priorities and the guidelines that are used by NRAs when assessing road safety measures.
- Part B regarding Data Sources: This part of the questionnaire focuses on data availability, data needs, quality of data and definitions among European countries and worldwide. Relevant questions aim at gathering the above information for each of the examined data categories:
  - road design data;
  - road operation data;
  - traffic data;
  - accident data;
  - user behaviour data / other related data.
- Part C regarding information on CMFs and road safety measures assessment: In this part, the criteria considered by NRAs in order to use a particular CMF during the assessment of alternative road safety measures to address a specific road safety issue are examined, in relation to data availability. These criteria may refer to CMF Applicability (i.e. if the CMF can be effectively applied to the specific problem at hand) or CMF Development (i.e. if the CMF is considered reliable and of high quality).
- Part D, aimed at gathering a summary of experience on road safety measures / CMFs. In this part and for a list of measures / CMFs, it was asked to identify the following, according to previous relevant experience of the NRA:
  - the need to implement the road safety measure in the country's road network;
  - the availability of assessment of measure / CMF;
  - the transferability of safety effect (i.e. if the measure is assessed in a different location, will the safety effect be similar and therefore transferable to the examined country?).
- Finally, a concluding section referred to the details of the person filling the questionnaire.

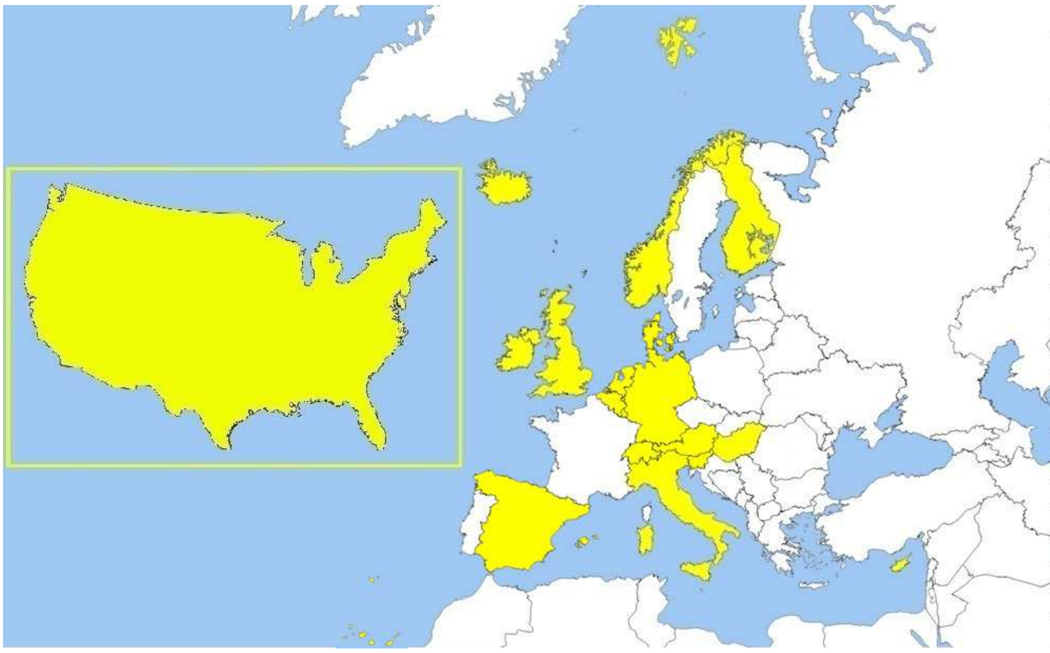
A total of **23 completed questionnaires** were received, mostly from National Road Authorities, but also from Road Managing Companies, Academia/Research Institutes or Highway Consultants. The questionnaires were received mostly from European Countries, as well as from the United States and Australia. As in almost every inquiry the answers were mostly given by a single expert working at a NRA, although in five questionnaires two or more experts cooperated to fill in the questionnaire. Therefore, it is possible that if different persons within the same NRA were questioned, the answers could be slightly different and this should be taken into account in the interpretation of the survey results.

The geographical distribution of the organizations that replied to the questionnaire survey, along with the respondent's organisation type are presented in the following Figures 3.1, 3.2 and 3.3.



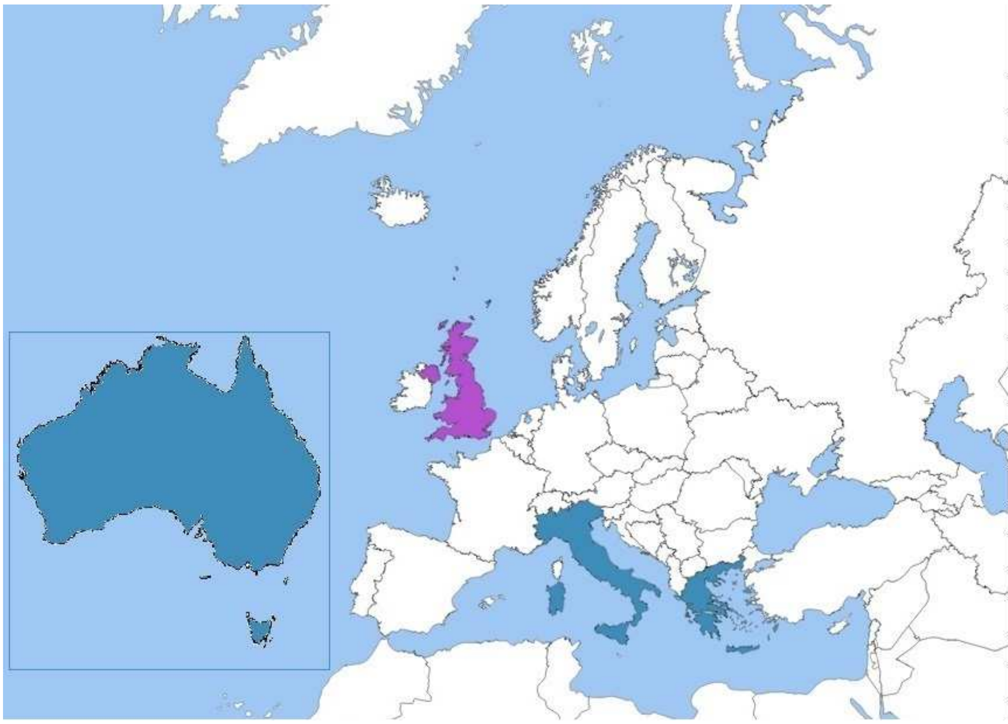
Country	Sent questionnaires	Received
Austria	1	1
Belgium	2	1
Cyprus	1	1
Denmark	1	1
Finland	1	1
Germany	1	1
Greece	1	1
Hungary	1	1
Iceland	1	1
Ireland	1	1
Italy	3	2
Luxembourg	1	1
Netherlands	1	1
Norway	1	1
Slovenia	1	1
Spain	1	1
Switzerland	1	1
UK	5	3
USA	2	1
Australia	1	1
Total	28	23

Figure 3.1: *Geographical distribution of responses to questionnaire survey.*



Country	Respondent's Organisation type
Austria	National Road Authority
Belgium	National Road Authority
Cyprus	National Road Authority
Denmark	National Road Authority
Finland	National Road Authority
Germany	National Road Authority
Greece	-
Hungary	National Road Authority
Iceland	National Road Authority
Ireland	National Road Authority
Italy	National Road Authority
Luxembourg	National Road Authority
Netherlands	National Road Authority
Norway	National Road Authority
Slovenia	National Road Authority
Spain	National Road Authority
Switzerland	National Road Authority
UK	National Road Authority (*2)
USA	National Road Authority
Australia	-

Figure 3.2: *Geographical distribution of responses to questionnaire survey by NRAs.*



Country	Respondent's Organisation type
Austria	-
Belgium	-
Cyprus	-
Denmark	-
Finland	-
Germany	-
Greece	Academia/Research Institute
Hungary	-
Iceland	-
Ireland	-
Italy	Academia/Research Institute
Luxembourg	-
Netherlands	-
Norway	-
Slovenia	-
Switzerland	-
UK	Other (Highway consultant)
USA	-
Australia	Academia/Research Institute
Total	

Figure 3.3: *Geographical distribution of responses to questionnaire survey by organisations other than NRAs.*

3.2 Information regarding APM development and use by European NRAs

3.2.1 Decision making process

Part A of the questionnaire provides interesting information regarding the procedures followed by NRAs and other organisations when assessing road safety measures. According to the questionnaire responses, most NRAs and other organizations use a specific procedure for assessing alternative road safety measures (83% responded "*always*" or "*usually*", compared to 17% that responded "*rarely*" or "*never*"), with Cost-Benefit Analysis (CBA) being the most commonly used procedure, used by 81% of the organizations, followed by Net Present Value (NPV) and Cost-Effectiveness Assessment (CEA) (see Figure 3.4). The most commonly used procedure included in the category entitled "*other*" is the First Year Rate of Return (FYRR), by 8.7% of the organizations. It should also be noted that NRAs seem to exhibit increased preference for the CBA procedure, compared to other organizations (academia / research institutes and highway consultants). Specifically, all NRAs that reported using a specific procedure for assessing alternative road safety measures, use Cost Benefit Analysis (CBA).

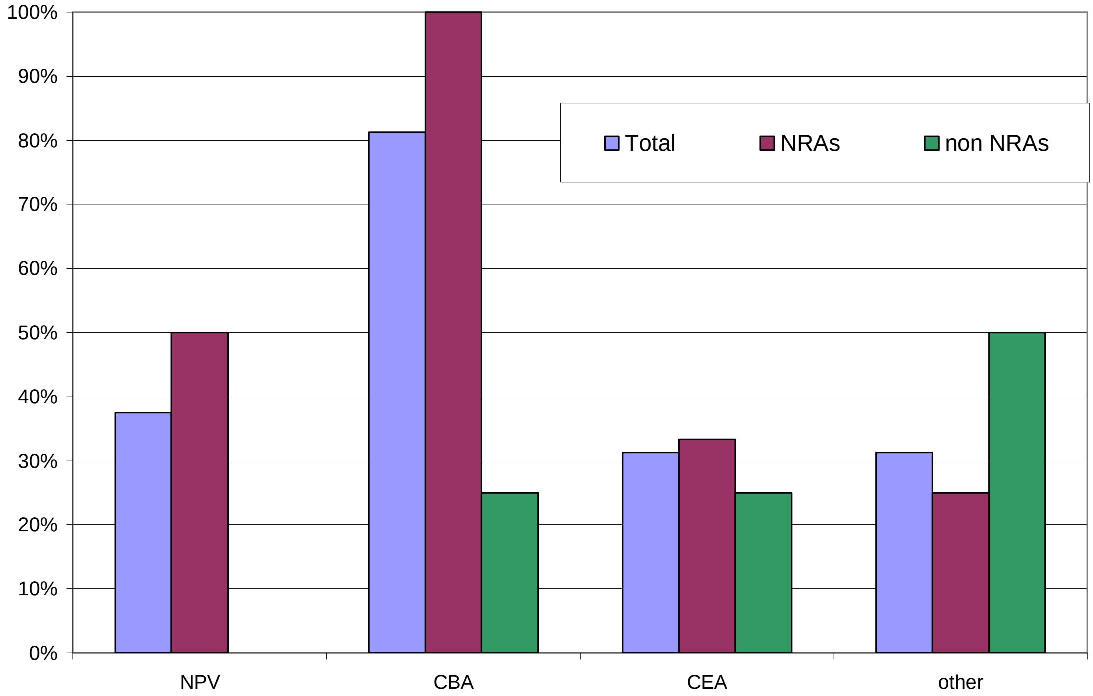


Figure 3.4: *Applied procedures for assessing alternative road safety measures.*

Despite the fact that most NRAs and other organizations use a specific procedure for assessing alternative road safety measures, most do not use Accident Prediction Models (APMs) or Crash Modification Factors (CMFs) during the assessment procedure (30% responded "*always*" or "*usually*", compared to 70% that responded "*rarely*" or "*never*").

The aspects / criteria considered by NRAs and other organizations during the assessment of alternative road safety measures are presented in the following Figure. It seems that the safety effectiveness of countermeasures is of far greater importance than the implementation cost, the effective lifespan, previous experience or public acceptability.

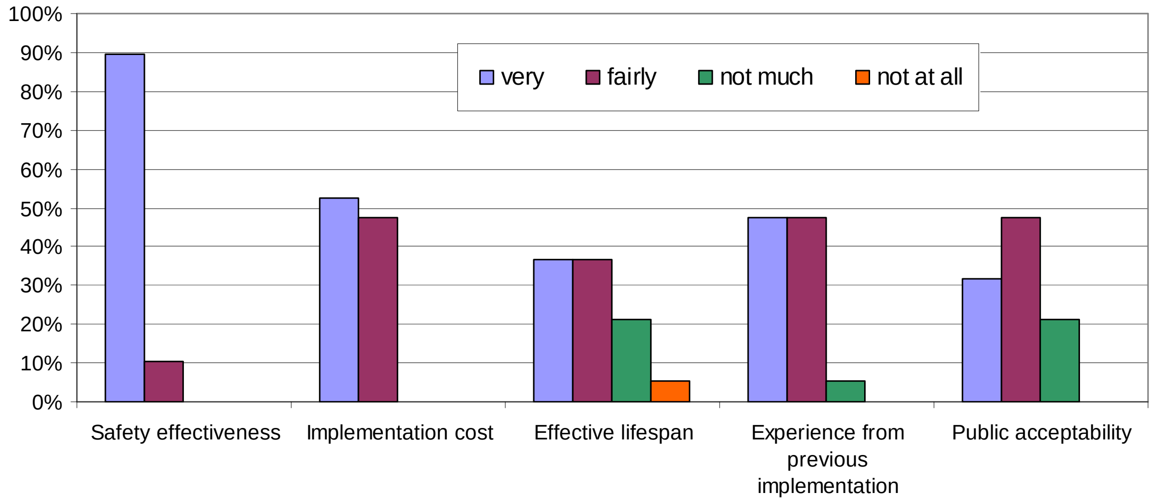


Figure 3.5: *Aspects / criteria considered by NRAs and other organizations during the assessment of alternative road safety measures.*

On the availability and use of guidelines or manuals, regarding the assessment of road safety measures, 61% reported that such guidelines, officially approved, exist in their country. Additionally, 50% reported that they use ("*always*" or "*usually*") other guidelines, manuals (not officially approved) or other studies, regarding road safety measures assessment, compared to 50% that answered that they "*rarely*" or "*never*" use not officially approved sources of information. The relevant guidelines, manuals, studies etc. according to the questionnaire survey, are summarized in the following table.

Table 3.1: *Guidelines, manuals and studies used by NRAs and other organizations for assessment of road safety measures.*

no	Country	Title	Link (if available)
A. OFFICIALLY APPROVED GUIDELINES - MANUALS			
1	Australia	AustRoads Guides	http://www.austroads.com.au/
2	Cyprus	Included in the inter-urban and urban design standards of PWD	
3	Denmark	Handbook of safety effects of road engineering measures - "Håndbog, Trafiksikkerhed, Effekter af vejtekniske virkemidler, 2. udgave, Rapport nr. 507, Vejdirektoratet, 2014" - in Danish	http://www.vejdirektoratet.dk/DA/viden_og_data/publikationer/Lists/Publikationer/Attachments/802/H%C3%A5ndbog,%20trafiksikkerhed_web.pdf
4	Denmark	Handbook of road safety calculations - "Håndbog i trafiksikkerhedsberegninger, Rapport 220" - in Danish	http://arkiv.cykelviden.dk/filer/rap220.pdf
5	Finland	No official guidelines, however mandatory use of dedicated estimation tools: Tarva (while improving existing road) or IVAR (while new roads or major reallocation of traffic included)	
6	Germany	FGSV (1997): Empfehlungen für Wirtschaftlichkeitsuntersuchungen an Straßen	http://www.fgsv-verlag.de/catalog/_pdf-files/132.i.pdf
7	Ireland	National Roads Authority: Project Appraisal Guidelines	http://www.nra.ie/policy-publications/project-appraisal-guideli/

no	Country	Title	Link (if available)
8	Ireland	National Roads Authority: Traffic and Transport Assessment Guidelines (2014)	http://www.nra.ie/policy-publications/road-safety/Transport-Assessment-GuidelinesMay2014.pdf
9	Italy	"Linee guida per la gestione della sicurezza delle infrastrutture ai sensi dell'articolo 8 del Decreto Legislativo n. 35/2011" (implementation of the European Directive 2008/96/CE) & "Linee guida per le analisi di sicurezza delle strade" (Ministry of Infrastructures and Transportation, 2001)	
10	Italy	Italian Guidelines for Managing Road Safety (DM 2 May 2012 n.182)	
11	Norway	Included in Design Manuals	
12	Slovenia	Slovenian Roads Agency: Methodology for identification of hazardous locations and implementation of countermeasures on the national roads network (in Slovenian only)	http://www.dc.gov.si/fileadmin/dc.gov.si/pageuploads/pdf_datoteke/METODOLOGIJA_ZA_DOLOCITEV_NEVARNIH_MEST_IN_ZA_NJIHOVO_ODPRAVO_NA_DRZAVNEM_CESTNEM_OMREZJU_-_Celje.pdf
13	Switzerland	Konkrete Vorgehensvorgaben zur Unterstützung der Sachbearbeiter bei der Anwendung der ISSI befinden sich in Normen des Schweizerischen Verbands der Strassen- und Verkehrsfachleute (VSS). - in German, Italian or French: SNR 641 721: Road Safety Impact Assessment (RIA) SN 641 722: Road Safety Audit (RSA) SNR 641 723: Road Safety Inspection (RSI) SNR 641 724: Black Spot Management (BSM) SNR 641 725: Network Safety Management (NSM)	http://www.astra.admin.ch/themen/verkehrssicherheit/03967/06050/index.html?lang=de
14	UK	Welsh Government: Guidelines for the Submission of Road Safety Schemes (2011)	http://wales.gov.uk/topics/transport/roads/localsafescheme?lang=en
15	UK	Dpt for Transport, The Highways Agency: Design Manual for Roads and Bridges (DMRB)	http://www.dft.gov.uk/ha/standards/dmrb/
16	UK	GD04 Safety Risk Assessment	
17	UK	HD19 Road Safety audits	
18	USA	AASHTO (2010). The Highway Safety Manual. American Association of State Highway and Transportation Officials (AASHTO). Washington DC.	http://www.highwaysafetymanual.org
B. OTHER GUIDELINES / MANUALS / STUDIES USED (NOT OFFICIALLY APPROVED OR USED IN OTHER COUNTRIES THAN THE ONES THAT APPROVED THEM)			
1	Greece, Hungary, Italy	AASHTO (2010). The Highway Safety Manual. American Association of State Highway and Transportation Officials (AASHTO). Washington DC.	http://www.highwaysafetymanual.org
2	Greece, Italy	CEDR (2008). Best Practice on Cost Effective Road Safety Infrastructure Investments. Conference of European Directors of Roads (CEDR).	http://www.cedr.fr/home/fileadmin/user_upload/Publications/2008/e_Road_Safety_Investments_Report.pdf
3	Cyprus	Dutch Road Safety Manuals	
4	Greece, Hungary, Italy, Norway, the Netherlands	Elvik, R., Hoye, A., Vaa, T. & Sorensen, M. (2009). The Handbook of Road Safety Measures. Emerald Group Publishing Ltd.	http://books.google.gr/books?id=JuTAZmIseeAC&printsec=frontcover&dq=The+Handbook+of+Road+Safety+Measures&hl=el&sa=X&ei=XnlrU-XBDMTNygPK44LgAg&ved=0CDEQ6AEwAA#v=onepage&q=The%20Handbook%20of%20Road%20Safety%20Measures&f=false

no	Country	Title	Link (if available)
5	Iceland	Erke, A., Elvik, R. (2006). Road Safety Measures: A Catalogue of Estimated Effects.TØI-report 851/2006, Norway	https://www.toi.no/getfile.php/Publikasjoner/T%C3%98I%20rapporter/2006/851-2006/851-2006-summary.pdf
6	USA	FHWA (2010). Highway Safety Improvement Program (HSIP) Manual. Report no. FHWA-SA-09-029. Herbel, S., Laing, L., McGovern, C.	http://safety.fhwa.dot.gov/hsip/resources/fhwasa09029/fhwasa09029.pdf
7	USA	FHWA (2012): Integrating the HSM into the Project Development Process, Report no. FHWA-SA-11-50. Van Schalkwyk, I., Wemple, E.A., Neuman, T.R.	http://safety.fhwa.dot.gov/hsm/hsm_integration/hsm_integration.pdf
8	Italy	FHWA: Crash Modification Factors Clearinghouse	http://www.cmfclearinghouse.org/index.cfm
9	USA	FHWA: Crash Modification Factors in Practice	http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/
10	Slovenia	HEATCO D5 recommendations for road safety	
11	Switzerland	Internal documents (unpublished)	
12	Greece	OECD-ITF (2012). Sharing Road Safety: Developing an International Framework for Crash Modification Functions. OECD Publishing.	http://www.internationaltransportforum.org/Pub/pdf/12Sharing.pdf
13	Belgium	Reports from an independent group of experts	
14	Cyprus	UK Manual for Roads and Bridges	
15	Cyprus	UK/DfT Standards and Manuals	
16	Germany	Various studies such as: 1.Safety effects of milled shoulder rumble strips along motorways. 2. Possibilities of faster realization and prioritization of structural measures to improve road safety at black spots. 3. Quantification of road safety effects of different construction, design and operational forms on rural roads. 4. Evaluation of Bypass Roads from Road Safety Point of View. 5. AOSI – Improvement of traffic safety on German single carriageway two-lane roads. 6. Evaluation model for traffic safety on roads.	http://www.bast.de/DE/Publikationen/Archiv/Infos/infos-node.html;jsessionid=32E0B7A58FEBFD89CC1EBF0B33BE9C18.live2051 & http://www.bast.de/DE/FB-V/Publikationen/Berichte/Berichte_node.html
17	Spain	1. State of the Practice for Cost-Effectivenness Analysis (Cba) and Resource Allocation (PIARC , 2012). 2. Procedimiento de estudio, diseño y gestión de medidas de seguridad vial en las infraestrcuturas (Pardillo, J.M., 2004). 3. Evaluacion Economica de Proyectos De Transporte Manual (2010)	

3.2.2 Information on CMF and road safety measures assessment

In the following figures, the elements/criteria considered by NRAs and other organisations when selecting a CMF or road safety measure are presented. Figure 3.6 summarizes criteria related to the applicability of the CMF/measure assessment (i.e. whether it is relevant and can be safely applied to address the examined problem), whereas Figure 3.7 presents criteria related to the quality and reliability of the CMF, according to its development characteristics (date range, country, sample size, statistical methodology etc.).

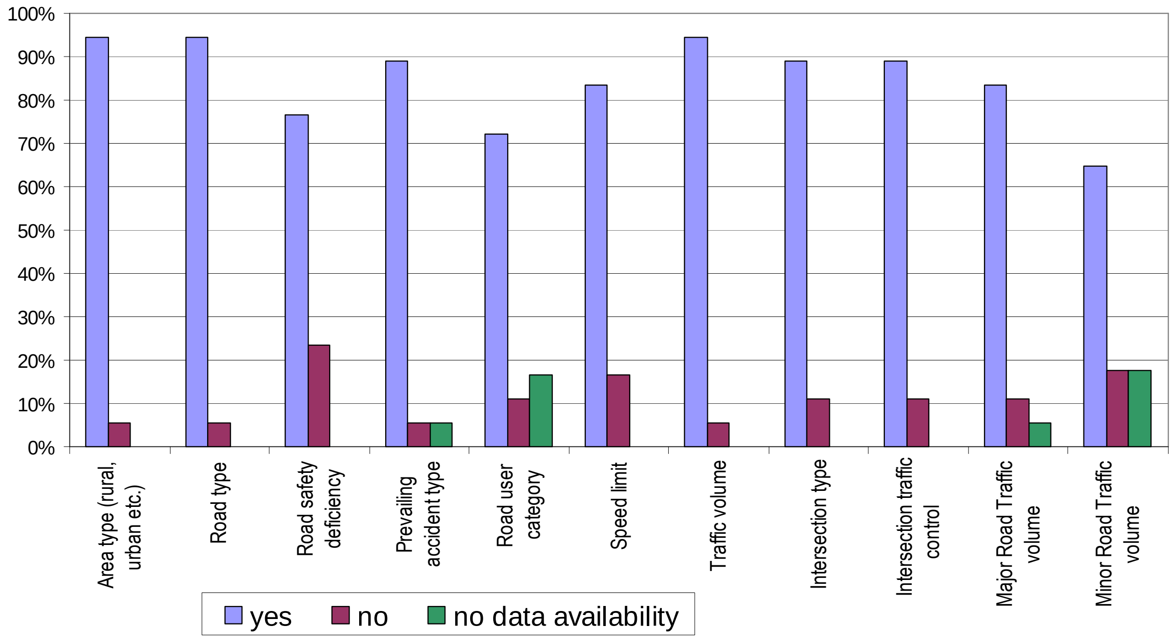


Figure 3.6: *Elements / criteria considered by NRAs and other organizations when selecting a CMF or road safety measure, related to the CMF's applicability.*

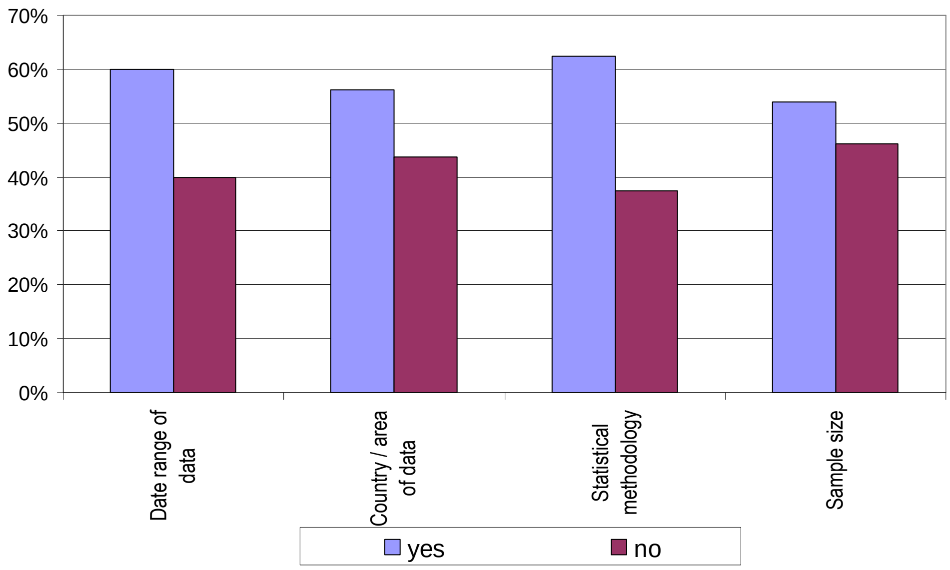


Figure 3.7: *Elements / criteria considered by NRAs and other organizations when selecting a CMF or road safety measure, related to the CMF's development characteristics.*

From the answers in the questionnaire survey, as depicted in Figures 3.6 and 3.7, it seems that most of the examined criteria are of similar importance to NRAs when selecting CMFs for application. Even in the cases of "*road safety deficiency*" or "*minor road traffic volume*" criteria, which exhibit the lowest percentages, more than 60% of NRAs or other organisations answered that they consider them when selecting CMFs. Therefore, the examination and inclusion of such information in the PRACT CMF repository should certainly be considered, depending on data availability.

It should also be noted that all of the NRAs and other institutions responded that they would consider useful a CMF reliability rating, based on its development data, methodology and sample size.

3.2.3 Summary of experience on road safety measures / CMFs

The experience of NRAs and other institutions on road safety measures and CMFs, according to the questionnaire responses, is summarised in the following tables, for motorways (Table 3.2) and two-way two-lane rural roads (Table 3.3). The tables present the qualitative estimation (high / low) of:

- the **need** to implement the road safety measure in the country's road network;
- the **availability** of assessment of measure / CMF;
- the **transferability** of safety effect (i.e. if the measure is assessed in a different location, will the safety effect be similar and therefore transferable to the examined country?).

Table 3.2: *Experience on road safety measures / CMFs for motorways and divided freeways.*

MOTORWAYS & DIVIDED FREEWAYS (without at grade intersections)	NEED		AVAILABILITY		TRANSFERABILITY	
Countermeasure - CMF	HIGH	LOW	HIGH	LOW	HIGH	LOW
Realignment (of road segments)	18.8%	81.3%	26.7%	73.3%	54.5%	45.5%
Rectangular rapid flashing beacons	21.4%	78.6%	7.1%	92.9%	45.5%	54.5%
Dynamic feedback speed signs	33.3%	66.7%	40.0%	60.0%	63.6%	36.4%
Landscaping and vegetation	35.3%	64.7%	14.3%	85.7%	63.6%	36.4%
Audible road markings	47.1%	52.9%	35.7%	64.3%	81.8%	18.2%
Sight distance and sight obstructions	61.1%	38.9%	21.4%	78.6%	63.6%	36.4%
Animals and wildlife related safety treatments	25.0%	75.0%	15.4%	84.6%	30.0%	70.0%
Advanced warning devices/signals/beacons	62.5%	37.5%	26.7%	73.3%	72.7%	27.3%
High friction treatments (including anti-skid/slip)	73.3%	26.7%	42.9%	57.1%	63.6%	36.4%
Skid resistance (in general)	64.7%	35.3%	40.0%	60.0%	63.6%	36.4%
Effects of Friction on Motorcycle Crashes	21.4%	78.6%	15.4%	84.6%	36.4%	63.6%
Variable message signs	58.8%	41.2%	43.8%	56.3%	63.6%	36.4%
Roadside features						
presence of a barrier	66.7%	33.3%	50.0%	50.0%	75.0%	25.0%
barrier class	42.9%	57.1%	23.1%	76.9%	72.7%	27.3%
use of passively safe structures (tested according to EN 12767)	58.8%	41.2%	25.0%	75.0%	58.3%	41.7%
embankment slope	35.3%	64.7%	14.3%	85.7%	45.5%	54.5%
replacement of barriers terminals with crashworthy terminals	56.3%	43.8%	28.6%	71.4%	66.7%	33.3%
crash cushions	61.1%	38.9%	43.8%	56.3%	76.9%	23.1%
motorcycle protection devices	53.3%	46.7%	21.4%	78.6%	54.5%	45.5%
clear zone width	75.0%	25.0%	26.7%	73.3%	50.0%	50.0%
Workzones	86.7%	13.3%	35.7%	64.3%	50.0%	50.0%
Number of lanes	61.5%	38.5%	61.5%	38.5%	60.0%	40.0%
Curvature	66.7%	33.3%	42.9%	57.1%	63.6%	36.4%
Superelevation (cross slope)	46.7%	53.3%	8.3%	91.7%	70.0%	30.0%
Lane width	50.0%	50.0%	38.5%	61.5%	60.0%	40.0%
Shoulder Width	50.0%	50.0%	38.5%	61.5%	60.0%	40.0%
Median Width	57.1%	42.9%	30.8%	69.2%	60.0%	40.0%
Effect of traffic (volume/capacity - % trucks & buses)	68.8%	31.3%	21.4%	78.6%	40.0%	60.0%
Effect of ramp entrance/exit (distance to the analysed section)	53.3%	46.7%	23.1%	76.9%	45.5%	54.5%
Longitudinal grade	28.6%	71.4%	30.8%	69.2%	50.0%	50.0%
Rumble strips	58.8%	41.2%	37.5%	62.5%	75.0%	25.0%
Automated speed enforcement (section or average)	64.7%	35.3%	43.8%	56.3%	66.7%	33.3%
Lighting	38.9%	61.1%	37.5%	62.5%	72.7%	27.3%

Table 3.3: *Experience on road safety measures / CMFs for two-way two-lane rural roads.*

TWO-LANE, TWO-WAY RURAL ROADS	NEED		AVAILABILITY		TRANSFERABILITY	
Countermeasure - CMF	HIGH	LOW	HIGH	LOW	HIGH	LOW
Realignment (of road segments)	66.7%	33.3%	35.7%	64.3%	66.7%	33.3%
Kerb extensions (also called bulb-outs or bump-outs)	26.7%	73.3%	18.2%	81.8%	70.0%	30.0%
Rectangular rapid flashing beacons	28.6%	71.4%	27.3%	72.7%	50.0%	50.0%
Dynamic feedback speed sign	53.3%	46.7%	38.5%	61.5%	72.7%	27.3%
Landscaping and vegetation	43.8%	56.3%	9.1%	90.9%	50.0%	50.0%
Audible road markings	68.8%	31.3%	33.3%	66.7%	72.7%	27.3%
Bicycle treatments						
Bicycle lanes	40.0%	60.0%	21.4%	78.6%	27.3%	72.7%
Bicycle boxes	14.3%	85.7%	0.0%	100.0%	30.0%	70.0%
Bicycle loops	15.4%	84.6%	0.0%	100.0%	30.0%	70.0%
Effect of rumble strips on bicycles	26.7%	73.3%	0.0%	100.0%	30.0%	70.0%
Sight distance and sight obstructions	73.3%	26.7%	35.7%	64.3%	50.0%	50.0%
Animals and wildlife related safety treatments	35.3%	64.7%	16.7%	83.3%	36.4%	63.6%
Advanced warning devices/signals/beacons	60.0%	40.0%	23.1%	76.9%	45.5%	54.5%
High friction treatments (include anti-skid/slip)	71.4%	28.6%	36.4%	63.6%	60.0%	40.0%
Friction (in general)	61.5%	38.5%	20.0%	80.0%	55.6%	44.4%
Effects of Friction on Motorcycle Crashes	40.0%	60.0%	20.0%	80.0%	30.0%	70.0%
Rail crossings at-grade	33.3%	66.7%	33.3%	66.7%	50.0%	50.0%
Raised islands and pedestrian refuge islands	53.3%	46.7%	20.0%	80.0%	55.6%	44.4%
Sharrows (bicycle shared lane markings on travelled lanes)	28.6%	71.4%	9.1%	90.9%	20.0%	80.0%
Variable message signs	56.3%	43.8%	14.3%	85.7%	63.6%	36.4%
Roadside features						
presence of a barrier	81.3%	18.8%	35.7%	64.3%	66.7%	33.3%
barrier class	61.5%	38.5%	18.2%	81.8%	60.0%	40.0%
use of passively safe structures (tested according to EN 12767)	73.3%	26.7%	30.8%	69.2%	66.7%	33.3%
embankment slope	52.9%	47.1%	30.8%	69.2%	50.0%	50.0%
replacement of barriers terminals with crashworthy terminals	64.7%	35.3%	15.4%	84.6%	50.0%	50.0%
crash cushions	41.2%	58.8%	9.1%	90.9%	50.0%	50.0%
motorcycle protection devices	46.7%	53.3%	0.0%	100.0%	45.5%	54.5%
Workzones	76.9%	23.1%	18.2%	81.8%	55.6%	44.4%
Curvature	71.4%	28.6%	33.3%	66.7%	50.0%	50.0%
Superelevation (cross slope)	46.7%	53.3%	10.0%	90.0%	44.4%	55.6%
Lane width	66.7%	33.3%	30.8%	69.2%	54.5%	45.5%
Shoulder Width	78.6%	21.4%	33.3%	66.7%	50.0%	50.0%
Shoulder Type (paved/unpaved)	80.0%	20.0%	30.8%	69.2%	50.0%	50.0%
Effect of traffic (volume/capacity - % trucks & buses)	71.4%	28.6%	16.7%	83.3%	30.0%	70.0%
Longitudinal grade	60.0%	40.0%	25.0%	75.0%	54.5%	45.5%
Rumble strips	70.6%	29.4%	30.8%	69.2%	58.3%	41.7%
Automated speed enforcement (section or average)	58.8%	41.2%	30.8%	69.2%	66.7%	33.3%
Driveway density (frequency of accesses)	64.7%	35.3%	30.8%	69.2%	58.3%	41.7%
Passing Lanes (overtaking lanes)	62.5%	37.5%	41.7%	58.3%	70.0%	30.0%
Two-way left turn lanes (central lane used dedicated for left turns)	40.0%	60.0%	36.4%	63.6%	60.0%	40.0%
Segment Lighting	57.1%	42.9%	41.7%	58.3%	54.5%	45.5%
Intesection skew angle	46.7%	53.3%	25.0%	75.0%	50.0%	50.0%
Intersection Left-turn lanes	73.3%	26.7%	40.0%	60.0%	66.7%	33.3%
Intersection Righ-turn lanes	57.1%	42.9%	38.5%	61.5%	60.0%	40.0%
Intersection Lighting	66.7%	33.3%	26.7%	73.3%	54.5%	45.5%
Signal timing (including optimizing and re-timing intervals)	46.7%	53.3%	30.8%	69.2%	40.0%	60.0%
Roundabouts	75.0%	25.0%	60.0%	40.0%	63.6%	36.4%

***Table 3.3** (continued): Experience on road safety measures / CMFs for two-way two-lane rural roads.*

TWO-LANE, TWO-WAY RURAL ROADS	NEED		AVAILABILITY		TRANSFERABILITY	
Countermeasure - CMF	HIGH	LOW	HIGH	LOW	HIGH	LOW
J-turns/restricted crossing u-turn intersections	28.6%	71.4%	25.0%	75.0%	50.0%	50.0%
Countdown signals or signs	8.3%	91.7%	9.1%	90.9%	11.1%	88.9%
Right-in, right-out designs (channelization to prevent left turns)	42.9%	57.1%	0.0%	100.0%	40.0%	60.0%

According to the questionnaire survey, the countermeasures / CMFs presenting the highest **need** in motorways and divided freeways are “workzones” (86.7%), “roadside features: clear zone width” (75.0%), “high friction treatments” (73.3%) and “effect of traffic - volume/capacity - % trucks & buses" (68.8%), whereas the lowest need is exhibited by “realignment of road segments” (18.8%), “rectangular rapid flashing beacons” (21.4%), “effects of friction on motorcycle crashes” (21.4%) and animals and wildlife related safety treatments (25.0%).

In two-lane, two way rural roads, the highest need is exhibited by “roadside features: presence of a barrier” (81.3%), “shoulder type - paved/unpaved” (80.0%), “shoulder width” (78.6%) and workzones (76.9%), whereas the lowest by “countdown signals or signs” (8.3%), and several bicycle treatments: “bicycle boxes” (14.3%), “bicycle loops” (15.4%) and “effect of rumble strips on bicycles” (26.7%).

As far as **availability** of a CMF or countermeasure assessment is concerned, in motorways and divided freeways the highest availability is exhibited by “number of lanes” (61.5%), “roadside features: presence of a barrier” (50.0%), “variable message signs” (43.8%), “roadside features: crash cushions” and “automated speed enforcement”, both at 43.8%. The lowest by “rectangular rapid flashing beacons” (7.1%), “superelevation” (8.3%), “landscaping and vegetation” (14.3%) and “roadside features: embankment slope”, also at 14.3%.

In two-lane, two way rural roads, the highest availability is exhibited by “roundabouts” (60.0%), “passing lanes” (41.7%), “segment lighting” (41.7%) and “intersection left turn lanes” (40.0%), whereas the lowest by “roadside features: motorcycle protection devices”, “right-in, right-out designs” and several bicycle treatments: “bicycle boxes”, “bicycle loops” and “effect of rumble strips on bicycles”, all at 0%.

Finally, regarding the **transferability** of countermeasures / CMFs, according to the questionnaire responses, in motorways and divided freeways, the highest transferability is exhibited by "audible road markings" (81.8%), "crash cushions" (76.9%), "presence of barriers" (75.0%) and rumble strips (75.0%), whereas the lowest by "animals and wildlife related safety treatments" (30.0%), "effects of friction on motorcycle crashes" (36.4), "effect of traffic - volume/capacity - % trucks & buses" (40.0%) and "rectangular rapid flashing beacons", “embankment slope” and “effect of ramp entrance/exit” all at 45.5%.

In two-lane, two way rural roads, the highest transferability is exhibited by “dynamic feedback speed signs” (72.7%), “audible road markings” (72.7%), “passing lanes” (70.0%) and “kerb extensions” (70.0%). The lowest transferability is exhibited by "countdown signals or signs" (11.0%), "sharrows (bicycle shared lane markings on travelled lanes)" (20.0%) and “bicycle lanes” (27.3%).

The data included in the above tables, along with additional information from the review of pertinent literature, will be used in the next steps of the PRACT project to identify measures that combine high need for implementation with low CMF availability. Such measures present increased research interest and further research should focus on providing reliable relevant CMFs.

3.3 Information regarding data sources

For safety evaluation of different design elements in road networks several information about road design, road operation and traffic related parameters as well as comprehensive accident information are necessary. All these data are an essential basis for accident surveys and also for accident prediction models. The questionnaire part on potential data sources tried to identify the availability of different road related data sources and their usage for road safety assessment and also the general availability of accident information.

A general differentiation was made between the road categories of Motorways and Freeways (generally dual carriageway roads) and two-lane two-way rural roads. The results of the 23 questionnaire responses and respective descriptive statistics on the potential data sources are presented in the following chapter.

3.3.1 Situation on road design data

The relevant information on road design are data about horizontal curvature (e.g. curve radii, element length), vertical curvature (gradient, curve radii, element length), road width and number of lanes as well as the lateral road design respectively the roadside environment like sight obstacles and planting. The data situation for all those elements – especially data availability and data need for safety assessment – is summarised in the following figure.

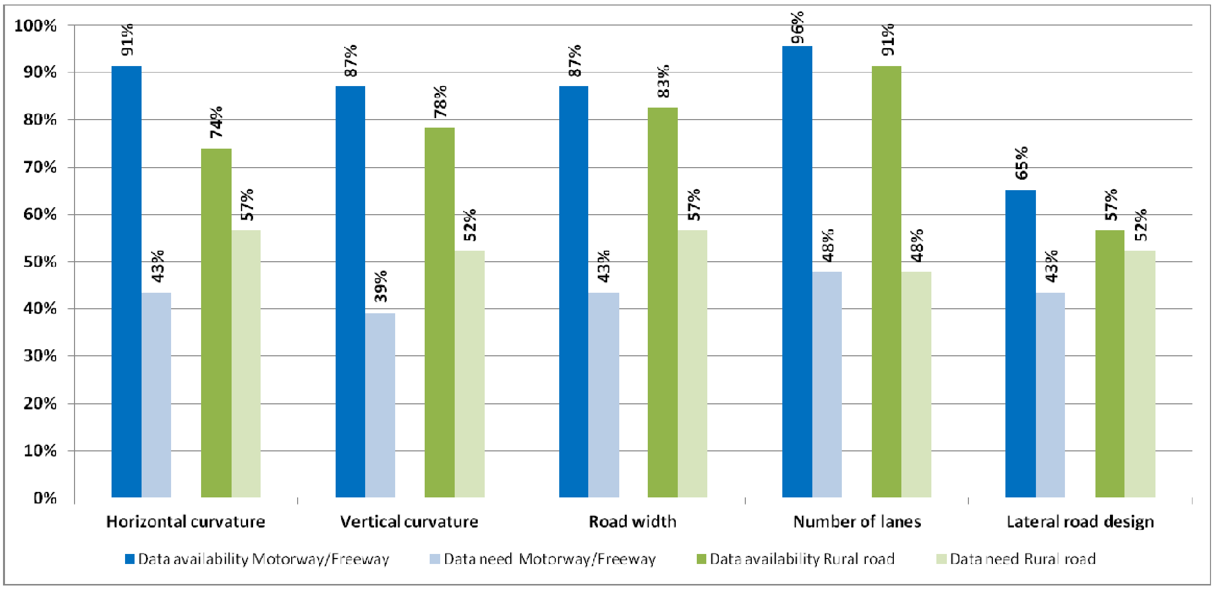


Figure 3.8: *Availability and need of road design data for safety assessment on different road classes.*

In Figure 3.8 there are two general tendencies. Firstly there are obvious differences between Motorways/Freeways and rural roads with a weakening data availability on rural roads because of a lower traffic importance in the road network than higher ranked Motorways or Freeways. Secondly the differentiation between general data availability and data need for assessment of road safety measures has to be discussed. In general, there are more data available than needed for safety evaluation (i.e. data is available in the road administration but is not used in appraisal of road safety). So it can be assumed the road design data are mainly needed for other purposes than for safety assessment.

The greatest amount of information is available for the number of lanes in the road network (96 percent). If more detailed information is needed – like for horizontal and vertical curvature as well as road width – there is a recognisable decrease of data availability, because data deployment requires costly elicitation and implementation in databases. The lowest data availability rate exists for lateral road design (65 percent), because this information is not directly connected to the road elements. The tendencies for data availability between the different design aspects and Motorways/Freeways compared to rural roads are similar.

After data availability and data need some more points of data sources have to be considered. The information for road design data are often gathered by data collections on the road site (70 percent of answers). This is often used for older existing roads. In addition there is the possibility to implement design elements of recently designed roads in the databases (52 percent of answers). The general progress of computer applications simplifies the data management for new roads without additional road inspections. For older roads subsequent data surveys are costly and are rarely performed. It can be highlighted that 43 percent of the responders use both methods, 35 percent just one method and for 22 percent the data sources of road databases are not defined.

In the majority of cases (83 percent) the road design parameters are linked with the road network chainage. 13 percent responded negatively to this question and 4 percent did not answer. In some cases the linkage to road chainage is just available for some road types and also some design elements.

65 percent of responders have skid resistance pavement ratings available, 30 percent don’t have such information and the remaining responders did not answer. The time interval for those measurements varies between 1 and 5 years as a maximum and is partly limited to some road types or special network sections.

For 91 percent the road design data is stored in a databank. Further forms of storage are GIS applications, which are used by 65 percent. 48 percent have additional visualisations. It can be highlighted that 43 percent use all three forms of data storage. 22 percent use two forms, which are GIS applications and the often linked respective databases. 30 percent just use one special form which is in general the database. In one case there is no systematic storage of road design data.

The road design information are administrated by road authorities respectively road administrations or commissioned managing companies. In some cases the data management is scattered among the whole country (e.g. for rural roads in Germany the federal states or in Switzerland the cantons). In some cases there are also differences in responsibilities between different road classes (Motorway/Freeway versus rural roads). As a general rule the data are not publicly available (2/3 of responders). Some administrations have some parts of data for public access, just a minority allows general public access. But basically there is the possibility of requesting the data for research purposes and professional usage for accident analysis.

3.3.2 Situation on road operation data

Beside road design data further information about road operation are relevant for road behaviour and accident occurrence and therefore for potential safety assessment of roads. That´s why the information about availability and need of posted speed limits, road markings, other road signage, the type of junction control (e.g. priority control, stop control, signalled control) as well as data about the signalling in the case of signalled junctions are sought within the PRACT questionnaires. An overview about the data situation of those road elements is given in the following figure.

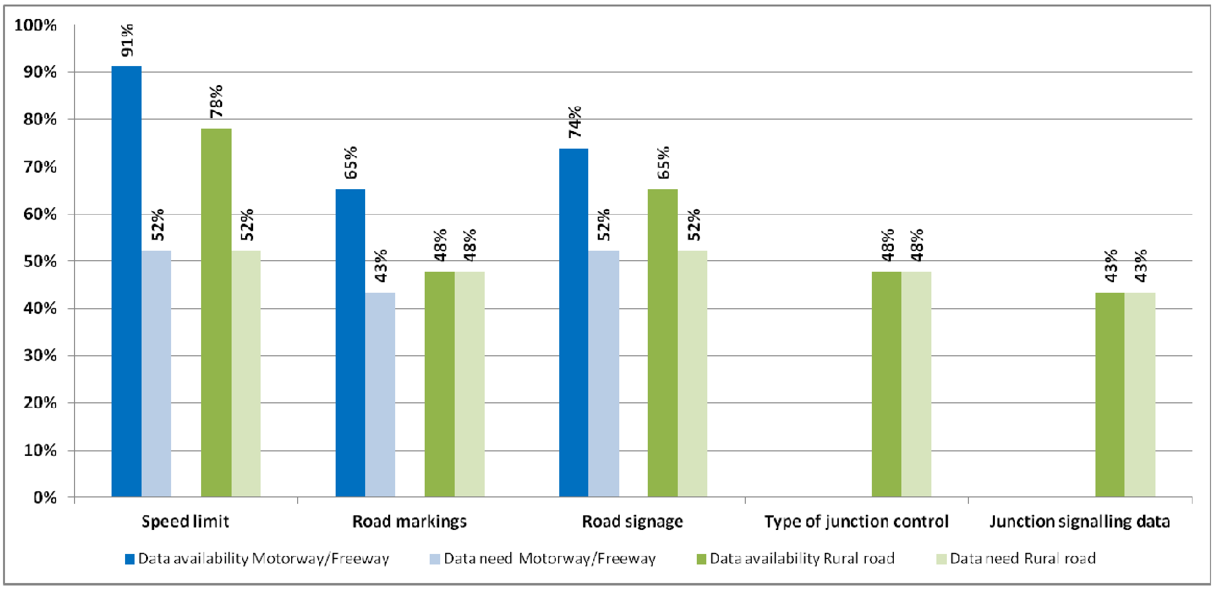


Figure 3.9: *Availability and need of road operation data for safety assessment on different road classes.*

It can be seen that information about the posted speed limits on road sections is very common on Motorways and Freeways. Up to 91 percent of the responders have access to those data. Other road signage information (e.g. no overtaking) are available for about 74 percent on those roads, information about road markings is more rare (65 percent). When the traffic importance decreases (rural roads instead of Motorways/Freeways) the data availability decreases too.

Generally it can be summarized that for road operation data the same tendencies already noted for road design data can be found. There is an obvious difference between data availability on Motorways/Freeways and on two-lane two-way rural roads and generally a difference between data availability and data need for safety assessment. In comparison between road design and operation data, it is surprising that road operation data is less common than road design data, whilst the information about signage and markings is relatively easy to obtain. Moreover the need of this information is lower because design deficiencies of roads are more strongly correlated to road safety than road operation data. Nevertheless this information has a not negligible impact on traffic behaviour and accident occurrence (first of all the posted speed limits).

In the case of road junctions, the types of junction control and signaling data are just relevant for rural roads, because priority control or signalled control are not typical junction types for higher classified Motorways or Freeways. For rural roads it is noticeable that the considered junction information is not very common. Generally less than 50 percent enter such data in databases and use them for safety assessment, whereby there is stronger data need than data availability.

Regarding the data actuality (updating rate of databases) different answers were possible. If the responders selected 'every two years' for scheduled update and 'at every change' for general procedure, then just the highest update rate is relevant for this evaluation. As a result 48 percent of responders update those road operation databases at every change. 13 percent have annually updates and 17 percent realise updates every three years or in a longer chronology. 22 percent did not answer this question.

As a general rule road operation data are not publicly available. Just 9 percent have open access, 65 percent aren’t public and 26 percent have partly some selected information for public. Generally there is the possibility for data transfer for research purposes, on request.

3.3.3 Situation on traffic related data

The most relevant information for accident prediction models are data related to traffic volume on the road sections. Especially the annual average daily traffic (AADT) is a very high correlated variable for safety assessment. Moreover the percentage of heavy vehicle traffic can be an influencing variable for traffic safety. The data situation for those traffic related boundary conditions is depicted in the following figure.

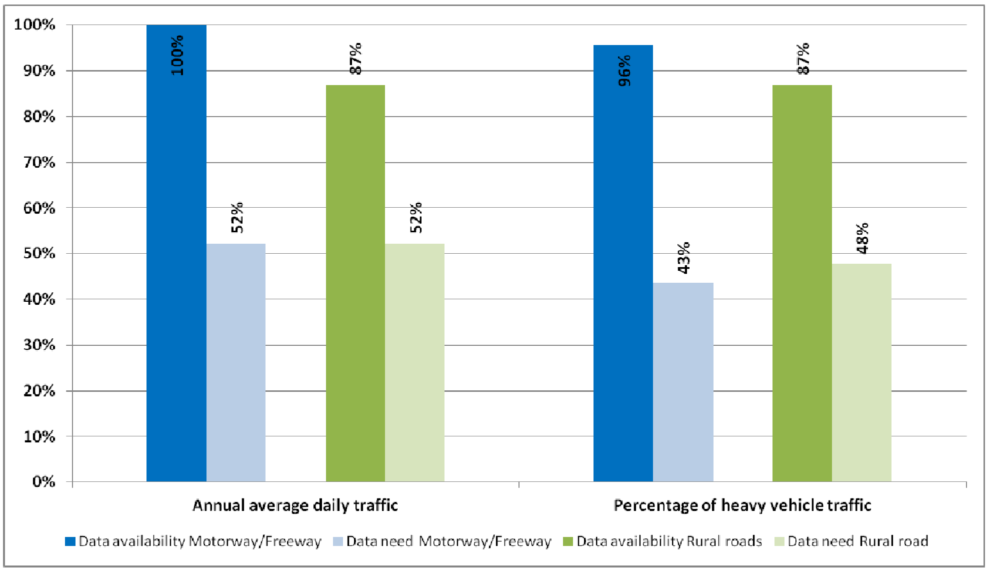


Figure 3.10: *Availability and need of traffic related data for safety assessment on different road classes.*

Regarding the Motorways and Freeways the general data availability for AADT is at about 100 percent (excepting partial availability gaps in the road network or some states). For the percentage of heavy vehicle traffic the result is 96 percent. Considering the rural road network the data availability reach 87 percent for both traffic parameters, there the varying of data availability increases.

It should be noted that the use of traffic data in safety assessment is currently limited to 52 percent of the respondents and this is likely due to a lack of quantitative APM models allowing to use the traffic data in expected crash estimations.

For the boundary value for differentiation between normal and heavy vehicle traffic various strategies are noticeable within the questionnaire responses. More than 60 percent of responders use consistently a boundary value of vehicle mass of more than 3.5 tons for differentiation of heavy vehicle traffic. All others use varying forms of classification. For example Hungary use a deviant declaration of vehicle mass of more than 7.5 tons. For other examples the vehicle length is decisive, especially Norway (more than 5.5 meters) or the Netherlands with two respective vehicle classes (5.6 to 12.2 meters and more than 12.2 meters). In Australia heavy vehicles are defined just by the use of the number of axles. So any vehicle with more than two axles or with dual tires on the rear axle counts as a heavy vehicle.

In contrast to road design and road operation data the information about traffic related parameters on roads are often publicly available. 57 percent of the responders have an open access and further 13 percent just a partially access to such traffic related information. This is likely a result of the general developments in traffic management systems and closely connected to this the provision of public information for road users. So there will be good data coverage especially on higher classified roads (which have the highest traffic volumes) for those informational purposes, which also can be used for safety evaluation and accident prediction modelling.

3.3.4 Situation on accident and user behaviour data

Finally the most important information for all kinds of accident surveys are extensive accident databases. This chapter is subdivided in two parts, firstly information about some basic accident data and secondly some related user behaviour data which may have also an impact on accident occurrence and accident severity.

Basis accident and accident participant data

The availability and need of basic accident data like accident types, accident causes, accident severity (e.g. accidents with killed, serious/slight injured persons) and some additional outside accident influences (e.g. weather, driving and lighting conditions) are shown in Figure 3.11.

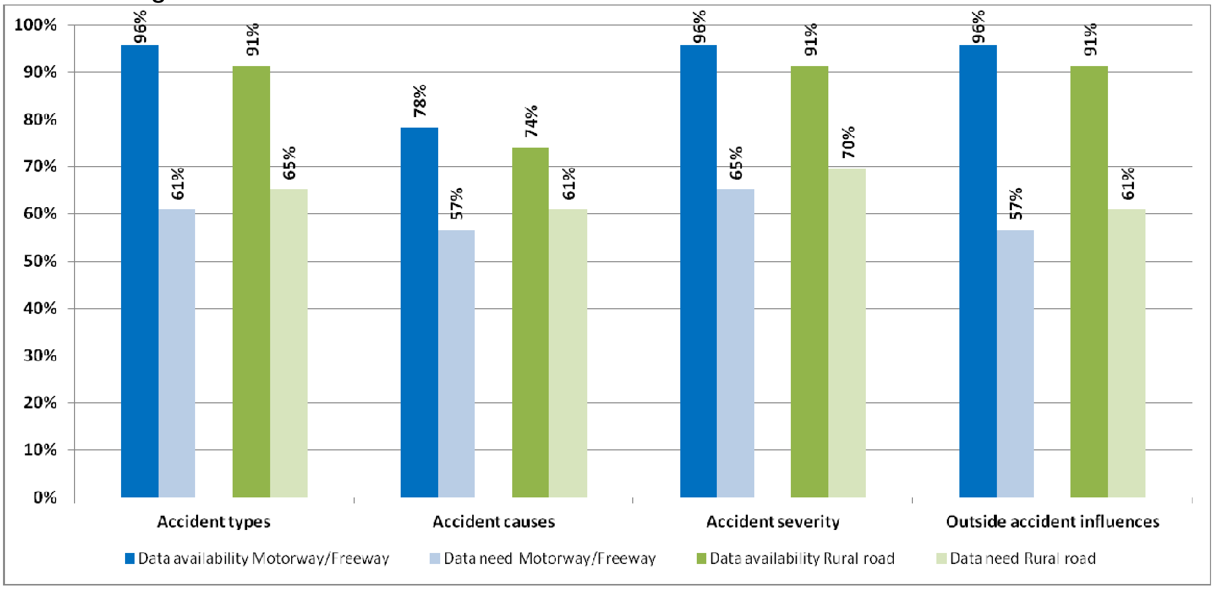


Figure 3.11: *Availability and need of basic accident data for safety assessment on different road classes.*

Generally there is a very high level of data availability for accident types, accident severity and additional outside accident influences for the considered road categories (Motorways/Freeways and two-lane two-way rural roads). So these accident elements can be assumed as the elementary accident data. It is notable that the availability rate of prevailing accident cause data is somewhat lower, so characterisation of accidents in this way is less common within the respondent countries.

As with the coherences of road related parameters, there is an obvious rate drop between general data availability and data use for road safety assessment for the considered accident data, therefore, the data need is generally in a similar magnitude for accidents and road data. In comparison to road data, where some road information may be used for the development of different CMFs in certain countries and not in others the lack in the use of accident differentiation for accident assessment is somewhat surprising.

Information about accident participants, like accident perpetrator, number of casualties (fatalities, seriously or slightly injured persons) and further information about accident participants (e.g. age, sex, occupants) or the type of road user category (e.g. car, pedestrian, bicyclist) are depicted in Figure 3.12.

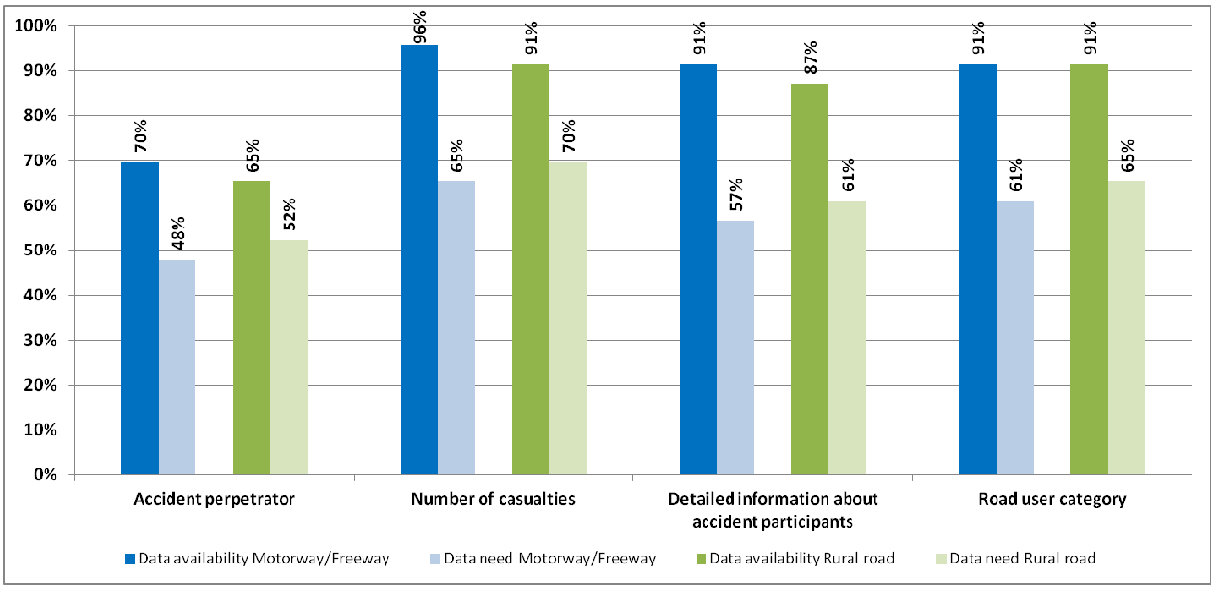


Figure 3.12: *Availability and need of data about accident participants for safety assessment on different road classes.*

For the accident participant data the number of casualties and other detailed information of the persons involved is also available at a high level within the polled institutions. The determination of an accident perpetrator has an exceptional position within the accident participant information, but generally there are strong coherences between accident causes and the determination of an accident perpetrator so the similarities are hardly surprising.

For historic aspects of accident databases the following knowledge could be gathered through the questionnaire. Approximately 2/3 of the responders have access to digital accident databases for more than the last 15 years. But generally accident analyses were performed for a limited number of the past years (e.g. the last 3 or 5 years), so that accident chronology for several decades is insignificant for safety assessment of road sections (because of potential changes of road design or road operation). Nevertheless it can be noted that digital accident databases are available over all responders for several years. In all cases there is a delay between the accident data being recorded and being available in the databases that varies country to country and is between 6 months and 3 years.

For the localisation of accidents within the road network there are, in general, two options, firstly road segment numbering together with the road chainage and secondly georeferencing. 35 percent of the responders use only road section numbering with an accident respective chainage. However, there is a suggestion that such information is not always correctly recorded (whereby there are also local differences). 17 percent locate accidents just with geo coordinates. The remaining 48 percent use both methods of accident localisation. Therefore, the road segment numbers are often derived from the collected geo coordinates. Finally it can be assumed that the data quality of accident localisation increases with the use of georeferencing (e.g. GPS).

Regarding detailed additional accident data there are possibilities of accident descriptions, accident sketches or in depth accident studies (including reconstruction or photogrammetric surveys). Thereby a short text description of the accident is the most common form for additional information, 78 percent of the responders make use of accident descriptions. The description of how the accident occurred is only available in the police reports. In some cases accident descriptions are not included in databases. Further detailed accident data like accident sketches are often not mandatory, so that a reduced number of responders (61 percent) use those tools. Accident diagrams are often available for accident black spots. The most costly accident data is information from in-depth accident studies. Such surveys are generally limited to the most serious accidents or small samples of predefined accident characteristics. But about 50 percent of the responders have the option to access these limited data sets.

The use of different additional accident information is often limited to chosen accident categories. In general the effort increases with increasing accident severity (most effort can be expected for fatal accidents). 30 percent of the responders use all three forms of additional accident tools. Nevertheless a minority do not have access to any of this additional accident information.

As a general rule, accident data is gathered by the police. After data processing the information is forwarded to the national statistical offices but also provided to the road authorities for black spot management. In some cases the police provide accident data to the road authorities of provinces or regions and they provide the aggregated accident information to the federal statistical offices. The sequence of collaboration of these three institutions can vary in different countries.

The analysis of accident information is predominantly pertinent to the road authorities (black spot management and identifying accident countermeasures). For preparation of annual accident statistics the statistical offices are mainly responsible, in very few cases the road authorities. Generally the police are also involved in accident analyses because they are responsible for executive measures (e.g. speed control and inflicting regulatory offences and motoring fines). As an example in Germany the local accident commission for black spot management is a committee out of police, road construction authority and road traffic authority. Further accident analysis can be also be delegated from the road authorities to local or regional road safety observatories, municipalities (which prepare partly own road safety plans) and also research institutes (universities), engineering agencies or other road safety stakeholders.

As a general rule detailed accident information or generally accident databases are not publicly available because of the necessary strict compliance to data protection aspects. So basically the administrators of accident databases are not allowed to release any details about single, identifiable accidents (protection of confidential information). Detailed accident data can be requested just for accident analysis for research purposes by known and delegated institutions. Nevertheless some information are publicly available, like summaries of accident occurrence in the accident annual reports (e.g. limited publications through aggregated data in statistical yearbooks) or published results of the research. Moreover some road authorities also publish maps showing accident frequencies or accident rates and casualty frequencies as well as interactive tables with limited and well-chosen details of road accidents.

<u>Additional data about road user behaviour</u>

This last question on data availability is about additional accident information, which is focussed on road user behaviour/misbehaviour and may affect accident occurrence and accident severity. Such information includes details about alcohol-impaired driving, excessive speeding, seat belt use and also helmet use (e.g. for motorcyclists). This data should be generally recorded during accident investigation and so find its way into the resulting accident databases.

The questionnaire evaluation engendered doubts on the correct understanding of this last question, some comments of responders support this suspicion. For the most part answers are related to accident data but some responders answered referring to empirical surveys on a sample of sites or performed interviews and also statistics on recorded infringements. Nevertheless the results regarding user behaviour data are depicted below.

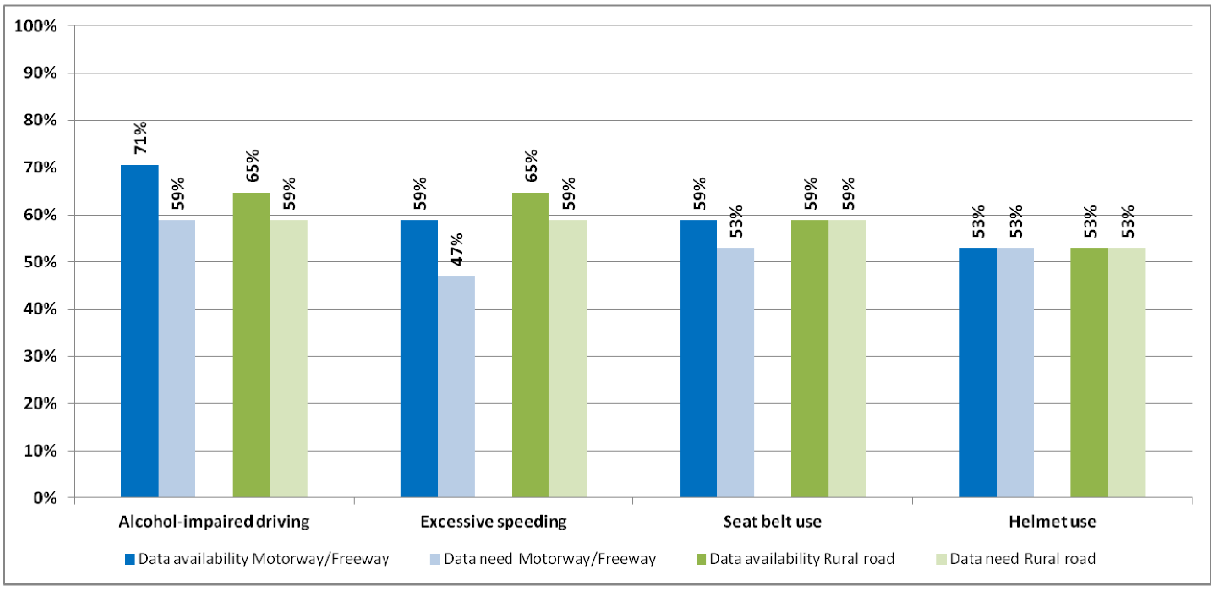


Figure 3.13: *Availability and need of data about road user behaviour/misbehaviour for safety assessment on different road classes.*

It is noticeable that there is limited data availability. Also the need for the data for safety assessment is relatively low. Conceivably, some misunderstanding of the questions intention can be seen as a reason for low data availability. In conclusion the questionnaire results on additional road user behaviour data should be treated with caution, therefore no further interpretations of the results are reasonable.

All of this information should generally be gathered during accident site inspections and therefore should be written in the police reports. This leads to better understanding of accident occurrence in the case of alcohol-impaired driving and excessive speeding as well as accident severity in the other cases.

In the case of suspected alcohol-impaired driving in an accident specific tests are usually performed for evaluating the alcohol concentration (breath or blood tests) and so the suspicious facts are clarified. The missing data availability could be attributed to the misunderstandings in questionnaire intention.

In the case of excessive speed a lack of information becomes more obvious. One reason for this could be the difficulty in ascertaining this information during the accident site inspections after the event and the legal processes involved in the aftermath of a fatal collision. In the case of the most non-fatal collisions the speed of the involved vehicles is likely based on subjective opinions as the police will be reliant on witness statements which may be unreliable or biased.

In the case of fatal collisions (and also some other severe injury accidents) the vehicle speeds at the point of impact are estimated during the collision investigation process. This would be part of the mentioned in-depth accident studies, because the accident reconstruction usually leads to more reliable speed estimations based on the vehicle and infrastructure damages.

But there is also the fact that those details forms part of the evidence for legal proceedings and it generally it is not integrated in the collision database used by road safety engineers.

So in some cases the police is reluctant to release this information even after the legal process has been completed.

Other important data, which is used for assessing road safety is for example accident costs. This monetarisation of accident consequences requires the evaluation of accident severity beside the exclusive consideration of accident quantity. Moreover relevant data on winter services, vehicle safety equipment (e.g. ABS, airbag) or finally medical/hospital data are partly involved in safety assessment.

4 Current practice in Accident Prediction Modeling

In recent years, Accident Prediction Modelling has been a very active research field and important progress has been made in all aspects of the model development process, from data collection to statistical methodologies and address of potential biases. According to relevant literature (Elvik 2011, Lord & Mannering 2010, RISMET 2011a), the following elements characterise a reliable, state-of-the-art approach to accident prediction modelling:

1. the models should be developed based on accident data samples of sufficient size, with an adequate mean number of accidents;
2. the functional form of the accident prediction model, used to describe the relationship between the dependent variable and the explanatory variables should be chosen based on an exploratory analysis;
3. the dependent variable should preferably be the number of accidents at a given level of severity. Accidents at different levels of severity should be modelled separately. If possible, different types of accidents should also be modelled separately;.
4. in order to ensure maximum between-section variation and minimum within-section variation, proper homogeneous road sections should be formed, on the basis of the model's key explanatory variables;
5. several potential biases should be addressed during the development and assessment of the model, such as potential biases due to co-linearity among explanatory variables, due to omitted variables and due to outlying data points.

Several interesting accident prediction models have been developed by various researchers, a brief overview of which is presented in paragraph 2.2 of the present report. The most comprehensive methodology seems to be the predictive method included in AASHTO Highway Safety Manual. Apart from the basic model (see paragraph 2.1.1 of the present report), the HSM Accident Prediction Model is complemented by a set of guidelines on the implementation of the methods and procedures included in the Manual (paragraphs 2.1.2 and 2.1.4), as well as a web-based database (FHWA CMF Clearinghouse) with CMF values and links to additional resources. Additionally, updates and additions to the HSM predictive method have recently been published, in order to address additional road types, such as freeways and interchange ramps (paragraph 2.1.3).

However, despite recent advances in the field of accident prediction modelling, most National Road Administrations (NRAs) and other organisations do not systematically use such methods during decision making for the implementation of road safety treatments. According to the questionnaire survey, only 30% responded that they use APMs "*always*" or "*usually*", compared to 70% that responded "*rarely*" or "*never*". If only NRAs are taken into account, the use of APMs is further reduced (26% for "*always*" or "*usually*" - 74% for "*rarely*" or "*never*"). It should also be noted that the use of APMs in decision making is more common in countries that have relevant approved guidelines or manuals, which is normally related to a more advanced road safety culture. The above information, according to the questionnaire survey, is summarised in the following table.

Table 4.1: *Use of Accident Prediction Models, of guidelines and other resources in road safety interventions decision making.*

COUNTRY	Respondent Institution	APM USE				Approved Guidelines		Use of other resources	
		always	usually	rarely	never	yes	no	always / usually	rarely / never
Australia	Academia	●				●		n/a	n/a
Austria	Road Authority			●			●	n/a	n/a
Belgium	Road Authority				●		●		●
Cyprus	Road Authority			●		●		●	
Denmark	Road Authority			●		●		n/a	n/a
Finland	Road Authority		●			●		n/a	n/a
Germany	Road Authority			●		●		●	
Greece	Academia			●			●		●
Hungary	Road Authority			●			●	n/a	n/a
Iceland	Road Authority				●		●	●	
Ireland	Road Authority		●			●			●
Italy	Academia		●			●		●	
Italy	Road Authority				●	●			●
Luxenbourg	Road Authority				●		●		●
Netherlands	Road Authority			●			●	●	
Norway	Road Authority	●				●		●	
Slovenia	Road Authority				●	●		●	
Spain	Road Authority				●		●	●	
Switzerland	Road Authority			●		●			●
USA	Road Authority		●				●	●	
UK (Wales)	Road Authority	●				●			●
UK	Highway Consultant			●		●			●
UK	Road Authority			●		●			●
	TOTAL:	13,0%	17,4%	43,5%	26,1%	60,9%	39,1%	50,0%	50,0%

n/a: no answer

Futhermore, the examination of Tables 3.2 and 3.3 (experience on road safety measures / CMFs) and Figure 3.8 (availability and need of road design data for safety assessment on different road classes) in conjunction possibly reveals further evidence regarding the different existing approaches for road safety assessment. More specifically, for certain elements of road design data there seems to be a high need - low availability for CMFs (according to Tables 3.2 and 3.3), combined with low road data need - high data availability for road safety assessment (according to Figure 3.8). This is particularly evident in the case of road width of freeways, suggesting that CMFs are needed but not available and the necessary data for evaluation (data sources) are available but not used for safety assessment. There are several possible explanations for this difference:

- It is possible that road design data are indeed available, there is an increased need for relevant CMFs, however these CMFs have not yet been developed.
- It is also possible that certain answers in the questionnaire are of limited reliability, mainly due to the limited experience of NRAs in dealing with CMFs, which is evident from the reduced percentage of positive responses ("always" or "usually") in the use of APMs in decision making.
- Especially for the questionnaire from Denmark, it should be noted that CMFs aren't used for safety assessment, because it is common to perform accident analysis (site visits, conclusions about specific site conditions and accident factors) and therefore they don't need explicit data about road width for checking the road layout against road standards. So it is possible that the relevant road design data (eg. road width) is available in databases, to be used not for the purpose of safety assessment, but possibly for other (eg. operational) procedures.

5 Data sources

Comprehensive and high quality data are fundamental requirements for road safety analysis and accident prediction modeling. Further discussion of the gathered information and comments from the national road authorities within the PRACT questionnaire is an essential part of the following chapter. Road data and accident data sources have been analysed separately, because these are usually different data sources as well as different administrating institutions (road authority versus police).

5.1 Discussion and inventory of road related data

The main problems of road design and road operational data sources are evident through the comments of the responders. To name but a few there are problems with data actuality (how current the data stored are), the variability in data availability nationwide and also some differences in the level of detail. This means that generally speaking there are no comprehensive data administrations with routine updates and also several gaps in data availability in the road network, especially on older existing roads. In some cases data are just available for recently designed roads, not existing ones, because of the additional costly data surveys. One last point is that in many cases databases are not maintained by a central authority. Thus, if a nationwide analysis is required, it is possible that several departments of different authorities must be contacted in order to gather the required data.

For traffic related data sources the situation is a little bit better, because the information is generally available for large parts of the road networks. Moreover such information is gathered by continuous traffic counting installations like inductions loops in the road surface and, in the best case, combined with an online data evaluation (real time traffic information for traffic management). If data is stored in the long term, then the possibility of historical data evaluation arises.

Another point on data sources is the general need of road data for road safety assessment. Summarizing on all considered road features (road design, operational and traffic related variables) it is notable that this detailed information is not often used for network wide accident analysis. In some cases the implementation of specific road safety measures is derived from an accident analysis, not from checking the road layout against road standards. Therefore it is preferable – but not always necessary – to know the exact parameter values. The accident analysis will always include a site visit and conclusions about accident factors and possible measures can often be drawn without knowing the exact radii and gradient. But this approach analyses road safety after the road accidents occurs (reactive approach versus a safety evaluation in a preventive way). The main advantage of design element analysis is the possibility to provide recommendations about which elements are promoting accidents, so that the authorities are able to tackle those accident prone parameters.

The following inventories are based on questionnaire responses and show general data availability in road networks. Due to the fact that the questions of the questionnaire – which are relevant for inventory – were answerable with 'yes' or 'no' (respectively 'available' or 'not available') and numerous relevant comments of the responders were noticed, a further differentiation was needed. Those comments, which generally identify limitations of data availability (e.g. general availability but no nationwide coverage, restrictions on special parameters or varying levels of detail) were defined as a separate group. So the limited data availability as an intermediate stage between the strict answers 'yes' and 'no' was marked as an separate element. Similar definitions apply for accident inventories too.

Table 5.1: *Inventory for data availability of road related data* ***(motorways/freeways).***

Road category 1: Motorways/Freeways		**Road design data**					**Road operation data**					**Traffic related data**	
Country	***Respondent institution***	Horizontal curvature information	Vertical curvature information	Road width	Number of lanes	Lateral road design	Posted speed limit	Road markings	Road signage	Junction control	Signalling data	Annual average daily traffic (AADT)	Percentage of heavy vehicle traffic
Australia	Academia												
Austria	Road authority												
Belgium	Road authority												
Cyprus	Road authority												
Denmark	Road authority												
Finland	Road authority												
Germany	Road authority												
Greece	Academia												
Hungary	State institution												
Iceland	Road authority												
Ireland	Road authority												
Italy	Academia									n/a	n/a		
Italy	Road authority												
Luxembourg	Road authority												
Netherlands	Road authority												
Norway	Road authority												
Slovenia	Road authority												
Spain	Road authority												
Switzerland	Road authority												
U.S.A.	Road authority												
UK (Wales)	Road authority												
UK	Highway consultant												
UK	Road authority												

general availability — limited availability (e.g. not nationwide or restricted on special parameters) — no availability

Table 5.2: Inventory for data availability of road related data ***(two-lane two-way rural roads).***

Road category 2: two-lane two-way rural roads		**Road design data**					**Road operation data**					**Traffic related data**	
Country	***Respondent institution***	Horizontal curvature information	Vertical curvature information	Road width	Number of lanes	Lateral road design	Posted speed limit	Road markings	Road signage	Junction control	Signalling data	Annual average daily traffic (AADT)	Percentage of heavy vehicle traffic
Australia	Academia												
Austria	Road authority												
Belgium	Road authority												
Cyprus	Road authority												
Denmark	Road authority												
Finland	Road authority												
Germany	Road authority												
Greece	Academia												
Hungary	State institution												
Iceland	Road authority												
Ireland	Road authority												
Italy	Academia												
Italy	Road authority												
Luxembourg	Road authority												
Netherlands	Road authority												
Norway	Road authority												
Slovenia	Road authority												
Spain	Road authority												
Switzerland	Road authority												
U.S.A.	Road authority												
UK (Wales)	Road authority												
UK	Highway consultant												
UK	Road authority												

general availability | limited availability (e.g. not nationwide or restricted on special parameters) | no availability

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Table 5.3: *Inventory for sources of supply of road related data.*

Sources of supply for road related data			
Country	***Respondent institution***	Motorways/Freeways	two-lane two-way rural roads
Australia	Academia	-	-
Austria	Road authority	-	-
Belgium	Road authority	Road Authority	Road Authority
Cyprus	Road authority	GIS Team, road design section	GIS Team, road design section
Denmark	Road authority	-	-
Finland	Road authority	-	-
Germany	Road authority	BASt	Federal States
Greece	Academia	Authority of the respective road (e.g. Ministry of Infrastructure)	Authority of the respective road (e.g. Ministry of Infrastructure)
Hungary	State institution	Hungarian Roads Ltd.	Hungarian Roads Ltd.
Iceland	Road authority	The Icelandic Road and Coastal Administration	The Icelandic Road and Coastal Administration
Ireland	Road authority	Road Authority (Data split between network operations and safety section)	Road Authority (Data split between network operations and safety section)
Italy	Academia	Road networks managers	Road networks managers
Italy	Road authority	Motorways Managing Companies	National Road Authority (ANAS)
Luxembourg	Road authority	Road Authority	Road Authority
Netherlands	Road authority	Rijkswaterstaat	Rijkswaterstaat (only for state roads)
Norway	Road authority	Public Road Administration	Public Road Administration
Slovenia	Road authority	Motorway Company of the Republic of Slovenia	Slovenian Roads Agency
Spain	Road authority	National Road Authority	National Road Authority
Switzerland	Road authority	ASTRA	Cantons
U.S.A.	Road authority	Administrated by each State (states provide the data to HSIS)	Administrated by each State (states provide the data to HSIS)
UK (Wales)	Road authority	Welsh Government	Welsh Government
UK	Highway consultant	Department for Transport	Department for Transport
UK	Road authority	Highway Agency for motorways	Trunk roads and local highway authorities

5.2 Discussion and inventory of accident data

The crucial problems of accident data are data quality, no gapless availability and generally very different approaches for the implementation of accident databases.

Regarding data quality, general problems with data acquisition and their further processing is quite common worldwide. In general road accident information would be compiled at the accident locations by police officers. Often there is a balancing act between improved data surveys to reach high quality databases and the main goal of rescuing persons or the reopening of the road to the general traffic to reduce congestion. So some of the considered accident characteristics are either not often or not reliably assessed, because they are often based on the brief police officers opinion on collision factors (subjective assessment). Further reasons for data gaps is the necessity to derive accident characteristics out of the surveyed data at the accident location in the aftermath of the local inspections. This often causes additional workload for the police. For example this is one of the main points for the low data availability of accident causes. The low data usage in safety assessment programmes often leads to a lack in data determination need.

Data gaps are also affecting parts of the road network (just certain road categories) as well as different states (here the levels of detail can vary throughout the country). Furthermore data gaps arise due to chosen accident categories for implementation in the accident databases. Such subsets are established by different determinations and approaches. As a general rule all accident categories should be surveyed and included in the databases but typically the data quality decreases with decreasing accident severity (no one will perform a full accident inspection because of a damaged wing mirror without other accident consequences). Generally there are different levels for those limitations. Some countries include different accident characteristics of all accident categories in their databases. Other ones ascertaining accident characteristics only for fatal accidents, further countries only for the most serious accidents (furthermore some countries don’t differentiate between serious and slight injury).

Generally the availability of historic accident databases is basically acceptable over all countries. All of them have access to accident data for several years. Some comments gave hints for the chronology development of accident databases. Generally the progressing development in computerized databases has introduced improvement in data quality and quantity. For example in Switzerland there were just basic statistics up to 1992, whereas since 1992 data with increasing quality and additional attributes are stored; since 2011 the data is of an acceptable quality. It can be assumed that similar developments affect other countries too. The Netherlands reported that all accident information is based on police reported data and that the registration rate decreased enormously after the police switched to a new IT system. So maybe the simplifications of computerized data management can introduce complications in obtaining the increasing necessary data for every accident. Now the Netherlands is trying to improve this. But there are some other historic limitations too. For example the timeframes for chronological development of accident databases, their content and data quality are varying across different areas/states. One last point is timely availability, and the further processing required in the aftermath of accident occurrence before data is released. In one case accident characteristics are only available in databases after a significant delay (about 3 years after an accident). In this given case the problem limits the effectiveness of black spot management in particular the possibility of applying timely infrastructural countermeasures, as well as general research on accident occurrence.

Finally one last point on data availability which affects all countries and every accident database is the number of unreported cases. But generally unreported accidents are thought to be extremely rare on Motorways/Freeways and rare on rural roads, because of the often serious accident severity in relatively high driven speed environments.

Regarding the surprisingly common disuse of different accident characteristics for accident differentiation in road safety assessments, it would be interesting to see how special accidents at special locations of the road network are identified and filtered out of databases in the polled countries (e.g. analyses of overtaking accidents or driving accidents without involvement of further participants). One potential reason for such disuse of accident differentiation would be that in some cases just overarching accident analysis are undertaken on different road sections. This means that where accident black spots are identified in the road network further investigations of accident occurrence are performed and countermeasures are derived just for these sections. Through the black spots analysis a more in-depth accident differentiation for the whole road network (where maybe only infrequent accidents can be found but no accident accumulations can be determined) becomes not relevant.

As for road related data, an inventory of accident data sources was considered. Due to the relatively clear responsibilities for accident data (accident recording by the police, accident collection and analysis by road authorities or statistical offices) an inventory for accident sources of supply is seen as not necessary.

Table 5.4: *Inventory of accident data availability* ***(motorways/freeways).***

Road category 1: Motorways/Freeways		Basic accident data				Data about accident participants			
Country	***Respondent institution***	Accident types	Accident causes	Accident severity	Outside accident influences	Accident perpetrator	Number of casualties	Information about acc. participants	Road user category
Australia	Academia	general	limited	general	general	general	general	general	general
Austria	Road authority	general	general	general	limited	general	general	general	general
Belgium	Road authority	limited	limited	limited	limited	limited	limited	limited	limited
Cyprus	Road authority	general	general	general	general	general	general	general	general
Denmark	Road authority	general	no	general	general	no	general	general	general
Finland	Road authority	general	no	general	general	no	general	general	general
Germany	Road authority	general	general	general	general	general	general	general	general
Greece	Academia	general	limited	general	limited	limited	general	limited	limited
Hungary	State institution	general	general	general	general	general	general	general	general
Iceland	Road authority	general	limited	general	general	limited	general	general	general
Ireland	Road authority	general	limited	limited	general	no	general	general	general
Italy	Academia	limited	limited	limited	general	limited	general	general	general
Italy	Road authority	limited	limited	limited	limited	limited	limited	limited	limited
Luxembourg	Road authority	general	general	general	general	general	general	general	no
Netherlands	Road authority	general	general	general	general	general	general	general	general
Norway	Road authority	general	no	general	general	no	general	general	general
Slovenia	Road authority	general	general	general	general	general	general	general	general
Spain	Road authority	general	general	general	general	general	general	no	general
Switzerland	Road authority	general	general	general	general	general	general	general	general
U.S.A.	Road authority	general	general	general	general	no	general	general	general
UK (Wales)	Road authority	general	general	general	general	general	general	general	general
UK	Highway consultant	general	general	general	general	general	general	general	general
UK	Road authority	general	no	general	general	no	general	general	general

general availability

no availability

limited availability (e.g. restricted on locations, accident categories or low data quality)

Table 5.5: *Inventory of accident data availability* ***(two-lane two-way rural roads).***

Road category 2: two-lane two-way rural roads		**Basic accident data**				**Data about accident participants**			
Country	***Respondent institution***	Accident types	Accident causes	Accident severity	Outside accident influences	Accident perpetrator	Number of casualties	Information about acc. participants	Road user category
Australia	Academia	general	limited	general	general	general	general	general	general
Austria	Road authority	no	no	no	no	no	no	no	no
Belgium	Road authority	limited	limited	limited	limited	limited	limited	limited	limited
Cyprus	Road authority	general	general	general	general	general	general	general	general
Denmark	Road authority	general	no	general	general	no	general	general	general
Finland	Road authority	general	no	general	general	no	general	general	general
Germany	Road authority	general	general	general	general	general	general	general	general
Greece	Academia	general	limited	general	limited	limited	general	limited	limited
Hungary	State institution	general	general	general	general	general	general	general	general
Iceland	Road authority	general	limited	general	general	limited	general	general	general
Ireland	Road authority	general	limited	limited	general	no	general	general	general
Italy	Academia	limited	limited	limited	general	limited	general	general	general
Italy	Road authority	limited	limited	limited	limited	limited	limited	limited	limited
Luxembourg	Road authority	general	general	general	general	general	general	general	general
Netherlands	Road authority	general	general	general	general	general	general	general	general
Norway	Road authority	general	no	general	general	no	general	general	general
Slovenia	Road authority	general	general	general	general	general	general	general	general
Spain	Road authority	general	general	general	general	general	general	no	general
Switzerland	Road authority	general	general	general	general	general	general	general	general
U.S.A.	Road authority	general	general	general	general	no	general	general	general
UK (Wales)	Road authority	general	general	general	general	general	general	general	general
UK	Highway consultant	general	general	general	general	general	general	general	general
UK	Road authority	general	no	general	general	no	general	general	general

general availability
no availability
limited availability (e.g. restricted on locations, accident categories or low data quality)

The following inventory concerns the general approach for accident data gathering. Therefore no differentiation between road categories was made. Nevertheless it should be considered that very detailed accident analyses just are undertaken for fatal accidents (limited on different accident categories).

Table 5.6: *Inventory of detailed accident information* ***(all road categories)****.*

General approach - all road categories		Data availability				
Country	***Respondent institution***	General accident databases	Accident descriptions	Accident sketches or diagrams	In depth accident studies	Accident localisation method
Australia	Academia					both methods
Austria	Road authority					georeferenced
Belgium	Road authority					road chainage
Cyprus	Road authority					both methods
Denmark	Road authority					road chainage
Finland	Road authority					road chainage
Germany	Road authority					both methods
Greece	Academia					road chainage
Hungary	State institution					both methods
Iceland	Road authority					georeferenced
Ireland	Road authority					both methods
Italy	Academia					road chainage
Italy	Road authority					road chainage
Luxembourg	Road authority					georeferenced
Netherlands	Road authority					both methods
Norway	Road authority					road chainage
Slovenia	Road authority					both methods
Spain	Road authority					both methods
Switzerland	Road authority					both methods
U.S.A.	Road authority					road chainage
UK (Wales)	Road authority					both methods
UK	Highway consultant					georeferenced
UK	Road authority					both methods

general availability
no availability
limited availability (e.g. restricted accident categories)

6 Conclusions

Within the context of the PRACT Research Project (Predicting Road ACcidents - a Transferable methodology across Europe), the present report (Deliverable D1) comprises of an overview of currently used Accident Prediction Models (APMs) by different National Road Administrations (NRAs) in Europe and worldwide, as well as the currently used data sources for the development and application of APMs.

The report includes the results of a questionnaire survey, dispatched to several NRAs in Europe and worldwide, in order to collect detailed information on APMs developed and used by them, as well as information on microscopic data used for the development and implementation of APMs (crash data, traffic data, road design data and other related data). Furthermore, a review of relevant international literature was carried out, with focus in particular in identifying those modelling approaches and specific models that may be applicable or transferable in the European context. On the basis of the questionnaire data and of the literature review results, a synthesis of current practices regarding APMs was developed. Also based on the questionnaire responses, complemented with additional information from the literature, a description and discussion of available data sources for the development of APMs is included, which will be taken into account in the following Work Packages of the PRACT Project.

As far as current APM practices are concerned, an interesting observation resulting from the questionnaire survey is that, despite recent advances in the field of accident prediction modelling, most National Road Administrations (NRAs) and other organisations do not systematically use accident prediction methods during decision making for the implementation of road safety treatments. Furthermore, the use of APMs in decision making is more common in countries that have relevant approved guidelines or manuals, which is normally related to a more advanced road safety culture.

Relevant existing models constitute a valuable framework that can be further developed to allow for reliable accident prediction, depending on the availability of data. Several transferability issues have been examined by pertinent research and it seems that, depending on the availability of reliable historical accident data, certain accident prediction models can be transferred to conditions different from the ones for which they have been developed, if selected according to scientifically valid criteria.

The overview and discussion on APM practices is expected to assist in the identification and prioritisation of CMF needs, which will be addressed within Work Package 2 of the PRACT project. An initial approach has already been attempted within the present deliverable, based on the questionnaire survey, by identification of those CMFs / road safety measures that exhibit high need for implementation combined with low CMF availability (according to the NRAs experience). This identification will be further developed and enhanced in the next steps of the PRACT project.

Finally, the overview of existing APMs and CMF related research will constitute part of the background information that will be organised and presented in a web-based CMF repository on the gathered knowledge about APMs and CMFs, to be developed within Work Package 4 of the PRACT Project.

7 Acknowledgement

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Web-based Resources, CMF Databases and Road Safety Toolkits:

1. AustRoads Road Safety Engineering Toolkit: http://www.engtoolkit.com.au/
2. FHWA CMF Clearinghouse: http://www.cmfclearinghouse.org
3. iRAP Road Safety Toolkit: http://toolkit.irap.org/
4. Federal Highway Administration (FHWA). *How to Develop and Use CMFs*: http://www.cmfclearinghouse.org/resources_develop.cfm
5. Federal Highway Administration (FHWA). *How to Develop and Use SPFs*: http://www.cmfclearinghouse.org/resources_spf.cfm

Annex A: Reviews

1. Elvik, R., Hoye, A., Vaa, T. & Sorensen, M. (2009). The Handbook of Road Safety Measures (2nd Edition). Emerald Group Publishing Ltd.

Scope

The handbook aims to provide a systematic overview of current knowledge regarding the effects of road safety measures, by presenting state-of-the-art summaries of current knowledge regarding the effects of 128 road safety measures on road safety.

Methodology

More specifically, the handbook aims to provide answers to the following questions:

- Which measures can be used to reduce the number of traffic accidents or the severity of injury in such accidents?
- Which accident problems and types of injury are affected by the different measures?
- What effects on accidents and injuries do the various road safety measures have according to international research?
- What effects do the measures have on mobility and the environment?
- What are the costs of road safety measures?
- Is it possible to make cost–benefit evaluations of the measures?
- Which measures give the greatest benefits for traffic safety seen in relation to the cost of the measures?

In particular, the handbook seeks to develop objective knowledge about the effects of road safety measures by relying on an extensive and systematic search of literature and by summarising this literature by means of formal techniques of **meta-analysis** that minimise the contribution of subjective factors that are endemic in traditional, narrative literature surveys. A systematic meta-analysis framework has been used to assess the validity of the studies that are quoted. Moreover, the need to develop crash modification functions (CMF) in order to describe systematic variation in the effects of road safety measures is stressed.

The road safety evaluation studies examined within the handbook were assessed in terms of four types of validity:

- Statistical conclusion validity: sampling technique, sample size, reporting of statistical uncertainty in results, measurement errors, specification of crash or injury severity.
- Theoretical validity: identification of relevant concepts and variables, hypotheses describing the relationships between variables, knowledge of causal mechanisms.
- External validity: generalisability of the results of a study
- Internal validity: basis for inferring a causal relationship between treatment and effect, statistical association between treatment and effect, clear direction of causality, dose-response pattern, specificity of effect, control of confounding factors.

Data

The data used for the meta-analysis of road safety infrastructure investments were gathered through a systematic literature search that included previous Norwegian editions of the handbook, scientific journals, reports issued by selected research institutes, conference proceedings, the library of the Institute of Transport Economics, bibliographical databases, as well as a large number of references found in studies that were retrieved from the aforementioned sources. The oldest study included in the handbook dates back to 1939 and the most recent was published in 2009.

An important criterion for study inclusion is to have quantified, or at least have tried to quantify, the effect of one or more road safety measures on the number of accidents, accident rate and the number of injuries or risk of injuries. Studies that have evaluated the effects of road safety measures by relying on proxy measures for safety, such as conflicts between road users or changes in road user behaviour, rather than accidents or injuries, were considered less relevant.

Results

The handbook results in a detailed presentation of existing knowledge classified, according to each road safety measure, including descriptions and analysis of the problem and objective, of the measure, of the effect on accidents (including CMFs), of the effects on mobility and on the environment, and of available information regarding the measure's cost and cost - benefit analysis. A total of **128 measures** have been included, classified in the following categories:

- road design and road equipment,
- road maintenance,
- traffic control,
- vehicle design and protective devices,
- vehicle and garage inspection,
- driver training and regulation of professional drivers,
- public education and information,
- police enforcement and sanctions,
- post-crash care, and
- general purpose policy instruments.

In the handbook it is also demonstrated that the safety effect of a measure may vary from place to place, depending on the design of the measure, the number of accidents at the spot, any other measures that have been implemented, etc. An attempt has been made to identify sources of variation in the findings of different studies and to try to form as homogeneous groups as possible when presenting estimates of the effects of measures on road safety.

2. AASHTO (2010 - 2014). The Highway Safety Manual, American Association of State Highway and Transportation Officials (AASHTO).

Scope

The Highway Safety Manual (HSM) focuses on providing quantitative information and tools to facilitate improved decision making based on road safety performance. It assembles currently available information and methodologies on measuring, estimating and evaluating roadways in terms of crash frequency (number of crashes per year) and crash severity (level of injuries due to crashes). The HSM presents tools and methodologies for consideration of safety across the range of highway activities: planning, programming, project development, construction, operations, and maintenance.

Methodology

The Highway Safety Manual (HSM) is organized into four parts:

Part A provides key information and the context for understanding how to apply and integrate safety analysis related to the common activities within highway planning, design, and operations. It also includes Part A explains the relationship of the HSM to planning, design, operations and maintenance activities. Part A also includes an overview of human factors principles and fundamentals of the processes and tools described in the HSM. Finally, it includes a discussion of issues related to the reliability of crash data and to calibration techniques to modify the tools for local use, because of differences in factors, such as driver populations, local roadway and roadside conditions, traffic composition, typical geometrics and traffic control measures.

Part B presents suggested steps to monitor and reduce crash frequency and severity on existing roadway networks. It includes methods useful for identifying improvement sites, diagnosis, countermeasure selection, economic appraisal, project prioritization, and effectiveness evaluation. Several new network screening performance measures are introduced to shift the safety analysis focus away from traditional crash rates, in order to deal with the major limitation associated with crash rate analysis i.e. the incorrect assumption that a linear relationship exists between traffic volume and the frequency of crashes.

Part C provides a predictive method for estimating expected average crash frequency of a network, facility or individual site, and it introduces the concept of safety performance functions (SPFs). The estimate is applied to a given time period, traffic volume and constant geometric design characteristics of the roadway and can refer to the existing conditions, alternative conditions or proposed new roadways. The methods are provided for road segments and intersections for different facility types (rural two-lane roads, rural multilane highways, urban and suburban arterials).

Part D summarizes the effects of various treatments such as geometric and operational modifications at a site and provides Crash Modification Factors (CMFs), to quantify the change in expected average crash frequency as a result of these modifications. These concern roadway segments, intersections, interchanges, special facilities and road networks. These CMFs are claimed to be readily applicable to any design or evaluation process where optional treatments are being considered.

Regarding the CMF development, the following procedure was followed to document available knowledge using a consistent approach:

1. Determine the estimate of the effect on crash frequency, user behaviour, or CMF of a treatment based on one published study.
2. Adjust the estimate to account for potential bias from regression-to-the-mean and/or changes in traffic volume.
3. Determine the ideal standard error of the CMF.
4. Apply a Method Correction Factor to the ideal standard error, based on the study characteristics.
5. Adjust the corrected standard error to account for bias from regression-to-the-mean and/or changes in traffic volume.

The CMFs were evaluated during the Inclusion Process, based on their standard errors, in order to determine whether thay were sufficiently reliable and stable. In general, a standard error of 0.10 or less was considered as inclusion criterion. For further assessment of relevant literature, several expert panels were formed and convened to support the inclusion processes.

<u>Data</u>

The information regarding CMFs included in the Highway Safety Manual was based on an extensive literature review of published transportation research, mostly dated from the 1960's to June 2008.

<u>Results</u>

In the HSM important fundamental principles of road safety are presented, several safety analysis methods are discussed, including a **predictive method** to estimate crash frequency and severity and a large number of Crash Modification Factors (CMFs) are collected, based on existing literature, making it a very useful tool for road safety practitioners. Additionally, for several treatments a CMF is not available, but instead a trend regarding potential change in crashes is presented. A total of **162 treatments** have been examined, classified into the following categories:

<u>Road way Segments:</u>

- Roadside Elements (10 treatments)
- Alignment Elements (5 treatments)
- Roadway Signs (5 treatments)
- Roadway Delineation (11 treatments)
- Rumble Strips (4 treatments)
- Traffic Calming (3 treatments)
- On-Street Parking (4 treatments)
- Treatments for Pedestrians and Bicyclists (20 treatments)
- Highway Lighting (1 treatment)
- Roadway Access Management (2 treatments)
- Weather Issues (5 treatments)

<u>Intersections:</u>

- Intersection types (6 treatments)
- Access Management (2 treatments)
- Intersection Design Elements (14 treatments)
- Intersection Traffic Control and Operational Elements (25 treatments)

<u>Interchanges:</u>

- Interchange Design Elements (12 treatments)

<u>Special Facilities and Geometric Situations:</u>

- Highway-Rail Grade Crossings Traffic Control and Operational Elements (8 treatments)
- Work Zone Design Elements (3 treatments)
- Two-Way Left-Turn Elements (1 treatment)
- Passing and Climbing Lanes (1 treatment)

<u>Road Networks:</u>

- Network Planning and Design Elements (2 treatments)
- Network Traffic Control and Operational Elements (4 treatments)
- Elements of Road-Use Culture Network Considerations (14 treatments)

In 2014 the HSM supplement was published including two new chapters with the models for Freeways and Interchanges.
For freeways four different sets of models are given for the following combinations:
- Single vehicle – fatal and injury crashes
- Single vehicle – property damage only crashes
- Multi vehicle – fatal and injury crashes
- Multi vehicle – property damage only crashes

The prediction models for freeway segments address the following area types and cross section combinations:
- rural freeway with four through lanes;
- rural freeway with six through lanes;
- rural freeway with eight through lanes;
- urban freeway with four through lanes;
- urban freeway with six through lanes;
- urban freeway with eight through lanes;
- urban freeway with ten through lanes.

The speed-change lane models address ramp entrances and ramp exits for each of the area type and lane combination listed above.
Severity distribution functions were also developed using these data. These functions allow to estimate the expected crash frequency for each of the four severity levels of the K, A, B, C scale for injury crashes (K=fatal; A=incapacitating injury; B=non-incapacitating injury; C=possible injury).
The procedure for freeways is divided in two different sets of models distinguishing between freeway segments and freeway speed-change lanes. As in the published original HSM approach each model consists of a safety performance function (SPF) and a set of crash modification factors (CMFs). The SPF is used to estimate the crash frequency for segments and speed-change lanes with "base conditions" in terms of design elements and operating conditions. The CMFs are used to adjust the SPF estimate whenever one or more elements or conditions deviate from the base ones.

3. ROSEBUD Research Project (2006). Examples of assessed road safety measures - a short handbook

Available on-line at: http://partnet.vtt.fi/rosebud/products/deliverable/Handbook_July2006.pdf
Scope
ROSEBUD Research Project (Road Safety and Environmental Benefit-Cost and Cost-Effectiveness Analysis for Use in Decision-Making) is a thematic network funded by the European Commission to support users at all levels of government (European Union, national, regional, local) with road safety related efficiency assessment solutions for the widest possible range of measures. Its main intention was to rate the efficiency of road safety measures.
Methodology
The methodology applied for achieving the desired objectives included the following:
1. Screening of efficiency assessment experiences - state of the art. Determination of the current knowledge base available for evaluating the profitability of traffic safety measures.
2. Barriers to the use of efficiency assessment tools in road safety policy and proposals for surmounting obstacles and barriers.
3. Advancement of existing techniques of evaluating road safety measures.
4. Testing of the implementation of efficiency assessment tools at the European level.

The recommendations include ways to systematize the values of safety effects, mainly by documenting the effects on the basis of either a meta-analysis or traditional literature surveys, and by providing for theoretical effects based on known relationships between risk factors and crashes. They also include criteria for examining the local findings on safety effects of road infrastructure improvements. Based on the above, a framework for the assessment of road safety measures was developed, based on **Cost Benefit or Cost Effectiveness Analysis** methods, as well as a short handbook of assessed road safety measures.

Data
ROSEBUD was based on internationally available knowledge and experience gathered in the application of monetary evaluation techniques by scientists, politicians and practitioners.
Results
A total of **54 road safety measures** were assessed and are presented in the handbook, categorised by focus of measure:

- 18 user related measures, categorised into Training & Education, Traffic Law & Enforcement, and Incentives,
- 16 vehicle related measures, categorised into Active Safety, Passive Safety, and Telematics & Safety, and
- 20 infrastructure related measures, categorised into Road Design, Road Construction, and Maintenance.

A second level of categorisation, applied in parallel to the above, refers to the target groups, e.g. Pedestrians, Bicycles, Motorbikes, Coaches and Goods Vehicles, or the age groups, e.g. Children, Novice Drivers and Elderly.
For each assessed measure, a short description is provided along with an example of additional information. The assessment method (CBA or CEA) and the assessment result (poor, acceptable, excellent), as well as their sources, are highlighted in a table.

4. CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments, Conference of European Directors of Roads, Paris.

Available on-line at:
http://www.cedr.fr/home/fileadmin/user_upload/Publications/2008/e_Road_Safety_Investments_Report.pdf
Scope
The report presents the findings of a research project assigned and funded by CEDR and compiled by the National Technical University of Athens in 2008, aiming to assist and guide for more efficient National Road Authorities, by quantifying and subsequently classifying several infrastructure related road safety measures. The objective of this research was the identification of best practice on cost-effective infrastructure related road safety investments, based on the international experience attained through extensive and selected literature review and additionally on a full consultation process including questionnaire surveys addressed to experts and relevant workshops.
Methodology
Within the project, the following methodology was applied: Initially, a **review** of selected reference documents from European and national research projects, together with a set of key publications and other scientific papers, reports, and national studies was carried out, whereas further information regarding road safety strategies in the European countries was collected by a relevant questionnaire survey.
At a second stage, based on the aforementioned review, an exhaustive **list of 55 road safety infrastructure investments** covering all types of infrastructure was initially compiled. Individual investments were classified according to the infrastructure investment area and the type of investment and thereafter, they were analysed on the basis of safety effects, implementation costs, other (non-safety) effects, and cost-effectiveness. For each type of infrastructure, all investment areas were examined, including design-related infrastructure investments (e.g. road alignment improvements) and management-related infrastructure investments (e.g. traffic control).
These investments were subsequently ranked by road safety experts, in relation to their safety effects and implementation costs, during a full consultation process involving presentations, discussions and detailed commenting. Ranking was based on the assumption that investments presenting greater safety effects and lower implementation costs should be given priority. On the basis of this ranking, a set of **five most promising investments** was distinguished in terms of cost-effectiveness, mainly falling within five specific investment areas: Roadside treatments, Speed limits, Junction layout, Traffic control at junctions and Traffic calming schemes.
For these five most promising investments, an **in-depth analysis** was carried out, regarding safety effects, other (mobility, environmental, etc.) effects, and implementation costs. The cost-benefit ratio of the investments, according to relevant studies was presented and the conditions under which the cost-

effectiveness of each investment could be maximised or minimised were subsequently described resulting in the identification of good practice. Moreover, on the basis of this in-depth analysis, the strengths and weaknesses of each of these most promising investments were presented and possible barriers to implementation were identified.

Data

The data used for the meta-analysis of road safety infrastructure investments were collected from selected reference documents from European and national research projects, together with a set of key publications and other scientific papers, reports, and national studies (135 references in total). In addition, further information regarding road safety strategies in the European countries was collected by a relevant questionnaire survey.

Results

The report results in the identification of best-practice through the cost-effectiveness analysis of infrastructure related road safety investments. The results suggest that the overall cost-effectiveness of a road safety infrastructure investment is not always in direct correlation with the safety effect and is recommended that cost-benefit ratios and safety effects are always examined in conjunction with each other in order to identify the optimum solution for a specific road safety problem in specific conditions and with specific objectives.

5. The Cochrane Collaboration (2014). The Cochrane Injuries Group Reviews: "Prevention of road traffic injuries".

Available on-line at: http://injuries.cochrane.org/injuries-group-reviews

Scope

Cochrane Reviews are systematic reviews of primary research in human health care and health policy, aiming to investigate the effects of interventions for prevention, treatment and rehabilitation in a healthcare setting. They are designed to facilitate the choices that doctors, patients, policy makers and others face in health care. A sub-topic of the Reviews is the prevention of road traffic injuries.

Methodology

The methodology applied for the development of the Cochrane reviews has the following four steps:

1. Collate: gathering of published and reported material from around the world, in every language, on any given medical subject.
2. Assess: review of all the research against rigorous methodological criteria.
3. Synthesise: analysis and compilation of the findings of all the scientifically valid studies and generation of reports that illustrate an intervention's effectiveness.
4. Disseminate: provision of easily digestible summaries of the information, accessible to everyone, on Cochrane Summaries.

Data

The data for the development of the Cochrane Reviews were collected from published and reported material from around the world.

Results

The following 26 interventions for road safety have been examined by the Cochrane Injuries Group:

- Prevention of bicycle-related injuries:
  - Cycling infrastructure for reducing cycling injuries in cyclists (protocol stage).
  - Non-legislative interventions for the promotion of cycle helmet wearing by children (2012).
  - Bicycle helmet legislation for the uptake of helmet use and prevention of head injuries (2010).
  - Interventions for increasing pedestrian and cyclist visibility for the prevention of death and injuries (2009).
  - Helmets for preventing head and facial injuries in bicyclists (2009).
- Prevention of injuries to motor vehicle occupants:
  - Interventions to promote the use of seat belts (protocol stage).
  - Interventions for promoting booster seat use in four to eight year olds travelling in motor vehicles (2012).
  - Mobility management for prevented, reduced, or delayed driving in teenagers (protocol stage).
- Prevention of motorcycle-related injuries:
  - Motorcycle rider training for the prevention of road traffic crashes (2010).
  - Motorcycle helmet legislation for preventing injuries in motorcyclists (protocol stage).

- Helmets for preventing injury in motorcycle riders (2009).
- Increasing motorcycle and rider conspicuity for preventing death and injury in motorcyclists (protocol stage).

- Prevention of pedestrian injuries:
  - Safety education of pedestrians for injury prevention (2012).
- Prevention of traffic crashes:
  - Vision screening of older drivers for preventing road traffic injuries and fatalities (2014).
  - Speed cameras for the prevention of road traffic injuries and deaths (2012).
  - Red-light cameras for the prevention of road traffic crashes (2012).
  - Mobility management for prevented, reduced, or delayed driving in teenagers (protocol stage)
  - Graduated driver licensing for reducing motor vehicle crashes among young drivers (2011).
  - Street lighting for preventing road traffic injuries (2010).
  - Organisational travel plans for improving health (2010).
  - Area-wide traffic calming for preventing traffic related injuries (2009).
  - Alcohol and drug screening of occupational drivers for preventing injury (2009).
  - Alcohol ignition interlock programmes for reducing drink driving recidivism (2009).
  - Increased police patrols for preventing alcohol-impaired driving (2008).
  - School-based driver education for the prevention of traffic crashes (2008).
  - Post-licence driver education for the prevention of road traffic crashes (2008).

For each of the above interventions, the Reviews summarize their effectiveness and also report on the quality of the examined studies as well as the consistency of the results. The findings of these Cochrane Reviews provide guidance on the effectiveness of interventions for road safety in the hope that governments, urban planners, and individuals will be encouraged to improve road safety as a matter of urgency.

6. PROMISING Research Project (2001). Cost-benefit analysis of measures for vulnerable road users.

Available on-line at: http://cordis.europa.eu/transport/src/promisin.htm

Scope

The PROMISING research project (Development and Promotion of measures for vulnerable road users with regard to Mobility Integrated with Safety taking into acount the INexperience of the different Groups) was commissioned by the European Union, with the objective to show the potential for reduction in casualties of vulnerable road users like pedestrians, cyclists, motorised two wheelers and young drivers, by technical non restrictive-measures.

Methodology

Within the PROMISING research project, four groups of vulnerable road-users were distinguished: pedestrians, cyclists, riders of motorised two-wheelers, and young car drivers. The common approach for these groups was to analyse safety problems, to make an inventory of measures and to evaluate the restrictiveness and the cost and benefits of the measures. However, the approach differed in some respects. For pedestrians and cyclists, walking and cycling were considered a mode of transport and transport criteria were combined with safety criteria. For motorised two wheelers and young drivers, the most important safety measures were selected and mobility aspects of these measures were considered.In Work Package 5 of the PROMISING project, the technique and application of **cost benefit analysis** was described and the costs and benefits of 20 measures selected by the other WP's were calculated. During the project, consultations took place with an international forum of interest groups and in four countries during a national forum with representatives of governments and interest groups.

Data

The data used for the cost benefit analysis of the selected measures were gathered from various European Countries, depending on their availability.

Results

Regarding the assessment of measures, cost-benefit analyses were made for the following **20 measures**, designed to improve safety and mobility for vulnerable and inexperienced road users:

1. Roundabouts
2. Road lighting
3. Integrated area wide urban speed reduction schemes

4. Environmentally adapted through roads
5. Upgrading pedestrian crossings
6. Parking regulations
7. Front, side and rear underrun guard rails on trucks
8. Local bicycle policy to encourage mode switching from car driving
9. Bicycle lanes
10. Bicycle paths
11. Advanced stop lines for cycles at junctions
12. Mandatory wearing of bicycle helmets
13. Improving bicycle conspicuity
14. Daytime running lights on cars
15. Daytime running lights on mopeds and motor cycles
16. Mandatory wearing of helmets for moped and motorcycle riders
17. Design changes on motorcycles
18. Graduated licensing – lowered age limit for driver training
19. License on probation – lowered BAC-limit for novice drivers
20. Disco buses

7. SUPREME Research Project (2007). Handbook for measures at the Country level & Handbook for measures at the European level.

Available on-line at: http://ec.europa.eu/transport/road_safety/pdf/projects/supreme.pdf

Scope

SUPREME research project (SUmmary and Publication of Best Practices in Road Safety in the EU MEmber States plus Switzerland and Norway) was commissioned by the European Commission and involved a total of 31 national and international road safety organisations as project partners. The main objectives of the project were the sound identification and publication of Best Practice from the vast amount of available measures, and the development of a strategic approach and a framework for dissemination activities of the key findings in the 27 target countries.

Methodology

The methodological approach of the project was based on:

- A comprehensive discussion and definition of Best Practice as a foundation for tool development i.e. in particular the questionnaires for standardised reporting of examples.
- A detailed focus on selection criteria which have played a major role as analytical backbone of the study.
- A detailed data collection in 27 countries (25 EU Member States plus Norway and Switzerland). The collection was organised and supervised by a network of country experts.
- Additionally, a questionnaire with an open, narrative format was used to gather information from key road safety experts in European as well as international road safety institutions.
- Subsequently, an in-depth-analysis of all collected measures was carried out in order to select the “final” set of Best Practice measures. This task was carried out along 9 areas of road safety work by selected experts of the SUPREME consortium, involving several analytic steps and feedback loops.
- Finally, all 27 country expert were asked to give feedback to the selection of Best Practice Measures and to report about state of implementation from a national perspective as well as about the intended dissemination strategies at national level.

Data

Data used in the SUPREME Research Project were collected from the 27 involved countries (25 EU Member States plus Norway and Switzerland), with the collection being organised and supervised by a network of country experts.

Results

The project resulted in the development of two handbooks: the "Handbook for measures at the Country level" and the "Handbook for Measures at the European Level". The evaluated safety measures were ranked as best, good or promising practices as follows:

- In order to be labelled as ‘Best Practice’, a measure should comply with most of SUPREME’s internal selection criteria, in particular its effectiveness in terms of expected reduction of road

crashes, deaths and serious injuries should have been demonstrated in previous scientific evaluation work;
- ‘Good Practice’ measures fit in with most of the criteria, but suffer from a lack of data in the criteria ‘scientific evaluation of the effects’ and/or ‘cost benefit ratio’;
- ‘‘Promising Practices’ are mainly “new” measures that have not yet been subject to a full-fledged evaluation but, according to expert opinion, have a high potential of improving road safety, or (in the case of the handbook at the european level) measures that are not yet implemented at the European or international level but have shown to be successful in one or several Member States.

In the "Handbook for measures at the Country level" **55 measures** are identified as best, good or promising practices, in the following areas: Institutional Organisation of Road Safety, Road infrastructure, Vehicles and Safety Devices, Education and Campaigns, Driver Training, Traffic Law Enforcement, Rehabilitation and Diagnostics, Post Crash Care, and Road Safety and Data collection.
In the "Handbook for measures at the European level" **31 measures** are identified as best, good or promising practices, in the following areas: Policy Framework for Efficient Road Safety, Vehicle Safety, Road Infrastructure Safety, Enforcement of Traffic Law, Tackling Novice Drivers’ Higher Risks, Campaigns, Post-Accident Care, Data Collection and Analysis, and Practices from Related Policy Areas - e.g. Environmental Protection and Advocating Health.
The Handbooks provide a brief description of each measure, a presentation of involved stakeholders and an analytic outline on effects and costs, including Benefit/Cost ratio, if available. In addition, useful links for more information are presented.

8. OECD/ITF (2013). IRTAD Annual Report. Organisation for Economic Co-operation and Development/International Transport Forum.

Available on-line at: http://www.internationaltransportforum.org/pub/pdf/13IrtadReport.pdf
Scope
The IRTAD Annual Report 2013 provides an overview for road safety indicators for 2011 in 37 countries, with preliminary data for 2012, and detailed reports for each country.
Methodology
Within the country reports, the recent road safety measures (2010-2012) implemented in each country are summarized, as well as the National Road safety targets and strategies. However, the effectiveness of measures and strategies is usually not indicated.
Data
The data included in the IRTAD Annual Reports are provided at annual basis by road authorities, administrators and stakeholders from each member country.

9. NHTSA (2013). Countermeasures that work: A Highway Safety Countermeasure Guide For State Highway Safety Offices - 7th Edition. National Highway Traffic Safety Administration (NHTSA)

Available on-line at: http://www.nhtsa.gov/staticfiles/nti/pdf/811727.pdf
Scope
The guide is intended to be a key reference to assist State Highway Safety Offices (SHSOs) in the USA selecting effective, evidence-based traffic safety countermeasures for major road safety problem areas. The Guide describes strategies and countermeasures that are relevant to SHSOs, summarizes their use, effectiveness, costs, and implementation conditions and includes references to the most important publications (research summaries and individual studies) in the field.
Methodology
The guide is organized in sections, according to each road safety problem / research area. Each section starts with a brief literature review on the road safety problem, followed by a presentation of the related strategies and countermeasures. More than 115 individual countermeasures are examined and typically one page is devoted to each countermeasure. In each case, the countermeasures are ranked in terms of their effectiveness on the basis of a rating in stars; the use, costs and time needed for implementation are also assessed. Effectiveness is measured by reductions in crashes or injuries:

- 5 stars - The measures are demonstrated to be effective by several high-quality evaluations with consistent results
- 4 stars - Demonstrated to be effective in certain situations
- 3 stars - Likely to be effective based on balance of evidence from high-quality evaluations or other sources
- 2 stars - Effectiveness still undetermined; different methods of implementing this countermeasure produce different results
- 1 star - Limited or no high-quality evaluation evidence

The use of the measures is ranked high (i.e. more than two-thirds of the states, or a substantial majority of communities), medium, or low (i.e. fewer than one-third of the states or communities). The implementation costs are ranked high (i.e. requires extensive new facilities, staff, equipment, or publicity, or makes heavy demands on current resources), medium, or low (i.e. can be implemented with current staff, perhaps with training; limited costs for equipment, facilities, and publicity). Finally, the time to implementation is ranked long (i.e. more than one year), medium, or short (i.e. three months or less). A 'varying' option for the above rankings is also used in several cases.

Data

The data for the development of the guide were collected from published and reported material from the US, dating from 1984 to 2013.

Results

A total of **116 countermeasures** are presented in the guide, related to the following road safety problems and research areas:

- Alcohol-impaired and drugged driving (32 countermeasures)
- Seat-belts and child restraints (15 countermeasures)
- Aggressive driving and speeding (8 countermeasures)
- Distracted and drowsy driving (8 countermeasures)
- Motorcycle Safety (9 countermeasures)
- Young drivers (11 countermeasures)
- Older drivers (8 countermeasures)
- Pedestrians (13 countermeasures)
- Bicycles (12 countermeasures)

The countermeasures refer mainly to legislation, enforcement, training and communication measures and infrastructure treatments. Quantitative CMFs are generally not included in the guide, and the effectiveness of the countermeasures is demonstrated by means of the aforementioned qualitative star rating.

10. Federal Highway Administration (FHWA): FHWA Clearinghouse CMFs. USA

Available on-line at: http://www.cmfclearinghouse.org

Scope

The CMF Clearinghouse, available at www.CMFClearinghouse.org, offers transportation professionals a central, Web-based repository of CMFs, as well as additional information and resources related to CMFs. In the site are available interesting guides to develop CMFs and SPFs.

CMFs develop methodology

The guide then introduces various methods for developing CMFs. Discussion of these methods is not intended to provide step-by-step instruction for application. Rather, this guide discusses study designs and methods for developing CMFs, including an overview of each method, sample size considerations, and strengths and weaknesses. A resources section is provided to help users identify an appropriate method for developing CMFs based on the available data and characteristics of the treatment in question. The resources section also includes a discussion of considerations for improving the completeness and consistency in CMF reporting.

SPFs develop methodology

This guidebook is intended to provide guidance on developing safety performance functions (SPFs) from the Highway Safety Manual (HSM) (AASHTO, 2010). The guidebook discusses the process to develop jurisdiction specific SPFs. It is intended to be of use to practitioners at state and local agencies and to researchers.

Results
The CMF Clearinghouse developed a star quality rating system to indicate the quality or confidence in the results of the study producing the CMF. While the reviewers applied as objective as possible set of criteria: study design, sample size, standard error, potential bias, and data source; the star quality rating still results from an exercise in judgment and a degree of subjectivity. The star rating is based on a scale (1 to 5), where a 5 indicates the highest or best rating.

11. AustRoads. Road Safety Engineering Toolkit

Available on-line at: http://www.engtoolkit.com.au/
Scope
The Road Safety Engineering Toolkit is a reference tool for road engineering practitioners in state and local governments in Australia and New Zealand. It outlines best-practice, low cost, high return road environment measures to achieve a reduction in road trauma. The Toolkit seeks to reduce the severity and frequency of crashes involving road environment factors. The Toolkit draws together existing road safety engineering knowledge as far as possible into one web-based Toolkit for easy access by practitioners.
Methodology - Data
The information included in the Toolkit is based on extensive research into the effectiveness of crash countermeasures, retrieved from relevant studies in Australia and New Zealand. In addition to the originally included data, road safety practitioners are encouraged to submit case studies which will be evaluated and possibly included in the knowledge framework of the Toolkit.
Results
A total of **67 treatments**, all concerning road infrastructure, has been examined and is presented in the Toolkit, organized according to:

- dominant crash types (17 categories),
- related safety deficiencies (44 categories),
- road user groups (6 categories)\.

For each treatment, the following information has been gathered and presented in the Toolkit:

- Description of the treatment.
- Key benefits associated with the treatment.
- Issues concerning implementation of the treatment.
- Crash reduction effectiveness (CMFs).
- Qualitative cost rating (on a 1-5 scale).
- Qualitative treatment life estimation (on a 1-4 scale).
- Reference to technical papers, studies and guides concerning the treatment.

12. International Road Assessment Programme (iRAP) Road Safety Toolkit. Collaboration of International Road Assessment Programme (iRAP), Global Transport Knowledge Partnership (gTKP) andWorld Bank Global Road Safety Facility

Available on-line at: http://toolkit.irap.org/
Scope
The Road Safety Toolkit provides information on the causes and prevention of road crashes that cause death and injury. Building on decades of road safety research, the Toolkit aims to help engineers, planners and policy makers develop safety plans for car occupants, motorcyclists, pedestrians, bicyclists, heavy vehicle occupants and public transport users.
Methodology - Data
The information included in the Toolkit is based on research into the effectiveness of treatments, retrieved from existing relevant studies and toolkits.
Results
A total of **58 treatments** have been examined in the Toolkit: 42 about road infrastructure, 5 about vehicles and 11 about people. Search for the most suitable treatment within the web-based toolkit can be performed according to:

- dominant crash types (8 categories),
- road user groups (6 categories).

For each treatment, the following information has been gathered and presented in the Toolkit:
- Description of the problem and the treatment.
- benefits associated with the treatment.
- Issues concerning implementation of the treatment.
- Crash reduction effectiveness (qualitative).
- Qualitative cost rating.
- Qualitative treatment life rating.
- Reference to technical papers, studies and guides concerning the treatment.
- Reference to related case studies (if available)

13. 2BESAFE Research Project (2011). 2-wheeler Behaviour and Safety

Available on-line at: www.2besafe.eu

Scope

2BESAFE research project (Two Wheeler Behaviour and Safety) was commissioned by the European Commission and investigates issues related to two-wheeler behaviour and safety in order to define the parameters of their behaviour resulting in their high risk. Other project sub-objectives concern the obtaining of know-how on the risk factors for two-wheelers and on their behaviour and the design of tools to represent two-wheeler behaviour efficiently.

Methodology

First, the possible causes for two-wheeler road accidents were investigated obtaining data from accident databases to define specific scenarios that contain high risk for two-wheelers. Next, two-wheeler behaviour, conspicuity and risk perception were investigated using a set of tools part of which was designed/customised within the framework of the project. Such tools were instrumented two-wheelers for naturalistic riding studies, questionnaires, riding simulators and video tools. The synthesis of the project results led to the design of measures for the improvement of two-wheeler road safety.

Data

Accident data were collected from international accident databases. The assessment of measures was based mainly on experts' opinions.

Results

In Part C of the Deliverable "Guidelines, Recommendations and Research Priorities" of the 2BESAFE project, a total of **143 measures** has been assessed and presented, classified as follows:
- Road Infrastructure (34 measures),
- Vehicles and Safety Devices (30 measures)
- Conspicuity and Lights (9 measures)
- Environmental Issues (2 measures)
- Protective Equipment (10 measures)
- Driver Education and Licensing (20 measures)
- Traffic Law and Enforcement (10 measures)
- Road Safety Education and Campaigns (10 measures)
- Rehabilitation and Diagnostics (3 measures)
- Post Accident Care (3 measures)
- Road Safety Data and Data Collection (5 measures)
- Measures involving other Vehicles (4 measures)
- Other Measures (3 measures)

For each measure, a short description is provided, along with an example of the measures implementation and an attempt to determine possible benficiaries of the measure. Short comments are included regarding the relevant safety problem, its size and scientific background, issues on the measure's implementation, the expected impact and the riders' perspective. Finally, the experts' assessment of the measure is summarized in a table, providing a **five star qualitative assessment** of the measure overall as well as of eight important aspects: size, total impact, safety impact, efficiency, transferability, implementation, acceptance and sustainability.

14. OECD / ITF (2012). Sharing Road Safety: Developing an International Framework for Crash Modification Functions, OECD Publishing.

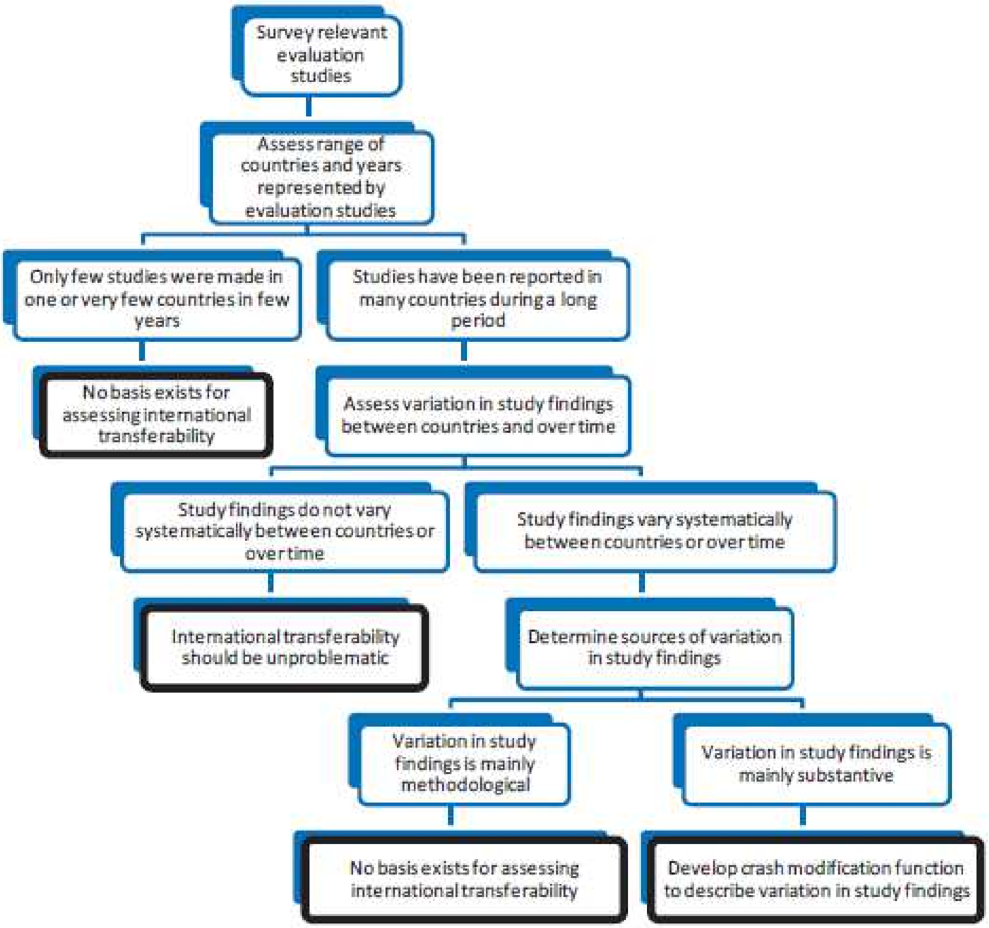
Available on-line at: http://www.internationaltransportforum.org/Pub/pdf/12Sharing.pdf

Scope

The report analyzes the issue of Crash Modification Functions (CMFs) transferability, focusing on the Range of Replications technique and how it can give an indication of the stability of research results across countries and years. The report provides also preconditions that should be fulfilled before applying the range of replications technique. The technique can be fruitfully applied to assess external validity when a large number of studies have been reported during a long period of time.

Methodology

The proposed methodology for assessing the international transferability of road safety evaluation studies and CMFs is summarized in the following flow-chart.



Results

The report highlights the growing demand for reliable crash modification factors (CMFs) that relate safety effectiveness to interventions, and suggests that transferable CMFs from one situation to another are a valuable tool in spreading effective safety policies. The report has documented ways to address the issue of CMF transferability, by analysing the extent to which a CMF is dependent on the circumstances in which it was developed, and provides a framework that illustrates how studies can control for the most important confounding factors related to the countermeasure analysed and thus provides guidance for uniform screening and control procedures. In this regard, the report serves as a useful guide for transferring road safety measures and in supporting countries in their efforts to collaborate on essential road safety research.

15. Federal Highway Administration (FHWA) (2005). Roadway Safety Design Synthesis. USA.

Scope

The objectives of this research project are: (1) the development of safety design guidelines and evaluation tools to be used by TxDOT designers, and (2) the production of a plan for the incorporation of these guidelines and tools in the planning and design stages of the project development process.

Methodology

The Roadway Safety Design Synthesis is divided into seven chapters. The first chapter introduces the Synthesis. The subsequent six chapters synthesize the available quantitative information for various roadway facilities. These “quantitative” chapters are titled:

- Freeways
- Rural Highways
- Urban Streets
- Interchange Ramps
- Rural Intersections
- Urban Intersections

Each chapter contains two main parts:

The first part describes safety prediction models that predict the expected number of crashes that will occur on a particular roadway segment, interchange ramp, or intersection. These models are compared and discussed, providing a roadway designer some insight into the model types and design-related factors that correlated with crash frequency. The safety performance models in each chapter were used to generate the crash rates shown in the corresponding chapter of the Roadway Safety Design Workbook.

The second part of each chapter contains accident modification factors (AMFs) for various design-related factors that have been found to be correlated with crash frequency. AMFs represent the relative change that occurs in crash frequency when a particular geometric component is added, removed, or changed in size. As such, it is multiplied by the expected crash frequency before the change to estimate the expected crash frequency after the change. An AMF in excess of 1.0 is an indication that the corresponding change will increase crash frequency. An AMF less than 1.0 indicates that the change will decrease crash frequency.

16. Safer BraIn Research Project (2011). Innovative Guidelines and Tools for Vulnerable Road Users Safety in India and Brazil

Available on-line at: http://www.saferbrain.eu/LinkClick.aspx?fileticket=vamjUF-g1vk%3d&tabid=228

Scope

SaferBraIn (Innovative Guidelines and Tools for Vulnerable Road Users Safety in India and Brazil), co-financed by the European Commission within the VII Framework Programme, aimed at increasing the level of safety Pedestrians and Cyclists in India and Brazil.

Methodology

To achieve the project's objectives, the main risk factors for Vulnerable Road Users in India and Brazil were analyzed and, based on European experience and best practice, innovative methodologies and tools for planning, designing and maintaining safe infrastructures were developed. The transferability of these methodologies and tools was also analyzed. A Decision Support System (SaferBraIn DSS) was developed, based on European experience, to support decision makers and technicians in defining the more cost-effective road safety measures for reducing pedestrian and cyclist traffic accidents, and in preventing dangerous situations through road safety audit and inspection. To assess the effectiveness and efficiency of the innovative methodologies and tools, pilot projects, in India and in Brazil, were implemented, focusing on road safety audits of renewal designs and on the assessment of pedestrian crossings safety. Feedbacks from pilot projects were used to review recommendations and guidelines about safe road infrastructure design, road safety management, road safety audit and inspection.

Results

In the Deliverable "Innovative Guidelines and Tools for Vulnerable Road Users Safety in India and Brazil" of the Safer Brain project, a total of **16 measures** has been assessed and presented, classified according to the design area, as follows:

- Crossing the Road (Mid-block or at Intersections):
  1. Zebra crossings (controlled crossings)
  2. Pelican/Puffin/Toucan/Pegasus Crossings (Controlled Crossings)
  3. Pedestrian refuges / pavement build-out (uncontrolled crossings)
  4. Dropped kerbs and tactile paving
  5. Bridges and underpasses (Grade-Separated Crossings)
- Along the Roadway (Where VRU is Not Trying to Cross)
  1. Footways / sidewalks / pavements
  2. Bollards and barriers
  3. Cycle way / cycle paths
  4. On-road cycle ways and coloured roadways
- Vehicle-Related
  1. Vehicle-activated signs (VAS)
  2. Vertical-deflection methods to reduce traffic speeds
  3. Horizontal-deflection methods for reducing traffic speed
  4. Enforcement / safety / speed cameras
  5. Signage and Road Markings
- Area-Wide Scheme
  1. Shared Space / Home Zones
  2. Pedestrianisation

For each infrastructure measure, in order to allow for an informed decision about whether a specific type of infrastructure would be effective on a specific road scheme, the following information has been provided:

- Advantages of using the measure,
- Disadvantages of using the measure,
- Comments regarding the transferability of the measure to the local conditions in India and Brazil
- General guidance for use.

17. National Cooperative Highway Research Program (NCHRP) - Transportation Research Board (TRB): Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges. USA, 2012

Scope

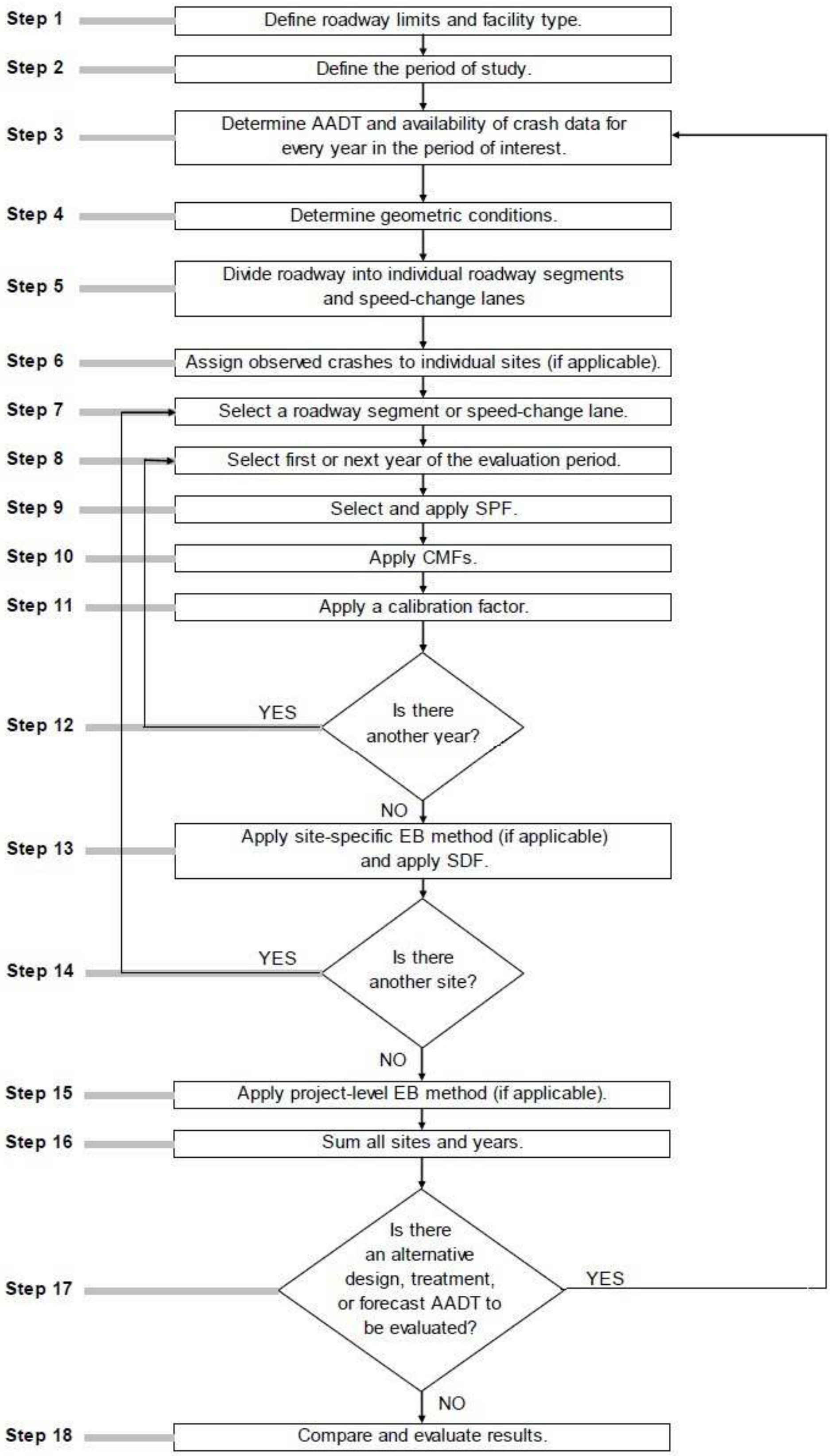
This research was undertaken to address this need by developing methodologies suitable for inclusion in the HSM. To accomplish this objective, data were assembled that included a wide range of geometric design features, traffic control features, traffic characteristics, and crash records for freeway segments, ramp segments, and crossroad ramp terminals.

The objectives of this research are identified in the following list.

- Develop an overall framework for the enhancement of safety prediction methodologies for freeways and interchanges to support decision making for planning, network, corridor analysis, and individual site analysis.
- Develop analytical models and procedures within the overall framework.
- Develop a safety analysis tool that automates the framework, models, and procedures.
- Develop a chapter for the future edition of the HSM that documents the methodology.
- Document the models to support their inclusion in the IHSDM.

Methodology

The methodology for evaluating freeway or interchange safety is envisioned to mirror the chapters described in Part C of the HSM (Highway, 2010)


Step 1
Define roadway limits and facility type.
Step 2
Define the period of study.
Step 3
Determine AADT and availability of crash data for every year in the period of interest.
Step 4
Determine geometric conditions.
Step 5
Divide roadway into individual roadway segments and speed-change lanes
Step 6
Assign observed crashes to individual sites (if applicable).
Step 7
Select a roadway segment or speed-change lane.
Step 8
Select first or next year of the evaluation period.
Step 9
Select and apply SPF.
Step 10
Apply CMFs.
Step 11
Apply a calibration factor.
Step 12
YES
Is there another year?
NO
Step 13
Apply site-specific EB method (if applicable) and apply SDF.
Step 14
YES
Is there another site?
NO
Step 15
Apply project-level EB method (if applicable).
Step 16
Sum all sites and years.
Step 17
Is there an alternative design, treatment, or forecast AADT to be evaluated?
YES
NO
Step 18
Compare and evaluate results.

<u>Results</u>

The method addresses freeway segments and freeway speed-change lanes. It includes crash modification factors that describe the observed relationship between crash frequency and horizontal curvature, lane width, shoulder width, median width, barrier length and offset, ramp-related lane changes, rumble strip presence, clear zone width, and the extent of recurring congestion.
This report also documents a safety prediction method for ramps that is suitable for incorporation in the HSM. The method addresses ramp segments, C-D road segments, and crossroad ramp terminals. For segments, it includes crash modification factors that describe the observed relationship between crash frequency and horizontal curvature, lane width, shoulder width, barrier length and offset, a change in the number of basic lanes, presence of a ramp-to-ramp merge or diverge point, and ramp-related lane changes on a C-D road.
The safety prediction method for crossroad ramp terminals includes crash modification factors that describe the observed relationship between crash frequency and exit ramp control, exit ramp lanes, presence of turn lanes on the crossroad, presence of driveway access points, distance to the adjacent ramp terminal, median width, presence of protected-only left-turn operation, presence of right-turn channelization, and skew angle.

18. FGSV (2003). Empfehlungen für die Sicherheitsanalyse von Straßennetzen (ESN), Forschungsgesellschaft für Straßen- und Verkehrswesen. Köln.

English translation: **Guidelines for safety analysis of road networks (NSM)**

Scope

This guidelines represents the state of the art of accident analysis on German road networks (different from literature No. 19 which consider accidents locally). The main aim of these recommendations are the analysis and identification of safety deficits in existing road networks on federal, state, county and municipal level and the assessment of lacks in road design. These guidelines provide a decision support for investments regarding safety countermeasures.

Methodology

Through the guideline character of this reference there will be just methodical recommendations for accident analysis subsequently.
Chapter 2: The main parameters for safety assessment are accident rates and accident cost rates (risk and costs of accidents depending on vehicle miles) and also accident density and accident cost density (frequency and costs of accidents depending on road length).
Chapter 3: For safety analysis copious accident collectives should be considered. Therefore a long and actual period under consideration should be used preferably (3 years are advisable within road networks). The basis of analysis are annual accident costs, which can be calculated by summarizing the economic losses through accidents differentiated in the defined 6 accident categories in Germany (influential for the categorization is the most serious accident consequence: accident with killed, serious injured or slightly injured persons as well as accidents with serious or slight material damage or influence of alcohol). The accident cost rates for monetization of damage due to an accident are differentiated in motorways, inter-urban roads (both out of towns) and thoroughfares and access roads in towns.
Chapter 4: For safety analysis in road networks two definitions for shaping road segments are given (first based on road network structure for analyzing design parameters, second based on accident occurrence). The segments should be as long as possible for significant safety analysis. The safety assessment is carried out through the calculation of a safety potential, which is in general the difference between accidents cost which could be expected by road design conform to the design guidelines and the real accident costs. The safety potential (SIPO) is therefore the existing accident cost density minus the 'not preventable accident cost density' which are expectable at different design standards. The 'not preventable accident cost density' is the expectable basic load of accidents based on basic accident cost rate (differentiated in motorways, rural roads, urban roads) combined with the AADT of the road segment. The safety potential in the future is predictable by involving traffic trends. By preparing a rank order of road sections with the calculated safety potential the sections with the most necessity of countermeasures can be identified.

19. FGSV (2012). Merkblatt zur örtlichen Unfalluntersuchung in Unfallkommissionen (M Uko). Forschungsgesellschaft für Straßen- und Verkehrswesen. Köln.
English translation: **Guidelines for Blackspot Management (BSM)**
Scope
This guidelines represents the state of the art of accident analysis in Germany, especially black spot identification (different from literature No. 18 which consider road networks). The prevention of accident black spots within local accident surveys is task of the accident commission (police, traffic and road construction authority) (§44 German Highway Code). They identify and analyse accident black spots and resolve countermeasures together with an implementation and impact analysis. The tools and principles for accident analysis, safety assessment and identifying accident risk and black spots are mentioned here.
Methodology
Through the guideline character of this reference there will be just methodical recommendations for accident analysis subsequently.
Chapter 1: Every road user has a basic risk for accident involvement. Moreover there are a lot of boundary conditions (e.g. road deficiencies) which can have an additional negative impact on traffic safety and lead to accident occurrence. The regulation of the negative impacts of the road is task of the accident commission. To ensure their work, a consistent accident elicitation by the police is necessary with a number of accident facts (e.g. location, participants, sketch and report of accident progress, accident types and conditions).
Chapter 2: Basis of accident analysis are accident maps (georeferenced) with the essential information of accidents, which are named below: 6 accident categories (the most serious accident consequence is decisive: accident with killed, serious injured or slightly injured persons as well as accidents with serious or slight material damage or influence of alcohol), 7 accident types (conflict situation which lead to an accident: e.g. turning accident, driving accident without second participants), 7 special conditions (e.g. involvement of pedestrians, bicycles, deer). Two different types of accident maps are differentiated: firstly accidents with personal damage within 3 years and secondly all accidents within 1 year, because accident black spots with slight and serious consequences are very different.
Chapter 3: The definitions of accident black spots are provided (accidents occurs repeatedly due to road deficits). Spotty (intersections or curves) and linear (longer road section) accident black spots are divided, when the defined limit of accidents is reached. The limits are differentiated by accident types, area (urban, nonurban) and in nonurban areas by motorways and rural roads. The definition for spotty black spots at rural roads is: the number of accidents with serious personal damage * 5 + number of accidents with slight personal damage * 2 ≥ 15 within 300 meters (for road sections) and within 50 m around the intersection centre (for intersections). The same equation is used for motorways. Here the consideration is differentiated in driving direction and with other extent (1000 m for road sections and 250 m before/after the deceleration/acceleration lanes for intersections). The definition for linear black spots at rural roads is ≥ 3 accidents with serious personal damage with max. 600 m gap between adjacent accidents. For motorways no linear black spots are defined because of the large extent of spotty accident black spots. All black spots can be ranked by means of accident numbers and costs for ensuring measures with the most safety potential. Here accident numbers and costs are decisive for spotty black spots and the accident density (frequency and costs of accidents depending on road length) for linear black spots. Accident costs rates are calculated unregular and involve economic losses like disability, costs for rehabilitation and repair due to the accident. They are differentiated in road types and accident categories.
Chapter 4: For identifying countermeasures within accident black spots an detailed accident analysis with the following tools can be conducted. Accident lists for identifying structural similarities (similarities within accident types, boundary conditions like rain or deer), accident diagrams (sketch with all accidents within the black spot together with the driving direction of accident participants in the location), local inspection (considering the conflictual traffic situations) and additional elicitations (e.g. speed).
Chapter 5: Deduction of short- and long-dated countermeasures based on the analysis.
Chapter 6/7: The implementation of countermeasures and their effects afterwards (before-after-comparison) have to be controlled by the accident commission. The work of the accident commission

is finished, if the accident(costs) can be reduced in a high and positive percentage and the limits of accident black spots are no longer reached.

20. Maier R., Berger R., Schüller H. (2013). Bewertungsmodell für die Verkehrssicherheit von Landstraßen - Evaluation model for traffic safety on rural roads, Federal Highway Research Institute (BASt).

English translation: **Evaluation model for traffic safety on rural roads**

Scope

Aim of this project was the elaboration of safety effects of different road design and operation features on rural roads, because knowledge on this elements are outdated, not differentiated or based on small data bases. Research for elaboration of a "German manual on the assessment of road traffic safety" (HVS) is based on basic accident cost rates on roads (safety level with legit design). This basic risk together with additional factors for design deficits will lead to an accident cost rate of a road segment. But the HVS draft contains just estimations for safety evaluation, which have also methodological issues. This is starting point for this project. Multivariate analysis are used (first German APM for rural roads), because they involve a variety of influencing variables for safety assessment and have a lot of benefits opposite to monocausal surveys as they were carried out in Germany in the past. For HVS simplified factors will be elaborated out of the complex APMs.

Literature

The safety effects will be elaborated for the new cross-section types of the German guidelines for construction of rural roads (RAL). Just the ESN [No. 18] actually contains basic accident cost rates (parameter for safety level), but just for two-lane rural roads, which are nearly detectable in the whole rural road network. This will be differentiated here. The main influencing variables are mentioned: for cross-sections (road width, number of lanes, central barriers), for horizontal road layout (curve radii, bendiness, aligned sequences of curve radii), for vertical road layout (gradient, spatial alignment, sights), road operation (speed, markings, lateral road design). Some of this aspects and their safety effects will be described summarised within literature No. 21, 29, 30.

Methodology

The sections were matched with the new cross-sections types of RAL for classification. The assignment was made with the help of number of lanes, lane width and markings. The road sections were subdivided in sections, intersection areas (50 m around intersection centre) and approaching area in forefront of intersections (300 m around intersection centre). Rural roads were identified with place name signs and a transition area of 100 m. For sections different segments were determined with homogenous features with impact on accident occurrence (AADT, predicted and permissible speed, lane width).

For accident analysis multivariate models were used for safety analysis because they include different influencing variables and their interaction. The following main aspects were covered within methodological description: APM structure, distribution functions and overdispersion, types of variables and definition of variables, correlating variables, parameter estimation and their rendition, link function, modelling process, goodness of fit. The model results can be compared with accident rates and accident density. By modelling within different accident categories (accident severity) models for evaluation of economic losses due to accident costs can be established. The modelling procedure will be just used for estimating safety effects properly within this project. For HVS it is not foreseen to develop or use APMs, but a simplified procedure will be developed for better practicability. Finally significance tests and residuum analysis (standardised residuals, leverage, Cook-distances) were described.

The modelling will be performed within different accident severities, because effects of variables are different for serious and slight accidents. Three model types were differentiated: models for accident category 1-3, for category 4+6 and models for category 5. The models will be created for every defined cross-section types as well as intersections separately. Finally the basics of accident analysis were described by MUko (Lit. No. 19). The previous determination of basic accident cost rates was just based on experiences (30 %-quantile of observed accident cost rates). These values will be scheduled significantly in this report, by transferring model results into basic accident cost rates and additional factors (constructional or operational deficits). The representativity of accident sample compared to Germany as a whole was proved finally.

<u>Data</u>

All in all 3.600 km road sections (nearly only A-roads) in 6 German federal states (Bavaria, Brandenburg, Baden-Wuerttemberg, Rhineland-Palatinate, Saxony, Saxony-Anhalt) were analysed. Accident data are used with different time periods in different federal states (general timeframe 2005-2009).

<u>Results</u>

Chapter 4 (Results for road sections):

Used variables: AADT (DTV), cross-section width (FBB), lane width (FSB), shoulder width (RSB), bendiness (KU), hilliness (HK), amount of dropping below the minimum of horizontal (KHM) and vertical curve radii (MinRad), amount of trees on shoulder (BB) and wood (WS), amount of errors in horizontal curve radii relations (FRT), amount of spotty danger points (abutments or railroad crossings) (PGS) or deficits through junctions (Akp) as well as their combination (PgsAkp), settlement structure. Some models will use AADT as categorical variable in addition to exposition for modelling effects through exceedance of designated AADT for road classes. All these variables will be possible additional factors on basis accident cost rate. All in all 80 variables and their combinations were tested within 4 cross-section types and within the 3 accident categories.

Significant features for "cross-section type 11" (example for serious accidents):

$$U(P) = e^{-8{,}08} * DTV^{0{,}77} * L * e^{(FSB+RSB+(0{,}09*FRT)+(0{,}06*HK)+(0{,}07*MinRad)+(0{,}54*BB)+(0{,}26*WS)+(0{,}02*PgsAkp))}$$

10 variables are identified with significant effects. Generally amount of accidents increase with increasing AADT, with width dropping below the minimum and deficits in lateral road design. Effects through speed limits couldn´t be determined. For "cross-section type 9", 8 variables are identified with significant effects, for "three-lane cross-section types" as well as for "cross-section type 21" 7 variables. The significance and involvement of variables varied within the different cross-section types and accident categories. The results for every cross-section type are translated in a basic function for accident rates. This function just involve AADT, not design features or additional risks. Risks are calculated later as additional factors to the basis function. If all 3 partial basic functions (3 accident categories) were summarised, one function for whole basic accident occurrence arises, described by 2 parameters (kUKR, fUKR). These aggregated accident rate functions show comprehensible coherences for the 4 cross-section types (within their limits of use) depending on AADT. The models are valid for the involved threshold values of variables, extrapolations are not acceptable.

The basic accident rate functions were monetarised and the accident cost rate functions analysed depending on AADT. The functions were mainly influenced through serious accidents because of higher amount of economic losses. The basic functions are seen as predictable loads of accidents, not as 'not preventable accident cost density' like in ESN (Lit. No.18). The result provide an accident cost rate depending on AADT, which is more precisely and should be used instead of the constant accident cost rates within HVS draft.

Afterwards the additional factors for design deficits are calculated (add-ons to basic functions). Also the add-ons depends on AADT, therefore their amounts in safety effects are involved. The amount of safety effects (AUKR,i) is composed by calculated base values and/or variable attributes (depending on variable type). Crucial for the base values are the APM parameters and significances/involvements within the 3 categorized accident severity models. The base values are proven in a sanity check. If more than one deficits existing on a road section, the add-ons are multiplicative included for estimating road safety. The procedure is user friendly and accurate adequately and was prepared for HVS update.

$$UKR_{Strecke} = \left(\prod_{i=1}^{n}(1 + A_{UKR,i})\right) * gUKR_{Ä}$$

$$gUKR_{Ä} = k_{UKR} * DTV^{f_{UKR}}$$

Chapter 4.10 (Results for approaching area in forefront of intersections and towns):

Generally positive effects on accident occurrence (as well as shifting in accident type distribution) and severity can be expected though varied driving behaviour in the approaching area. Influencing variables are different types of flow regulations in the approaching area. For this different types reduction factors for accident cost rates are estimated by the change in number of accidents and accident severity. The results are involved in the safety evaluation of the whole road section between two intersections.

Chapter 5 (Results for intersections):
APMs just prepared for not signalized T-junctions (because of an adequate sample size). Involved variables: amount of minor AADT (DTVuz), presence of traffic islands for right turning vehicles together with oncoming left turning lanes (DRLF), junction within curves, set-up of lanes not regularly (FSnreg), missing of left turning lanes. The most relevant variables are AADT for the whole junction as exposition and the AADT minor. The following procedure is based on the method for road sections. Due to the small collective of junctions, the results can just be seen as estimations.

21. Vieten M., Dohmen R., Dürhager U., Legge K. (2010). Quantifizierung der Sicherheitswirkungen verschiedener Bau-, Gestaltungs- und Betriebsformen auf Landstraßen. Federal Highway Research Institute (BASt). Berichte der Bundesanstalt für Straßenwesen, Heft V 201, Bergisch Gladbach.

English translation: **Quantification of road safety effects of different construction, design and operational forms on rural roads**

<u>Scope</u>

Accident cost rates represent in general just the mean accident occurrence in a road network. Basis accident cost rates describe the expectable accident occurrence on roads which are designed according to the current guidelines. But a road network contains both, roads build according to the guidelines and roads not compliant to guidelines. The aim of this project was to determine basis accident cost rates out of such a inhomogeneous sampling collective by statistic analyses and develop a basis for quantification of safety effects which have different forms of construction, design and operation on rural roads.

<u>Methodology</u>

The rural road network was subdivided in sections, intersections area (50 m around intersection centre) and approaching area in forefront of intersections (50 m - 500 m around intersection centre). A minimum length for road sections was determined (1.500m) to have enough space between two intersections (2 x 500 m approaching area + 500 m section). Additional data were gathered (e.g. road width, number of lanes and operational aspects of intersections).

<u>Data</u>

Usage of road information and accident databases (2002-2006, accident category 1-4) of 4 German federal states (Bavaria, Brandenburg, North Rhine-Westphalia, Rhineland-Palatinate) were analysed.

<u>Results</u>

Accident occurrence on sections: Accident rates are decreasing with increasing road width at two lane single carriageway roads (about 60 % from 5 m up to 8 m). Accident rates of three lane single carriageway roads are 20 % safer as the widest two lane cross-section. Accident rate of four lane dual-carriageway roads are 25 % below three lane single carriageway roads. The accident cost rates show similar results.

Accident occurrence at approaching areas of intersections: Accident rates for approaching areas are below the rates of the road sections and show the similar tendencies regarding the road width. For additional number of lanes the accident rates increase slightly in approaching areas compared to sections. Approaching areas of signalled intersection have the best safety level (speed limit 70 km/h is prescribed). Accident cost rates are analogous.

Accident occurrence at intersections: Intersections were differentiated in intersections with and without left turning lanes. T-junctions are safer than intersections. Accident occurrence decrease with signalisation and additional left turning lanes. Roundabouts seems to be in general very safe. The application range of different intersections types have to be considered (AADT). Accident cost rates are analogous.

Deduction of basic accident parameters: Until now just basic accident cost rates of ESN (Lit. No.18) are known (experience values without general methodology behind). Firstly a 'moving' histogram (kernel density estimation) was created to assess a frequency distribution of established accident parameters over all network sections. Sections without accidents were regarded in a separate class. Secondly the frequency distribution was adjusted to an normal distribution (accident rates are normal distributed). The assumption is, that roads not compliant to guidelines have a low amount in the road network and their accident parameters are above the mathematical expectation of normal distribution. After distribution adjustment (least squares method) the mathematical expectation was calculated and basic accident rates were deduced (not basic accident cost rates, because they are weighted by accident severity). Basic accident cost rates were calculated by multiplying basic accident rates with mean accident costs. It was proven, that no uniform factors between mean accident cost rates and basic accident cost rates are existing.

22. RIPCORD-ISEREST Research Project (2007). Accident Prediction Models and Road safety Impact Assessment: results of the pilot studies. RIPCORD - ISEREST Consortium, Internal Report D2.4. Reurings M., Janssen T., Eenink R., Elvik R., Cardoso J., Stefan C.

Scope

Road authorities need a good insight in the variables, which explain the accident level on their roads. Therefore APMs are build up for different road types and RIAs for aggregating APMs to road networks. This report consists of the performance of four pilots and the comparison with the state-of-the-art.

State-of-the-art:

APMs are a (set of) function(s) which describe road safety depending on different variables and are widely known and used. RIAs does the same but have been applied only a few times because they need good quality data. The basics of APMs are presented subsequently. Here model basic form, possible set of explaining variables, overdispersion, goodness of fit, model predictive performance, sources of errors (omitted variable bias, co-linearity of explanatory variables which lead to unstable estimations of model coefficients, usage of average values like AADT) are discussed. Finally some criteria for high quality of models are stated (e.g. separate models for different levels of severity, road/intersection/accident types should be created and disaggregated models should be used, tests of residuals, internal variable correlation or predictive performance should be checked, variables should be entered stepwise in the model).

Results

3.1 Pilot results Austria: APM for four types of severity on Austrian motorways.
see also: Stefan, C.: Predictive Model of injury accidents on Austrian motorways, KfV, Vienna, 2006
3.2 Pilot results Norway: Broad survey (RIA) of 139 road safety measures (45 were included in impact assessment of the scenarios) for halving the number of fatal or seriously injured persons within the National Transport Plan 2010-2019. Four different scenarios were analysed (optimal use of road safety measures, "National" optimal use of road safety measures, continuing or strengthening present policies). The largest reduction of number of killed or injured road users is obtained by the optimal use of road safety measures, but the halving was not reached. **see also:** Elvik, R.: Prospects for improving road safety in Norway, Institute of Transport Economics, Oslo, 2007
3.3 Pilot results Portugal: APM within 7 road classes of Portuguese road network. **see also:** Wichert, S./Cardoso, J.: Accident Prediction Models for Portuguese Motorways, LNEC, Lisbon, 2006
3.4 Pilot results Netherlands: APM for urban and rural roads in Haaglanden (area around The Hague).
see also: Reurings, M./Janssen T.: Accident prediction models for urban and rural carriageways, Based on data from The Hague region Haaglanden, SWOV, R-2006-14, Leidschenda, 2002
3.5.1 Comparison: 4 APMs for motorways in Austria and Portugal as well as for urban and rural roads in the Netherlands are compared.

Austria Motorways $ACC = 2.4 \times 10^{-4} \times AADT^{1.05} \times Length^{0.89} \times 0.99^{PHGV}$

Portugal Motorways $ACC = 6.7 \times 10^{-4} \times AADT^{0.92} \times Length^{0.93}$

Netherlands Urban $ACC = 0.55 \times AADT^{0.32} \times Length^{1.0}$

Netherlands Rural $ACC = 0.047 \times AADT^{0.50} \times Length^{0.96}$

3.5.2 Comparison of additional pilots in Portugal/Netherlands:
The additional Pilots/APMs results show remarkable but explainable differences in different study areas (e.g. influence of road section length or AADT). **see also:** Wichert, S./Cardoso, J.: Accident Prediction Models for Portuguese Single Carriageway Roads, LNEC, Lisbon, 2007
Reurings, M./Janssen T.: De relatie tussen etmaalintensiteit en het aantal verkeersongevallen op enkelbaans- en dubbelbaanswegen, SWOV, Leidschendam, 2007
5. Discussion of practical use: Developing APMs is not an easy task. APM requires much data of good quality and detail that is usually not available. A standard tool for testing the significance of difference between expected and real accident values should be made available for safety assessment. RIAs give a clear insight in which measures are needed to meet the road safety targets that were set.

23. RIPCORD-ISEREST Research Project (2005). Accident Prediction Models and Road safety Impact Assessment: a state of the art. RIPCORD - ISEREST Consortium, Internal Report D2.1. Reurings M., Janssen T., Eenink R., Elvik R., Cardoso J., Stefan C.

Scope
State-of-the-art of APM and RIA (incl. EIA) are presented for rural/urban roads and intersections. Conclusion: "As it happens it is not possible to give a general APM or RIA that can be applied in different situations or even countries. The event of a road accident is far too rare and complex to be able to catch this in a simple model."

State-of-the-art:
The chapter dealt with the following aspects. Choice of explanatory variables (assumption that accident rates and exposure are enough to describe accident occurrence are no longer tenable, a set of variables and risk factors describe this much better, variables are constrained by data availability, models should use variables that have major influence on accidents and can be measured valid and reliable and are not highly correlated), choice of model form, modeling process (GLM, parameter estimation, scaled deviance, overdispersion, negative binomial distribution, goodness of fit), dual-state models, residuals, explained variation, interpretation ("correlation is necessary for causation, but not sufficient"), predictive performance (APMs are not in fact prediction models but explanatory models, [Partyka, 1991] tested a good fitted model on basis of the years 1960-1982 to predict accidents for the following years 1982-1989 and showed that explaining past trends does not ensure that future trends can be reliably predicted because the assumption that everything else remain constant is never correct), sources of error (omitted variables, co-linearity of variables, wrong functional forms for variables → argument and function averaging). A good model is the simplest possible model that adequately fits the data.

Results
3. Review of APMs for rural roads: Comprehensive description of relevant APMs for rural roads is given (ensuring that the data collection and fitting process is the same and definitions are stated and comparable).
3.1 APMs for rural road sections: (additional literature analysis advisable)
3.1.1: APMs for main rural dual carriageway roads in Egypt.
Over 30 models were tested using different functional forms. Just AADT and average annual travelled distance used. s**ee also:** Abbas, K.A.: Traffic safety assessment and development of predictive models for accidents on rural roads in Egypt, in: Accident Analysis and Prevention, 36, p. 149-163, 2004
3.1.2: APMs for curves and tangents on two-lane rural roads in Portuguese road network.
see also: Cardoso, J.L.: Design consistency and signing of curves on interurban single carriageway roads, Report, 197/01-NTSR, LNEC, Lisboa, 2001
Cardoso, J.L.: Detection and low-cost engineering improvement of inconsistent horizontal curves in rural roads, 12th International conference "Road Safety on three continents", FERSE/VTI/TRB, Moscow, September 19-21, 2001
Cardoso, J.L.: Study on the relations between road characteristics, speed and accidents; Application to two-lane two-way rural roads, PhD Dissertation, LNEC-IST, Lisboa, 1996
Cardoso, J.L.: Design consistency of horizontal alignment in rural roads, SAFESTAR deliverable report of TASK 5.1, LNEC, Lisboa, 1997
Cardoso, J.L.: Models on the relations between workload, speed variation, road characteristics and accident frequencies, SAFESTAR deliverable report of TASK 5.4, LNEC, Lisboa, 1998
3.1.3: Models (not APM) for two-lane two-way rural roads. Different models of tangents and curves, curved segments and straight segments were developed using length, width, slope.
see also: Kalakota, K.R./Islam, M.N./Senevirathe, P.N.: Influence of geometric design variables on accident rates on two-lane rural highways, in: International Conference Road Safety in Europe, FERSI, Berlin, 1992, VTI Report 380A pt2, p. 207-26, 1992
Kalakota, K.R./Senevirathe, P.N.: Accident prediction models for two-lane rural highways, Mountain Plains Consortium, North Dakota State University, 1994/05
3.1.4: Linear regression model at major roads in Colorado (length, AADT, distance traveled)
see also: Khan, S./Shanmugam, R./Hoeschen, B.: Injury, fatal and property damage accidents models for highway corridors, in: Transport Research Record, 1665, p. 84-92, 1999

3.1.5: Generalized linear regression models for two-lane two-way rural roads in Finland using paved width, speed limit, curvature, hilliness, minor access density, length, traffic flow.
see also: Kulmala, R./Roine, M.: Accident prediction models for two-lane roads in Finland, Traffic safety theory and research methods, April 26-28, 1988, Amsterdam, Session IV: Statistical analysis and models, 1988
3.1.6: APMs for single and dual carriageway roads with minor junctions in UK.
see also: Mountain, L./Fawaz, B./Jarret, D.: Accident prediction models for roads with minor junctions, in: Accident Analysis and Prevention, 28, p. 695-707, 1996
3.1.7: APM for rural Highways in New South Wales Australia using lane/shoulder width, horizontal/vertical curves, driveway density, turning lanes, passing lanes, pavement type.
see also: Prinsloo, B./Goudanas, C.: Development of a crash prediction model for rural roads in NSW, 21st ARRB Transport Research Conference, Queensland, Australia, 2003
3.1.8: APMs for two-lane single carriageway roads in US. Different models for different accident types (because relation between accident frequency and AADT varies with the type of accident being predicted) using length, AADT, speed limit, lane/shoulder/pavement width.
see also: Qin, X./Ivan, J.N., Ravishanker, N.: Selecting exposure measures in crash rate prediction for two-lane highway segments, in: Accident Analysis and Prevention, 36, p. 183-191, 2004
3.1.9: APMs for rural intersections and links in New Zealand using road geometry, intersection control, speed limit, type of land use and variables of special road sites (speed in isolated curves, width at narrow bridges, number of trains at railway crossings).
see also: Turner, S.: Accident prediction models, Transfund New Zealand Research Report, 192, 2000
Turner, S. et al.: New Zealand accident prediction models and their application, in: Transport: our highway to a sustainable future: proceedings of the 21st ARRB and 11th REAAA Conference, Cairns, Queensland, Australia, 18-23 May 2003
3.1.10: Interactive Highway Safety Design Model (IHSDM) for US single carriageway two-lane roads from safety and operational point of view. Evaluation modules: policy review, crash prediction review, design consistency, intersection review, traffic analysis. APMs for links using lane/shoulder width, curve length, radius, superelevation, grade, number of passing lanes and driveways.
see also: Krammes, R.A./Hayden, C.: Making two-lane roads safer, in: Public Roads, 66(4), p.16-21, 2003
Harwood, D.W. et al.: Prediction if the expected safety performance of rural two-lane highways, Publication FHWA-RD-99-207, Federal Highway Administration, Washington D.C., 2002
3.1.11: APM of IHSDM was fitted to data from US two-lane two-way rural state highways.
see also: Vogt, A., Bared, J.G.: Accident models for two-lane rural roads: segments and intersections, Report FHWA-RD-98-133, FHWA, Washington D.C., p. 179, 1998
Vogt, A., Bared, J.G.: Accident models for two-lane rural segments and intersections, in: Transportation Research Records, 1635, p. 18-29, 1998
3.1.12: APMs for rural roads in Netherlands, Portugal, UK, Sweden within MASTER project using lane width, link length, speed limit, bendiness, gradient.
see also: Baruya, A.: Speed-accidents relationships on European roads, in: 9th International Conference Road Safety in Europe, Bergisch Gladbach, Germany, 1998
Baruya, A.: Speed-accidents relationships on different kinds of European roads, Deliverable D7 - Master 4th Framework project, EC, 1998
3.1.13: Model for relationship of roadside encroachment events & run-of-the-road accidents.
see also: Miauo, S-P., Estimating vehicle roadside encroachment frequencies by using accident prediction models, in: Transportation Research Record, 1599, p. 64-71, 1997
3.2 APMs for rural intersections: (additional literature analysis advisable)
Collocation of 5 different APMs for intersections (not previously considered).
3.3 Discussion:
Several forms were used for accident prediction modeling (power, logarithmic, exponential, linear and polynomial form) were just used in 3.1.1. There are a number of explanatory variables which were used as significant variable in the different 13 models. AADT (12 times) and section length (10 times) are variables in almost all models. Moreover the minor access density, carriageway and shoulder width are used in various models (every five times). So it is advisable that APMs should use these variables. Furthermore different forms of estimating the model coefficients were used. Generalized linear modeling, normal linear regression, zero inflated regression and accident modification factors beside AADT and segment length are used to adjust the expected accident frequency. But it is

advisable to use GLM with Poisson or negative binomial distribution. Finally some authors developed models within different road types, accident types and different accident severity. These disaggregated models are better (better fit and are more simple) for accident estimation.
5. Road safety impact assessment (RIA): Two possible techniques for safety assessment of new roads. First RIA for assessing safety effects of road or traffic schemes (variants) and second road safety audit (RSA) for estimate safety performance of specific designs. Aim is similar, scope (networks vs. individual road) and timing are different (RIA precede RSA).
5.2.: Subsequently the model 'Regional Road Safety Explorer' was described regarding to SWOV. The explorer calculates the safety situation in prognosis year 2010 from a reference year 1998 considering road length, traffic volumes and crashes of 1998, plans for sustainable safe road categorization, growth in roads/traffic up to 2010 and road safety measures.
see also: Janssen, S.T.M.C.: Het gebruik van de verkeersveiligheidverkenner in de regio, Report R-2005-06, SWOV, Leidschendam, 2005
5.4 RIA method applied in a case study: Assessment of road safety of planned infrastructure in Maastricht (part of DUMAS project). RIA for urban area.
5.5 RIA applied to a regional road network: (motorway network in Netherlands)
see also: Dijkstra, A.: Application of a road safety impact assessment to a regional road network, Proceedings of Road Safety on Four Continents, October, 5-7, Warsaw, 2005
5.7 SafetyAnalyst: Set of software tools for improving safety on highways in US. Consists of six tools: Network Screening Tool (accident black spots), Diagnosis Tool (causes for accident occurrence), Countermeasure Selection Tool, Economic Appraisal Tool, Priority Ranking Tool, Evaluation Tool (before/after evaluation). More information: http://safetyanalyst.org/index.htm
5.8 EIA type road safety impact assessment: Different examples of tools in different countries for assessing road infrastructure investments. Bundesverkehrswegeplan (German Transport Master Plan) is the most comprehensive mandatory assessment method. One part are general economic cost-benefit analysis. The economic evaluation of safety impacts is based on cost resulting from accidents, so if accidents are avoided than economic benefits can be attained.

24. RIPCORD-ISEREST Research Project (2008). Safety Performance Function, RIPCORD - ISEREST Consortium, Deliverable D.10. Dietze M., Ebersbach D., Lippold Ch. Mallschutzke K., Gatti G., Wieczynski A.

Scope

Two possible procedures for safety assessment, firstly safety assessment on past accident occurrence, secondly statistical models (APMs, SPFs) to predict potential accident scenarios. Numerous variables are possible (human factors, traffic facilities, traffic and vehicle conditions, environment). Road geometry most important for road engineering, but especially driving behavior (leads to unsafe maneuvers) is important. The developed SPFs therefore contains typical engineering parameters and human factors/driver behavior. Several correlation models were established using accident rates and accident cost rates.

State-of-the-art:

The system "Driver-Vehicle-Road" and the interactions (control loop of Durth, 1974),with driver as controller, vehicle as control path, road as reference variable, disturbance variables, perception and processing are described initially. Subsequently a comprehensive literature review of behaviour influencing variables is covered. Generally the driving behaviour (speed, acceleration) is influenced by geometry (straights, curve radii, curvature change rate, lane width, sights distance, balanced elements)and traffic conditions (traffic volume, heavy vehicle ratio, average travel speed, percentage of no-passing zones). Afterwards the basics of accident analysis are presented for Germany. Here accident maps, accident structures (accident types/kinds/causes/categories), accident costs (global/adapted costs), accident indicators (accident density/rates, basic accident costs) are involved. Subsequently a comprehensive literature review of road design and safety is covered. The effects of curve radii, curvature change rate, grades, vertical curves, lane width, shoulder width, lane + shoulder width, surface cross slope, sight distance are mentioned. As a summary it can be stated that driving is a complex task which include several interactions of driver, road, and vehicle.

Methodology

The consideration of driving behavior is explained. In general geometry influences driving behavior and driving behavior influences accidents. Additional parameters for behavioral and accident prediction are human perception, information processing and decision making, which have to be included in SPFs. Therefore simulator studies and field experiments are performed, but numeric weights to psychological parameters couldn't be derived. Expectations are integral part of behavior and road design determines the workload in a special situation. Percentage of increase of workload can be derived by speed differences between elements. Driving behavior was integrated in SPF due to steadiness of the road design. Therefore a classification of road alignment was conducted for SPFs by speed forecast models/behavior. Classification between transition areas (curves which cause speed difference > 10 km/h) and sections with similar alignment (constant speed profile). An algorithm for alignment analysis for pre-classification and the proving with speed forecast models is described. The defined sections are attributed to geometry data. For each section type road design data (CCR, width, AADT) are divided in two sets of same size which represents the design characteristics. For accident analysis just driving accidents and accidents in longitudinal direction are considered (strongly connected to geometry).

<u>Data</u>

500 km of Saxony road network northerly Dresden with 3 years of accidents (2003-2005).

<u>Results</u>

5.1 No structural differences are visible in accident occurrence between study area and German average.

5.2 Correlation Models: The correlation between accident parameters and infrastructure are used to establish separate models for the defined road sections. The used geometric parameters are curvature change rate for sections with similar alignment and curve radii as well as speed difference for transitions. Further the road width, traffic volume and both differentiated accident types were taken into account. Here a summary: If traffic volume increase the accident risk and severity increase, above 4000 veh/24h both decrease. Narrow roads are chancier than wider roads. Wider roads with less traffic volume and narrow roads with higher traffic volume have highest accident severity. High curvature change rate increases accident risk and severity. Same correlations for wider roads, narrow roads have inconsistent results. Up to speed difference of 20 km/h accident risk increases, above it inclines again. Accident risk is higher in curves with less traffic volume. In curves with less traffic volume accident severity increases with inclining speed difference, but with high traffic volume in inclines up to speed difference of 20 km/h than decrease.

5.4 Safety performance function: Most safety procedures (black spot management, audits) consider current or past situation. This SPF is an APM and will combine engineering and human factors based on the established correlation models which were derived from analysis of real accident data. Developed SPF can be used for road network outside urban areas on paved tow-lane single carriageway roads outside intersections. Precondition for SPF application are data of road horizontal geometry, cross section design and traffic data in the road network. Than the investigated roads have to be classified regarding their effects on driving behavior and safety (sections with similar alignment and transitions). Calculation of AR and ACR for these sections using the correlation models, so SPF will show statistically possible accident occurrence. But an additional reference value is needed like basic AR or basic ACR to evaluate safety. Safety potential is difference between calculated (predicted) accident parameters by SPF and basic accident parameters. If predicted ACR is higher at one sections than basic ACR than investigated section is above the average. For further distinction of safety potential it is possible to group the range above basic accident parameters, e.g. bACR+5%/bACR+10%. Results of safety potential can be displayed within road network maps.

25. RIPCORD-ISEREST Research Project (2007). Black Spot Management and Safety Analysis of Road Networks - Best Practice Guidelines and Implementation Steps, RIPCORD - ISEREST Consortium, Deliverable D.6. Sorensen M., Elvik R.

<u>Scope</u>

Content of this report is the state-of-the art of the best currently available approaches for black spot management (BSM, for Germany see also No. 19, MUko),) and network safety management (NSM, for Germany see also No. 18, ESN). Approaches and quality of BSM and NSM differs from country to country and is characterized by a lack of standardized methods and definitions. Goal of this report was to describe the steps for implement a best practice guideline for BSM and NSM after analyzing state-of-the-art and current practice.

<u>State-of-the-art report/results:</u>

2. Summary of differences between state-of-the-art and best practices:
Four criteria for evaluate best practices are mentioned. Random fluctuations (rely on expected number of accidents not on recorded accidents), systematic variation (account as many as possible factors for road safety by using APM), local risk factors (identify sites where expected number of accidents is higher than in similar sites), severity (prevent most serious accidents). Afterwards BSM and NSM are describes independently, but several requirements are the same (e.g. data). In different countries different developments are visible. Some stop doing BSM and instead focus on NSM (e.g. Sweden, England), in other countries NSM supplement (not replace) BSM (e.g. Germany, Norway). Implementation step should start with implementation of BSM, after a period of time NSM should supplement, finally it is recommended to focus primarily on NSM. If NSM and BSM are used in parallel (most relevant situation of most European countries), this will be the most complex situation, so it would be relevant to combine both approaches.
3. BSM: Characteristics of state-of-the-art and best practice guidelines for BSM (summary):

	State-of-the-art	Best practice
Classification of sites	– Dividing of road system into clearly defined sites	– Same as state-of-the-art
Identification principle	– The empirical Bayes method	– Simple model based method
Identification criterion	– Higher expected accident number than the normal expected number – Severity is not included	– The absolute difference criterion – Predefined number or a certain share – Severity is not a part of the identification
Analysis	– Binomial tests of accident patterns – Blinded matched pair comparison	– General accident analysis, collision diagram, inspection, traffic and road analyses – Comparing with normal accident pattern – True/false assessment
Evaluation	– Empirical Bayes before-and-after design – Should always be made	– Before-after-study with correction for trends, traffic and regression – Should not always be made, it depends of data

State-of-the-art approach are best currently known methods from theoretical point and best practice guidelines from practical point of view. BSM is a reactive tool based on historic accident data. Quality of accident varies in Europe. Accident model development needs the following steps: 1. determination of field of application, 2. variable selection, 3. data collection, 4. estimation method, 5. regression analysis, 6. goodness of fit, 7, empirical Bayes estimation. State-of-the-art approach needs all 7 steps, best practice just 5 first steps.
4. NSM: Overall differences between NSM and BSM:

	BSM	NSM
Philosophy	– A remedial and retrospective nature	– Both a remedial and retrospective nature and a preventive and prospective nature
Severity	– Not included in the identification	– Included in the identification
Length	– Up to about 0.5 kilometres	– Between 2 and 10 kilometres
Frequency	– Every or every second year	– Every second to fourth year

	State-of-the-art	Best practice
Classification of sites	– Dividing of road system into clearly defined sites	– Dividing of road system in 2-10 km homogeneous sections
Identification principle	– The empirical Bayes method	– Simple model based method – Use of not accident based method should be examined
Identification criterion	– Higher expected accident number than the normal number – Severity is included	– The absolute difference criterion – Predefined number or a certain share – Severity is integrated by weighting the severity categories according to monetary valuations
Analysis	– Binomial tests of accident patterns – Blinded matched pair comparison	– Extended collision diagram, general inspection, traffic and road analyses – Comparing with normal accident pattern – True/false assessment
Evaluation	– Empirical Bayes before-and-after design – Should always be made	– Before-after-study with correction for trends, traffic and regression – Should not always be made, it depends of data – Further research how to evaluate combined retro- and prospective treatment

The annexes contain an overview of different approaches for BSM and NSM for different states.

26. Maher M., Summersgill I. (1996). A comprehensive methodology for the fitting of predictive accident models. Accident Analysis and Prevention, Vol.28, pp.281-296.

<u>Scope</u>

This paper reports on the progress of the continuing TRL junction accident studies, which have now covered 4-arm roundabouts, rural T junctions, urban 4-arm traffic signals, urban links and T junctions, urban crossroads, 3-arm signals, mini roundabouts, rural crossroads, rural single carriageways and rural dual carriageways. The models developed in these studies are also described, with their implications for the effect of design on junction safety. The paper also describes various technical problems which needed to be addressed in order to ensure that the application of GLMs would produce robust and reliable results.

<u>Methodology</u>

Models were developed at three different levels. Level 1 models are coarse models which relate total accidents, and a limited disaggregation of these into vehicle-only accidents and pedestrian accidents, to some simple flow function. Variables representing major features (especially those used to stratify the sample) are also tested at this level and included as simple multiplicative factors. The level 2 models are essentially a stage in the development of level 3 models. The latter retain the same flow function as the corresponding level 2 model, but in addition include all the relevant geometric, signal, and other variables. These higher level models were more demanding of data, but it was believed that through disaggregation, it would be easier to establish genuine and better-fitting relationships between accidents and flows and geometry.

<u>Data</u>

An extensive national reconnaissance survey was conducted as part of each study to identify suitable sites, from which the sample of sites for study was drawn. The survey usually included about twice to three times the number of sites required for study. The sample of sites was selected so as to be stratified according to important variables, which were the vehicle and pedestrian flows and the main features of the layout. The sample was selected at random within each stratum so as to avoid bias. The accident data consisted of records of all reported injury accidents occurring at the sites.

<u>Results</u>

There are certain technical problems which need to be addressed in order to ensure that the application of GLMs will produce robust and reliable results. This paper dealt with a number of such problems, proposed some extension or modification to the basic methodology, and hence constituted a comprehensive methodology for the development of predictive accident models. The technique issues addressed in this study are:

(1) The low mean value problem: for pure Poisson models, even in those circumstances when the value of SD itself could be appreciably below the standard target value , the drop in SD could

be used (albeit with some caution) as the basis of a significance test to decide on the inclusion of extra terms in the model.

(2) Modelling overdispersion: The conclusion from a large number of empirical studies, then, is that the NB model is the most appropriate way by which to model overdispersion.

(3) Estimating the uncertainty of predictions: When the predictions are aggregated over all accident types and perhaps over all arms of the junction, the coefficient of variation for the total prediction will be appreciably smaller.

(4) It is concluded that it is better to use the aggregate form of the data, in that the form of the model then allows what is believed to be a plausible interpretation of the actual error structure.

(5) The simulation experiments indicated that, with the 12 or 16 hour counts employed in previous TRL studies, the magnitude of the bias due to the random error in the flow estimates was sufficiently small to be ignored.

(6) This study also showed that the uncertainty in predictions can be summarized by combining predictions with site observed values.

27. Ye Z., Zhang Y., Lord D. (2013). Goodness-of-fit testing for accident models with low means. Accident Analysis and Prevention, Vol.61, pp.78-86.

Scope

This study has two objectives. The first objective is to examine the accuracy and reliability of traditional test statistics for the GOF of accident models subjected to low sample means. The second objective intends to identify a superior test statistic for evaluating the GOF of accident prediction models.

Methodology

Several GOF test statistics have been proposed to evaluate the fit of models, but their performance and complexity vary greatly. Therefore, simple but accurate and reliable alternative test statistics are highly desirable to account for the LMP commonly observed in crash studies.

A simple criterion to assess whether or not a test statistic is appropriate for testing the GOF of regression models is to examine the test statistic's performance for a single distribution (Poisson or NB) with known parameters. This study examined the mean and variance of different statistics under a single distribution context to judge their appropriateness for the GOF of GLM.

Data

To show how different GOF test statistics affect the fit of Poisson models, two examples using observed crash data are provided. For the first example, the data were collected at 59 four-legged unsignalized intersections in1991 in Toronto, Ontario. The dataset includes the number of crashes and entering AADT for the major and minor approaches at each site. For the second example, the data were collected at 88 frontage road segments in the State of Texas. The dataset includes the number of serious injury crashes, segment length, and AADT.

Results

The results of this study show that the Pearson's X^2 statistic tends to overestimate GOF values for low mean values.

For Poisson regression models, the Power-Divergence statistic ($PD_{\lambda 2/3}$) follows an approximate χ^2 distribution and is the best test statistic for measuring the GOF for these models. This statistic performs better than the other three statistics for almost all μ values, except when μ is very low. However, when μ is very small, no test statistics can provide accurate and stable results of GOF tests. This statistic is preferred to the Pearson's X^2 statistic for all cases.

For NB distributions with low sample mean values, this paper found that the traditional statistics do not have accurate estimates of the power of fit. Under such conditions, the more complex grouping method is recommended as a remedy. For better illustrations, three examples using observed crash data were used to show the differences of test statistics in GOF tests for Poisson and NB models. Further work should be done to investigate and improve the GOF test of NB models, since this type of model is more often used for modeling crash data.

The results of this study provide guidance on the use of the grouped G^2 method. It is found that the G^2 method or the grouped G^2 method is an appropriate test statistic only when the grouped mean is 1.5

or higher. Theoretically, the grouped G^2 method can be used for samples with extreme low means (e.g. less than 0.3). However, when grouping a sample with a low mean value to achieve a grouped mean of 1.5 or higher, the grouped sample size will be significantly reduced, which may lead to issues associated with small samples.

28. Turner S., Singh R., Nates G. (2012). The next generation of rural road crash prediction models: final report, NZ Transport Agency research report 509, Final Report.

Scope

The purpose of this research was to develop the next generation of rural crash prediction models for two-lane rural roads. The objectives were to update crash prediction modelling methods to align with recent developments overseas (for example the use of homogenous rural road sections rather than sections of a fixed length), develop a relationship database containing all the key variables for rural roads, and create a database that could be used by university students and New Zealand researchers for further analysis. The next generation of rural crash prediction models were developed by crash type, which would include key road features that could be changed by engineers. Some preliminary analysis is undertaken on the effects of access density on the crash rate on higher volume rural roads.

Methodology

A three-stage process was used to develop the models for this project. In the scoping study (stage 1) the research team identified the key variables/data collection methodology and sample size required for developing the model. The pilot study (stage 2) involved testing the data collection methods identified during the scoping stage and refinement of the data set and collection methods based on the findings. This report provides the outcomes of the final stage (stage 3) of the process, which focused on the development of crash prediction models for New Zealand rural roads.

Generalised linear crash prediction models were developed for key crash types including head-on, loss-of-control and driveway crashes. For head-on and loss-of-control crashes, an analysis of straight, curved and all sections was undertaken. For driveways the analysis was for both curved and straight sections combined. New Zealand was divided into five regional groupings, including Auckland, the West Coast and three super regions. In addition, the models quantify the safety impact of key road features, many of which can be influenced or changed by highway safety engineers, including: traffic flow (AADT), segment length, minimum radius of curvature, average gradient, seal width, SCRIM coefficient, mean texture depth, region, KiwiRAP roadside hazard rating, approaching vehicle speed, number of accessway trips.

Data

The included sections of the New Zealand state highway network (6829km) were split into 17,087 curved elements (2195km) and 13,490 straight elements (4634km). A relational database was developed in Excel which outlined all the elements of the state highway network with their corresponding variables. This study drew upon data from four sources:

1 RAMM database contains roading data for road assessment and maintenance management for New Zealand state highways. Most of the data used in this study was derived from this database.

2 KiwiRAP is a road assessment programme which is associated with the International Road Assessment Programme (iRAP). The data from KiwiRAP was used in assessing the level of roadside hazards along the state highways.

3 Koorey database was compiled as part of Koorey's thesis (2009). 'Cleaned' crash data for years 2002 to 2006 and approach speed data was used from this database which originally sourced its data from CAS and the RAMM database.

4 NZ Transport Agency videos were used to identify the location of accessways along certain sections of state highways.

Results

The models support previous research findings which show that wider and steeper roads, and those carrying more traffic, have a higher number of crashes. Traffic volume is particularly important for head-on crashes, as evidenced by the near-linear relationship between crashes and daily traffic volume. However loss-of-control and driveway-related crashes also show a significant relationships with traffic volume.

The models also indicate the significant benefits that can be achieved by improving the condition of the road surface, particularly the micro-texture. Models for both straight and curved sections show large reductions in the number of loss-of-control and head-on crashes when the condition of the road surface is improved. While the micro-texture, which has been measured through the SCRIM variable in this study, is shown to be the most important measure of the road surface because of its significant in both the straight and curved section models, the macro texture was shown to be important for loss-of-control crashes, particularly on straight segments.

29. Lamm R., Beck A., Zumkeller K. (1999). Analyse von Zusammenhängen zwischen Verkehrssicherheit und Straßenentwurf auf Außerortsstraßen - Analysis of relations between traffic safety and road design on rural roads. Straßen- und Tiefbau Jg. 53, 1999, H. 12, S. 6-12.

English translation: **Analysis of relations between traffic safety and road design on rural roads**

Scope

The content of this article is a comprehensive assessment of road design parameters and their coherences to accident occurrence. Therefore 4 different databases (used in 4 different accident studies) are involved, compared and safety effects deduced. Accident rates and accident cost rates were used for safety evaluation. Evaluated design parameters are: road width, horizontal curve radii, bendiness of single curves, gradient, sights, horizontal curve radii relations and AADT. The different results of absolute safety effects can differ over the 4 considered databases due to involvement of different accident types and timeframes. Therefore the safety discussions are based on trends of accident parameters over the range of design parameters (regression) and not on absolute values.

Data

4 different databases (used in 4 different accident studies) are involved, compared and safety effects deduced.

Results

Regarding the safety effects of the examined parameters, the study's results are the following:

- *Road width:* Road width below 5,5 m is critical for road safety, road width between 6,0 and 7,5 m is favourable for road safety, the safety gains above 7,0 m are just slight (two databases show a slight increase of accident parameters)
- *Horizontal curve radii:* Accident risk decrease with increasing curve radii (single curve). Strong decrease in accident parameters under 400 m curve radii (watershed in accident occurrence), strongest decrease below 100 m radii. The safety effects differ depending on the curve radii relations of two consecutive curves (well matched curve radii are safer).
- *Bendiness of single curves:* Allows meaningful safety estimations of single curves in the contrary to the mean bendiness over a longer road sections. General increase of accident risk with increasing bendiness. Strongest increase obviously for bendiness above 200 gon/km. Between 200 and 800 gon/km the accident risk and severity increase five-fold. In general the risk is higher by wet lanes and during darkness.
- *Gradient:* Gradient between 0 and 4 % are relatively safe. Gradient below 6 % in general just a slight impact on accident occurrence. Above 6 % a strong increase of accident rates was determined. Steep hill upwards is safer than downwards.
- *Sights:* Increase of traffic safety with increasing sights. Very high accident rates at sight below 100 m. Above 150 m sight just marginal safety gains are ascertainable.
- *Curve radii relations:* Quotient of considered radii and previous radii. Quotient below 0,8 increases the accident rate. Radii relations below 0,2 lead to a soaring accident rate. Above 0,8 just marginal safety gains are ascertainable. Balanced radii relation lead to traffic safety.
- *Sequence of design elements:* Considered sequences (straight - curve or straight - clothoids - curve). General increase of traffic safety with increasing curve radii (just slight safety gains above 350 m curve radii). Below curve radii of 300 m the sequence with clothoids is safer than without clodhoids, above 300 m no differences are conspicuous.
- *AADT:* For AADT a u-shaped accident rate is visible. Critical for traffic safety are low and high AADTs. The accident cost rates decrease continuously.

The mentioned points are results for single influencing variables. But different factors can be overlaid. To get partial solutions for this problem, multiple regressions are used (simple linear models, no APMs). The dominant influencing factor is bendiness of single curves (safety issues increase with increasing bendiness). So a classification system ('good', 'useful', 'poor' road design) was deduced referring to bendiness for identifying safety issues.

30. Leutzbach W., Zoellmer J. (1989). Zusammenhang zwischen der Verkehrssicherheit und den Elementen des Straßenentwurfs - Relationship between traffic safety and road design elements. Bundesminister für Verkehr, Abt. Straßenbau.

English translation: **Relationship between traffic safety and road design elements**

Scope

The study focuses in the examination of the relationship between traffic safety and road design parameters in two-lane rural roads in Germany, by examination of the effects of several design parameters in accident occurence.

Methodology

The relations between accident occurrence and road design parameters were examined by calculated accident parameters. All in all the safety effects of road width, curve radii, bendiness, gradient, traffic volume, curve radii relations (radii ratio) and transition from straight to curves were evaluated. Beside the evaluation of safety effects of one influencing variable, the overlay of additional variables (lighting and road conditions, traffic volume) and their coherences were proved (simple correlations). These two-time regressions delivered just some marginal additional effects (just mentioned later if there are noteworthy effects). The results are based on trend analysis of regressions between accident parameters and design element classification.

Data

The databases of 1500 km of two-lane rural roads in Baden-Wuerttemberg and accident data of 8 years (from 1978 to 1985) were used for safety assessment.

Results

Regarding the safety effects of the examined parameters, the study's results are the following:

- *Road width:* Decreasing accident rate with decreasing road width up to mean road widths. Afterwards an increase of accident rates was visible at large widths (U-shaped). Accident cost rates have similar coherences but without an increase at large widths. Coefficient of determination better for accident rates (accident costs are additional influencing variable).
- *Curve radii:* Between r<100m and r=1.000m accident rates and cost rates dropped by two-thirds. Large radii lead to a slight increase. Gains in traffic safety above r=400m are low.
- *Bendiness:* Accident rates are slightly increasing with increasing bendiness. The accident cost rates show a reversed U-shape (accidents increase with increasing bendiness but accident severity drops at high bendiness due to lower speed). Wet road surfaces are awkward at high bendiness.
- *Gradient:* Accident rate increase slightly with increasing gradient. Between 0-3% the safety effect are stronger than between 3-6%. The negative effects of high gradient increase with low traffic volume and large road width.
- *Traffic volume (AADT):* Obvious decrease of accident rate from low AADT up to AADT = 12.000 vehicles/day. Higher traffic volume leads to a renewed (slight) increase of accident rate. Accident cost rates show a degressive decrease with increasing AADT.
- *Curve radii relation (radii ratio):* Radii ratio below 0,15 has obviously high accident parameters, which are decreasing heavily. Ratio>0,25 the accident parameters are decreasing slightly. The negative effects of unbalanced radii relations increase with low traffic volume and narrow road width.
- *Transition from straight to curves:* Differentiated in sequences 'straight before radii' and 'clothoid before radii'. For both considered sequences the accident rates are decreasing expectably with increasing curve radii. The sequence 'clothoid before radii' is much better at r<200m. From r>200m no differences between both sequence types are recognisable.
- In general accident occurrence underlies a variety of influencing variables. Functional coherences are stricter for accident rates than for accident cost rates. The functional coherences are stricter for the partial collective of accident type 1 and 6 (most expectable on rural road sections) than for all accident types but tendencies are the same.

31. Federal Highway Administration (FHWA) (2014): Interactive Highway Safety Design Model (IHSDM): Making Safety a Priority in Roadway Design. USA.

Scope

IHSDM is a decision-support tool. It provides estimates of a highway design's expected safety and operational performance and checks existing or proposed highway designs against relevant design

policy values. Results of the IHSDM support decisionmaking in the highway design process. Intended users include highway project managers, designers, and traffic and safety reviewers in State and local highway agencies and in engineering consulting firms.
Methodology
The IHSDM Crash Prediction Module (CPM) is intended to be a faithful software implementation of HSM Part C, which includes crash prediction methodologies for two-lane rural highways, multilane rural highways, and urban/suburban arterials.

32. Persaud B., Lord D., Palmisano J. (2002). Calibration and Transferability of Accident Prediction Models for Urban Intersections, Transportation Research Record 1784, Paper No. 02-3293, pp.57-64.

Scope
This paper documents a research effort that demonstrates the complexity of calibrating accident prediction models for urban intersections. These complexities relate to the specification of the functional form, the accommodation of the peculiarities of accident data, and to the transferability of models to other jurisdictions.
Methodology
Models are estimated for three and four-legged signalized and unsignalized intersections and, for each of these four intersection types, separate models for injury (fatal + non-fatal) and all accident severities combined (injury plus property damage only). The model forms were selected after conducting exploratory analyses on the data using the “ID” method proposed by Hauer & Bamfo (*7*). The goal of the method is to compare the Empirical Integral Function (EIF) graph thus created with pre-established cumulative probability graphs of well-known functions (power, gamma, polynomial, etc.) in order to indicate the most appropriate relationship between the dependent variable and the candidate covariates.
Regarding the transferability of accident prediction models, this study used Toronto intersection data as the sample for a “new” jurisdiction, and calibrated recently published intersection models (3,4) for Toronto conditions using a procedure recently proposed for the application in the Interactive Highway Safety Design Model (IHSDM). As a test of the calibration procedure, predictions from the Toronto models so calibrated were then compared to predictions from the models presented earlier in this paper.
Data
Toronto data of 1990-1995 are used to estimate models for 3- and 4-legged signalized and unsignalized intersections. Vancouver and California data are also used to test the transferability of the accident prediction models.
Results
The results indicate that the models calibrated directly for the Toronto data are all quite reasonable in that the general shape of the graphs is consistent with that for other published models.
The results of the model transferability procedure tests are mixed. The results indicate that it would be reasonable to assume that the model calibrated for 3-legged unsignalized intersections in Vancouver can be recalibrated for application in Toronto using the Harwood et al. (*5*) procedure. However, the California models for signalized intersections and for unsignalized 3-legged intersections do not appear to fare as well, generally predicting more accidents than the Toronto models when the minor road AADT is low. Similarly, the Vancouver unsignalized intersection models, which predicted well for 3-legged intersections, predict quite different accident frequencies than the Toronto 4-legged models, particularly for higher minor road AADTs. It can also be concluded that the model transfer procedure works best when the model form and AADT exponents for the other jurisdictions are similar to those calibrated for Toronto.

33. Hauer E., Bamfo J. (1997). Two tools for finding what function links the dependent variable to the explanatory variables. Conference of the International Co-operation on Theories and Concepts in Traffic Safety, Lund, Sweden, 5-7 November 1997.

Scope

This paper has been motivated by interest in finding the model equation that expresses average accident frequency (the dependent variable) as a function of traffic flow, traffic control, and road features (the explanatory variables). While the context here is specific, the methods to be discussed are general and may apply equally to multivariate statistical models of transportation demand, pavement distress, weather change, or educational achievement.
The aim of this paper is to suggest two tools capable of guiding the choice of an appropriate functional form for the model equation and whether a candidate explanatory variable promises to be useful. Both tools are based on the idea that cumulative (integral) functions may reveal order where atomic presentations of the same data fail.

<u>Methodology</u>

The Integrate-Differentiate (ID) method is illustrated for the one-explanatory variable case. The functional form is sought to relate the expected accident frequency to traffic flow.
Its application is of advantage when the scatterplot of dependent versus explanatory variable is a formless cloud to which almost all functional forms could apply. The central idea of the ID method is that the formless cloud turns into a fairly definite pattern when the data is represented as an Empirical Integral Function. The transformation of a scatterplot into an Empirical Integral Function requires no assumptions and involves no loss of information.
This study further shows how the ID method can be used to build model equations with several explanatory variables. The approach applies only to model equations which are the product of several functions, each with one explanatory variable. The main idea is to examine one function at a time and to move the functions already examined into the denominator of *k*.
The CURE method is tied to the examination of residuals after regression constants were estimated. Its purpose is twofold. First, it can be used to examine whether the chosen functional form indeed fits the explanatory variable along the entire range of its values represented in the data. If not, it informs the search for a better functional form. Second, it can also be used to ascertain whether a candidate explanatory variable, one not yet used, should be introduced into the model equation. The central idea is that even when the usual plot of residuals does not show any systematic drift, by examining the cumulative residuals, potentially important patterns may emerge.

<u>Data</u>

This study used accident data for 1796 rural, two-lane, 0.05 mile long, homogeneous, non-contiguous, road sections in Maine.

<u>Results</u>

The use and usefulness of the ID method has been demonstrated on data about single-vehicle non-intersection accidents on rural two-lane roads in Maine. In one instance of application, it proved possible to first identify the power function of traffic flow and the parabola as candidate functional forms, and then to determine that the power function is the more suitable candidate of the two. In the next instance of application, the ID method was used to determine the functional form in which the explanatory variable ‘road section length’ should enter the model equation. The results confirm that what is logically sound is strongly supported by data, and demonstrate that for road sections shorter than 0.1 miles the logical relationship is violated and concluded that such road sections must not be used in modelling.

34. Federal Highway Administration (FHWA) (2010). A Guide to Developing Quality Crash Modification Factors. Report No. FHWA-SA-10-032. Gross F., Persaud B., Lyon C.

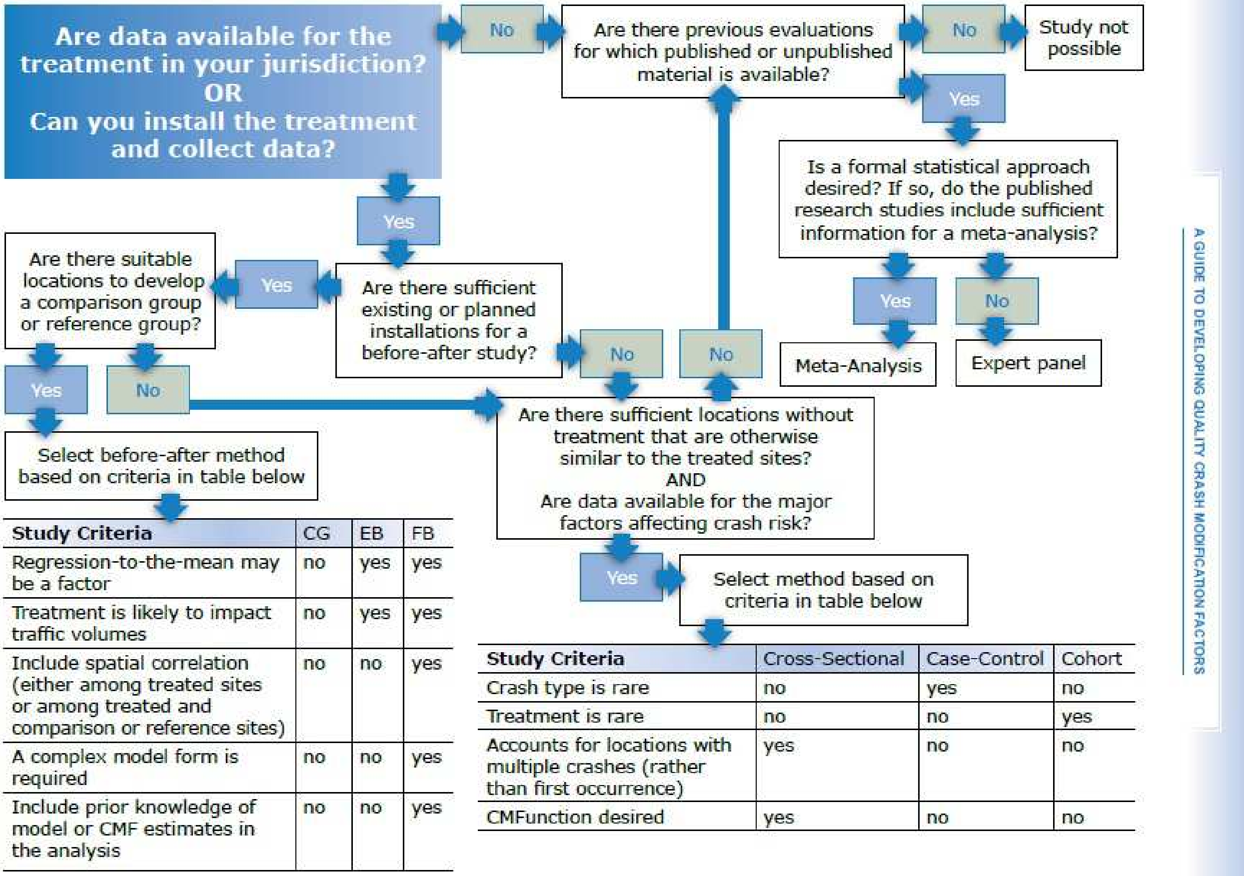
[The work is included in reference 10]

<u>Scope</u>

The purpose of this guide is to provide direction to agencies nterested in developing crash modification factors (CMFs). Specifically, this guide discusses the process for selecting an appropriate evaluation methodology and the many issues and data considerations related to various methodologies.

<u>Methodology</u>

The guide then introduces various methods for developing CMFs. Discussion of these methods is not intended to provide step-by-step instruction for application. Rather, this guide discusses study designs and methods for developing CMFs, including an overview of each method, sample size considerations, and strengths and weaknesses. A resources section is provided to help users identify an appropriate method for developing CMFs based on the available data and characteristics of the treatment in question. The resources section also includes a discussion of considerations for improving the completeness and consistency in CMF reporting.



Study Criteria	CG	EB	FB
Regression-to-the-mean may be a factor	no	yes	yes
Treatment is likely to impact traffic volumes	no	yes	yes
Include spatial correlation (either among treated sites or among treated and comparison or reference sites)	no	no	yes
A complex model form is required	no	no	yes
Include prior knowledge of model or CMF estimates in the analysis	no	no	yes

Study Criteria	Cross-Sectional	Case-Control	Cohort
Crash type is rare	no	yes	no
Treatment is rare	no	no	yes
Accounts for locations with multiple crashes (rather than first occurrence)	yes	no	no
CMFunction desired	yes	no	no

35. Haleem K., Gan A., Lu J. (2013). Using multivariate adaptive regression splines (MARS) to develop crash modification factors for urban freeway interchange influence areas. Accident Analysis and Prevention 55 (2013) pp12–21

Scope

The study aims in the development of **CMFs for interchange influence areas on urban freeways** in the state of Florida, US, regarding the effect of changes in median width and inside and outside shoulder widths, in the "total" number of crashes, the number of "fatal and injury" crashes, as well as two most frequent crash types: rear-end and sideswipe.

Methodology

In order to develop the required CMFs, the study utilizes a promising data mining method known as **Multivariate Adaptive Regression Splines** (MARS). To fit a MARS model, three main steps are applied. In the first step, i.e., the “constructive phase”, basis functions are added to the model using a forward stepwise procedure. The predictor and the knot location that contribute significantly to the model are selected. In this stage, interactions are also introduced to examine if they could improve the model’s fit. In the second step, or the “pruning phase”, the basis functions with the least contribution are eliminated using backward deletion. To overcome overfitting, a generalized cross-validation statistic is usually used, where a penalty for model complexity is accounted for. The last step is the “selection phase”, which selects the optimum MARS model from a group of recommended models based on the fitting and predictive capability of each.

Data

Roadway and Traffic features (e.g., inside shoulder width, outside shoulder width, lane width, median width, number of lanes, annual average daily traffic or AADT, etc.) were extracted from the Roadway

Characteristics Inventory (RCI) database maintained by the Florida Department of Transportation (FDOT).
Crash data (four years of data from 2007 to 2010) were extracted from the Crash Analysis Reporting (CAR) system, also maintained by FDOT.
<u>Results</u>
The study results in the development of CMFs regarding the effect in crash numbers of changes in median width and inside and outside shoulder widths. It was found that increasing the outside shoulder width from 10 to 12 ft could reduce the total, rear-end, and FI crashes by 23%, 18%, and 10%, respectively. In the same context, increasing the median width also reduces the rear-end, sideswipe, total, and FI crashes. It was found that a 42-ft reduction in the width (from 64 ft to 22 ft) could increase the rear-end, sideswipe, total, and FI crashes by 473%, 318%, 263%, and 223%, respectively. Moreover, a 2-ft increase in the inside (or left) shoulder width (from 10 ft to 12 ft) could reduce FI crashes by 33%. Interestingly, 4-ft inside shoulders also provide safety benefit, possibly as they are rarely used by drivers due to their relative narrowness.

36. Dell'Acqua G., Russo F. (2010). Accident prediction models for road networks. 4th International Symposium on Highway Geometric Design, Valencia, Spain, 2-5 June 2010.

<u>Scope</u>
This paper illustrates road safety statistical models to predict Injury accidents. Since 2003 the Department of Transportation Engineering at the University of Naples has been conducting a large scale research program based on the accident data collection in Southern Italy.
<u>Methodology</u>
Two accident prediction models were calibrated: one asassociated with two-lane rural roads and the other with multilane roadways. Explanatory variables were used including traffic flow, lane width, vertical slope,
After the calibration a validation procedure for crash prediction models for roads with rural and urban roadways and for multilane roadways was applied. This method evaluates the accuracy of two injurious accident prediction equations by analyzing the differences in observed and predicted values. The validation procedure estimates the following synthetic statistical parameters:

- Residual values estimated from the difference between predicted fatal crash values and the observed fatal crash values.
- MAD (Mean Absolute Deviation)
- MSE (Mean Squared Error)
- I, constant value equal to the square root of MSE divided by the mean of the predictive injurious crashes

<u>Data</u>
The collected data of the number of accidents covered a period of three years from 2003 to 2005 and relate to the road network of the Province of Salerno in Southern Italy. The analyzed roadways are composed of multilane roadways for 242 kilometers and Major and Minor two-lane rural roads for 3,101 kilometers
<u>Results</u>
Two accident prediction models were then validated using an accident database which had not been used to calibrate the prediction models. These two accident prediction models are statistically significant because the residual values are in a limited range around the mean.
All the parameters included in the model are significant to a 95% level of confidence, and the adjusted coefficient of determination (ρ^2) of the model is 67.3%.

37. Caliendo C., Guida M., Paris A. (2007). A crash-prediction model for multilane roads, Accident Analysis and Prevention, Vol.39, pp.657–670.

<u>Scope</u>
The paper sets out to study crash data of accidents occurring in Italy on multilane roads. The objective is to identify a specific prediction model to estimate crash frequency as a function of traffic flow, infrastructure characteristics, pavement surface conditions (including whether wet or dry) and sight distance.

Methodology
For the purpose of the subsequent statistical analysis, homogeneous road sections were first identified, i.e. segments for each carriageway having constant horizontal curvature and longitudinal slope. For these segments the following major variables did not change: width and number of lanes, type and width of shoulders, median width and type.
Given the data set of accident counts and section traits, the first step is to test the presence of "overdispersion", in order to discriminate between the Poisson model and the NB or NM models.
Once the model type is chosen, and in order to decide which subset of the full set of potentially explanatory variables should be included in the regression model, a stepwise forward procedure based on the Generalized Likelihood Ratio Test (GLRT) was used.
To measure the overall goodness-of-fit (g.o.f) in Linear Regression Models the so-called coefficient of determination, R^2 is often used.
Data
A 5-year monitoring period extending from 1999 to 2003 was carried out on a four-lane median-divided motorway. This infrastructure was 46.6 km long, and the horizontal alignment contained tangents and circular curves without any transition curves. Vertical alignment consisted of gradients and circular curves.
Some 1916 accidents were considered in this study, 21 of which were fatal and 594 were injury accidents.
Results
The models developed in this paper for Italian motorways appear to be useful for many applications such as the detection of critical factors, the estimation of accident reduction due to infrastructure and pavement improvement, and the predictions of accidents counts when comparing different design options. Thus this research may represent a point of reference for engineers in adjusting or designing multilane roads.

38. Montella A., Colantuoni L., Lamberti R. (2008). Crash Prediction Models for Rural Motorways,Transportation Research Board ISSN: 0361-1981.

Scope
In the paper, crash prediction models for estimating the safety of rural motorways are presented. Separate models were developed for total crashes and severe (fatal plus all injury) crashes. Generalized linear
modeling techniques were used to fit the models, and a negative binomial distribution error structure was assumed.
Methodology
Generalized linear modeling techniques were used to fit the models, and a negative binomial distribution error structure was assumed. The model parameters and the dispersion parameter were estimated by the maximum likelihood method by using the GENMOD procedure in SAS. Separate models were developed for all crashes and severe (fatal plus all injury) crashes.
First, to determine which explanatory variables (in addition to exposure variables) significantly affect crash frequency alone, simple models were estimated with one independent variable in each. Nonsignificant variables were excluded from further investigation. Then, the models were developed by the stepwise forward procedure, with one explanatory variable being added at each step. The decision on whether to keep a variable in the model was based on two criteria. The second criterion was related to the improvement in the goodness-of-fit measures of the model that includes that variable.
Several measures can be used to assess the goodness of fit of the models.
To measure the goodness of fit in linear regression models, the coefficient of determination R^2 is used.
Another goodness-of-fit measure used was the Akaike information criterion (AIC).
Data
The study used a sample of 2,245 crashes (728 severe crashes) that occurred from 2001 to 2005 on Motorway A16 between Naples and Canosa in Italy.
Results
For total crashes, the best model includes curvature, operating speed reduction, length of the tangent preceding the curve, and year effect, all with a positive sign; the difference between the friction demand and supply, deflection, and upgrade, all with a negative sign. All the parameters had a logical

and expected sign. The most important result was that measures of design consistency significantly affected road safety, not only on two-lane rural highways but also on motorways. As the difference between the friction demand and supply decreases, crash frequency is expected to increase. Given that existing curve superelevation is frequently smaller than the superelevation required by the standards and that superelevation adjustment is a feasible and quick measure, this result has a relevant practical effect for the selection of safety measures.

39. Hauer E., Bonneson J., Council F., Srinivasan R., Zegeer C. (2012). Crash Modification Factors Foundational Issues. TRB 2012 annual meeting of the Transportation Research Board, Washington, 22-26 January 2012.

Scope

The conceptual framework described in this paper aims to provide guidance for research about CMFs and for meta-analyses. The central claim is that CMFs are random variables and are not universal constants that apply everywhere at all times. The smaller the standard deviation of a CMF, the more confident the related decision making can be. Therefore, the aim of research into CMFs is to reduce their standard deviations.

Methodology

Several fundamental issues are discussed in this paper as following.

(1) How CMFs are Used: The main use of the estimate θˆ (*a*, *b*) of θ(*a*, *b*) is to predict what is expected to be the safety effect of doing *a* instead of *b* in some specific circumstance. The safety effect of implementing *a* instead of *b* is usually measured by the expected change in the number of target crashes (by severity).

(2) CMFs as Random Variables: it should not be assumed that θ(*a*, *b*) is a universal constant that has the same value always and everywhere. Rather, θ(*a*, *b*) should be viewed as a random variable,the value of which depends on a host of factors. These factors, taken together, will be referred to as the circumstances of implementation. Since θ(*a*, *b*) is a random variable, it has a probability distribution with a mean and a variance. For some actions, the θ(*a*, *b*) may vary little from one implementation to another, and therefore the variance will be small; for other actions the variance may be large. How large is the variance of θ(*a, b*) is an empirical question, and ways to answer it will be described. Thinking of θ as a random variable allows the question of transferability to be correctly framed.

(3) Observations and Missing Data: A prediction of θ is insufficiently accurate when some likely-to-occur values of θ lead to the decision to implement and other likely-to-occur values lead to the opposite decision. Decisions based on insufficiently accurate predictions are in danger of being wrong. It follows that rational decision making about actions that have safety consequences requires three estimates: the current estimate θ of *E*{θ}, its standard error *s*{θ}, and an estimate of σ{θ}. Whereas the decision to implement or not implement is based on θ, both *s*{θ} and σ{θ} are needed to know whether the decision can be made with confidence.

(4) Effective CMF Research: To reduce the chance of wasting resources by making bad decisions, Var*{θ} must be reduced. Two approaches are discussed: conducting more studies, and making θ a function of circumstances

Data

Arizona and British Columbia data are used to illustrate the models. However, the data set is not clearly described.

Results

For tomorrow's research to contribute to future research cumulation, its results must be reported in the requisite detail. At a minimum, it must contain the relevant estimates of θ and their standard errors, but, preferably, it should contain the estimates of μ_a, Var{μ_a}, μ_b, and Var{μ_b}. In addition, it must contain information about the relevant circumstances of the implementation. The relevant circumstances are those that might materially affect the θ. Only then will subsequent researchers be in a position to make θ a function of circumstances; only then will the chance of making incorrect decisions be substantially diminished.

40. Caliendo C., De Guglielmo M., Guida M. (2013). A crash-prediction model for road tunnels, Accident Analysis and Prevention, Vol.55. pp.107-115.

Scope

The objective of this paper is to identify specific prediction models to estimate crashes in road tunnels as a function of traffic and of geometric infrastructure characteristics.

Methodology

Thus, in the paper, in order to decide which subset of the full set of potentially explanatory variables should be included in the regression model, a procedure based on the Generalized Likelihood Ratio Test (GLRT) was used.

In the present paper they are interested in modeling the number of “non-severe” and “severe” crashes, which are expected to be positively correlated random variables. Two different regression models are take in account: the Negative Multinomial (NM) regression model and the Random Effects Negative Binomial (RENB) regression model.

In order to get a better fit to tunnel data, the present paper proposes a specific functional to take in account the AADTL variable.

Data

A 4-year monitoring period extending from 2006 to 2009 was considered for Italian motorway tunnels. The database consisted of 260 tunnels with unidirectional traffic only, 232 of which were two-lanes tunnels while the remaining 28 were three-lane tunnels.

The total length of the tunnels monitored was 303 km, with a total length of two-lane tunnels of 276 km and 27 km for three-lane tunnels, respectively. During the monitored period, crash data and traffic flow were collated. Accident data were extracted from the official reports of the Motorway Management Agencies (MMA) of these tunnels.

The total number of injured persons was 777, and in addition there were also 18 fatalities. In two-lane tunnels 1950 accidents were registered (670 of which were severe crashes) while in three-lane tunnels 354 accidents were counted (95 of which were severe crashes).

Results

The results of the bivariate statistical analysis shows that the number of both non-severe and severe crashes occurring in unidirectional motorway tunnels increases with the tunnel length, the annual average daily traffic per lane, the percentage of trucks, and the number of lanes. These results tend to confirm the hypothesis that longer tunnels are associated with a greater number of accidents due to the drivers’ diminishing concentration with increasing length; and that, in free-flowing conditions, as AADT per lane and/or percentage of trucks increase, the frequency of lane changing and overtaking movements increase so that more accident are expected. Additionally, by means of an increasing number of lanes, the opportunities for lane change increase so that more traffic conflicts and consequently more accidents should also be expected.

41. Peltola H., Rajamäki R., Luoma J. (2013). A tool for safety evaluations of road improvements, Accident Analysis and Prevention, Vol.60, pp.277-288.

Scope

We demonstrate a safety evaluation tool called TARVA. It uses EB safety predictions as the basis for selecting locations for implementing road-safety improvements and provides estimates of safety benefits of selected improvements.

Methodology

This paper presents specific software called TARVA to maximize efficient use of existing reliable safety knowledge. TARVA provide a common method and database for (1) predicting the expected number of road accidents if no measures are implemented for selecting locations for safety treatments and (2) estimating the safety effects of road safety improvements in order to evaluate the cost-effectiveness of combinations of safety measures. The underlying logic of TARVA is combining general safety (accident model) with information from local safety factors (accident record) using the EB method. The estimation of safety effects of road improvements is a four phase process:

(1) For each entity (homogeneous road section or crossing, or level crossing) the most reliable estimate of the expected accident number is calculated.

(2) To predict the number of accidents without road improvements, the most reliable estimate of the number of accidents can be corrected by the growth coefficient of the traffic.
(3) The effects of the measures on injury accidents are estimated based on the predicted number of accidents and planned measures for which the average impacts on injury accidents have been estimated.
(4) Measures can also affect the severity of accidents still occurring on the road after treatment. TARVA takes these effects into account with severity reduction coefficients. Using the evaluated injury accident reduction percentage and available knowledge on the average severity (fatalities per 100 injury accidents) and its change, TARVA produces an estimate of yearly-avoided fatalities.

To demonstrate the contents and use of TARVA in practice, this study describes the creation and use of the version intended for evaluations on Finnish highways.

<u>Data</u>

Finnish highway accident data from 2007 to 2011 is used in this study. Road groups are divided by road class, with/without housing, wide/narrow, junction type, AADT and speed limit.

<u>Results</u>

The results showed that the most accurate estimates are produced by EB models, followed by simple accident prediction models and the same average number of accidents for every entity. Reliably predicting the number of accidents if no measures are implemented is highly crucial for selecting the locations to be treated in an optimal way. Additionally it is essential for estimating the safety effects of road improvements. Estimates on crash modification factors might be transferred from other countries but their benefit is greatly limited if the number of target accidents is not properly predicted. Without proper knowledge and tools one can end up making huge errors in cost-effectiveness estimates, and traffic safety work is ineffective. The authors also suggest that making predictions and evaluations using the same principle and tools will remarkably improve the quality and comparability of safety estimations.

42. Hauer E. (1997). Observational Before-After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety. Emerald Books.

<u>Scope</u>

Scope of the publication is to assist road safety practitioners in understanding, planning, analysing and interpreting observational Before-After Studies, regarding the effect of highway and traffic engineering measures on road safety.

<u>Methodology</u>

In order to achieve the aforementioned objective, the publication is organised in three parts:

In **Part I**, essential background information is included regarding road safety as well planning and analysis of an observational Before-After Study, such as:

- a presentation of the basic logic behind attempts to estimate the effect of any kind of treatment,
- a discussion on what safety is and how it can be measured,
- a discussion on road accident data; what accidents are being counted and are therefore available for safety estimation in comparison to what accidents should be considered in a Before - After Study, and
- an analysis of the role of prediction and estimation within a Before - After Study, as in predicting the safety of the road entity in the "after" period, if the examined treatment had not been applied, in contrast to estimating the safety of the treated road entity in the "after" period.

In **Part II**, an attempt to adapt conventional approaches to the realities of observational studies is performed, that includes:

- a presentation of a unified framework for all Before - After Studies,
- a criticism on Before - After Studies with no comparison group,
- a discussion on how changes in traffic flow and other similar factors can be accounted for,
- a discussion on how using a comparison group can assist in accounting for several factors, and
- recommendations on how to combine results from several entities, sites or studies.

Finally, **Part III** of the monography is devoted to the exposition of new approaches to the interpretation of observational Before - After Studies, such as the Empirical Bayes approach, and a suggestion of a more coherent approach to the conduct of an observational Before-After Study, based on a multivariate model.

43. Cafiso S., D'agostino C. (2012). Safety Performance Function for motorways using Generalized Estimation Equations, Procedia – Social and Behavioral Sciences, Vol.53, pp.900-909.

Scope

The study shows a procedure of analysis for motorways network offering a comparison between the conventional analytical techniques based on GLM (Generalized Linear Model) and a different approach based on GEE (General Estimating Equation). The GEE model, incorporating the time trend, is compared in terms of results and reliability in the estimation with conventional models (GLM) that do not take into account the temporal correlation of accident data.

Methodology

The paper presents six different APMs, two of which incorporate temporal trends in the calibration of models with the use of GEE. The remaining four APMs were calibrated using basic and multivariable models by the way of classical GLM and GEE without trend. The purpose of the paper was to investigate the accuracy of different models that incorporate temporal trends respect to the classical models which do not take into account the temporal correlation of crash data. The time trend models were calibrated with the use of SAS software for which a script was created ad hoc by which it was possible to generate models that have a different constant value depending on the year of analysis. In this way it is possible capture the variations in the expected number of accidents of sites investigated, due to the time correlation, compared to a year of analysis included in the time period analyzed. Analyzing the results it can be stated that the time correction generates a better goodness of fit of models that incorporate temporal trends. It also corrects over-underestimation of the standard errors of the regression coefficients and of the dispersion parameter obtained by the more traditional GLIM approach. Improving accuracy in the calibration of regression parameters and standard errors improve the quality of the SPMs and lead to more refined results when the EB approach is used to control the phenomenon of regression to the mean.

Another advantage is related to the possibility of using a broader period of analysis. In fact, GEE that incorporate temporal trends are not affected by the extension of the period of analysis for two reasons. The first is that the data are analyzed as repetitions of the variables in different years and therefore although this reduces the size of the sample, makes sure that the analyst can use more years of analysis. The second is that the temporal correlation that is generated between the sites in different years does not generate errors related to the type and size of the correlation matrix used in the calibration of the model and this allows to insert all the years available. This characteristic is useful especially when long period of observations are needed to increase the sample size or to carry our before/after studies. In contrast, the calibration of the models with GEE is critical in case of missing value and therefore requires a quality and detail of data higher than the traditional techniques.

Data

The application of the proposed safety performance function is performed on segments of the A18 CT-ME from the years 2003 to 2009 excluding 2004 because during year 2004 the Agency has adequate safety barriers in different parts of infrastructure changing the homogeneity of the segments within the year of analysis. The whole dataset consists of 652 segments of variable length and more than 70 m. Accident take into account are fatal and injury, for an amount of 451 accident in six years of analysis.

Results

In general, the models which do not consider time trend analyzes used the database as whole do not taking into account the repetition of the segment in different years, therefore, considering a larger sample than model with time trend of t times where t is the number of years of analysis. This is the reason for the lower value of dispersion parameter in models that incorporate temporal trends than the other. In practical terms, analyzing the results, the traditional models that incorporate temporal trends would underestimate the expected number of accidents in the years 2003, 2006 and 2007 while we overestimated the value of the 2005 expected number of accidents, all related to last year of analysis. Referring to the dispersion parameter, has to be noted that difference in the estimation of the dispersion parameter can produce different results when the Empirical Bayes procedure is applied.

44. Cafiso S., D'agostino C., Persaud B. (2014). Investigating the influence on safety of retrofitting Italian motorways with barriers meeting a new EU standard. TRB 2014 annual meeting of the Transportation Research Board, Washington, 12-16 January 2014.

Scope
The paper seeks to quantify the effect on the frequency of fatal+injury crashes of retrofitting motorways with barriers meeting the new standards, by performing an empirical Bayes before-after analysis based on data from the A18 Messina-Catania motorway in Italy.
Methodology
To consider time trend in the estimation of the CMF an empirical Bayes before-after study was used, the change in safety is given by the comparison between the number of reported crashes in the after period (A) and the expected number of crashes that would have occurred in the "after" period without the treatment (B). For the B period an empirical Bayes (EB) procedure was used to first estimate the number of crashes predicted at the treated sites based on reference sites with similar traffic and physical characteristics.
The SPF was calibrated considering an average AADT value for the whole period of analysis (7 years) and the sums of crashes for each segment. The estimation obtained for each year was than corrected with a multiplier given by the ratio of the sums of yearly observed crashes and the SPF estimates for the reference sites.
Consistent with the state of research in developing these models, the negative binomial error distribution was assumed for the count of observed crashes. For the empirical Bayes evaluation, the negative binomial dispersion parameter was estimated from the calibration of the SPF using a maximum likelihood methodology.
Data
The data used for this investigation are based on an Italian rural motorway, the "A18" Messina-Catania, which is approximately 76 km long. The cross section is made up of two 3.75 m travel lanes and a 3 m emergency lane in each direction. Carriageways are divided by a median with barriers. The analysis periods are from 2002 to 2004 for the before period and from 2006 to 2009 for the period after the barriers were installed in 2005. In the seven years of analysis, 327 severe (fatal plus injury) crashes occurred as reported in the official statistics on motor vehicle collisions provided by the Italian National Institute of Statistics.
Results
The point estimates are encouraging in that they indicate a strong enough safety benefit for ran-off road crashes, without any change in non-ran-off road crashes. However, the large standard deviation indicates that the sample of treated sites is not yet large enough to estimate a robust CMF with sufficient statistical significance. The results are encouraging enough to suggest that barrier retrofit should continue since they indicate benefit cost ratios in the range of 6 to 16, depending on the AADT (which is in the range 10,000 – 30,000 per direction), and assuming a retrofit cost of about $335,000 per km (€250,000 /km), unit crash cost of $535,000 (€400,000/km), and a 20 year service life.

45. Cafiso S., Di Graziano A., Di Silvestro G., La Cava G., Persaud B. (2010). Development of comprehensive accident models for two-lane rural highways using exposure, geometry, consistency and context variables, Accident Analysis and Prevention, Vol.42, pp.1072-1079.
Scope
This paper describes a novel and extensive data collection and modelling effort to define accident models for two-lane road sections based on a unique combination of exposure, geometry, consistency and context variables directly related to the safety performance.
Methodology
The first part of the paper documents how these were identified for the segmentation of highways into homogeneous sections.
On the basis of the data collected, the following parameters were identified in order to divide the sample into homogeneous sections:

- Average Annual Daily Traffic (AADT) to describe the exposure to accident risk.
- Curvature Change Rate (CCR) and average paved width (W) to describe main road geometry characteristics.

- Road Side Hazard rating (RSH) to describe roadside conditions.

Next part, is a description of the extensive data collection effort that utilized differential cinematic GPS surveys to define the horizontal alignment variables, and road safety inspections (RSIs) to quantify the other road characteristics related to safety.

The final part of the paper focuses on the calibration of models for estimating the expected number of accidents on homogeneous sections that can be characterized by constant values of the explanatory variables. The models proposed are based on the Generalized Linear Modeling approach (GLM), which has the advantage of overcoming the limitations of conventional linear regression in accident frequency modeling. In particular, it facilitates the assumption of a Negative Binomial error structure, which is more pertinent to accident frequency variation.

Data

The survey was conducted on a sample of 168.20km of two-lane local rural roads located in Italy. A GPS survey was used to collect horizontal alignment information (curvature and tangent length) and road safety inspections (RSIs) were conducted in order to quantify the characteristics of the other feature (cross section, density of driveways, and roadside hazard). A 5-year analysis period was chosen for the investigation period to compensate for the low traffic flow and accident frequencies usually expected on local rural roads.

Results

14 variables belonging to four main groups (exposure, geometric, consistency and context) were identified and used to estimate several models using the Generalized Linear Modeling approach with a Negative Binomial error structure. Three models were selected as recommended models based on practical considerations, statistical significance, and on goodness of fit indicators:

- Model 1 includes only the exposure variables, length (LHS) and traffic volume (AADT).
- Model 15 includes length (LHS), traffic volume (AADT), driveway density (DD), curvature ratio (CR) and the standard deviation of the operating speed profile (s).
- Model 19 includes length (LHS), traffic volume (AADT), driveway density (DD), roadside hazard rating (RSH), curvature ratio (CR) and number of speed differentials higher than 10 km/h (∆V10).

46. FHWA CMF Clearinghouse: How to Develop and Use CMFs. Federal Highway Administration (FHWA).

Available on-line at: http://www.cmfclearinghouse.org/resources_develop.cfm

Scope

The part "How to Develop and Use CMFs" of the FHWA CMF Clearinghouse aims to provide guidance for the identification of opportunities to consider and quantify safety in specific activities, for the development of reliable Crash Modification Factors and the application of CMFs, including guidance on how to estimate the combined treatment effect when multiple treatments are installed at a given location.

Contents

The part "How to Develop and Use CMFs" of the Clearinghouse contains the following resources:

1. **CMFs in Practice series**

   The CMFs in Practice Series includes two reference documents with background information on crash modification factors and safety performance functions and five separate guides that identify opportunities to consider and quantify safety in specific activities, along with the presentation of relevant case studies. Specifically, the series consists of the following sections:

   - Introduction to Crash Modification Factors - defines crash modification factor and highlights key factors to consider when applying CMFs.
   - Introduction to Safety Performance Functions - defines safety performance functions and highlights various application scenarios, as well as calibration requirements.
   - Quantifying Safety in the Roadway Safety Management Process: When used in the roadway safety management process, CMFs can help teams select countermeasures and prioritize projects through an economic evaluation. A case study highlights the Strategically Targeted Affordable Roadway Solutions program in Virginia.

- Quantifying Safety in Road Safety Audits: CMFs can be applied in the Road Safety Audit (RSA) process to quantify the safety effects of treatments and justify RSA team's suggestions to the project owner. A case study shows how CMFs were applied by the Michigan Department of Transportation in a RSA.
- Quantify Safety in Alternatives Development and Analysis: CMFs can be applied in the analysis of alternatives to quantify the safety performance of alternative designs. This is illustrated in two case studies, one regarding the selection between two intersection designs as part of a new interchange by the Colorado Department of Transportation and another to illustrate how CMFs were used in conjunction with SPFs by the Arizona Department of Transportation in the development and analysis of alternatives.
- Quantify Safety in Design Decisions and Exceptions: CMFs can be applied to quantify the safety impacts of individual design elements and evaluate the overall impact of design exceptions on the safety performance of a facility. One case study illustrates how CMFs were applied by the California Department of Transportation to estimate the safety impacts of proposed engineering improvements after 24 collisions occurred over a three-year period on a section of US 199. Another case study illustrates how CMFs were applied in conjunction with safety performance functions (SPFs) by the Missouri Department of Transportation to quantify the safety performance of various design elements.
- Quantify Safety in Value Engineering: CMFs can be applied in the Value Engineering process to explicitly consider and quantify safety impacts of opportunities identified by the study team. A case study illustrates how CMFs were applied in conjunction with SPFs by the Missouri Department of Transportation to quantify the safety impacts of opportunities related to the cross section and roadside design.

2. **Recommended Protocols for Developing CMFs** (NCHRP, 2012)**:**
   The CMF Protocols provide guidance for the development and documentation of research studies that develop CMFs. The major goal of these protocols is to describe what pieces of the research study should be documented by the study authors and how various potential biases should be addressed.
   The main sections of this document are as follows:
   - Knowledge section - basic knowledge on each of the study types that can be used to develop CMFs and other basic issues related to the development of CMFs. It features a description of potential issues that can bias the study results and recommendations as to how these biases should be addressed.
   - General documentation - list of the general details on the research study that can be used to determine where it is appropriate to apply the CMF. These items are recommended for documentation by any research study that develops CMFs.
   - Biases documentation - list of the potential biases for each study design. These items are recommended for documentation by any research study that develops CMFs.
   - Appendices: A. Summary of Literature, to identify and briefly summarize relevant literature related to each study design.
     B. Method Correction Factor Tables from HSM Inclusion Process, to present the tables showing how HSM reviewers determined which method correction factor would be used for each CMF study that was reviewed for inclusion in the HSM, and
     C. Summary of the CMF Protocols Documentation Requirements, list of all documentation requirements presented in the CMF Protocols document.
3. **A Guide to Developing quality CMFs** (FHWA, 2010)**:**
   The purpose of this guide is to provide direction to agencies interested in developing crash modification factors (CMFs). Specifically, this guide discusses the process for selecting an appropriate evaluation methodology and the many issues and data considerations related to various methodologies.
   The guide includes a background of CMFs (definition of CMFs and related terms, purpose and application, and general issues related to CMFs), and an outline of various methods for developing CMFs, such as Before-After with Comparison Group Studies, Empirical Bayes Before-After Studies, Full Bayes Studies, Cross-Sectional Studies, Case-Control Studies, Cohort Studies, and Alternative Approaches for Developing CMFs. Finally, a resources section is provided to help users identify an appropriate method for developing CMFs based on the available data and characteristics of the treatment in question. The resources section also includes sample problems

as well as a discussion of considerations for improving the completeness and consistency in CMF reporting.

4. **Investigation of Existing and Alternative Methods for Combining Multiple CMFs** (FHWA, 2011)**:**
   This technical report aims to discuss several issues associated with the application of multiple CMFs and provide guidance on how to estimate the combined treatment effect when multiple treatments are installed at a given location.
   In the report, several existing methods for combining multiple CMFs are presented, such as: methods examined in NCHRP Project 17-25, methods presented in Highway Safety Manual and CMF Clearinghouse, Meta-Analysis methods and utilization of Crash Modification Functions. Next, issues related to the application of multiple CMFs are discussed, such as the assumption of independence, the logic of added benefit versus fallacy of additive effects, the lack of consistency (judgment), the applicability of CMFs, the lack of detailed CMF information and issues in computing a confidence interval. Several ideas and methods are explored for overcoming the identified issues, and, finally, the methods are applied and compared to existing CMFs for multiple treatments in an attempt to validate the new procedures.
5. **Better CMFs, safer roadways: Tips for building high-quality CMFs**
   This two-page flyer provides a basic overview on how to develop high-quality CMFs, with information on questions such as: “What does a quality CMF study look like?” and “Why is documentation important?”

47. FHWA CMF Clearinghouse: How to Develop and Use SPFs. Federal Highway Administration (FHWA).

Available on-line at: http://www.cmfclearinghouse.org/resources_spf.cfm

Scope

The part "How to Develop and Use SPFs" of the FHWA CMF Clearinghouse aims to provide guidance for the calibration of the Safety Performance Functions (SPFs) from the Highway Safety Manual as well as the development of SPFs.

Contents

The part "How to Develop and Use SPFs" of the FHWA CMF Clearinghouse contains the following resources:

1. **Safety Performance Function Decision Guide: SPF Calibration vs. SPF Development** (FHWA, 2013)**:**
   This guidebook is intended to provide guidance on whether an agency should calibrate the safety performance functions from the Highway Safety Manual or develop jurisdiction-specific SPFs. The guidebook includes a brief overview of other documents being developed by FHWA and NCHRP to facilitate the implementation of the HSM, followed by a brief discussion of “What are SPFs” and how SPFs are used for different applications, i.e., network screening, project level analysis, and determining the safety effect of improvements. Furthermore, the two options for obtaining SPFs for a jurisdiction (calibration of existing SPFs versus development of jurisdiction specific SPFs) are discussed along with a brief overview of the steps involved in the calibration and development of jurisdiction specific SPFs. Finally, the step by step process that an agency could use to obtain SPFs is presented.
2. **Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs** (FHWA, 2013)**:**
   This guidebook is intended to provide guidance on developing safety performance functions from the Highway Safety Manual. The guidebook includes a brief overview other documents being developed by FHWA and NCHRP to facilitate the implementation of the HSM, followed by a brief discussion of “What are SPFs” and how SPFs are used for different applications, i.e., network screening, project level analysis, and determining the safety effect of improvements. Next, there is a discussion of the statistical issues associated with the development of jurisdiction specific SPFs, such as: overdispersion, selection of explanatory variables, functional form of the model and the explanatory variables, overfitting of SPFs, correlation among explanatory variables, homogenous segments and aggregation, presence of outliers, endogenous explanatory variables, estimation of SPFs for different crash types and severities, and goodness of fit. This is followed by a step by step approach that can be used to develop jurisdiction specific SPFs. Finally, recent

developments in SPF development are discussed, such as: variance of crash estimates obtained from SPFs, temporal and spatial correlation, other model forms, Generalized Additive Models, Random Parameters models, Bayesian Estimation methods, and a brief overview of available software tools is provided.

3. **User's Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors (NCHRP, 2014):**
The use of Highway Safety Manual crash predictive models in any jurisdiction calls for calibration of safety performance functions and replacement of crash severity and collision type distribution tables and adjustment factors to local and current conditions. The Guide is focused on the predictive method found in part C of the HSM, that is used to estimate the expected average crash frequency of an individual site. The use of the predictive models calls for calibration of the HSM SPFs, and replacement of crash severity and collision type distribution tables and adjustment factors to local and current conditions (different climate, driver populations, animal populations, crash reporting thresholds and procedures, time periods etc.). This Guide's aim is to support the development of calibration factors and the adaptation of crash distribution tables and adjustment factors to local and current conditions.

48. Chen Y., Persaud B., Sacchi E. (2012). Improving Transferability of Safety Performance Functions by Bayesian Model Averaging, Transportation Research Board of the National Academies, Vol.2280, Highway Safety Data, Analysis, and Evaluation 2012.

<u>Scope</u>
This paper aims to address this issue by connecting model calibration, new modeling, and model selection with the aim of achieving better transferability. The paper proposes a Bayesian model averaging (BMA) approach in which no reasonable SPF, either calibrated or locally developed, would be discarded. In this approach, all competing models are assembled together to construct a unified model.

<u>Methodology</u>
First, the calibration factor approach was evaluated by the use of goodness-of-fit tests. Then, local models were developed and evaluated. For these models, a variety of random structures for frequentist and Bayesian approaches was explored with generalized linear regression, nonlinear mixed fitting, or Markov chain Monte Carlo simulation procedures.
Finally, a Bayesian model averaging approach that integrated all considered models was investigated as an alternative to traditional model selection. This methodology did improve model transferability over all ranges of covariates, suggesting that Bayesian model averaging can be a sound alternative to conventional model calibration, especially when the flexibility and estimation ease of this technique are considered. Moreover, this approach is conceptually superior to selection of a single best model because it explicitly addresses model uncertainty.

<u>Data</u>
Four groups of data were used. These data are for urban four-leg signalized intersections from Canada (Toronto, Ontario, Canada, and Edmonton, Alberta, Canada), a roundabout in Italy, and an undivided multilane highway segment from Ontario, Canada.

<u>Results</u>
The results of this exploratory study are promising enough to suggest that BMA can be used in practice as a viable alternative to conventional model calibration and selection. In particular, the BMA approach is a promising means to adapt and transfer HSM models for local conditions.

49. Montella A., Mauriello F. (2012) Procedure for Ranking Unsignalized Rural Intersections for Safety Improvement, Transportation Research Board, ISSN: 0361-1981

<u>Scope</u>
The paper presents a procedure for ranking rural unsignalized intersections that uses quantitative safety evaluations performed as part of the safety inspection process. The procedure might be effective for the selection of cost-effective treatments at intersections and might be quite helpful for administrations that do not have high-quality crash data and for those that manage low-volume roads for which crash data cannot give enough information to help prevent future crashes.

Methodology
The procedure in this paper assesses an SI (The SI is formulated by combining two components of risk: exposure of road users to road hazards and the probability of their becoming involved in a crash) that measures the safety performance of each intersection. Key elements in developing the procedure are the following:

- Ensure that the SI can be assessed as part of the safety inspection process without relevant supplementary work;
- Construct the process such that the results can be used to rank intersections where safety measures can give the greatest crash reduction;
- Construct the process such that the safety issues that contribute the most to safety problems are identified;
- Ensure that the SI is valid by comparing its results with crash history.

Data
In the paper a sample of 22 rural three-leg intersections was used, located in Italy on the national highways SS-6 Casilina and SS-7 Appia, was used to validate the procedure. Crash data were collected by analysis of police reports and integrated with detailed site inspections. Crash data refer to the period 2001 to 2009. In the analysis period, 79 crashes occurred. AADT volumes were provided by the highway agency.
Results
The SI has two main practical applications. High-risk intersections for which safety measures that can reduce crash frequency are available can be identified and ranked by the SI. Specific issues that contribute to unsafe conditions are identified to determine more appropriate safety measures. The RI of general safety issues ranks different types of safety measures at each intersection, whereas the SI of a single safety issue ranks the intersections in relation to a specific safety improvement program. Furthermore, the SI of the intersections can be integrated with the SI of the road segments and assessed according to the IASP procedure so as to perform an overall safety evaluation that takes into account both segments and intersections.
Because the available budget is frequently insufficient to undertake all safety measures, criteria to optimize the budget are needed. Optimization procedures, such as total enumeration and incremental benefit–cost methods, can be used get the most from safety investments by computing the benefits as the change in the SI attributable from the safety measures. To identify safety measures that provide maximum benefits within the limits of the available budget.

50. La Torre F., Domenichini L., Corsi F., Fanfani F. (2014). Transferability of the Highway Safety Manual Freeway Model to the Italian Motorway Network. In Transportation Research Record: Journal of the Transportation Research Board, No. 2435, Transportation Research Board of the National Academies, Washington, D.C.

Scope
The paper has been conducted on the primary Italian motorway network in order to evaluate the potential issues that occur applying this methodology to a network characterized by different environmental conditions, road characteristics, driver behavior and crash reporting systems, as compared to the ones where the HSM models have originally been developed
Methodology
The calibration coefficients can be evaluated through the following steps in according to the NCHRP model:
Segmentation process
Due to crash reporting issues, the freeway network has been divided into segments of 0.621 mi (1 km) length, with their centre in the milepost (the standard section starts at km “i” +500 km and ends at km “i+1” +500).
Crash Modification Factors (CMFs)
Given the proposed segmentation assumptions, some of the variables for which a CMF is given in the model, vary within freeway segments. In these cases an “equivalent” CMF has been calculated as a weighted average of the different conditions found in a segment.
Calibration procedure

The NCHRP calibration procedure has been applied with the following exceptions:

- Despite the fact that the NCHRP procedure recommends to consider a calibration period not longer than three years, five years were considered because of the congruence of available data in the analyzed period (without any major regulatory change or major construction works);
- Despite the NCHRP procedure recommends a minimum value of 100 crashes/years to calibrate a model, an exception has been considered for the speed-change lanes segments due to the limited number of crashes/years that occurred in these sections of the network (about an average of 50 crashes/years were considered).

Goodness of fit of the calibrated models
In this application the following indicators to assess the performance of the calibrated models have been adopted:

- Mean Absolute Deviation (MAD);
- Calibrated overdispersion parameter;
- Root Means Square Error (RMSE);
- Residual plots.

Data
The freeway network considered in this study has been represented by 56 freeway sections characterized by an average length of about 12.5 km, covering 700 km of freeway distributed along all the country. The period considered in this analysis is 5 years long (2005 to 2009).
Results
The results show a good transferability of the analyzed models to the Italian network and especially the freeway models for fatal and injury crashes. Some improvements could be made considering variable calibration factors within the datasets or crash modification factors local calibrations. The need for an improved localization of the crash data on the Italian road network has also been highlighted, mainly for speed-change lanes.
The calibration procedure applied to the Italian freeway network resulted in the 8 calibration factors required by the procedure.

51. Martinelli F., La Torre F., Vadi P. (2009). Calibration of the Highway Safety Manual's Accident Prediction Model for Italian Secondary Road Network. In Transportation Research Record: Journal of the Transportation Research Board, No. 2103, Transportation Research Board of the National Academies, Washington, D.C.

Scope
In the study reported in this paper the HSM segment model calibration procedure has been applied to the Arezzo province road network in order to evaluate the effective transferability of the HSM model.
Methodology
In the study reported in this paper the HSM segment model calibration procedure has been applied to the Arezzo province road network in order to evaluate the effective transferability of the HSM model.
For the calibration the HSM procedure is applied to the network stratified criteria, and this can solve the problem of having a huge amount of “zero accidents” sections but, on the other hand, raises the problem of calculating the AMF of a “family” of sections for which a single feature can vary in a very wide range. The approach adopted in this study is to evaluate the length weighted average for all the parameters and then to calculate the AMF coefficient corresponding.
In accordance with HSM procedure the AMF considered are those accounting for: horizontal curves, lane width, shoulder width, driveway density and grade. Different possible calculation procedures have been analyzed to determine the overall calibration coefficient.
Data
Geometry database The considered rural two-lane highways road network has been reduced to 938 kilometers.

Traffic database All road segments in which the network have been divided are characterized by an AADT value and this allows to group them together according to the traffic categories proposed by HSM.

Accident database The database contains more than 6,000 events occurred between 2001 and 2005, for this analysis a three years long period has been chosen in accordance with the HSM prescription. The analysis period adopted is 2002-2004 due to an incomplete data reporting for 2001 and 2005, after this selection the amount of data available was reduced to 3,783.

Results
The results have been analyzed in terms of actual versus predicted and residual plots leading to the conclusion that the best approach is the base model with AMF calculation, applied to the stratified classes defined by the HSM procedure but with the calibration coefficient calculated not as a simple mean of each class coefficient but using a weighted average based on the total length of the sections in each class.

52. RISMET Research Project (2011). Road Infrastructure Safety Management Evaluation Tools.

Available on-line at: http://rismet.swov.nl/index.htm
Scope
The RISMET research project (Road Infrastructure Safety Management Evaluation Tools), part of the ERA-NET ROAD program aims at developing suitable road safety engineering evaluation tools which will allow the easy identification of both unsafe and potentially unsafe locations in a road network.
Methodology
Since evaluation tools rely on good quality data, RISMET reviewed available data sources for effective road infrastructure safety management in EU-countries, linked to a quick scan and assessment of current practices. This assessment expand upon what was learned in the RiPCORD-iSEREST project. Specific attention was paid to new developments such as 'Safe speeds and credible speed limits' (NL); 'Sustainable safety network categorisation and evaluation approaches' (NL); 'Inventory based traffic and safety management schemes' (Elvik; Sørensen). Furthermore, RISMET aims at exploiting results related to the development and use of Accident Prediction Models (APMs) in road safety management.
The **road safety engineering evaluation tools** examined within the RISMET project include:
1. Road Safety Audits
2. Safety inspections
3. Network screening
4. Accident modelling
5. Road protection scoring
6. Identification and analysis of hazardous road locations.
7. Road Safety Impact Assessment
8. Monitoring of road user behaviour
9. Traffic conflict studies and naturalistic driving behaviour studies
10. In-depth accident studies

Regarding **Accident Prediction Modelling in road segments**, data from German roads were used to develop several variations of Accident Prediction Models that were later evaluated on a 42Km long stretch of the Portuguese road IP 04.
As far as **APMs on junctions** are concerned, Poisson Regression, Poisson-Gamma Regression and Poisson Log-Normal Regression models were developed and assesed with methodologies such as Gelman-Rubin diagnostics (for convergence assessment), and deviance information criterion, effective model dimension, and posterior predictive checking (for model assessment).
Data
The data used for developing Accident Prediction Models for **road segments** were gathered from a large part of the road network of the German federal state Brandenburg, including Federal highways B “Bundesstraßen” (no autobahns) and State roads L “Landesstraßen”, with a total length of 4,912 km. For the above roads, 18,870 accidents with injuries of the years 2005, 2006, and 2007 were used in the analysis. All in all 672 people were killed, 7,220 people were seriously injured, and 17,653 were slightly injured.
Regarding APMs for **junctions**, the following data were used, depending on the country:

Norway:	Injury accidents over a six year period from 1997 to 2002, on 732 junctions on Norwegian national roads located in the counties of Østfold, Akerhus, Hedmark and Oppland.
Austria:	Injury accidents over a four year period from 2007 to 2010, on 213 junctions of the Austrian national road network located in the province of Lower Austria.
Portugal:	Injury accidents over a five year period from 2003 to 2007, on 257 junctions belonging to the Portuguese rural road (due to the low number of cases, staggered intersections and intersections with more than 4 approaches were removed from the sample).
The Netherlands:	Injury accidents from 27 roundabouts from the Netherlands (date range not specified). These data were used for developing APMs for rural roundabouts, in combination with similar data from Austria and Portugal.

Results

RISMET in general resulted in a set of guidelines and codes of practice for the development and use of comprehensive road safety engineering evaluation tools, with a specific focus on APMs. These system based tools will consider the relations between road design, road user behaviour, traffic, and road safety.

Regarding **Accident Prediction Modelling for road segments**, the analysis performed within RISMET concluded that the comparison of predicted results (data from German roads) to real accident occurrence in a single evaluated road in Portugal presented marked differences. This were attributed to numerous reasons, such as: "the entire road stretch is disproportionally unsafe, the longitudinal profile of this hilly road affects speed choice (a condition which is not frequent in normal roads and also not considered by the speed prediction model) and, the prediction is based on German data which means that a calibration must be done in order to consider national circumstances".

As far as **APMs on junctions** are concerned, according to the specific country / set of data examined, the following models were considered more appropriate:

1. Junctions - Norway: Poisson-Gamma Regression model.
2. Junctions - Austria: Poisson Log-Normal Regression model (however it possibly overestimates accidents on roundabouts).
3. Junctions - Portugal: Poisson-Gamma Regression model.
4. Junctions - Austria, Norway, Portugal (combined): Poisson-Gamma Regression model.
5. Non-roundabout Junctions - Austria, Norway, Portugal (combined): Poisson-Gamma Regression model.

Roundabout Junctions - Austria, Norway, Portugal, The Netherlands (combined): Poisson-Gamma Regression model.

Annex B: Questionnaire

Background

The PRACT project

PRACT is a project funded by the National Road Authorities of Germany, Ireland, UK and Netherlands within the Conference of European Directors of Roads (CEDR) 2013 Transational Research Programme - Safety. The project started in April 2014 and is expected to finish by March 2016. The **objective** of the PRACT project is to improve Road Infrastructure Safety Management by assisting Road Authorities and road designers with the necessary prediction tools to analyze potential safety issues, to identify safety improvements and to estimate the potential effect of these improvements in terms of crash reduction.

The PRACT project (Predicting Road ACcidents - a Transferable methodology across Europe) aims at developing a European accident prediction model structure that could be applied to different European road networks with proper calibration. An important product of the PRACT project will be the establishment of a European Accidents Prediction Models (APMs) and Crash Modification Factors (CMFs) **web repository** with an open access database and guidance for their application and transferability on the European road networks.

The research **partners** of the PRACT project are:
- Università degli Studi di Firenze (Italy) - Project Leader
- National Technical University of Athens (Greece)
- Technische Universität Berlin (Germany)
- Imperial College London (UK)

The following questionnaire was developed in order to collect relevant existing knowledge and experience from different national road administrations (NRAs) in Europe and worldwide, as well as from other road safety expert stakeholders on the assessment of alternative road safety measures. Within this concept, we would be grateful if you could fill-in the attached **PRACT questionnaire**.

Definitions

The following terms are used throughout the questionnaire:
- **Road Safety Measures / Treatments / Countermeasures / Interventions** are any modifications in road design, maintenance and equipment, traffic control, vehicle design, inspection and protective devices, driver training, public education, enforcement and post-accident care, that aim at reducing accident frequency or severity;
- **Accident Prediction Model (APM)** or Safety Performance Function (SPF) is an equation used to estimate or predict the expected average accident frequency at a location, as a function of traffic volume and road infrastructure characteristics (e.g. number of lanes, type of median, traffic control);
- **Crash Modification Factor (CMF)** or Function, or Accident Modification Factor represents the relative change in accident frequency due to a change in one specific

condition (when all other conditions and site characteristics remain constant). CMF is the ratio of the expected accident frequency after a modification or measure is implemented to the estimated accident frequency if the change does not take place;

- **Crash Reduction Factor (CRF)** is the percentage accident reduction that might be expected due to a change in one specific condition (when all other conditions and site characteristics remain constant). The CRF is equal to (1 - CMF);
- **Road safety measures assessment / evaluation** is the procedure applied by a road safety authority or stakeholder, in order to compare alternative measures or interventions, in terms of road safety, taking into account effectiveness, implementation cost and acceptability;
- **Cost-Effectiveness Analysis (CEA)** is based on the estimation of the ratio of the present value cost to the total estimated crash reduction, i.e. in contrast to cost-benefit analysis (CBA) the change in the estimated accident frequency is not converted to a monetary value;
- **Cost-Benefit Analysis (CBA)** is also a method to evaluate economic justification of a measure implementation project, based on the estimation of the ratio of the present-value benefits of a project to the implementation costs (Benefit-Cost Ratio - BCR = Benefits/Costs);
- **Net Present Value (NPV)** method is used to evaluate the economic justification of a measure implementation project, by expressing the difference between discounted costs and discounted benefits of the project. A greater than zero NPV indicates that the project is economically justified.

References

1. AASHTO (2010). The Highway Safety Manual. American Association of State Highway and Transportation Officials (AASHTO). Washington DC.
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3. Elvik, R., Hoye, A., Vaa, T. & Sorensen, M. (2009). The Handbook of Road Safety Measures. Emerald Group Publishing Ltd.
4. CEDR (2008). Best Practice on Cost Effective Road Safety Infrastructure Investments. Conference of European Directors of Roads (CEDR).
5. FHWA CMFClearinghouse. http://www.cmfclearinghouse.org/index.cfm
6. AustRoads Road Safety Engineering Toolkit. http://www.engtoolkit.com.au/
7. International Road Assessment Programme (iRAP) Road Safety Toolkit. http://toolkit.irap.org/

Part A. Decision making process

A1. How often do you / your organisation apply a specific procedure for assessing alternative road safety measures?

□ always □ usually □ rarely □ never

A2. Please state the procedure(s) you apply (more than one answer is acceptable).

□ NPV □ CBA □ CEA □ other

If you answered "other", please briefly describe the procedure:........................
....
....
....
....

A3. How often do you / your organization use Accident Prediction Models (APMs) or Crash Modification Factors (CMFs) when assessing road safety measures?

□ always □ usually □ rarely □ never

A4. How important do you consider each of the following aspects when assessing road safety measures?

- Safety effectiveness
  □ very □ fairly □ not much □ not at all
- Implementation cost
  □ very □ fairly □ not much □ not at all
- Effective lifespan
  □ very □ fairly □ not much □ not at all
- Experience from previous implementation
  □ very □ fairly □ not much □ not at all
- Public Acceptability
  □ very □ fairly □ not much □ not at all

A5. Are there, in your country, officially approved Guidelines or Manuals regarding the assessment of road safety measures?

□ yes □ no

If yes, please provide the relevant reference(s) and, if possible, attach the relevant documents in your reply...
....
....
....

A6. How often do you use other Guidelines or Manuals (not officially approved in your country) or other studies, regarding road safety measures assessment?

□ always □ usually □ rarely □ never

Please provide a reference to the Guidelines, Manuals or studies you use:

1. ....
....
2. ....
....
3. ....
....
4. ....

Part B. Data Sources

B1. Road Design Data

i. Are any of the following road design data sets available to you / your organization, across the whole of your state/country (if only a state and not the whole country is considered please indicate so in the comments) for the mentioned road types? Do you need them for assessing alternative road safety measures? (X all that apply) If you use any alternative or proxy variables, please identify them at the '*Comments*' column.

Road Design data	**Data availability**		**Data need**		**Comments**
	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-way rural roads	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-way rural roads	
Horizontal curvature information (curve radii, element length)					
Vertical curvature information (gradient, curve radii, element length)					
Road width					
Number of lanes					
Lateral Road design (roadside environment, sight obstacles, planting)					

ii. How is this information gathered?

□ from design data   □ from data collected on site

Comments: ....
....

iii. Is the above information linked to the road chainage?

□ yes   □ no

Comments: ....
....

iv. Are skid resistance pavement ratings available?

□ yes   □ no

If yes, please indicate the time interval between measurements ....

v. How are the Road Design Data stored?

□ databank
□ GIS application
□ visualization (photos)

vi. Who administers this road design information?
- □ for motorways etc:...
- □ for two-lane rural roads: ....

vii. Are these data publicly available?
- □ yes: ....
- □ no: ....
- □ partially: ....

If yes, please provide the link to data sources..
....

B2. Road Operation Data

i. Are the following road operational data sets available to you / your organization, across the whole of your state/country (if only a state and not the whole country is considered please indicate so in the comments) for the mentioned road types? Do you need them for assessing alternative road safety measures? (X all that apply) If you use any alternative or proxy variables, please identify them at the '*Comments*' column.

Road Operational data	**Data availability**		**Data need**		**Comments**
	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-way rural roads	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-way rural roads	
Posted speed limit					
Road markings					
Road signage					
Junction control at rural roads (e.g. priority control, stop control, signaled junction)	n/a		n/a		
Data about signalization at intersections and ramp metering	n/a		n/a		

ii. How often are the above data updated (data actuality)?

□ at every change □ annually □ every 2 years □ every 3 years or more

iii. Are these data publicly available?

□ yes: ....

□ no: ....

□ partially: ....

If yes, please provide the link to data sources..

....

B3. Traffic Data

i. Are the following road traffic data sets available to you / your organization, across the whole of your state/country (if only a state and not the whole country is considered please indicate so in the comments) for the mentioned road types? Do you need them (if available) for assessing alternative road safety measures? (X all that apply) If you use any alternative or proxy variables, please identify them at the '*Comments*' column.

Road Traffic data	Data availability		Data need		Comments
	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-way rural roads	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-way rural roads	
Annual average daily traffic (AADT)					
Percentage of heavy vehicle traffic					

ii. Please fill in the definition of heavy vehicles applied in your country:

....

....

....

....

iii. Are these data publicly available?

□ yes: ....

□ no: ....

□ partially: ....

If yes, please provide the link to data sources..

....

B4. Accident Data

i. Are the following road accident data sets available to you / your organization, across the whole state/country (if only a state and not the whole country is considered please indicate so in the comments) for the mentioned road types? Do you need them for assessing alternative road safety measures? (X all that apply). If you use any alternative or proxy variables, please identify them at the '*Comments*' column.

Road Accident data	Data availability		Data need		Comments
	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-way rural roads	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-ways rural roads	
Prevailing accident type					
Prevailing accident causes					
Prevailing accident perpetrator					
Accident severity (accident category e.g. fatal accident, accident with serious and slight injury, damage only accident)					
Number of fatalities, seriously injured and slightly injured persons					
Outside accident influences (weather, driving and lighting conditions)					
Information's about accident participants (e.g. age, sex, number of occupants)					
Information's about road user category (e.g. car, pedestrian, bicyclists, etc.)					

ii. For which years are digital accident databases available?

....

....

iii. How are the accident data linked with the road information?
Please describe (e.g. road segment numbering, georeferencing, road chainage)

....

....

....

iv. Are the following detailed accident data available?
- □ description of how the accident occurred
- □ accident diagrams
- □ in depth accident studies (including reconstruction, photogrammetric surveys)

Comments: ....
....

v. Which institution administers this accident information?
□ police □ statistical offices □ road authorities □ others
Comments: ....
....

vi. Which institution analyses this accident information?
□ police □ statistical offices □ road authorities □ others
Comments: ....
....

vii. Are the accident data sets publicly available?
- □ yes: ....
- □ no: ....
- □ partially: ....

If yes, please provide the link to data sources..
....

B5. User Behaviour Data / Other Related Data

i. Are the following user behaviour data sets available, across the whole country, to you / your organization for the mentioned road types? Do you need them for assessing alternative road safety measures? (X all that apply). If you use any alternative or proxy variables, please identify them at the '*Comments*' column.

Road Accident data	**Data availability**		**Data need**		**Comments**
	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-way rural roads	Motorways/ Freeways/ Dual carriageways roads	Two-lane two-ways rural roads	
Alcohol-impaired driving					
Excessive speeding					
Seat belt use					
Helmet use (for motorcyclists)					

vi. Are these data sets publicly available?

□ yes: ....

□ no: ....

□ partially: ....

If yes, please provide the link to data sources..
....

ii. Please add any other relevant data that your organization considers for assessing alternative road safety measures:

1. ....
....
2. ....
....
3. ....
....

Part C. Information on CMF and road safety measures assessment

C1. In order to select a CMF during the assessment of alternative road safety measures to address a specific road safety issue, which of the following elements or criteria do you consider? (if you consider an element useful but there is no data available in your country / organisation please check "no data availability")

CMF Applicability Criteria

- Implementation area (rural, urban etc.)
  □ yes □ no
- Road type (motorway, major road, secondary road etc.).
  □ yes □ no
- Already identified or suspected road safety deficiency.
  □ yes □ no
- Prevailing accident type/types.
  □ yes □ no □ no data availability
- Road user category (car occupants, pedestrians, bicyclists, motorcyclists etc.) that requires attention.
  □ yes □ no □ no data availability
- Speed limit.
  □ yes □ no □ no data availability
- Traffic volume.
  □ yes □ no □ no data availability

If the safety treatment is applied to an intersection:

- Intersection type (4-leg, 3-leg, staggered, roundabout etc.)
  □ yes □ no
- Intersection traffic control (stop signs, yield signs, traffic signals, no control etc.)
  □ yes □ no
- Major Road Traffic volume.
  □ yes □ no □ no data availability
- Minor Road Traffic volume.
  □ yes □ no □ no data availability

CMF Development Criteria: in using a CMF do you check these details on the CMF development to decide if the CMF is applicable to your case?

- Date range (from year Y1 to year Y2) of the data used for CMF development
  □ yes □ no
- Country / area of data used for CMF development
  □ yes □ no
- Statistical methodology used for CMF development
  □ yes □ no
- Sample size used for CMF development
  □ yes □ no

C2. Would you consider a CMF reliability rating useful, based on its development data, methodology and sample size?
□ yes □ no

Part D. Summary of experience on road safety measures (CMFs)

For each road safety measure (CMF), included in the following table, based on your experience, please fill in the appropriate boxes (high / low) regarding the:

1. **Need** to implement the road safety measure in your country's road network;
2. **Availability** of assessment of measure / CMF;
3. **Transferability** of safety effect (i.e. if the measure is assessed in a different location, will the safety effect be similar and therefore transferable to your country?).

MOTORWAYS & DIVIDED FREEWAYS (without at grade intersections)	NEED		AVAILABILITY		TRANSFERABILITY	
CMF	HIGH	LOW	HIGH	LOW	HIGH	LOW
Realignment (of road segments)						
Rectangular rapid flashing beacons						
Dynamic feedback speed signs						
Landscaping and vegetation						
Audible road markings						
Sight distance and sight obstructions						
Animals and wildlife related safety treatments						
Advanced warning devices/signals/beacons						
High friction treatments (including anti-skid/slip)						
Skid resistance (in general)						
Effects of Friction on Motorcycle Crashes						
Variable message signs						
Roadside features						
presence of a barrier						
barrier class						
use of passively safe structures (tested according to EN 12767)						
embankment slope						
Replacement of barriers terminals with crashworthy terminals						
crash cushions						
motorcycle protection devices						
clear zone width						
Workzones						
Number of lanes						
Curvature						
Superelevation (cross slope)						
Lane width						
Shoulder Width						
Median Width						
Effect of traffic (volume/capacity - % trucks &						

MOTORWAYS & DIVIDED FREEWAYS (without at grade intersections)	NEED		AVAILABILITY		TRANSFERABILITY	
CMF	HIGH	LOW	HIGH	LOW	HIGH	LOW
buses)						
Effect of ramp entrance/exit (distance to the analysed section)						
Longitudinal grade						
Rumble strips						
Automated speed enforcement (section or average)						
Lighting						

TWO-LANE, TWO-WAY RURAL ROADS	NEED		AVAILABILITY		TRANSFERABILITY	
CMF	HIGH	LOW	HIGH	LOW	HIGH	LOW
Realignment (of road segments)						
Kerb extensions (also called bulb-outs or bump-outs)						
Rectangular rapid flashing beacons						
Dynamic feedback speed sign						
Landscaping and vegetation						
Audible road markings						
Bicycle treatments						
Bicycle lanes						
Bicycle boxes						
Bicycle loops						
Effect of rumble strips on bicycles						
Sight distance and sight obstructions						
Animals and wildlife related safety treatments						
Advanced warning devices/signals/beacons						
High friction treatments (include anti-skid/slip)						
Friction (in general)						
Effects of Friction on Motorcycle Crashes						
Rail crossings at-grade						
Raised islands and pedestrian refuge islands						
Sharrows (bicycle shared lane markings on travelled lanes)						
Variable message signs						
Roadside features						
presence of a barrier						
barrier class						

TWO-LANE, TWO-WAY RURAL ROADS	NEED		AVAILABILITY		TRANSFERABILITY	
CMF	HIGH	LOW	HIGH	LOW	HIGH	LOW
use of passively safe structures (tested according to EN 12767)						
embankment slope						
Replacement of barriers terminals with crashworthy terminals						
crash cushions						
motorcycle protection devices						
Workzones						
Curvature						
Superelevation (cross slope)						
Lane width						
Shoulder Width						
Shoulder Type (paved/unpaved)						
Effect of traffic (volume/capacity - % trucks & buses)						
Longitudinal grade						
Rumble strips						
Automated speed enforcement (section or average)						
Driveway density (frequency of accesses)						
Passing Lanes (overtaking lanes)						
Two-way left turn lanes (central lane used dedicated for left turns)						
Segment Lighting						
Intesection skew angle						
Intersection Left-turn lanes						
Intersection Righ-turn lanes						
Intersection Lighting						
Signal timing (including optimizing and re-timing intervals)						
Roundabouts						
J-turns/restricted crossing u-turn intersections						
Countdown signals or signs						
Right-in, right-out (or left in/left out for UK & Ireland) designs (channelization to prevent left turns)						

Details of the person filling the questionnaire:

Name: ....

Family Name: ....

Organisation: ....

Organisation type:

□ National Road Authority

□ Road Managing Company

□ Academia/research institution

□ Other (specify) ....

Can we acknowledge you name in the report that will be produced?

□ yes □ no

Thank you for your time!